Enabling Floating Solar Photovoltaic (FPV) Deployment in Southeast Asia: *Overview with Considerations for Aquaculture PV*

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Presentation Outline

Technology Overview

Benefits and Considerations

Potential in Southeast Asia

Policy Barriers and Best Practices

Floating Solar Photovoltaics (FPV) and Aquaculture Photovoltaics (AquaPV)

Photo: Adam Warren (NREL)

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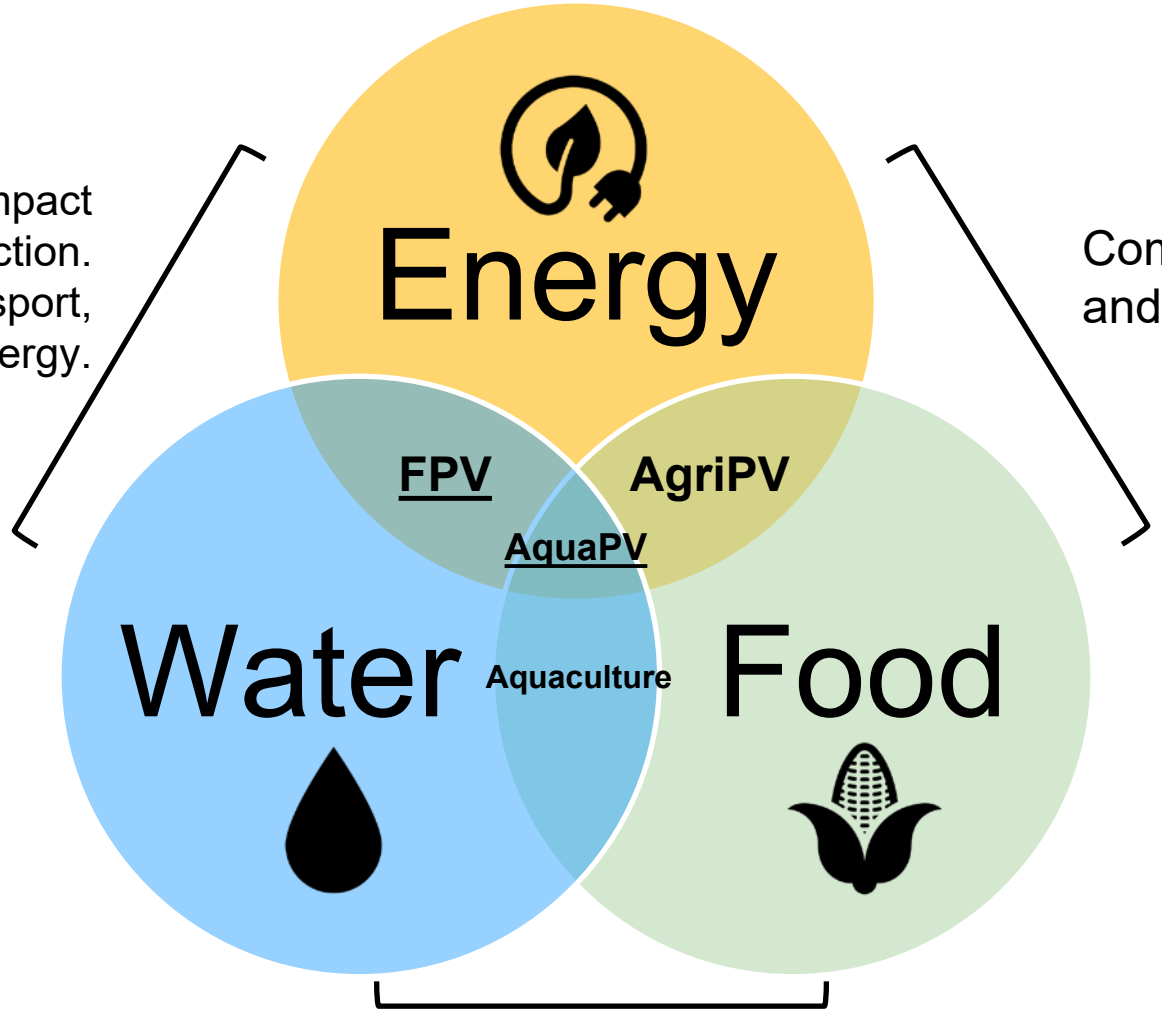
Energy-Water-Food Nexus

Limited water resources can impact energy production.
Water infrastructure (transport, treatment, etc.) requires energy.



Competing land use for food and energy production.

Land development impacts water quality and availability.
Water shortages and poor water quality limit food production.

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Technology Overview: FPV

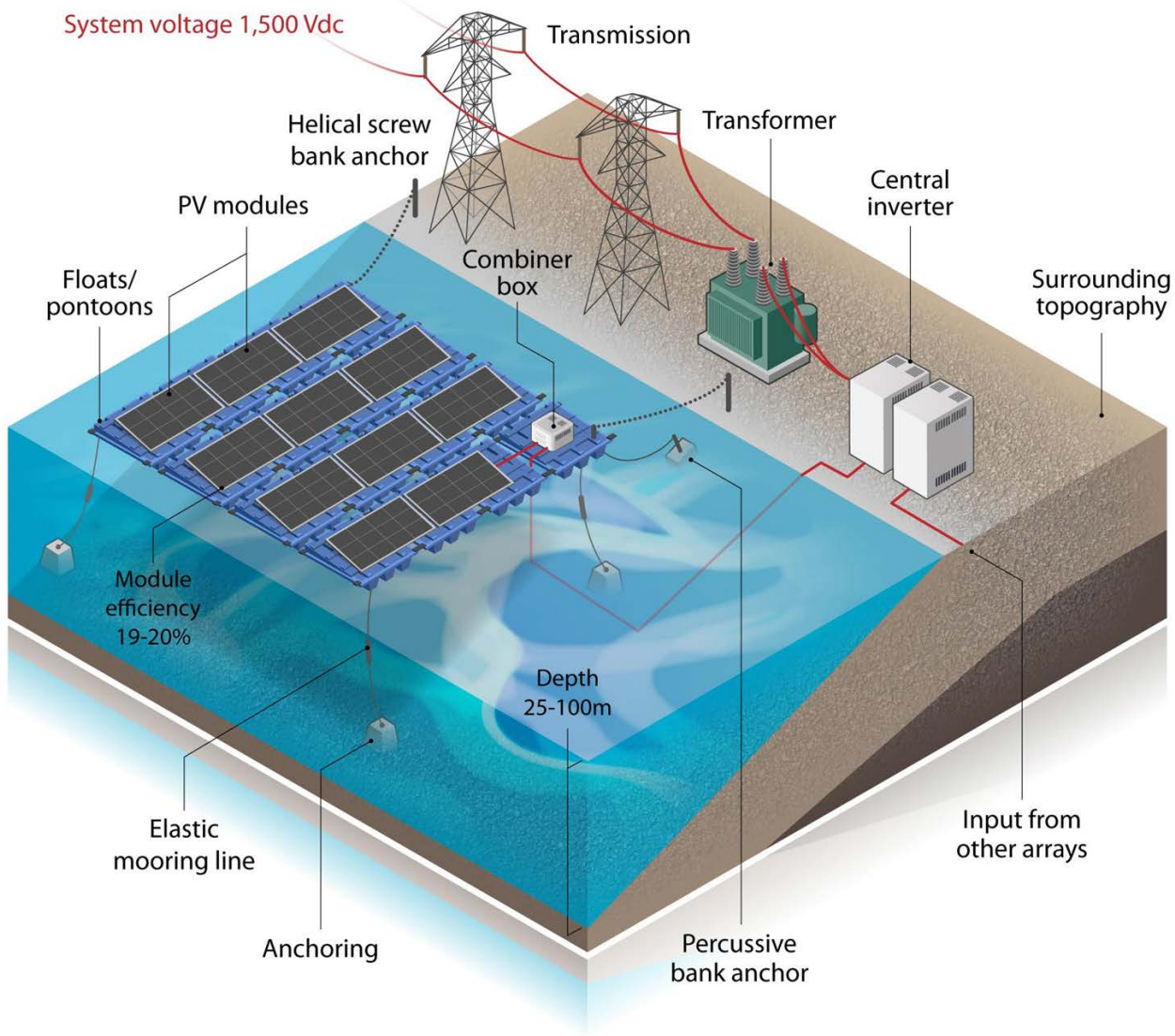


Figure. Schematic of Typical FPV System

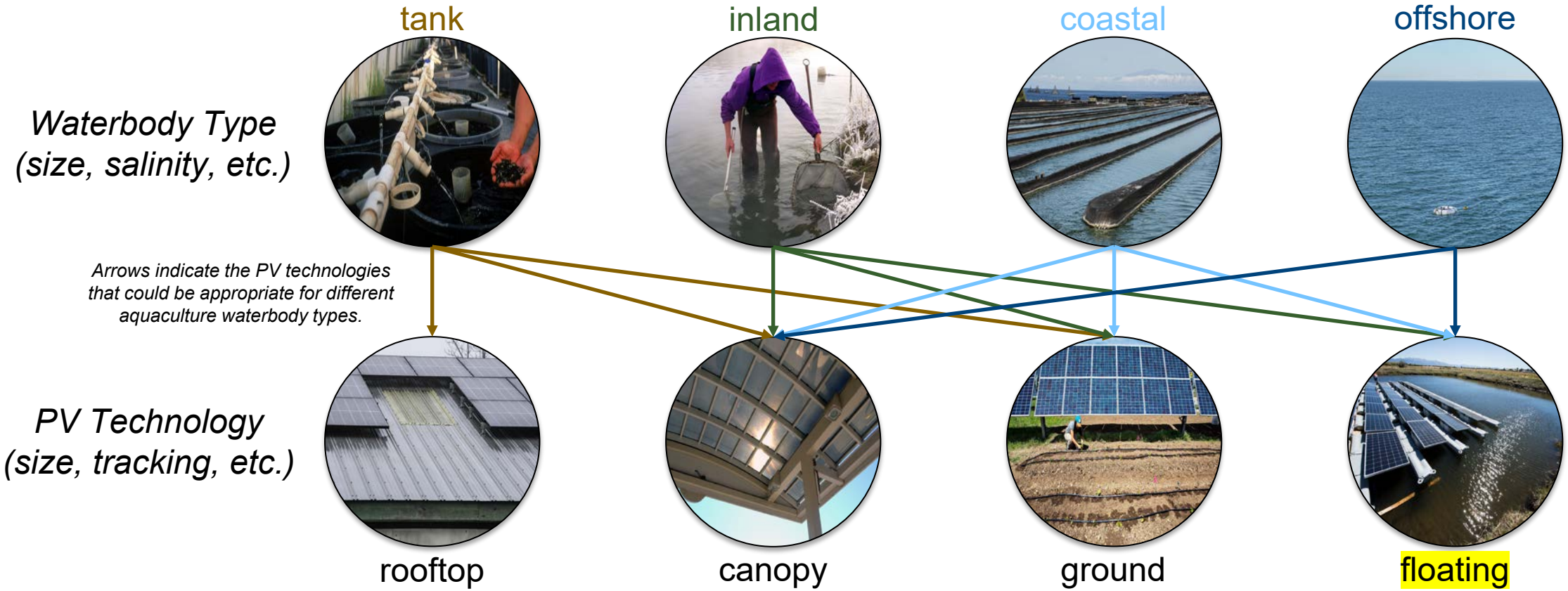
Image: Alfred Hicks (NREL)

- FPV uses the same PV modules as ground-mount or rooftop PV
- Historically, FPV has been sited on artificial waterbodies (e.g., reservoirs, retention ponds, etc.)
- FPV systems are mounted on floating platforms constructed with plastic and stainless steel
- FPV systems can reduce land-use by being co-located on existing waterbodies and can conserve water resources by reducing evaporation
- FPV panel efficiency can be increased due to the cooling effect of water

Source: Ramasamy and Margolis (2021)

Technology Overview: AquaPV

Aquaculture: cultivation of finfish, shellfish, crustaceans, and seaweeds on land or at sea for food
AquaPV: aquaculture + solar photovoltaics (using solar energy to power various aquaculture activities)



The PV technology best suited to the aquaculture site is highly site specific and can depend on factors such as location, available infrastructure, and energy needs (which can also depend on the aquaculture product itself).

Images (left to right, top to bottom): Robb Williamson, Warren Getz, Dennis Schroeder, Andrew Simms, Bryan Bechtold, Warren Getz, Werner Slocum, Dennis Schroeder (all NREL)

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Source: LiVecchi et al. (2019)

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Southeast Asia Context

Why are countries deploying FPV and AquaPV?

- Ambitious renewable energy targets
- Economic development opportunities
- Energy and food security considerations
- Abundant solar resources and waterbodies
- Land-use benefits for energy and food production
- Energy and financial savings at aquaculture sites

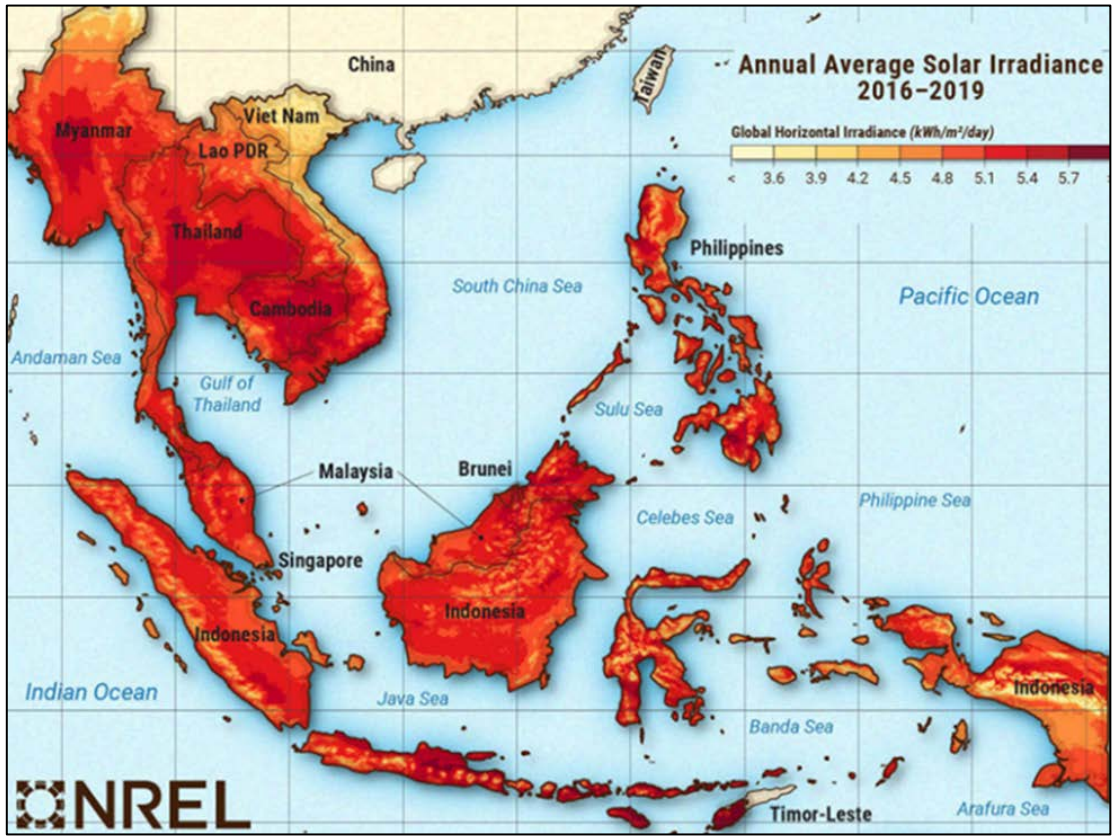
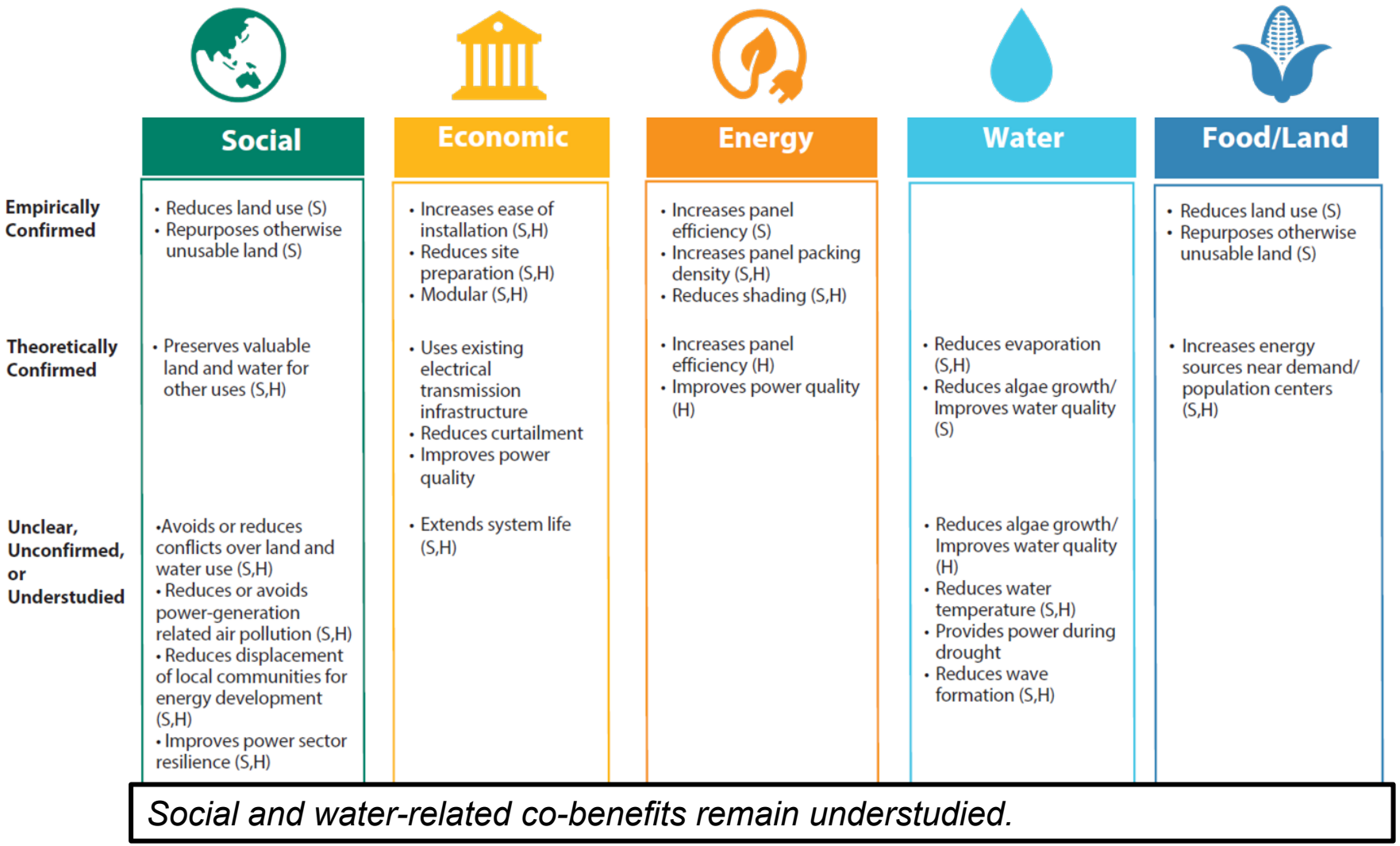


Figure. Solar Resource in Southeast Asia

Source: Maclaurin et al. (2022)

Benefits: FPV



	Social	Economic	Energy	Water	Food/Land
Empirically Confirmed	• Reduces land use (S) • Repurposes otherwise unusable land (S)	• Increases ease of installation (S,H) • Reduces site preparation (S,H) • Modular (S,H)	• Increases panel efficiency (S) • Increases panel packing density (S,H) • Reduces shading (S,H)		• Reduces land use (S) • Repurposes otherwise unusable land (S)
Theoretically Confirmed	• Preserves valuable land and water for other uses (S,H)	• Uses existing electrical transmission infrastructure • Reduces curtailment • Improves power quality	• Increases panel efficiency (H) • Improves power quality (H)	• Reduces evaporation (S,H) • Reduces algae growth/ Improves water quality (S)	• Increases energy sources near demand/ population centers (S,H)
Unclear, Unconfirmed, or Understudied	•Avoids or reduces conflicts over land and water use (S,H) • Reduces or avoids power-generation related air pollution (S,H) • Reduces displacement of local communities for energy development (S,H) • Improves power sector resilience (S,H)	• Extends system life (S,H)		• Reduces algae growth/ Improves water quality (H) • Reduces water temperature (S,H) • Provides power during drought • Reduces wave formation (S,H)	

Social and water-related co-benefits remain understudied.

Figure. Summary of FPV Co-Benefits (S = stand-alone, H = hybridized)

Many of these co-benefits can also apply to AquaPV installations.

Source: Gadzanku et al. (2021)

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Benefits: AquaPV

Additional research is needed to identify potential ecological impacts.

Reductions in the cost of energy, which can subsequently reduce the cost of food.

- Energy is often the most expensive component of aquaculture operations: used for pumping, aeration, lighting, etc.

Reductions in greenhouse gas emissions (many aquaculture farms rely on diesel generators).

Strengthens both food and energy security with domestic production and consumption.

Using PV panels to shade aquaculture systems (e.g., pond or tank) can reduce water temperature on hot days, which is beneficial for fish and shrimp growth.

PV panels covering the aquaculture system can protect farmed species from predatory birds.

PV panels covering water can reduce evaporation and therefore the water and energy consumption of the site.

Sources: Em Vo et al. (2021), Pringle et al. (2017)

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Potential in Southeast Asia: FPV

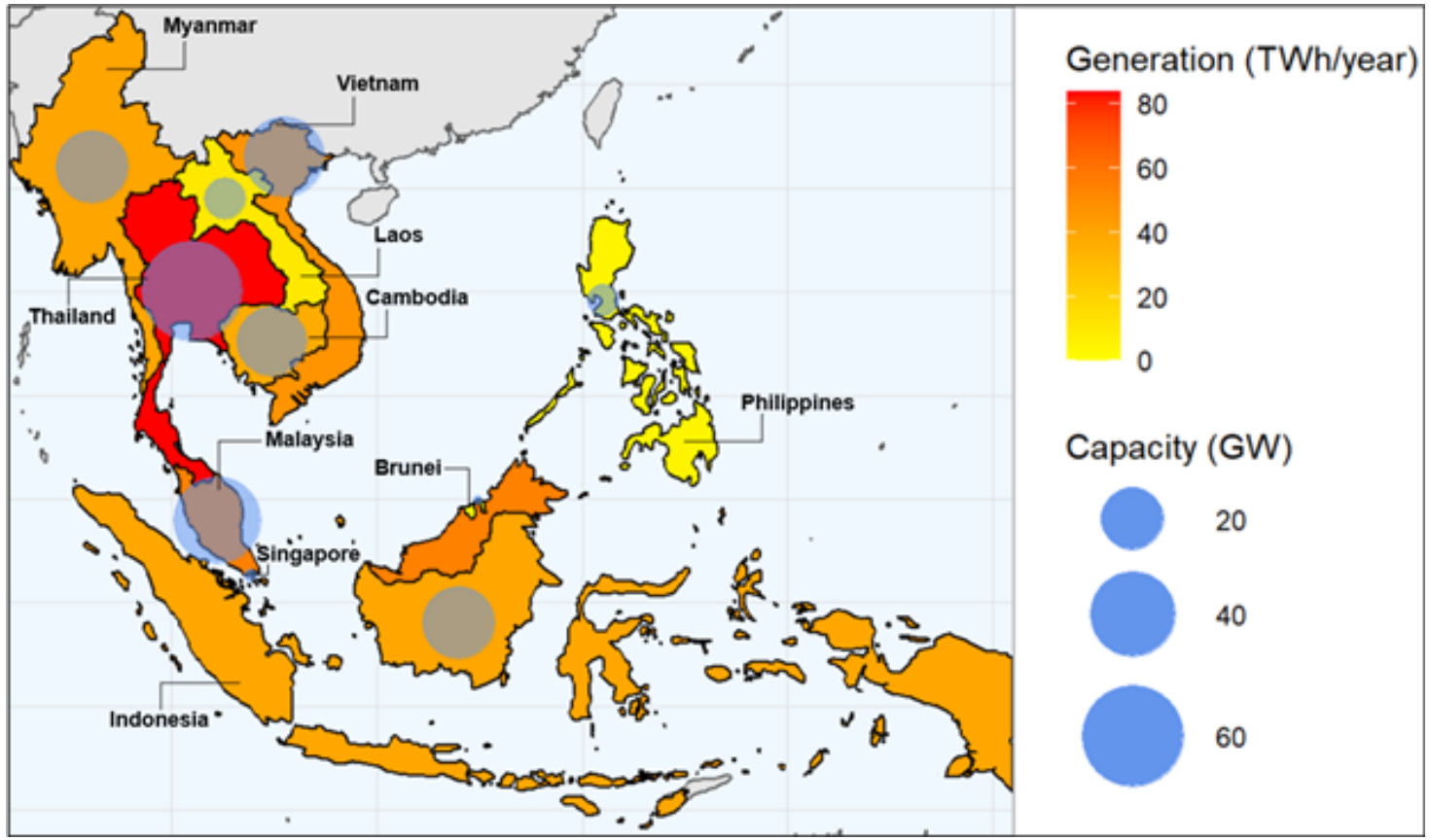

Figure. FPV Generation and Capacity Technical Potential for Reservoirs in Southeast Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50 m minimum distance-from-shore and 1000 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.

Source: Joshi et al. (2023, forthcoming)

Scope of Regional Study

Reservoirs (hydropower and non-hydropower)

Natural Waterbodies (e.g., inland lakes, ponds, etc.)

Waterbodies too far from roads (50 km) or in “protected areas” were excluded. Impact of transmission filters (25 km) was also examined for countries that had such data available.

These reservoirs and natural waterbodies could also be current or future sites for aquaculture.

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Potential in Southeast Asia: FPV

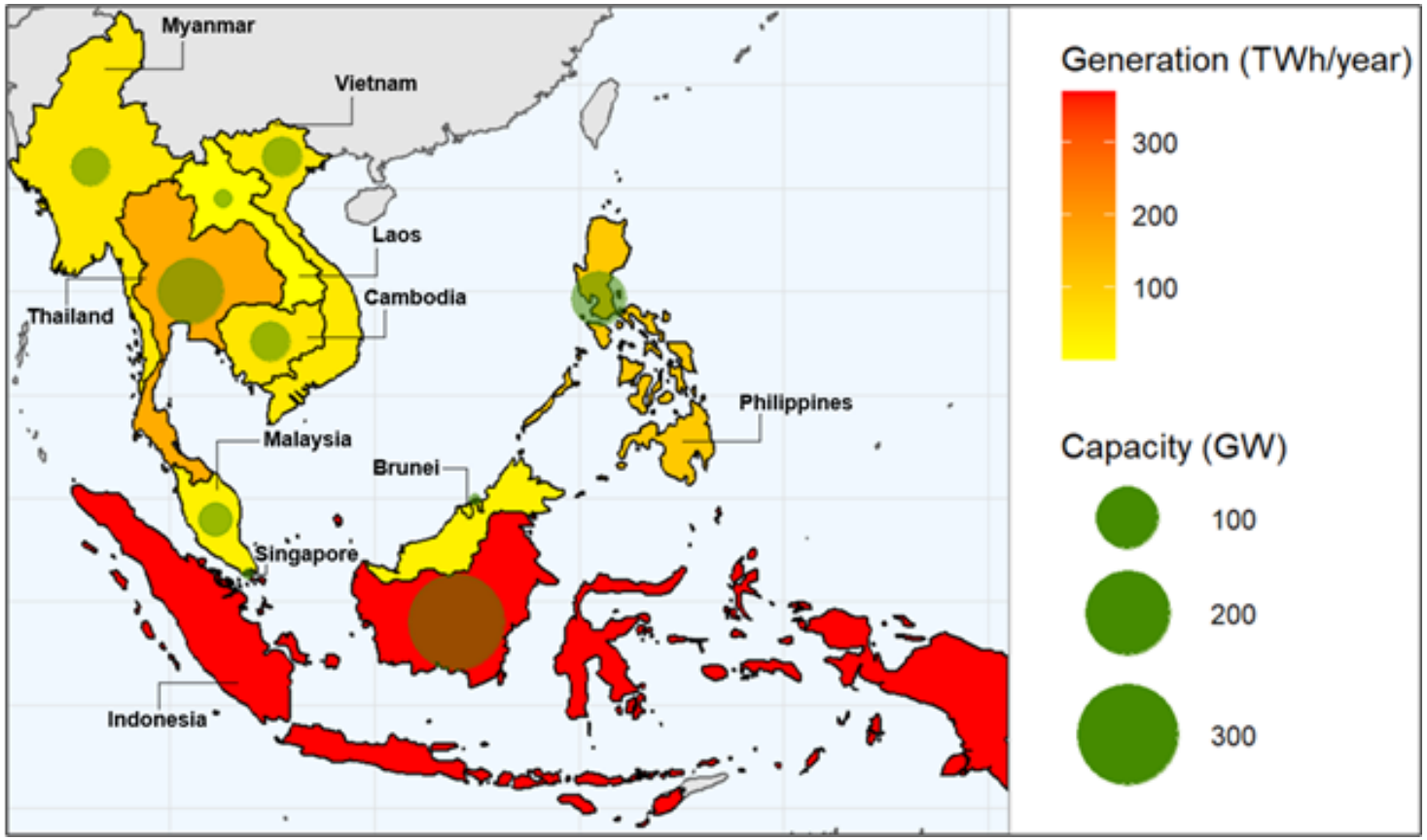

Figure. FPV Generation and Capacity Technical Potential for Natural Waterbodies in Southeast Asia

Note: These results assume fixed-tilt monofacial FPV panels, with a 50 m minimum distance-from-shore and 1000 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.

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Potential in Southeast Asia: AquaPV

- Global aquaculture energy demand is expected to increase significantly in the coming decades
  - Anticipated to increase from 1,278 TWh to 2,972 TWh by 2050
- Vietnam: fourth-largest producer of seafood from aquaculture
  - 4.8 million tons in 2021, expected to reach 6.0 million tons by 2027
  - 1.09 million hectares of inland aquaculture in 2021 (69% shrimp, 30% fish, 1% other)
    - Greater than the maximum area suitable for FPV in the NREL study
  - Many farms are in off-grid locations and rely on expensive diesel fuel

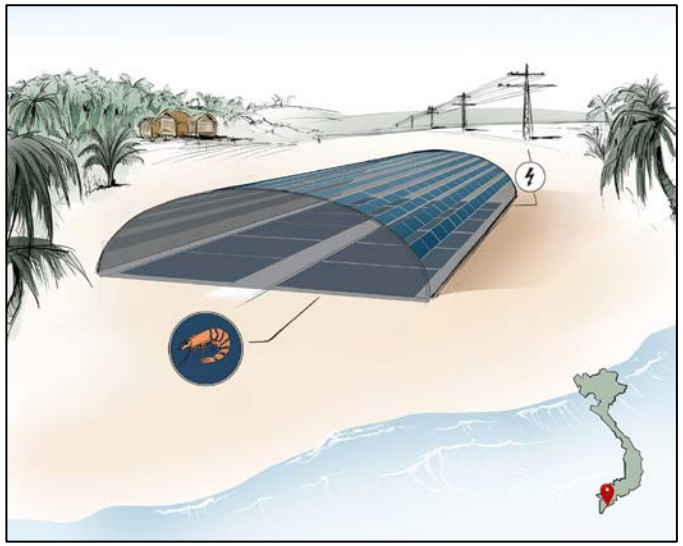

Figure. Sketch of Planned Shrimp AquaPV Greenhouse in Bac Lieu

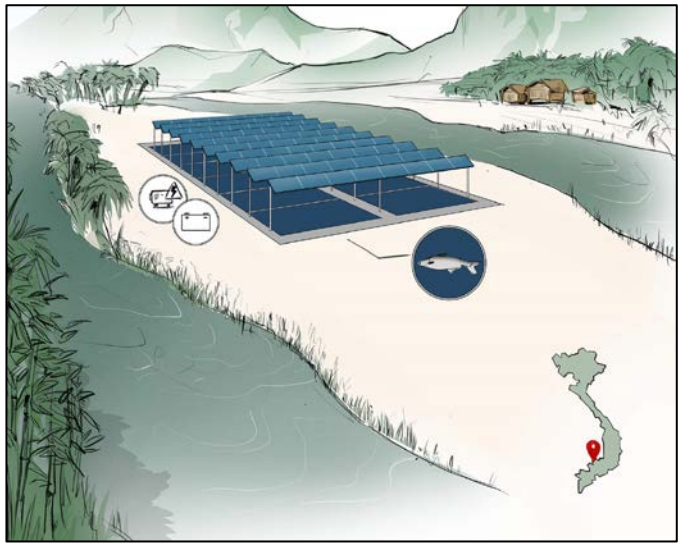

Figure. Sketch of Planned Pangasius AquaPV Plant in An Giang

Sources: Em Vo et al. (2021), Imarc Group (2022), Statista (2022)
Images: Fraunhofer ISE (2019)

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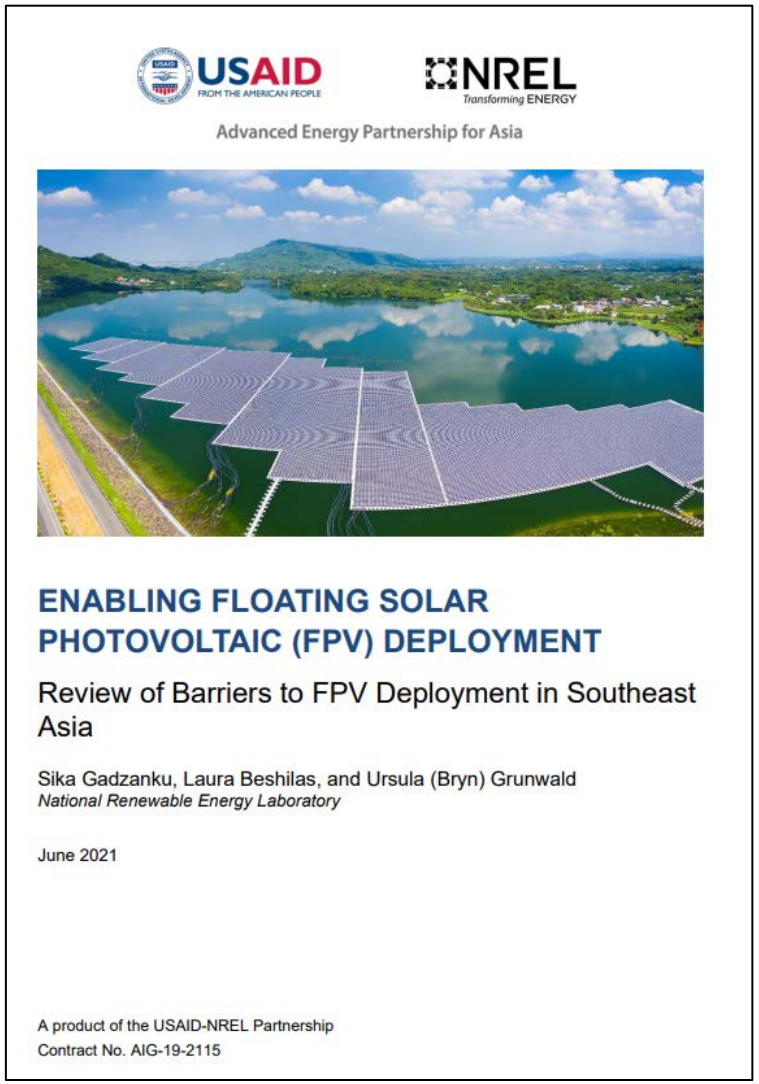
Policy Barriers and Best Practices: FPV & AquaPV



Many of the barriers and best practices identified for FPV in Southeast Asia are also relevant for AquaPV.

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Environmental and Cultural Considerations

Barriers

- Uncertainty about FPV ecological impacts may increase public opposition to projects and lengthen the environmental review process.
- Lack of public buy-in of FPV technology due to visual impacts and competing uses of waterbodies could stall project development.
- Previous negative experiences with RE projects may lead to an unfavorable public opinion of FPV systems.

Best Practices to Consider

- Government support for additional research and development (R&D) and analysis on the environmental impacts of FPV systems could shorten the environmental review process.
- Prioritizing obtaining public buy-in and support through outreach and engagement can avoid delays during the FPV project development process.
- Developing educational programs to inform the public about the benefits of FPV systems.

= particularly relevant to AquaPV

Source: Gadzanku et al. (2021)

Economic Considerations

Barriers

Subsidizing fossil fuels can create an uneven playing field, making it difficult for FPV systems to compete in the market.

Economic policy uncertainty may stall private sector interest in FPV systems.

Trained workforce shortages raise FPV deployment costs.

Best Practices to Consider

Creating clear, complementary, transparent, and consistent incentives for energy development can reduce uncertainty for FPV projects and reduce project development cost.

Consistent and targeted government support to FPV systems in the form of rebates, tax incentives, and competitive RE auctions could help de-risk FPV systems and attract private sector financing.

= particularly relevant to AquaPV

Source: Gadzanku et al. (2021)

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Regulatory Considerations

Barriers

Uncertainty about water rights may delay FPV project development and increase costs.

Lack of interagency cooperation and coordination may stall FPV deployment.

Lengthy, expensive, and unclear environmental approval processes for FPV systems can make projects less financially appealing.

Best Practices to Consider

Clear policies around water rights for FPV projects could reduce uncertainty during the project development process.

Engaging with policymakers and financial institutions to increase awareness of FPV systems can lead to increased support for investing in R&D and deployment projects.

= particularly relevant to AquaPV

Source: Gadzanku et al. (2021)

Case Study: Taiwan AquaPV Policy

What are the challenges and opportunities in implementing Taiwan's aquavoltaics policy? A roadmap for achieving symbiosis between small-scale aquaculture and photovoltaics

Yao-Jen Hsiao [a], Jyun-Long Chen [b,*], Cheng-Ting Huang [c]

[a] Institute of Applied Economics, National Taiwan Ocean University, Taiwan
[b] Marine Fisheries Division, Fisheries Research Institute, Council of Agriculture, Taiwan
[c] Department of Aquaculture, National Taiwan Ocean University, Taiwan

- ❑ Transforming small scale aquaculture into cooperative aquaculture can increase the feasibility of implementing the AquaPV policy by decreasing the risk and uncertainty to individual farmers
- ❑ Increasing efficiency of aquaculture practices through management techniques and smart technologies reduces the risk after PV installation
- ❑ AquaPV demonstration areas can provide complete information about environmental impacts and make the technology more appealing to both farmers and environmentalists
- ❑ Catering to the energy needs of local communities and aquaculture farmers increases the effectiveness of AquaPV policies

Source: Hsaio et al. (2021)

Thank you!

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NREL/PR-5R00-85264

References

Em Vo, Thi Thu, Hyeyoung Ko, Jun-Ho Huh, and Namje Park. “Overview of Solar Energy for Aquaculture: The Potential and Future Trends.” Energies, Overview of Maximum Power Point Tracking Methods for PV System in Micro-Grid, 14, no. 6923 (October 21, 2021). https://doi.org/https://doi.org/10.3390/en14216923.

Fraunhofer Institute for Solar Energy Systems (ISE). “Aqua-PV: ‘SHRIMPS’ Project Combines Aquaculture and Photovoltaics.” News, August 28, 2019. https://www.ise.fraunhofer.de/en/press-media/news/2019/aqua-pv-project-shrimps-combines-aquaculture-and-photovoltaics.html.

Gadzanku, Sika. “Enabling Floating Solar (FPV) Deployment: Policy and Operational Considerations.” Presented at the Asia Clean Energy Forum (ACEF), National Renewable Energy Laboratory (NREL), June 17, 2022. https://www.nrel.gov/docs/fy22osti/83228.pdf.

Gadzanku, Sika, Heather Mirletz, Nathan Lee, Jennifer Daw, and Adam Warren. “Benefits and Critical Knowledge Gaps in Determining the Role of Floating Photovoltaics in the Energy-Water-Food Nexus.” Sustainability 13, no. 4317 (April 13, 2021). https://doi.org/https://doi.org/10.3390/su13084317.

Gadzanku, Sika, Laura Beshilas, and Ursula (Bryn) Grunwald. “Enabling Floating Solar Photovoltaic (FPV) Deployment - Review of Barriers in Southeast Asia.” Golden, CO: National Renewable Energy Laboratory (NREL), June 2021. https://www.nrel.gov/docs/fy21osti/76867.pdf.

Gadzanku, Sika, Nathan Lee, and Ana Dyreson. “Enabling Floating Solar Photovoltaic (FPV) Deployment: Exploring the Operational Benefits of Floating Solar-Hydropower Hybrids.” Golden, CO: National Renewable Energy Laboratory (NREL), June 2022. https://www.nrel.gov/docs/fy22osti/83149.pdf.

Hsiao, Yao-Jen, Jyun-Long Chen, and Cheng-Ting Huang. “What Are the Challenges and Opportunities in Implementing Taiwan’s Aquavoltaics Policy? A Roadmap for Achieving Symbiosis between Small-Scale Aquaculture and Photovoltaics.” Energy Policy 153, no. 112264 (April 7, 2021). https://doi.org/10.1016/j.enpol.2021.112264.

Imarc Group. “Vietnam Aquaculture Market: Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027,” 2022. https://www.imarcgroup.com/vietnam-aquaculture-market.

Joshi, Prateek, Sika Gadzanku, and Evan Rosenlieb. “Enabling Floating Solar Photovoltaic (FPV) Deployment: FPV Technical Potential Assessment for Southeast Asia.” Golden, CO: National Renewable Energy Laboratory (NREL), *Forthcoming*.

LiVecchi, Al, Andrea Copping, Scott Jenne, Alicia Gorton, Robert Preus, Gary Gill, Robi Robichaud, Rebecca Green, Simon Geerlofs, Simon Gore, David Hume, William McShane, Carrie Schmaus, and Heather Spence. “Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets.” Washington, DC: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. April 2019. https://www.energy.gov/sites/prod/files/2019/03/f61/73355.pdf.

Maclaurin, Galen, Manajit Sengupta, Aron Habte, Grant Buster, Evan Rosenlieb, Mike Bannister, Michael Rossol, et al. “Development and Validation of Southeast Asia Solar Resource Data.” National Renewable Energy Laboratory (NREL), January 2022. https://www.nrel.gov/docs/fy22osti/81799.pdf.

Pringle, Adam M., R.M. Handler, and J.M. Pearce. “Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture.” Renewable and Sustainable Energy Reviews 80 (May 31, 2017): 572–84. https://doi.org/https://doi.org/10.1016/j.rser.2017.05.191.

Ramasamy, Vignesh, and Robert Margolis. “Floating Photovoltaic System Cost: Q1 2021 Installations on Artificial Water Bodies.” Golden, CO: National Renewable Energy Laboratory (NREL), October 2021. https://www.nrel.gov/docs/fy22osti/80695.pdf.

Statista. “Area of inland aquaculture in Vietnam in 2021, by product,” 2022. https://www.statista.com/statistics/1329495/vietnam-inland-aquaculture-area-by-product/

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