EXPLORING THE POTENTIAL FOR FLOATING PHOTOVOLTAIC SOLAR ON MAN-MADE RESERVOIRS IN THE UNITED STATES

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1 ABSTRACT

Floating photovoltaic solar systems (FPV) is a rapidly emerging technology across the globe. However, it has yet to make the same significant traction in the United States. Valuable utilization of renewable energy potential must be fully adapted to ensure energy security, mitigate and adapt to climate change threats, and foster sustainable development in the United States, and any viable technology that could contribute to these goals should be fully vetted. This research analyzes the potential for increased development of FPV systems sited on man-made reservoirs in the US. Key factors that contribute to successful utility-scale FPV and land-based solar project development were compared and analyzed to further understand the potential for an increased presence of FPV in the US. The analysis found that FPV provides multiple benefits over land-based solar relating to system energy efficiency, the environment, and the ability for hybrid energy production when sited on hydropower dam reservoirs. There is a high potential for increased development on man-made reservoirs, especially hydropower basins soon. As higher-profile projects come online throughout the US and more data becomes available, it will help bolster confidence for key industry stakeholders that the technology is feasible and does warrant significant investment. Developers and key industry stakeholders can utilize this research to gain a thorough understanding of the technology and how it compares to industry standards for land-based PV systems.

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3 INTRODUCTION

Floating photovoltaic solar systems ("FPV" or "floatovoltaics") is a rapidly emerging technology application where PV solar systems are sited directly on bodies of water. The industry has grown globally due to climate and greenhouse gas (GHG) reduction goals, energy security and improvements to energy resilience, competing land uses, and various other benefits. Since patents for the technology were first registered in 2008, there has been rapid FPV industry growth in China, Latin America, Japan, Southeast Asia, and Northern Europe in recent years, and it has been estimated that as much as 400 GW of capacity could be installed globally (World Bank Group et al., 2019). At the end of 2019, there was over 2.4 GW of operating FPV projects globally, with an estimated annual growth rate of 22% through 2024 (Cox, 2019). By the end of 2022, floating solar will account for 2% of global annual solar installations as it is expected to reach 13,000 MW of installed capacity. Global technical advisory group DNV has estimated that inland man-made bodies alone have the potential to support up to 4 TW of new power capacity globally (Hopson, 2020).

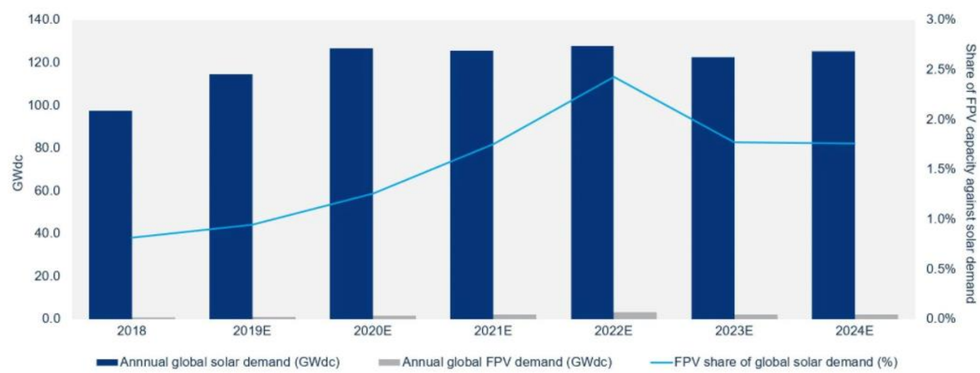

Figure 1: Annual global solar installations as percentage of annual global installations 2018-2024 (GW, DC). (Source: Cox, 2019).

Only four years ago, there were only two active floating solar arrays in the United States, but by the end of 2020, there were over 20 operating projects (Haggerty, 2020).

The IPCC's 2018 Special Report revealed that if civilization continues with business-as-usual activities, global warming levels are projected to reach 1.5ºC above pre-industrial levels between

2030 and 2052 (IPCC, 2018). Attaining and further sustaining net zero anthropogenic carbon emissions on a global scale would effectively halt global warming from anthropogenic sources potentially for multiple decades into the future (IPCC, 2018). To meet these goals, global carbon emissions will need to decrease well before 2030, which would need to be driven largely through a rapid and far-reaching transition in the energy sector. Significantly reducing U.S. carbon emissions from the energy sector will play a large role in the effort to meet this global goal. Valuable utilization of renewable energy potential must be fully adapted to ensure energy security, mitigate and adapt to climate change threats, and foster sustainable development in the United States. While utility-scale land-based photovoltaic solar projects have made a significant impact in the US generation portfolio, any potential pathways for increased greenhouse gas (GHG) emission reductions through new technologies should be fully vetted and employed if they prove to be beneficial and successful ventures. The purpose of this research is to examine what factors contribute to successful floating photovoltaic solar project development on man-made reservoirs in the US. This study aims to reveal both the benefits and challenges of this emerging market and technology to aid with the technology's potential expansion in the US that could influence and diversify the country's renewable energy generation.

The FPV technology sector is still emerging in the US because it is still perceived as an "unknown," which presents as risky to investors. However, FPV systems present multiple benefits when compared to land-based solar energy systems, ranging from reduced evaporation and algae growth in the water bodies to reductions in PV operating temperatures. As more high-profile and larger projects are developed throughout the country and data collection shows the technology is reliable and effective, substantial investment is expected. In a recent study, 24,419 man-made water bodies (i.e., industrial, irrigation, or hydroelectric basins and man-made lakes), in the continental states were identified as suitable hosts for FPV systems, where covering only 27% of the water surface with panels could generate up to 10% of US annual electricity production.

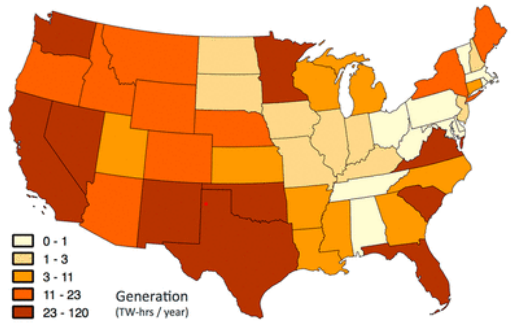

Figure 2: Potential annual generation from FPV projects covering 27% of feasible water bodies (24,419). (Source: Spencer et al., 2019).

Many of these identified water bodies are in water-stressed areas with high electricity prices and high land-acquisition costs. Idaho, Maine, New Mexico, and Oklahoma have been identified as having more FPV potential than their in-state electricity consumption and could even become solar electricity exporters to the rest of the country. Reservoirs were identified as particularly viable project hosts as they are already managed, have access roads and infrastructure that would make FPV system installation easier and less expensive, and have fewer environmental concerns than a natural water body (Spencer et al., 2019). These figures demonstrate the vast potential for the expansion of the field to scale up solar generating capacity.

This paper aims to answer the question: *what factors contribute to successful floating photovoltaic solar project development on man-made reservoirs in the US?* This research will examine the benefits, obstacles, policy and regulatory considerations, current market, and technical and developmental feasibility of utility-scale FPV (typically 1-5 MW) through existing literature and lessons learned from the development of both active floating PV and land-based PV projects. Extensive document analyses were conducted to identify factors that impact the successful development of both utility-scale land-based and floating solar projects, which were then compared to further understand the potential for successful FPV project development in the States. This study aims to reveal that floating PV solar systems have a high potential for increased project development in the United States when sited on man-made reservoirs, especially hydropower basins. These findings can be utilized by industry stakeholders, primarily renewable energy project developers, to further inform and reassure their decisions when considering prospective FPV projects in the US.

4 BACKGROUND

4.1 Floatovoltaics

Floating PV projects are being increasingly deployed across the globe as the dual renewable energy and environmental benefits are becoming more apparent as larger projects come online and the technology evolves. The world's first non-experimental FPV project, developed by Thompson Technology Industries, was installed at Far Niente Winery in California in 2008 which consists of over 1,000 Sharp 208 polysilicon modules sited on the winery's vineyard irrigation pond and generates 400 kW at peak output. The project effectively pairs PV power with water to save valuable vineyard acres and offset the winery's power usage that would otherwise host a land-based PV system. The savings in produce terms spared from removing Cabernet vines equals roughly US$ 150,000/year and generates enough energy to offset the winery's annual power usage to provide a net-zero energy bill (Renewable Energy Focus, 2008). Now, over a decade later, FPV projects are increasing in quantity, capacity, and geographic spread throughout the United States. Because FPV systems can be integrated within any human settlement and can be sited on both fresh and saltwater bodies (near coasts), their geographic potential is essentially limitless.

In March 2021, the Healdsburg Solar Project came online in the city of Healdsburg, California. The project is now ranked as the largest FPV project in the States at 4.78 MW. The project was developed, financed, and built by White Pine Renewables spans two wastewater treatment ponds in Sonoma County, and will provide 6% of the city's energy needs by generating over 6.5 million kWh annually (White Pine Renewables, 2021). The project was financed through a 25-year power purchase agreement that will offer the city a low, fixed-rate for electricity and extended savings on utility rates. It will also deter rising utility rates and operation & maintenance (O&M) costs as White Pine Renewables will be responsible for maintaining the project.

Figure 3: Healdsburg Solar Project, currently the largest FPV project in the US. Source: (White Pine Renewables, 2021).

Rosa-Clot & Tina found that further global development of the FPV sector will be driven by large-scale plants and extensive government programs or incentives. In 2018, the authors determined there were at least 40 governments that have FPV investment programs, feed-in tariffs, research centers, or active companies in the sector (2020).

4.2 Land-based PV

The utility-scale land-based PV industry in the United States has been generating reliable and clean power with a steady fuel price and average growth rate of 42% each year for the last decade (SEIA, n.d.(A)). Utility-scale solar development provides one of the most efficient and quickest ways to diversify the country's energy portfolio and significantly reduce carbon emissions amid the global climate crisis. The US currently has 49,124 MW of installed capacity of utility-scale solar, with a project pipeline of 96 GW through 2025. 4,238 MW of generating capacity was added in the fourth quarter of 2020 alone (Horwath, 2021). At the end of Q4 2020, the utility-scale contracted project pipeline reached 69 GW_{dc} (Davis et al., 2021). Declining costs, corporate interest in renewable energy, state-level government policies, and federal tax credits have been identified as key factors that have driven the expansion of the solar industry, even amidst the COVID-19 pandemic that had detrimental economic, social, environmental, and political impacts worldwide (Horwath, 2021). Growth over the next decade in the land-based PV industry puts the US in close reach of the Biden Administration's clean energy goals, but far more work will be required to achieve a 100% clean energy electric system throughout the country. According to SEIA, annual installations will need to increase from 20 GW in 2020 to at least over 80 GW by the end of 2030 to reach a total of 600 GW (SEIA, n.d.(A)).

5 METHODS

This research explores the factors that would contribute to the expansion of the United States FPV industry on man-made reservoirs through the scope of renewable energy project development. Document analyses were conducted to understand key variables that impact each stage of traditional solar project development. Analyzed documents include land-based and floating solar development handbooks by the World Bank and DNV GL, publications and data from the National Renewable Energy Laboratory (NREL), Environmental Protection Agency (EPA), Solar Energy Industries Association (SEIA), DNV, International Finance Corporation (IFC), Natural Resources Defense Council (NRDC), and numerous peer-reviewed academic journals. News articles were additionally considered for FPV development in the United States, given the nascent stage of research compared to land-based systems and to assess recently operating projects. The factors that impact development that were derived from this document analyses were organized in a table in the Results & Analysis section below to display key differences and similarities between land-based and floating PV systems. Variables that impact each stage of traditional solar project development included in this analysis are site assessment, feasibility studies, financing and contracting, system design, environmental & social assessments, procurement and construction, and operations & maintenance (O&M). Each category and factors contributing to them are discussed for both FPV and land-based PV to further understand the benefits, challenges, regulatory considerations, market opportunities, and technical and developmental feasibility of FPV in the United States.

6 RESULTS & ANALYSIS

Table 1 below summarizes key factors impacting both floating and land-based FPV development potential. Each category is further discussed in the following subsections to assess the potential for increased FPV project development in the United States.

Factors Impacting Development Potential	**Floating PV**	**Land-Based PV**
Site Assessment		
Solar Resource	• Global horizontal irradiance	• Global horizontal irradiance
Transmission Line Proximity & Substation Proximity	• Can utilize existing infrastructure • Ability to site with hydropower • Site within 50 mi. radius of transmission lines	• Interconnection costs often footed by developer ○ Can increase project costs by 3-33%

Location	• Near load center & populated region
	• Must avoid:
	  ○ airport boundaries
	• Likely existing access roads
	• Often utility-owned reservoirs (no lease/purchase cost for utility) or single-owner
	• Can exist in more populated areas, less NIMBYism
		• Majority on private land, some on BLM land
		  ○ Often multiple landowners
		• Must avoid:
		  ○ airport boundaries
		  ○ local, state, federal parks/land
		• More often in less populated areas
		• May need to construct access road

Water/Land Surface Use	• Manmade reservoirs, hydropower dams, industrial water bodies, mine subsidence areas, irrigation ponds • Excludes reservoirs that any small, used for fishing, navigation, or recreation • Does not compete with agricultural, residential, or industrial land • Little to no ground excavation • Potential for integration with aquaculture • Freshwater, low hardness, low salinity • Saves 2.7x avg. land on capacity basis compared to land-based PV	• 5-10 acres/MW of generating capacity • Likely further from POI • Land excavation & grading required • Competes with land for agricultural, residential, industrial use
Feasibility Studies		
Market Assessment	• Emerging market	• Existing, well-developed market

Federal Regulations	• No existing FPV-specific federal regulations	• BLM right-of-way application, planning & environmental requirements
		  ○ Federal Land Policy and Management Act
		    ▪ Solar and Wind Energy Rule
		• NEPA review required

State Regulations & Permitting	• GIA • Ecological risk assessments • Hybrid projects sited with hydro under state jurisdiction	• Most projects qualify under RPS (38 states) ○ Solar or distributed generation carve-out (22 states) • GIA • Ecological risk assessments
Local Regulations & Permitting	• Ability to permit in non-sensitive zones • Building permit or equivalent	• Solar ordinances • Avg. 3-5 years to complete permitting process

	• Production & exploitation license, if applicable • Surface rights or water agreements	• Civil works permits often required • Building permit or equivalent • Production & exploitation license, if applicable • Land rights agreements
Environmental & Social Assessments		

Environmental Impact	• Groundwater and soil tests including a water quality assessment and elemental composition analysis
	• Environmental Impact Statement (potentially multiple)
		• Environmental Impact Statement (potentially multiple)
		  o USFWS critical habitat areas
		  o USFWS protected areas
		• 3-5 years process when on public land, less for private
		• Soil, water, air resource impact

Shading Impact	• Central inverter can cause shading • Mountainous area can cause shading	• Tree cover density • Land use impact • Surrounding environment if not maintained
Water Use	• Water can be used from reservoir for cooling	• Wet, dry, or hybrid cooling systems • Typically 20 gal/MWh
Social Impact	• Generally less opposition and NIMBYism • Less obtrusive projects, often go unnoticed by public • Utilizing already developed reservoirs that are sitting untouched	• Opposition – requires constant and early engagement with landowners, townships, public utility commissions, stakeholders, etc. o NIMBYism is large issue
Safety	• Walking hazard from moving floats • Risk of falling in water when operating or maintaining • Fencing or gate around property may be required • Protective/barrier 'warning' floats may be required if alternate uses for water body	• Little to no concerns for workers or general public
Financing & Contracting		
LCOE		
OpEx (O&M)	$ .026/Wp/year	$ .013/Wp/year
CapEx (capital expenditure)	$.73/Wp (hypothetical)	$.62/Wp
Types of Offtake	PPA	PPA, BT, DT, etc.
Tax Incentives	• Potential inclusion in ITC, MACRS, QOZ	• ITC – 26% if COD 2022, direct-pay available • Modified Accelerated Cost Recovery System (MACRS) • Qualified Opportunity Zones (QOZ)
System Design		
Equipment	• Floats/pontoons • Water-safe cables • Waterproof IP67 junction box • PV modules (same as land-based) • Inverter • Battery	• PV modules • Inverter • Charge regulator • Transformer • Mounting system • Cabling • Tracking system (if applicable) • Battery • Frequency & voltage monitor
Performance	• Panel cooling more efficient than ground-mounted • Soiling losses • Typical lifespan of 25 years • Higher initial performance ratio (5-10%)	• Greenhouse effect • Soiling losses • Typical lifespan of 25 years • Can benefit from tracking, bifacial modules • Yield prediction is more established
Procurement & Construction	• PV module supply chain impacts • Easy construction of floats and system (depending on location, float structure & workforce)	• PV module supply chain impacts • Location, size, and workforce determines ease of installation • Heavy equipment required

	• Construction on site preferred, then transferred to water • Ample storage space needed for floats during construction • Launching ramp area needed • Divers may be needed to install anchoring system • Access road built if needed	• Civil Work: grading/drainage, access roads, fencing • Structural Work: post-installation, racking assembly • Electrical Work: module installation, collection system, grid connection • Reclamation
Operations & Maintenance		
Technical Maintenance	• Specific training required ○ New technology = less trained O&M workers in field • Fewer parts readily available for replacement • Structural component replacement required more often • Risk of corrosion and oxidation of metal parts in higher humidity	• Specific training required for O&M workers • Parts available for replacement
Cleaning & Site Upkeep	• Easy access pathways for cleaning • Removal of bird droppings, dust (soiling) removal • Cooling systems • Recycling panels post-decommissioning	• Landscaping, erosion reporting & control, spill prevention & containment • Routine mowing, herbicide application, pest treatment, maintenance of ditch & buffer area • Dust, snow impurities (soiling) removal • Cooling systems • Recycling panels post-decommissioning

6.1 Site Assessment

Site identification is the first step for successful project development. Viable man-made reservoir sites for FPV projects include but are not limited to manmade reservoirs, hydropower dams, industrial water bodies, mine subsidence areas, wastewater treatment ponds, and irrigation ponds. Early data collection and site assessment allow developers to make informed decisions about the project's viability. There are numerous considerations and data points that must be assessed for site selection, including but not limited to: solar resource; local climate conditions; water surface area; bathymetry; water level and wind speed; subsurface soil conditions; shading; soiling; environmental considerations; access to grid & substation; power availability; access rights; permits; and regulations (World Bank Group et al., 2019). While most sites will not embody each of these high-preference features, an analysis must be completed by developers to determine if benefits outweigh potential costs.

Every state has floating solar potential, regardless of the diversity of bodies of water and solar resources (Trabish, 2019). However, no two projects are the same and each comes with its own set of varying challenges for consideration. The current median range for existing FPV projects utilizes no more than 27% of the water surface area for the FPV system. However, percent water surface area coverage can range from <2% to >80%, and there has not been a significant connection between installation coverage and water body area: the large range accounts for the fact that many panel coverage percentages are determined by point-of-use power needs, grid capacity constraints, and alternative uses of the water body. Additionally, project engineers should quantify the tilt angle for installations to accurately understand the structural integrity, generation ability, and evaporation loss from individual FPVs and larger inventories of systems (Cagle, et al., 2020). Any man-made reservoirs that are small, used for fishing, navigation, recreation, are within an airport boundary, or are located over 50 miles from a transmission line are currently not considered feasible for FPV development and should be filtered out from any initial site considerations.

Solar irradiance plays a critical role in FPV potential site assessment as it determines the energy yield and project finances, just as it does for land-based PV projects. Climate conditions at the site and seasonal weather variations including precipitation, wind speed, temperature range, wind direction, pollution index, and storm statistics also must be analyzed to understand their impact on construction, foundations, system layout and design, and overall reliability of the project (World Bank Group et al., 2019). Wind and anticipated wave characteristic studies must be used to analyze potential sites on dams and reservoirs, along with bathymetry and water body characteristics. Bathymetry, or the mapping of the waterbed, can impact the position of the floats and the overall design of the anchoring and mooring system (World Bank Group et al., 2019). Reservoir operation can also impact water level variation due to hydropower generation or irrigation, which must be taken into consideration when siting the FPV project. Further, the conditions of the water body's subsurface soil can impact anchoring methods and locations, which would be either on the bottom or attached to the banks of the reservoir, depending on the topography of the banks. Geotechnical, civil, and structural experts will need to perform groundwater and soil tests including a water quality assessment and elemental composition analysis to determine the materials used for the system (World Bank Group et al., 2019). Because FPV projects benefit from open and flat-water bodies with minimal shading, developers must consider the central inverters of the arrays that may cast shadows if there is not adequate spacing throughout the system design. Environmental impacts must also be considered during the siting stage. Sites with minimal impacts on flora, fauna, air, and water should be considered because the construction and operating phases can alter these local ecosystems. Gorjian et al. recommend basins in unprotected areas with no specific plants, protected creatures, or environmental restrictions present (2021). Additionally, sites will likely need to be fenced in or secured to prevent tampering, trespassing, and to act as a safety measure.

A thorough understanding of siting impacts and the natural and built geography of renewable energy sources is growing increasingly important as demand and land use tensions (i.e., agriculture, forest, or wildlife conservation) simultaneously grow globally. Further, the spatialized links between FPV projects and the water body they are floating on can create techno-hydrologic, local ecological, and local ecosystem services impacts. It is necessary to understand the varying spatial qualities of FPV, such as roundness, to further understand how the systems interact with their local surroundings (Cagle et al., 2020). In doing so, stakeholders and investors can more confidently understand the impacts the technology may have, leading to further investment and project development.

6.1.1 Land Use

Renewable energy development has surged in recent years, calling for land completion, even in the seemingly vast US as developers scramble to procure the most viable project sites. Floating solar projects offer the ability to spare land that could otherwise be used for agriculture, tourism, development, or land that can be left as-is for carbon capturing. Ground-mounted PV can use vast amounts of land that can be expensive, can have more adverse environmental impacts, and can take up large zones of land. Cagle et al. found that FPV installations offer the ability to spare an average of 2.7 times the area of land-based PV projects that are installed on a capacity basis (2020). NREL estimated 2.1 hectares of land could be spared for agricultural or various other uses if FPV projects were installed instead of land-based systems (Spencer et al., 2019). Typical utility-scale PV plants can take up 5-10 acres per MW of generating capacity (SEIA, n.d.(A)). Further, FPV can utilize existing transmission infrastructure present at many potential reservoir sites, such as hydropower dams or wastewater treatment ponds, which can lower overall costs significantly. Land-based PV projects often pay high costs to connect to transmission infrastructure as they tend to be sited further from the point of interconnection (POI), which can increase direct plant-level costs by 3%-33% that are often footed by the developer (Berkeley Lab, 2019). As climate change worsens and temperatures continue to rise, agricultural land and green zones will become increasingly valuable and FPV presents a new pathway for increased renewable energy generation that can help mitigate this issue while simultaneously reducing carbon emissions.

6.2 Feasibility Studies

The timing and order of activities in prefeasibility, feasibility studies, and the financing or contracting stage can differ substantially based on each specific project. A thorough understanding of each concept assessed during feasibility studies is necessary for the increased development of floating solar technology in the United States.

6.2.1 Risk Analysis

Both land-based PV and floating PV projects can be owned by independent power producers (IPPs) or utilities depending on the region and existing regulatory framework. Therefore, the due-diligence process for bankability and risk analysis for FPV projects can be modeled off the process for land-based solar projects. However, various risks apply only to land or water, and these must be considered independently. Lenders, regulatory bodies, and insurers will need to evaluate the following summary of risks (non-exhaustive list) when considering a potential FPV project:

Risk Type	Description and Assessments
Political & legal environment	Assessment of current US legal and political framework, stability risks, new or changes to existing legislation, renewable energy incentives and targets, climate action plans.
Owner or sponsor	Experience in finance and technology, potential response to cost overruns.
Resource	Independent assessment of productivity, anticipated energy yield, solar irradiance resource at site, on-site data collection verification, climate change impact.
Technology	Track record of existing and emerging technologies, product reliability, product safety, environmental site assessment impact on technology.
Regulatory and Compliance	Current legal and regulatory environment in US, permits and licenses needed, land use rights, water rights, social and environmental impact assessment.
Construction	Assessment of engineering, procurement, and construction contractors, structure design and procurement, experience of float installers, testing and commissioning
O&M	Spare parts for maintenance, maintenance plan, system accessibility, insurability.
Decommissioning	Regulatory concerns, disposal or recycling plan, waste management considerations.

Table 2: Summary of key risk assessments for FPV projects. (World Bank Group et al., 2019).

A lack of suitable simulation tools that can be used to estimate electricity production and therefore levelized cost of energy (LCOE) can restrict company performance and the ability to make knowledgeable investment choices, which can subsequently impact banks' decisions to finance FPV projects (Oliveira-Pinto & Stokkermans, 2020). Most projects in the US so far have been "built with the individual companies' balance sheets" due to lack of financing from banks (Trabish, 2019). Because FPV is a newly emerging technology, project owners will need to work with lenders and stakeholders to determine which risks can be accepted and which need an adaptation or mitigation plan. Risk analysis can safeguard a project's financial structure before funding is secured as well as during construction and operation periods to guarantee that the project requirements and payback levels are sufficiently met (World Bank Group et al., 2019).

6.2.2 Market Assessment

The floating solar market has seen considerable growth over the last several years. Individual installations have steadily risen each year since 2013 (Cox, 2019). In 2019, the floating solar panel market demand around the globe was at 615.2 MW but is expected to expand at a compound annual growth rate of 28.9% throughout the next 7 years (Grand View Research, 2020). At the end of 2019, there were 338 projects installed in 35 different countries, up from 27 countries in 2018 (Cox, 2019). The global market generated revenue of $684.2 million in 2019 and is projected to rise to $2,301.8 million by 2026, according to a recent market research report (P&S Intelligence, 2020). As global power generation shifts from fossil fuels to renewable or clean fuel generation market growth is expected to grow, especially in areas that are land constrained. Several large plants that have come online in recent years, particularly in China, have influenced the current market. Geospatial factors like location and size primarily influence opportunities in the market. The United States has been identified as having the most market capacity at 1,260 GWp, an area factor of 100 Wp/m^2, and solar irradiance performance ratio of 80% due to the 34% of total water bodies and 32% of the total water surface area available in the country (Gorijan et al., 2021). The market potential in the US is projected to range from 1-5 MW projects that are primarily water utilities, commercial and industrial customers that install the projects for on-site competition, or behind-the-meter projects (World Bank Group et al., 2019). Without any major new policy developments at the federal and state level, the FPV industry in the US through 2030 is expected to triple the amount of installed capacity from 2020 levels to 324 GW. This is largely due to projections of falling prices while demand from utilities, states, distributed solar customers, and corporations continue to rise (Davis et al., 2021).

The market is divided into product types: tracking floating solar panels and stationary floating solar panels. Stationary floating solar panels represent the larger revenue share at 80.2% in 2019 primarily due to cost advantages from this technology when compared to tracking floating solar panels. Stationary panels are also considered less expensive to install than tracking, as they are constructed of low cost and high strength elastic. Additionally, tracking panels also require more maintenance due to the moving nature of their parts. However, there has been an increase in the development and manufacturing of tracking panels that have superior operational productivity due to the ability to track sunlight, which is projected to positively influence the demand side (Grand View Research, 2020).

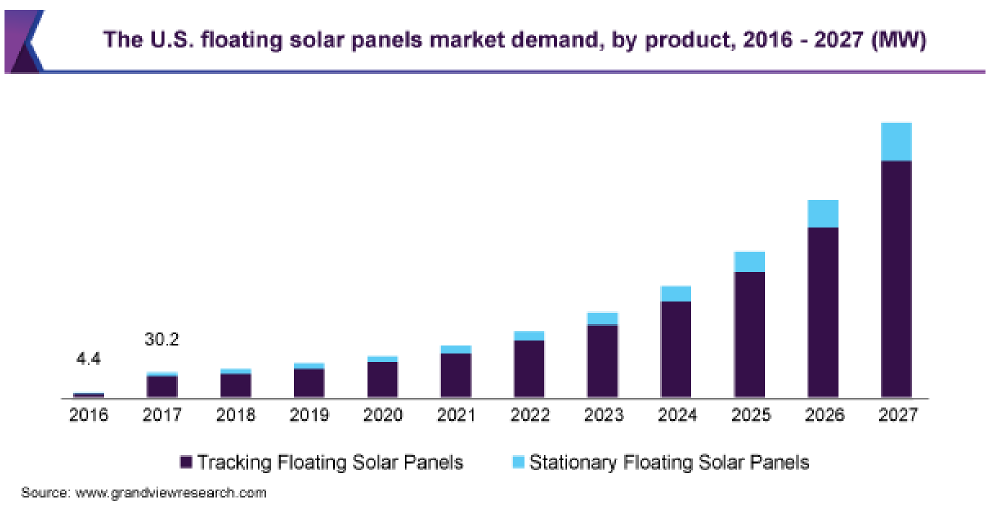

Figure 4 – Tracking floating solar panel demand is projected to increase substantially by 2027 (Grand View Research, 2020).

The US land-based solar market is highly established compared to floating solar. In 2020, the land-based PV market installed a record of 19.2 GW_{dc} of solar capacity, which was up 43% from 2019 and ranked first among all new electric-generating capacity technologies for the second year in a row. At the end of Q4 2020, the utility-scale contracted project pipeline reached 69 GW_{dc} (Davis et al., 2021).

6.2.2.1 Key FPV Companies & Market Share

The floating solar panel industry has grown into a highly competitive market on a global scale. Major industries across regions are concentrated, with Kyocera standing as the largest player of the major companies due to its global scale and numerous distributors. Primary industry leaders implement key strategies like research and development programs and product innovation. Ciel & Terre, for example, operates on a global scale as a top installer and has installed over 180 FPV projects, which is over half of the total installed farms worldwide. Key players like Ciel & Terre have provoked smaller and local players to expand their business strengths across regions to keep up with the developing market (Grand View Research, 2020). The company is currently leading US FPV developers with 5.2 MW of projects spanning New Jersey, California, Colorado, and Florida (Trabish, 2019). An overview of key companies active in the global FPV industry (non-exhaustive list) is provided below in Figure 4.

Figure 5: Overview of companies active in the global FPV industry. (Source: Haugwitz, 2020).

6.2.3 Policy & Regulatory Considerations

Currently, the United States does not have any specific regulations or guidelines for FPV applications. For existing projects, developers have followed state-specific ordinances, acts, and regulations relating to land use, water rights, and environmental assessments. Land-based solar, however, has a well-established federal application and review process. Applications for projects are processed and authorized as rights-of-way under Title V of the Federal Land Policy & Management Act and Title 43, Pt. 2800, of the Code of Federal Regulations. Any utility-scale PV project must also apply with the Bureau of Land Management's right-of-way application, planning, and environmental requirements. A National Environmental Policy Act review is also required (BLM, n.d.).

6.2.3.1 Licenses, permits, and authorizations

The lack of established precedent for issuing permits for installations has hampered development in the United States. Due to the lack of specific FPV regulations in the US, developers will need to comply with each county's understanding of state regulations. Permitting in non-sensitive zones (i.e. agricultural or industrial ponds) is understood to be less complex than land-based solar where various permits may be required due to the heavy civil works. Just as required for land-based PV projects, developers will procure several agreements and studies that are central to the permitting process, which can take anywhere from a few months to a few years to complete in extreme cases. A site control agreement, Generator Interconnection Agreement (GIA) with the utility to connect to the grid, a land-use and water rights infringement study, Phase 1 (and Phase 2 if needed) Environmental Site Assessment(s) (ESA), and ecological risk assessments are all typical requirements for land-based PV and would likely be required in the permitting stage for FPV projects. Surface rights, land rights, water agreements, a production & exploitation license, and building permits may be required for both technologies. Siting FPV plants on hydropower dams fall under state jurisdiction due to the higher liability level involved with the dam owner, which can make permits harder to obtain and may require additional feasibility studies (World Bank Group et al., 2019). Land-based PV developers will need to worth with local and state authorities such as a state public service commission or local township planning commissions to obtain special use permits or work together to enact solar ordinances. A general establishment of a framework of regulations and policies relating to FPV project development would reduce development costs and would spur further investment in the technology.

6.2.3.2 Supportive Government Policies

Government policies under the Biden Administration can promote further expansion of the FPV industry in the US. Biden recently pledged to halve greenhouse gas emissions by 2030 – a goal that will require an extensive expansion of the renewable energy industry and simultaneous divestment from fossil fuels. In a meeting in April 2021, 13 utilities including Exelon and National Grid urged the Administration to adopt various policies that would permit deep decarbonization of the power sector "including a clean electricity standard that ensures the power sector, as a whole, reduces its carbon emissions by 80 percent below 2005 levels by 2030" (Dennis & Eilperin, 2021). This meeting signals key players in the power sectors' desire to shift towards a clean energy industry and adopt any promising emerging technologies to capitalize on potential federal policies, such as a clean energy standard. The Biden Administration will continue to facilitate the expansion of renewable energy generation in the US re-entering the Paris Climate Accord, allowing renewable energy siting on public lands, and implementing clean energy goals for the US will all allow for further development of opportunities in the solar industry.

6.2.3.3 Renewable Portfolio Standards

A Renewable Portfolio Standard (RPS) requires that utilities sell and deliver a certain amount (in percentage, megawatt-hour, or megawatt terms) of renewable energy to their consumers by a specific date. These standards aim to diversify energy resources, encourage domestic generation, reduce emissions, promote economic development, and spur green job development. Renewable portfolio policies exist amongst a broader range of market and policy drivers for renewable energy growth, such as federal tax credits or net metering. Most policies differ significantly by state, so the scope of a particular policy can be limited to the state boundaries and actors that are impacted within that state. As of September 2020, 30 states, Washington, D.C., and four territories implement a renewable energy standard or goal (DSIRE, 2020). Certain regions like the northeast, mid-Atlantic, and west have experienced significantly higher adaptation of renewables through compliance with their state standards. Figure 6 below shows the current makeup of renewable standard policies throughout the United States.

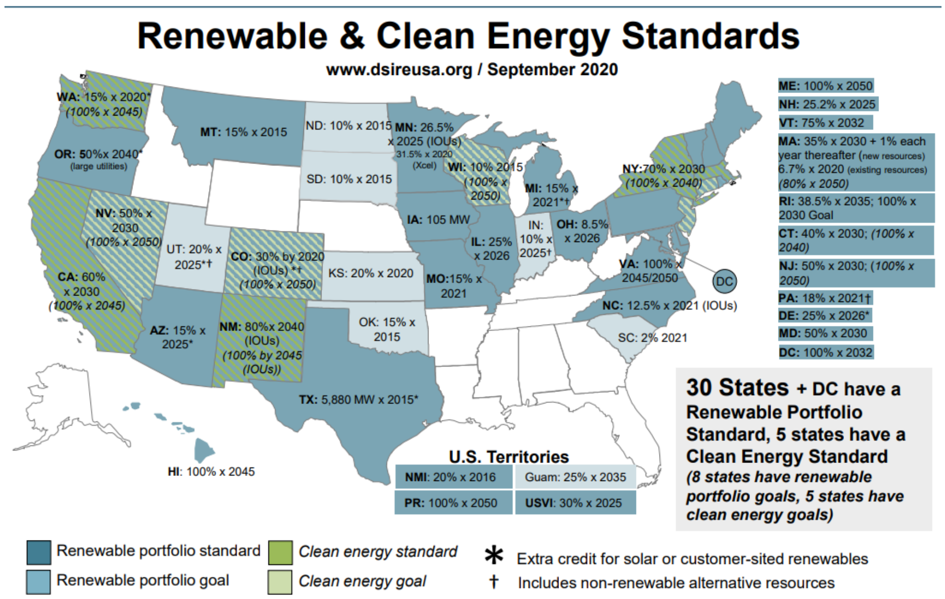

Figure 6: US Renewable & Clean Energy Standards as of September 2020. (Source: DSIRE, 2020).

States that have a mandatory or voluntary Renewable Portfolio Standard, Renewable Portfolio Goal, Clean Energy Standard, or Clean Energy Goal can modify their definitions of renewable energy sources to include floating solar technology. In doing so, floating solar projects can play a role in a state's goal to diversify its energy consumption while divesting from fossil fuels to lower overall GHG emissions from the energy sector.

6.3 Environmental & Social Assessments

Environmental and social impacts of an FPV or land-based PV project can vary considerably depending on project size, site, and local characteristics, and type of technology deployed. Federal, state, and local requirements must be abided by, as well as potential expectations and requirements established by financing institutions. In the early phases of project development, developers will need to vet direct and indirect impacts on the entire area of influence on the site's natural and built environment throughout the project's lifespan.

6.3.1 Environmental Impacts

A newly emerging technology like FPV can only be successfully deployed if there are minimum negative impacts on the environment. FPV has various benefits when compared to land-based PV solar systems, though both technology systems are not completely free of environmental impacts. However, once operating, FPV can be considered environmentally sound because it reduces evaporation from water reservoirs, improves the water quality of the reservoir, reduces water movement to minimize erosion, and reduces dust accumulation.

The United States' two largest man-made reservoirs, Lake Powell, and Lake Mead, both in Southwestern drought-prone desert areas, present two areas for significant water savings by operating FPV projects. The US Bureau of Reclamation estimated Lake Mead loses 800,000 acre-feet of water (6% of the Colorado River's annual flow) from surface evaporation due to the desert sun on average each year. Lake Powell loses nearly 860,000 acre-feet due to evaporation and bank seepage (Warburg, 2016). One proponent claimed that FPV projects can reduce evaporation rates in dry climates, such as South Australia, by up to 90% (depending on project scale, temperatures, etc.), so covering even a fraction of the two reservoirs could reduce evaporation by a considerable amount (Doran, 2014). For example, if only 6% of Lake Mead's surface had an FPV project installed, it could generate at least 3,400 MWs of electric-generating capacity, which is more than the Hoover Dam's generation capacity of 2,074 MWs (Warburg, 2016). Further, some of the energy generated could utilize underused transmission lines that were built out for the Hoover Dam. While recreational lake users may be opposed to portions of the lake being used for floating solar projects, the need for water reclamation is becoming increasingly apparent as beaches are receding. While this area is not necessarily land constrained, open desert area is becoming increasingly stressed as developers seek the high solar irradiance locations for their utility-scale land-based PV projects. Wildlife and environmental advocates have opposed the development of these utility-scale projects in at least 7 counties surrounding Lake Mead and Powell as the desert tortoise and other desert wildlife can be adversely impacted (Warburg, 2016). It is critical to maintain a balance between water supply and electric demand as climate change impacts are increasingly detrimental. Floating solar projects can play an important role, especially in the Southwest, where reducing water losses from evaporation will need to be considered as part of an overall conservation strategy.

Bird collisions are also reduced with FPV systems when compared to ground-mounted (Gorjian et al., 2021). While FPV systems could impact avian species such as water-feeding birds and surface divers, there are mitigation measures that can be taken by developers to avoid injury or loss. Limiting reservoir surface coverage can help prevent loss of avian habitat, or bird deterrence systems can be installed. One quick fix that works with a dual objective would be utilizing a water veil cooling system to not only keep the modules cool but also clean the modules and dissuade birds from resting or nesting on the panels (Rosa-Clot & Giuseppe, 2020). Additionally, the system could be installed outside the littoral zone of the water body to reduce the entanglement of shorebirds while also minimizing potential impacts on aquatic flora and fauna (World Bank Group et al., 2019). An additional significant environmental benefit of FPV is the reductions in abnormal algae growth or eutrophication, which a massive environmental issue throughout the US as it can lead to highly anoxic conditions causing fish death, such as the Lake Erie yearly algal blooms that stem from runoff pollution (Hooper et al., 2020). These benefits can vary by region, as FPV can reduce drinking water evaporation in more arid regions while in areas with more humidity, the systems can reduce algae growth (Trabish, 2019). In countries that are susceptible to famine, FPV is projected to substantially grow because the installation of the PV cells over water bodies reduces the growth rate of algae and reduces the evaporation rate, thereby preserving the cleanliness level of the water supply (Grand View Research, 2020).

Positive responses to FPV installations have been observed from ichthyic (fishlike) fauna. An FPV project in Colgnola, Italy is sited on a basin used for sport fishing, and the carps residing in the basin tended to stay under the platforms due to partial shading and small formation of algae under the HDPE piles, to the displeasure of the fisherman (Rosa-Clot & Giuseppe, 2020). Several projects, primarily in China and Southeast Asia, have co-sited FPV plants with activities related to shrimp or fish farms, which revealed the utilization of an FPV system generated a higher reliability factor and lower LCOE than a land-based PV system (Wasthage, 2017). The FPV synergy with ichthyic fauna presents cost savings for the owner while also reducing potential algae blooms and evaporation. Additionally, FPV limits the greenhouse effect when compared to land-based PV. Strong reductions of albedo effects on land-based PV plants can lead to a negative radiation energy balance, which contributes to global warming. On the contrary, floating PV plants do not alter the radiation balance. This can be considered a significant advantage, particularly if installed power is projected to increase dramatically (Rosa-Clot & Giuseppe, 2020).

Project developers will be responsible for obtaining numerous licenses, permits, approvals, etc. from local, state, and regional authorities and abide by US environmental laws. Environmental monitoring by trained individuals should be conducted during the construction and operational phases for review regularly to better understand potential impacts to the flora, fauna, water quality, etc. of the site.

6.3.2 Environmental Challenges

Environmental impacts, while far less than fossil fuel generation, are not nil for FPV systems and depend on the project size, technology type, and site conditions. Few studies have analyzed the impacts that FPV systems have on water bodies since the technology is still in the early stages of implementation, so the impact assessment phase of the project must collect site-specific data on all factors that impact water quality, such as bathymetry, level of resource, industrial, and agricultural extraction activities, and the presence of inundated biomass. For example, if too much of a hydropower reservoir's surface area is covered with an FPV system, it could impact an operator's ability to meet environmental requirements through selective withdrawal techniques (World Bank Group, et al., 2019).

The manufacturing process of PV modules, inverters, and other components do require large sums of energy and can release harmful substances into the environment. During the implementation and decommissioning phase, boats risk leaking polluting materials into the water (i.e., oil, fuel, etc.) that can harm the reservoir environment. Positioning of the ballasts for anchors on the bottom of the basin can lead to water mixing and cloudiness that could lead to habitat loss for fauna in the water. Noise pollution must also be considered at this stage, which is primarily linked to construction vehicles that could harm the surrounding environment (Gorjian et al., 2021). Additionally, the accidental release or use of cleaning detergents that are used to clean panels can impact water quality, flora, and fauna (World Bank Group et al., 2019). Recycling PV panels upon plant decommissioning also presents an environmental concern. While large portions of panel mass can be recovered, much is down-cycled into lower-grade materials (Dayrit, 2016).

Several environmental issues are specific to land-based solar plants that should be considered when comparing the technology to FPV. The large amount of land needed for utility-scale PV projects presents the largest environmental concern, as land acquisition may interfere with existing land uses and can impact wilderness or recreational management areas. The energy footprint of a PV plant can become incrementally high through the materials exploration, extraction, manufacturing, and disposal on the land. Clearing and grading on vast areas of land can result in soil compaction, changes to drainage channels, and can lead to increased erosion (Dayrit, 2016).

6.3.3 Occupational Safety

Any safety issues that may result from FPV project installation, maintenance, or operation must be considered during early development phases as well. Most health and safety-related impacts are like those at a large industrial facility or installation of a land-based solar plant, such as the risk of use of heavy equipment like cranes, hazardous materials, potential for loud noise and dust, and trip or fall hazards. Electrical hazards from the use of typical machinery, tools, and working near live power and electrical lines also pose an inherent risk (World Bank Group et al., 2019). FPV presents the additional risk for personnel working over water, where constant movement of the floats can pose a walking hazard or risk of falling into the water. Special equipment including life jackets, boats, wireless radios should be utilized, and personnel should be trained to account for the risks (World Bank Group et al., 2019).

6.3.4 Community Health & Safety

Public access presents a concern for community health and safety when an FPV project is accessible to the public, however, for projects specifically sited on man-made reservoirs, this is a lower concern than if sited on a lake or other water body. Gates can be used on access roads, or fences can be installed around the site if there is no right-of-way access. If public access is allowed at the site, developers can also install floating modular safety barriers around the system.

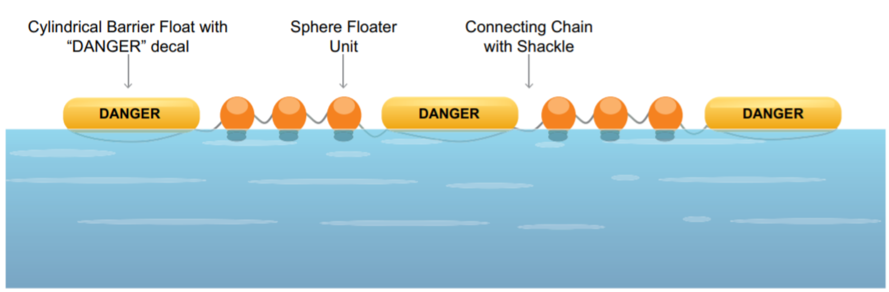

Figure 7: Example of a safety barrier float surrounding a PV project for the Bedok Reservoir in Singapore. (Source: World Bank Group et al., 2019).

6.4 Financing & Contracting

Utility-scale land-based solar often is contracted through a power purchase agreement (PPA) with an energy utility. PPAs offer the buyer a low, fixed-rate for electricity and extended savings on utility rates. It also deters rising utility rates and operation & maintenance (O&M) costs as the developer is often responsible for covering these fees. Existing FPV projects in the US have been contracted through PPAs between the developer and buyer, such as a municipality or water utility (White Pines Renewables, 2021).

6.4.1 Costs

The commercial pathway of FPV has been steadily and rapidly improving and is near or slightly higher than ground-mounted, utility-scale photovoltaic capital expenses. However, there are not enough projects in the US to accurately analyze the installation, maintenance, and operating costs as the technology and supporting components are constantly changing and evolving. This said, assessments can change considerably soon as the systems and development practices become more established.

6.4.2 Capital Expenditure (CAPEX)

Evaluations of the implementation costs for FPV systems must consider key system components. Floats, which are generally made of HDPE or glass fiber reinforced plastic can vary in costs depending on the type chosen. Floats typically account for approximately 25% of the capital expense breakdown of an FPV plant, which contributes to the minor cost discrepancy between land and floating PV projects. However, the higher costs of acquiring land and seismic-proof foundations, permitting costs, and civil works that are required for utility-scale ground-mounted PV systems often balance out the cost of the floating structures. Oliveira-Pinto & Stokkermans anticipate that costs of floaters will decrease soon due to economies of scale, and therefore, the same assumption can be made for FPV capital expenses (2020). Mooring system installation in deep water or reservoirs with large changing water levels can also add significant expenses. FPV requires special cables and connectors for water application, and Gorjian et al. recommend waterproof IP67 junction boxes, which can be more expensive (2021). The PV modules, other electrical components, inverters/and or batteries are the same that are used for ground systems. Additionally, the construction and labor costs of installing on water can cost more than ground-mounted systems (40 US$/h vs. 60 US$/h, respectively), though these prices can differ considerably across the United States and over time. However, these costs can be offset because the FPV system does not use soil and therefore eliminates soil leveling costs required for a ground-mounted project. While land-based PV installation labor typically costs less per hour, the installation time for a typical 3 MW ground-mounted project is 8 weeks due to the need to construct foundations and level land, while installations of FPV floats typically only take up to a week (Martins, 2019). Additionally, solar radiation data measurements, bathymetry, wind surveys, grid connection assessments, and environmental impact assessments represent additional costs required for projects sited on larger man-made lakes that typically range from $25-85 USD (Gorjian et al., 2021). Overall, Oliveira-Pinto and Stokkermans found that the FPV CAPEX is generally 25% higher than ground-mounted projects due to the floats, mooring, and anchor costs (2020). The World Bank Group calculated the CAPEX for a hypothetical fixed-tilt 50 MWp FPV project compared to a ground-mounted system of the same position. The CAPEX breakdown is summarized in Table 2 below.

Cost Component	**FPV System**	**Ground-Mounted PV System**
PV Modules	US$ .25/Wp	US$ .25/Wp
Inverters	US$ .06/Wp	US$ .06/Wp
Assembling Systems	US$ .15/Wp	US$ .10/Wp
Balance of System (BOS)	US$ .13/Wp	US$ .08/Wp
Total CAPEX	**US$ .73/Wp**	**US$ .62/Wp**

Table 3: Hypothetical CAPEX comparison for FPV vs. ground-mounted systems. (World Bank Group et al., 2019).

6.4.3 Operating expense (OPEX)

Primary costs related to the operational phase of the plant are comprised of lease or rental fees for the installation site, general & labor O&M costs, asset management, monitoring costs, cleaning, and insurance (DNV GL, 2021). Siting FPV plants on man-made reservoirs that cannot be used for other purposes, such as agriculture or construction, can lower these costs considerably. Utilities, especially water utilities, typically have free access to man-made water surfaces and have been working with private developers to diversify their renewable energy portfolios. FPV presents a cost-effective opportunity as utilities may not have the funding or access to acquire affordable large areas of land for land-based PV projects but can utilize free, unused water areas they already own for FPV (Trabish, 2019). O&M costs can include the replacement of failing or faulty devices (i.e., PV modules, inverters, electrical components) and cleaning the modules, which can be more expensive for ground-mounted projects. Maintenance costs for the moorings and floats require specialized training and modules may need to be cleaned more frequently if there is a high presence of bird droppings (Gorjian et al., 2021). When the FPV project is sited on a dam reservoir, probable values for floating installations are two-fold the OPEX of costs of ground-mounted systems, according to Rodrigues et al. (2020). However, the same study also concluded that OPEX will decrease by nearly 30% and 50% until 2030 and 2050, respectively. Another study by Martins (2019) found that the OPEX costs in the economic assessment phase for FPV vs. ground-mounted systems are US$ .026/Wp/year and US$ .013/Wp/year, respectively. Additionally, Haggerty stated that FPV and land-based PV are nearing price parity largely due to the lower operation and maintenance costs of FPV. FPV panels also stay cleaner because there are fewer soiling issues, the solar materials generally cost less and have more efficient anchoring and construction practices (2020).

6.4.4 Levelized cost of electricity (LCOE)

Many studies have carried out the LCOE of ground-mounted PV systems that consider the following variables: solar irradiance, climate zone, performance ratio, CAPEX, operating years, insurance, O&M, structure degradation rate, and financial leverage (Gorjian et al., 2021). While there are less than 30 active FPV projects in the US currently, several municipalities have been assessing the implementation of the technology. The second-largest project in Sayreville, New Jersey (4.4 MW) that is built on the town's drinking water treatment center reported costs as low as US$ 1.6/Wp, but plants below 1 MW maintained costs around US$ 3-5/Wp (Sylvia, 2019). However, these prices could fluctuate considerably as more utility-scale projects come online and geographically expand throughout the US. If FPV follows similar LCOE trends as land-based PV, LOCE should fall considerably. The median LCOE for utility-scale PV declined by 85% from 2010 to $40/MWh in 2019 without ITC incentives included (Bolinger et al., 2020).

6.4.5 Tax Incentives

Continued extensions of the Federal Investment Tax Credit (ITC) can also help facilitate the buildout of FPV projects. The program is considered one of the most important federal policy mechanisms to support the solar energy industry growth. Solar projects are eligible under the ITC of 26% if construction starts before the end of 2022, which is reduced to 22% in 2023, and 10% in 2024 (10% for commercial & utility-scale only, 0% for residential). Since the credit program was enacted in 2006, the solar industry has seen an average annual growth of 52% - with a total growth rate of 10,000% (SEIA, 2021). Biden's recent (March 31, 2021) rollout of an infrastructure plan called the American Jobs Plan includes a 10-year extension and phase-down of direct-pay ITC. A direct payment provision to the ITC would provide solar installers with a direct cash payment instead of a tax credit, which would encourage more installers or developers to take up solar projects. It would decrease installation costs directly instead of receiving the incentive once taxes are filed later (SEIA, 2021). If the tax incentive is amended to include floating solar in its language, it could spur interest from developers and FPV stakeholders to consider adding FPV to their portfolios.

The Modified Accelerated Cost Recovery System (MACRS) is another tax incentive that can be applied to utility-scale solar projects. MACRS depreciation allows the capitalized cost of solar energy equipment to be recovered over a five-year period via annual deductions. The market certainty provided by the incentive is an important driver of private investment for the solar industry. When an ITC grant is also claimed, the owner must reduce the product's depreciable basis by half the value of the ITC, resulting in an 85% deduction of the owner's tax basis (SEIA, n.d.(B)). Municipal wastewater treatment plants and water utility property are examples of qualified assets under the system that could host FPV plants and allow developers and utilities to benefit from the incentive (Kagan, 2021). Additionally, Qualified Opportunity Zones (QOZ) are a tax incentive utilized by utility-scale land-based PV developers that may also present opportunities for tax credits on FPV projects. A QOZ is an economically distressed area where certain new investments would be eligible for preferential tax treatment through either a temporary deferral, step-up in basis, or permanent exclusion. Qualifying localities now span 50 states as depicted in Figure 8 below. (IRS, n.d.).

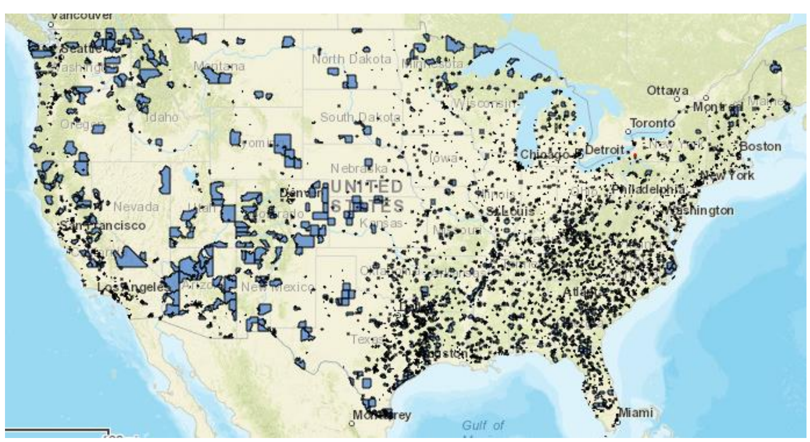

Figure 8: Map of Qualified Opportunity Zones for potential development sites. (Source: Opportunity Db, n.d.).

Floating solar projects sited in these zones could take advantage of the tax incentive, which would further spur the development of the utility-scale FPV industry in the states.

6.5 System Design

6.5.1 System Overview

The general layout of an FPV plant is like land-based PV, except the arrays and inverters are mounted on a float. FPV has benefited from lessons learned from the land-based PV industry, which has significantly reduced the risks associated with electrical aspects of the FPV system (World Bank Group et al., 2019). Currently, no single FPV technology or design is the clear market leader. Floating solar systems include floats or pontoons, module mounting structures, the mooring system to stabilize the floats, photovoltaic modules, BOS components, and inverters. The PV modules are mounted on top of the floats to convert incandescent solar irradiation into electricity (DNV GL, n.d.). The pontoons or floats keep the panels afloat through buoyancy and include ample space for human activity for operations and maintenance access.

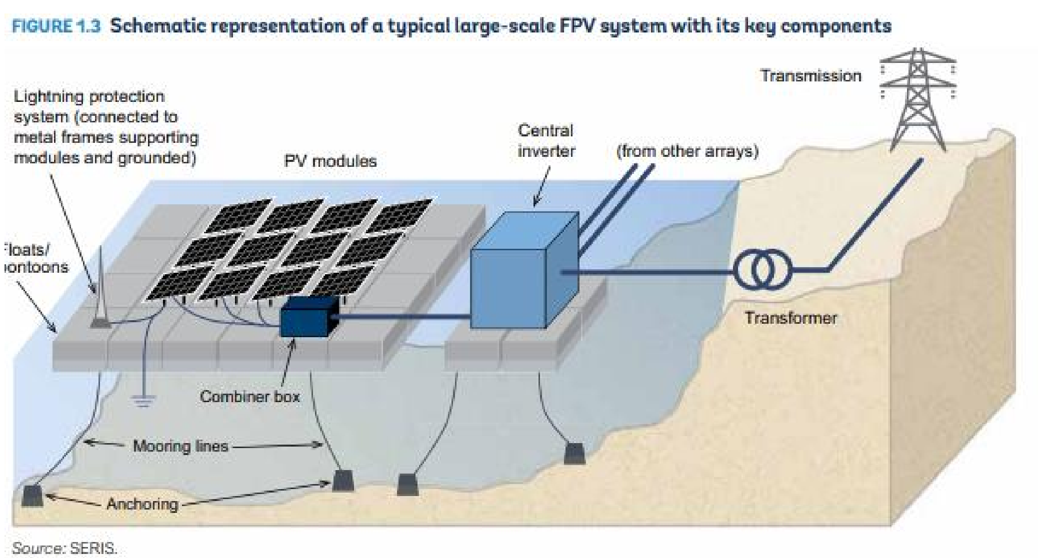

Figure 9: Schematic view of typical floating PV system and related components. (World Bank Group et al., 2019).

The MRac Floating PV Mounting System G4S, for example, uses HDPE material (the most common for FPV projects) and a new module design that can increase the efficiency of power generation and installation capacity and has a lifetime of over 25 years (Mibet Energy, n.d.). While flat, rigid PV panels are most widely used in the systems, flexible plans that can adjust with wave movement are becoming increasingly popular in the market, though they are still in the early stages of market implementation (Gorjian et al., 2021). One benefit of floating solar is that the shadow effects are insignificant or non-existent and the water the systems float on plays a major role in lowering the temperature of the panels, making the efficiency of FPV panels almost 11% higher than ground or roof-mounted photovoltaic panels (Gorjian et al., 2021).

6.5.2 Reliability & Resilience

6.5.2.1 Panel Cooling

Because water has a larger specific heat than ground, water bodies heat up more slowly during the day than nearby land. Additionally, water can eject heat through evaporation, and wind speeds are higher over water bodies as opposed to land due to the vegetation and elevation changes that can break up wind currents (Ibeke et al., 2017). Therefore, floating PV panels can reject more heat than land-based panels through convection and conduction, meaning that the operating temperature of FPV solar cells is lower than that of land-based cells, which makes floating panels more efficient. Ibeke et al. found that on the hottest part of the day in arid regions, FPV panels are 10-20°C cooler than ground-mounted, making the floating panels at minimum 5-10% more efficient with the ability to generate 20-25% more electrical energy throughout the day than land-based panels (2017). Trabish found that the cooling effect can increase power production by 1.5% to 22% (2019). Cooling techniques have also been proposed and tested in recent years to mitigate the negative effects of efficiency drops with high temperatures, especially for PV silicon crystalline cells. Forced, air, water veil, water spraying, circulation of forced water, and water submersion all represent cost-effective techniques for FPV plants due to the availability of water a lower energy consumption of pumping (Rosa-Clot & Giuseppe, 2020).

6.5.2.2 Siting on hydropower plant (HPP) dams

Siting floating solar on hydropower reservoirs has additional benefits over siting on lakes or ponds and can create mutual gains for both hydropower and solar power (Patel, 2020). NREL researchers recently determined 379,068 freshwater hydropower reservoirs around the world would be suitable hosts for FPV systems, subject to more in-depth siting analyses. The hybrid projects have the potential to generate as much as 7.6 TW/year of potential power from the floating solar plants alone (not accounting for the power generated from the HPP) (Lee et al., 2020). Rosa-Clot & Giuseppe analyzed the first 20 larger hydropower plants around the world and found that if 10% of the plant basin surface is covered with FPV, hydropower plant production would increase by 75% (2020). The same study analyzed 100 HPP in the US with a total generating capacity of 32,574 MW. To simply install FPV of power equal to that of the HPP, only 1.19% of the surface would need to be covered to produce 40.5% of the hydroelectric energy production. Installing an FPV plant equal to the HPP plant output and reducing the hydro turbines' power production during peak sun hours would maintain the energy injected into the grid at a constant rate (Rosa-Clot & Giuseppe, 2020). An array of 840 FPV panels were installed on the reservoir of a hydropower facility on the Rabagão River that had a capacity of 220 kW exceeded expectations according to the project developer, EDP Renewables (Agostinelli, 2020).

There are various additional benefits from creating a hybrid FPV-HPP system. The FPV plants do not take up additional land, which is an important factor when considering a hybrid facility. The orographic structure of basins that are generated by HPP dams are often complex and present an obstacle for finding nearby suitable land to host a large PV plant (Rosa-Clot & Giuseppe, 2020). Drought and rainfall fluctuations can impact the power generation capacity of hydropower systems which can be alleviated with FPV installation on the plant reservoirs. Because the floating PV systems reduce the rate of evaporation, the systems can assist in reducing the impact of droughts in high-temperature locations like the central and southwestern United States. Depending on the float design and parameters of the plant, but Rosa-Clot & Giuseppe found an 80% reduction in evaporating due to the hybrid design (2018). Kougias et al. found that the close water-energy interrelationship has fostered opportunities to attain the synergy among energy generation and water provision (2016).

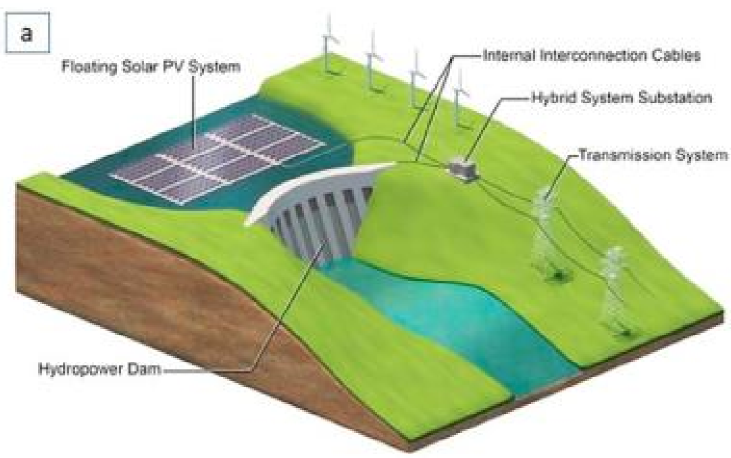

Figure 10: Schematic view of hybrid FPV-hydropower plant and the primary components. (Gorjian et al., 2021).

Additionally, FPV can utilize existing electricity transmission infrastructure at hydropower sites, can be sited close to demand centers with existing water supply reservoirs, and tends to have an improved energy yield due to lack of dust and cooling impacts of water – all of which can reduce overall costs for FPV systems (World Bank Group, et al., 2019; Rosa-Clot & Tina, 2018). The World Bank Group estimated that by covering only 3-4% of a hydropower reservoir with FPV, it could double the installed capacity and allow water resources to be managed strategically by utilizing solar output during the day (2019). However, Haas et al. (2020) found that covering the reservoir with 40-60% can eliminate algae to an optimum, maintained level without any loss of hydropower plant revenue.

Further, the combination of solar and hydropower could smooth the variability of solar output, and prevention of water evaporation can benefit hydropower production through increased water availability leading to increased energy generation (Fafan & Breyer, 2020; Liu, et al., 2019). Power output from FPV can reduce water consumption from the hydro plants that can alternatively be used to meet peak-demand load conditions (Gorjian et al., 2021). While many HPPs steadily produce electricity due to the constant flow of water year-round, some plants experience variations in water levels due to seasonal variations, which can lead to fluctuating energy production from the dams. FPV offers extra electricity production during the day to stabilize the dam output of the hydroelectric plant when water levels fluctuate (Thoubboron, 2020). This concept is particularly beneficial for areas with weaker electric grids where electric generators must continue to operate smoothly, and the grid remains stable.

Pumped Storage Power Systems (PSPS), which is a particular form of hydropower, can further complement a floating solar system by storing energy and addressing the problem of intermittent energy generation at solar facilities. Further, PSPS have been found to have the highest storage capacity and are considered more economical when compared to other energy storage systems, according to Ma et al. (2014). PSPS also improves grid stability, power quality, and overall dependability from the benefits of flexible regulation methods and solid load-floating capability. At a hybrid solar-hydro facility, operators could store surplus solar power using pumped-storage hydropower systems that utilize electricity to pump water to a higher elevation (Patel, 2020). All of these benefits should be taken into consideration by developers and stakeholders when considering expanding their development portfolios to include FPV technology, as land-based solar does not offer the same benefits when paired with hydropower sites.

6.5.2.3 Weather Resilience

The floating solar systems have been found to withstand extreme storms, fluctuating water levels, high winds, waves, and have survived hurricanes (Spencer et al., 2019). The top portion of the pontoons hosts numerous rectangular gutters which enable the system to withstand wind loads while simultaneously enabling electric wiring installation. The metal rods and pinned joints that fit the floats together also allow for the transmission of horizontal forces and vertical rotation, while rigid supports and anchors help withstand forces from wind and waves (Gorjian et al., 2021). Anchoring serves to spread the load generated by wind and water movement to reduce the overall movement of the solar platforms to avoid the risk of it hitting reservoir banks or being blown during storms (Agostinelli, 2020).

6.5.3 Technical Challenges

While FPV technology has been recognized in the industry as commercially viable due to the number of utility-scale projects that have been constructed, deployment in the US is still considered a challenge. This is primarily due to a lacking track record, lack of certainty regarding costs and environmental impacts, and the complexities surrounding the design, construction, and operating of the panels in and on water. Electrical safety, operations and maintenance, and anchoring and mooring issues also present technical challenges for the industry that must be considered when developing an FPV plant (World Bank Group et al., 2019).

The performance of conventional FPV systems can be impacted by several factors, primarily: the float structure; varying water levels and reservoir layout; and in-situ work for exploitation and construction. The design of adaptable floating modules for reservoir siting can be a complex task due to the variability of the layout, walls, and internal geometry of each reservoir. Low-tilt angles are typically preferred as they reduce the gap between rows to prevent shading and utilize more area, reduce wind uplift, and improve the system's structural behavior (Gorjian et al., 2021).

Further, the sector still lacks a concise understanding and quantification of the cooling effect and how it differs among existing floating solar technologies. Liu et al.'s study quantifies the impact of the cooling effect on solar, though thermal modeling that reveals the heat exchange between the modules and water for each technology has not yet been developed and merged into simulation tools (Oliveira-Pinto & Stokkermans, 2020). Land-based PV uses the widespread and popular simulation tool PVsyst® that is approved by most banks to estimate production; however, the tool does not have the option to simulate FPV systems. Obtaining credit would also be based on various other factors, such as the credit rating of the company and the overall success of FPV offtake in the States. The growing FPV sector will demand accurate energy yield analyses and will need to utilize this system to ensure bankability, though the lack of ability to use the technology for FPV simulations can impact production estimates (Oliveira-Pinto & Stokkermans, 2020).

6.6 Procurement & Construction

6.6.1 Procurement Management

FPV project developers will need to select an engineering, procurement, and construction (EPC) contractor through the typical tendering process in which the candidates' field experience and industry knowledge are considered. The EPC contractor is responsible for all design, engineering, material procurement, construction, commissioning, and testing. All required permits must be secured and approved before beginning construction, and a detailed engineering plan must be approved. A procurement management plan will allow for construction to run smoothly: planning, awarding contracts, managing relationships with suppliers, and closing on contracts or agreements should all be executed prior to construction (World Bank Group et al., 2019).

The global solar manufacturing industry is highly dependent on the supply of cheap and critical components from the Xinjiang province in China, including polysilicon PV products used in both land and floating PV projects. However, this presents an industry-wide issue as there are substantiated reports that the Chinese Communist Party has detained hundreds of thousands of Uighur Muslims and other minorities in internment camps that include “job training” programs requiring forced labor (Reinsch, 2021). Xinjiang is home to four of the five largest polysilicon factories around the world and their global production share reached 82% in 2020, while the US production share dropped to 5%. Solar companies with factories in the province have been directly linked to the programs that have been accused of using forced labor. While the US has already imposed trade remedies on solar cell and module imports from China, restrictions may fail to reduce human rights abuses and could also subsequently harm the US solar cell manufacturing business (Reinsch, 2021). FPV developers and stakeholders will need to navigate carefully when procuring materials that may be inadvertently associated with this complex supply chain situation and prepare for potential delays to project construction. A thorough understanding of these procurement sensitivities through effective management will enable the US industry to expand on FPV development, especially as more data and best practices are published as more plants come online.

6.6.2 Construction Management

A detailed construction plan that contains milestones, task interdependencies, and activity durations should be utilized as a starting point for the construction activities of an FPV project. Numerous stakeholders are involved at this stage, including construction managers, contractors and sub-contractors, machinery operators, suppliers, and the site owner to ensure all activities run smoothly and efficiently (World Bank Group et al., 2019). Construction workers will need to comply with engineering designs, the manufacturers’ installation manuals, and meet all environmental, social, health, and safety plans. Construction of an FPV project entails site preparation, material delivery, float assembly, deployment of mooring equipment and anchors, cable routing, electric equipment installation, and connection to the grid (World Bank Group et al., 2019).

Site preparation work can include the construction of an access road if needed. However, many man-made reservoirs or hydropower dams will already have the road in place. Site clearance, land-filling, evacuation, debris removal, and erection of fencing may also be completed at this project stage, just as it would for land-based PV. Storage space for the numerous floats and accessories must also be determined, and a suitable area with a gentle slope must be identified to construct a launch ramp. After components are assembled on land, workers can easily push assembled floats into the water from the ramp, which can then be towed by motorboat or pushed to the final system location for anchoring (World Bank Group et al., 2019).

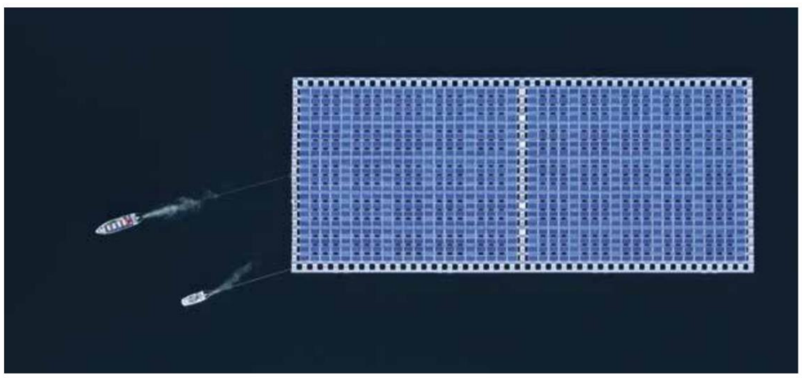

Figure 11: FPV island being towed to its final location for anchoring. (Source: World Bank Group, et al., 2019).

Cable routing must also be strictly managed during installation. Three DC interconnections must be completed during the float assembly process and managed to ensure the cables and connectors always stay above water unless submersible-grade cables are being used. If the floating island is anchored to the bottom of the reservoir, professional divers may be employed to moor and anchor the floats. If a substation is dedicated to housing inverters and not deployed on water, civil works will need to assemble a substation similar to a land-based PV station (World Bank Group et al., 2019).

The construction phase of land-based PV, while well-established throughout the industry, has does have a longer "checklist" of items that must be completed before the plant can come online. Civil work activities are comprised of grading of the entire site and drainage, access road construction, and fencing installation along the site perimeter. Structural work includes post installation and racking assembly. Typically, there are 750 posts installed per MW DEC capacity of a solar plant, which may require a pile driving machine. The racking system is then installed on the posts using fixed-tilt or single-axis tracker systems. Module, DC collection, and an inverter/transformer are also installed, and a substation or switchyard is constructed. Lastly, all areas outside the project perimeter fence that were impacted by construction activities are reclaimed to their prior state (IFC, 2015).

6.7 Operations & Maintenance

Due to the short lifespan of FPV technology globally, operation & maintenance guidelines are insubstantial and O&M comparisons between FPV and land-based solar have been deemed inconclusive (Alcala & Calderon, 2020). As the market expands and systems increase in capacity, O&M experience will grow accordingly and set forth best practices for stakeholders. Typical PV projects have a contracted O&M principal contractor. The contract aims to optimize the energy yield of the project and to guarantee a specific performance level based on pre-determined target levels, such as performance ratio and yield (World Bank Group et al., 2019). O&M of FPV projects will need to develop new skill sets and procedures that differ from land-based PV. New challenges for workers include accessibility, soiling, corrosion, and management of safety protocols that must ensure the structures and components are "touch safe" at all times due to the risk of transmitting power from water to land. Panels will need to be periodically cleaned to reduce soiling losses from dust and bird droppings, however, cooling system methods such as a water veil can help achieve this and reduce the need for site visits (Rosa-Clot & Giuseppe, 2020).

O&M practices for land-based PV systems are well established throughout the US, and there are significant amounts of contractors and field work crews with ample training in the field. The supply chain for replacement and spare parts needed for repairs is substantial and widespread. Land-based PV does require more surrounding environmental upkeep, including vegetation management, landscaping, routine mowing, herbicide application, pest treatment, and maintenance of buffer and ditch areas. Often, developers will plant pollinators and native grasses in the buffer zone around arrays or even inside the array area to increase pollinator colonies, which can benefit nearby agricultural practices and helps reduce the use of herbicides and mowing (Strata Clean Energy, n.d.).

7 DISCUSSION

While many of the necessary factors that contribute to the successful development of an FPV plant are similar to those of land-based PV, differences remain. This analysis found that there are significant benefits provided by floating solar on man-made reservoirs when compared to land-based PV systems. Perhaps the largest benefit is that the systems spare valuable and costly land, which can not only leave land for agricultural, industrial, developmental, and conservation uses, but also saves on real estate costs. The greatest potential for FPV in the US will be in areas where both agriculture and solar energy projects are competing for the same acres of land (Alacala & Calderon, 2020). The energy production and efficiency benefits also make a promising case for the technology when compared to land-based solar due to the cooling effect of siting on water. Of course, these benefits will vary by site and will form a key part of the feasibility analyses in the early stages of project development. The various environmental benefits of FPV systems can also not be overlooked. Evaporation reduction is especially beneficial for plants sited on reservoirs in arid regions, along with the ability to reduce toxic algae blooms – land-based PV does not offer either of these important benefits. Siting FPV projects on hydropower plants especially present a unique and highly profitable opportunity for developers in the United States, as both technologies work together to provide various benefits to the United States energy sector.

Just as any other energy system comes with obstacles for wide-scale development and market integration, floating PV also faces various challenges. A thorough understanding of challenges and potential solutions will help address the overall question of the technology's feasibility for development and integration into the United States renewable energy portfolio and will help stakeholders make informed decisions when considering FPV development, funding, regulations, etc. Primary obstacles that have been identified in the literature include a lack of certainty and public acceptance, the balance of system costs, operation and maintenance, permitting and commercial aspects including lack of clarity on licensing and permitting, water rights, and environmental impact assessments, which may require adjustments in regulatory framework (World Bank Group, et al., 2019; Cox, 2019). Risk analyses can help developers, lenders, and stakeholders identify which risks can be accepted and which need an adaptation or mitigation plan.

8 CONCLUSION

Floating PV solar has not gained the same traction in the US as in other areas across the globe as land is not as scarce near populations and transmission points of interconnection. As long-term data shows performance and maintenance results over decades and how arrays would impact water quality over time, the industry is expected to expand in the US. Increases in the number of higher-profile projects throughout the US can help bolster confidence for key industry stakeholders that the technology is feasible and does warrant significant investment. This study reveals key factors that are expected to contribute to the eventual adoption of the technology for utility-scale use on man-made reservoirs, especially hydropower basins.

Generating renewable energy using FPV technology is expected to play an increasingly important role in the effort to reduce global greenhouse gas emissions, especially as more fossil fuel plants are retired, making way for renewable generation to expand to meet growing demand from population growth and urbanization. As the technology continues to develop, costs and technological challenges will decrease. While FPV may not be the fix-all solution to climate and power challenges, it does have the potential to play a significant role in the effort, and developers across the US should begin to take a more serious look at the technology to expand and diversify their renewable energy portfolios.

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