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Floating Solar: An Emerging Opportunity at the Energy-Water Nexus

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Abstract: Texas is experiencing tremendous growth, which puts pressure on resources including water and electricity supplies. Texas leads the nation in renewable energy production and is experiencing tremendous growth in the solar energy sector, with the Solar Energy Industries Association reporting that Texas is on track to become the fastest growing utility-scale solar market in the United States within the next five years. In this market, a new photovoltaic (PV) technology, floating solar, is gaining attention. Floating solar PV systems use the same types of PV panels as land-based systems, but the panels are either floating in the water (tethered to the land or substrate) or are suspended over a water body. Floating solar panels typically produce more energy than similarly-sized terrestrial systems (because of the cooling effect and reflectivity of the water). The shading provided by the solar panels can also significantly reduce evaporation and can improve water quality by inhibiting the growth of some types of algae and inhibiting bromide converting to bromate. In a climate where much of the state is arid or semi-arid and the entire state is subject to drought, a technology such as floating solar can be part of the solution. Texas reservoirs, water and wastewater treatment facilities, power plant cooling ponds, and irrigation ponds all have the opportunity to realize multiple benefits from floating solar that could not be achieved with a standard ground-mounted PV installation.

Keywords: floating solar, energy-water nexus, renewable energy, emerging energy technologies

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Terms used in paper

Acronyms	Descriptive name
AMTA	American Membrane Technology Association
AWEA	American Wind Energy Association
CHP	combined heat and power
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
Gal/kWh	gallons per kilowatt hour
GTM	generative topographic mapping
GW	gigawatts
LAPW	Los Angeles Department of Water and Power
MGD	million gallons per day
MW	megawatt
NREL	National Renewable Energy Laboratory
PV	photovoltaics
SAWS	San Antonio Water System
SEIA	Solar Energy Industries Association
TDA	Texas Desalination Association
TWDB	Texas Water Development Board
WEF	water-energy-food
USCB	U.S. Census Bureau

INTRODUCTION

Texas is experiencing tremendous growth. According to the U.S. Census Bureau, Texas has five of the 11 fastest-growing cities and five of the eight cities that added the most people (USCB 2016). This growth will place additional pressure on many of the state's electric supply and water systems. This paper describes the challenges that Texas is facing at the energy-water nexus, explains how renewable energy can be a part of the solution, and provides details on one innovative use of solar PV technology, called floating solar, which can have a wide variety of applications and benefits for both power production and water quality and quantity.

ENERGY-WATER NEXUS

The phrase "energy-water nexus" refers to the fact that it takes energy to treat, store, and move water, and it takes water to produce energy. This is particularly noteworthy in Texas, which has the highest production and energy use of the 50 states, both because of its size and because of the prevalence of energy intensive industries. This is an active area of research in Texas, including the University of Texas at Austin's Webber Energy Group's research[3], University of Texas San Antonio[4] Energy-Water Nexus Research Group, the Texas A&M Water-Energy-Food (WEF) research group[5], several non-profit organizations, and others. The approaches to these issues are complex and wide ranging, from improving efficiency, to identifying new supply, and changing policy.

Water use related to power production in Texas

In 2008, the Texas Water Development Board (TWDB) published the report "Water Demand Projections for Power Generation in Texas" (King and Duncan 2008). The report noted that in 2006, "The typical water consumption rate in gallons per kilowatt hour (gal/kWh) for the Texas power generation fleet is 0.2-0.7 for coal and natural gas using steam turbines,

[3] For more information see: http://www.webberenergygroup.com/research/energy-water-nexus-research/

[4] For more information see: http://texasenergy.utsa.edu/research/energy-water-nexus/

[5] For more information see: http://wefnexus.tamu.edu/

0.6 for nuclear, 0.23 for natural gas combined cycle units using cooling towers, and 0.0 for wind turbines. The water consumption rates are a factor of both the type of power generation unit and the cooling system employed." Technologies like wind (as cited in the TWDB report) or floating solar do not require water withdrawals, and thus there is no water consumed for floating solar-based power generation.

Energy use related to water supply in Texas

Drinking water and wastewater systems account for approximately 1% of the total energy use in the United States (Pabi et al. 2013). The U.S. Environmental Protection Agency (EPA) has noted that for many municipalities, drinking water and wastewater plants are the largest energy consumers, often 30-40% of the total energy consumed by the municipality (EPA 2016). As growth increases and demand for water supply increases, desalination will likely play an increasing role in meeting Texas' water supply needs. Desalination is significantly more energy intensive, and thus more costly, than more traditional fresh water supply. In 2012, TWDB found the average cost to produce 1 acre-foot (about 326,000 gallons) of desalinated water from brackish groundwater ranged from approximately $357 to $782, or $1.25 to $2.60 for 1,000 gallons, including capital, operational, and maintenance costs. One specific example is the El Paso Water Utilities, which says the cost to produce its desalinated water is 210% more than the cost for fresh groundwater and 70% more than surface water. Up to half of the cost is tied to the energy required for treatment.[6]

About 95% of the desalination plants in Texas use a reverse osmosis for desalination, where the brackish water is pushed at high pressure through a semi-permeable membrane, causing freshwater to diffuse through the membrane and leaving behind the more saline water. This is a highly energy-intensive process, although progress is being made to improve the energy intensity and cost efficacy (Wythe 2014).

Other notable facts about desalination in Texas:

- Nearly 100 inland desalination facilities across Texas produce 138 million gallons per day (MGD) of water from the 2.7 billion acre-feet of brackish water from aquifers (TDA 2014).
- The Kay Bailey Hutchison Desalination Plant in El Paso is the world's largest inland desalination plant, with a capacity of 27.5 MGD (El Paso Water 2014).
- The Southmost Regional Water Authority Brackish Groundwater Treatment Facility in Brownsville has a capacity of 10 MGD (Brownsville Public Utilities Board 2015).
- The San Antonio Water System (SAWS) operates a 12 MGD facility. Plans are already under way to expand the capacity to 30 MGD by 2026 (San Antonio Water System 2017).

Aside from the three major plants, most of the others are small and used intermittently. However, in the long term, brackish water from local aquifers and the Gulf of Mexico will likely be necessary to meet the growing water needs in Texas.

RENEWABLE ENERGY IN TEXAS

As energy efficiency programs are spreading, and water-saving methods are being implemented at power generation facilities, challenges remain. One of the ways that Texas is approaching the challenges of the energy-water nexus is to integrate renewable energy technologies. As evident from the TWDB report, renewable energy technologies such as wind and solar are less water-intensive methods of producing electricity. Both wind and solar technologies have been deployed in Texas in the last 20 years with different intensities and results.

It was in 1999 when Governor George W. Bush signed legislation that deregulated the electric utilities across much of Texas, which is credited with spurring Texas' leadership in renewable energy. Before deregulation, utilities typically controlled the generation, transmission, and retail sales of electricity. Since deregulation, generated electricity is sold on the wholesale market to regulated transmission and distribution utilities, and customers can choose retail electric providers. This initial legislation also included a requirement to have at least 2,000 megawatts (MW) of renewable generating capacity by 2009. That goal was exceeded in 2005. The goal was then raised to 10,000 MW by 2025. That goal was exceeded in 2011. By April 2016, Texas had over 19,000 MW of renewable energy generating capacity, most of that from wind turbines. Texas leads the nation in production of electricity using wind turbines (Spindle and Smith 2016). For the 12-month period ending in July 2016, 12.14% of the energy production in Texas was from wind turbines (AWEA 2019). On the other hand, solar production is a significantly smaller percentage but is growing rapidly in the state.

There remains a perception that producing electricity using photovoltaics (PV) is a relatively new and untested technology. However, Albert Einstein first published a paper on the PV effect in 1905 (DOE 2001). In 1953, scientists at Bell Laboratories made PV cells from silicon (Perlin 2016), greatly increasing their efficiency, and this is the technology used in the majority of PV panels in use globally. By 1959, PV cells were commercially available. In the 1970s the price of PV panels dropped from $100 per watt to $20 per watt and began being used in remote locations where it was challenging to connect to the grid.

[6] Early desalination plants required 7.0 to 9.0 kilowatt-hours per cubic meter of water. Newer technologies are reporting 2.5 to 3.5 kilowatt-hours per cubic meter of water (AMTA 2016).

In 2016, PV panels can be purchased for less than $1.00 per watt, and panel prices continue to drop.[7] Generative Topographic Mapping (GTM) Research and the Solar Energy Industries Association (SEIA) report, "U.S. Solar Market Insight, Q2 2016" noted that Texas is on track to become the fastest-growing utility-scale solar market in the United States within the next five years (SEIA 2016). The report also notes that:

- In 2015, over $375 million was invested in solar in Texas, a 48% increase over 2014.
- Texas is currently 10th in the nation in solar installations and is expected to rise to second in just five years.
- Installed prices have dropped 66% from 2010.

FLOATING SOLAR

The concept of floating solar is simple: PV panels (like those used for traditional terrestrial systems) that float on water bodies. Solar PV plants use the same technologies as traditional ground-mounted PV plants. But floating solar is creating new opportunities to scale up solar energy around the world, particularly in countries with high population density, competing uses for available land, or where natural or artificial water bodies are available for different reasons or uses. The deployment of PV panels on surface water bodies has grown considerably in the last four years, going from a worldwide installed capacity of 10 MW at the end of 2014 to 1.1 gigawatts (GW) by September 2018, according to the market report presented by the World Bank Group and the Solar Energy Research Institute of Singapore. According to this study, the most conservative estimate of floating solar's overall global potential based on available man-made water surfaces exceeds 400 GW, which is equal to the 2017 cumulative installed PV capacity globally (World Bank Group; ESMAP; SERIS 2018).

Floating solar is a relatively new application of PV technologies, with markets growing in Asia, Australia, and Europe. Over 250 floating solar plants have been documented around the world from 5 kW (Ciel & Terre 2019) to 40 MW (Daley 2017). The market in the United States is expected to grow along with the global market at still undetermined rates. In general and according to the Solar Energy Industries Association (SEIA 2018) PV capacity installed in the United States is expected to more than double over the next five years, and by 2023, over 14 GW of PV capacity will be installed annually. According to a recent paper published by the National Renewable Energy Laboratory (NREL), a total of 24,419 man-made water bodies were identified as being suitable for floating PV generation in the United States. Floating PV systems covering just 27% of the identified suitable water bodies could produce almost 10% of current national generation. Many of these eligible bodies of water are in water-stressed areas with high land acquisition costs and high electricity prices, suggesting multiple benefits of floating PV technologies (Spencer et al. 2019).

Given the tremendous population growth that Texas is experiencing, innovative approaches to water and energy are needed. Wind and PV require significantly less water to generate electricity when compared to more traditional methods of electricity generation (IEA 2012). Texas has shown leadership in renewable energy technologies and is expected to experience rapid growth in the PV market. Floating solar is currently a niche PV application, but it offers a number of water and energy benefits for many different applications in Texas.

State-of-the-art of floating solar

Although floating solar is not a new topic in research journal and conferences, the number of publications is limited. For instance, 53 documents appear in Scopus searching by the words *floating* and *solar* as of July 2018. Only 16 of these papers are based on floating solar power plants. Six of these papers have been published in 2018, four in 2017, three in 2016, two in 2014, and one in 2011.

The most-cited paper is a review defining the state-of-the-art of floating PV technology, in which technology status and various design options are presented with potential applications, pros, and cons (Sahu et al. 2016). Other papers discuss pilot projects or study the application of floating solar in countries including Bosnia and Herzegovina (Pasalic et al. 2018), the United Kingdom and Japan (Patel 2014), India (Patel 2014; Mittal et al. 2017a; Mittal et al. 2017b), Bangladesh (Rahman et al. 2017), the United Arab Emirates (Safarini et al. 2017), Portugal (Proctor and Patel 2017), and Indonesia (Handara et al. 2016). Regarding applications, just one paper describes a use other than power generation, which is water desalination (Ni et al. 2018).

Regarding technology, most of the papers are focused on PV but two papers study the use of concentrated solar (Diendorfer et al. 2014; Ni et al. 2016). Ni et al. studied in 2016 the feasibility of an innovative, low-cost, scalable, floating solar receiver able to generate 100 °C steam under ambient air conditions without optical concentration, while Diendorfer et al. studied in 2013 the applications of different floating concentrated solar technologies under the geospatial conditions of the Mediterranean Sea. The feasibility of developing floating structures made of varying materials such as coconuts (Fauzan et al. 2017) or plastics like and high-density polyethylene (Sahu and Sudhakar 2017) are discussed in the existing literature too.

[7] Note: these prices are for the PV panels, not PV installation nor permitting. For estimates on installed rooftop PV costs in Texas, see, for example: https://solarpowerrocks.com/texas/

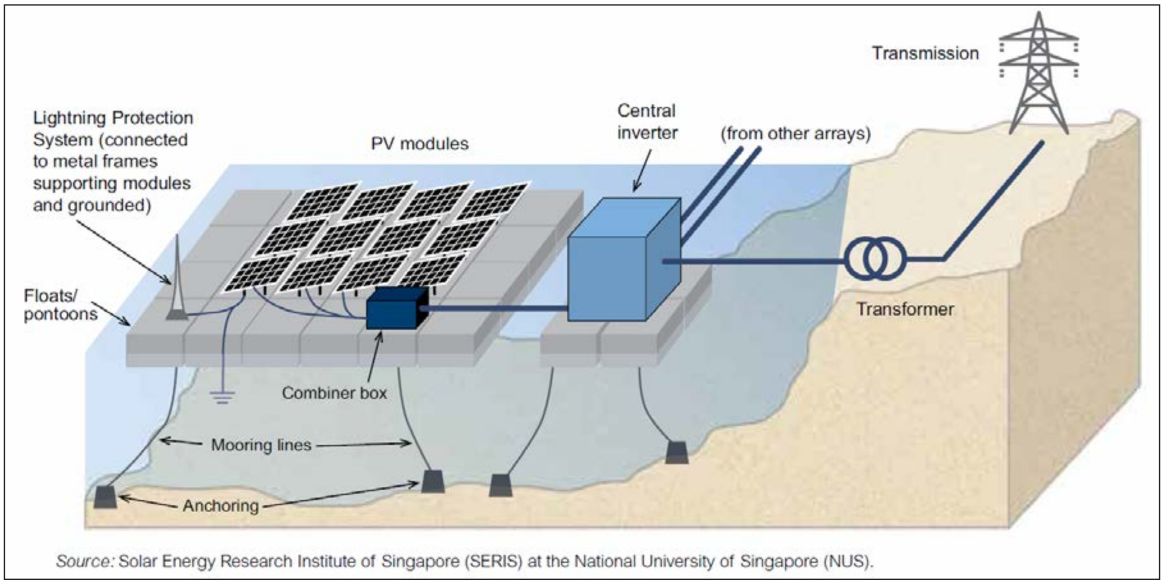

Figure 1. Floating solar scheme (World Bank, ESMAP; SERIS 2018).

While the solar industry currently has ongoing research attention, research is needed on the unique aspects of floating solar, such as floating structures and adapted technology development addressing different installation, maintenance, operation, and ownership challenges in different locations and under different conditions. For instance, it is expected that traditional business models applied to solar energy will be applicable to floating solar, but more research is required on this new approach.

System design

As mentioned before, floating solar consists of regular PV panels that are installed over a body of water. Typical systems are designed to float on water and can adjust to variations in water levels (Pickerel 2015). Other installations are designed in a fixed position over a water body but are still sometimes referred to as floating solar (e.g. an installation in Gujarat, India where the panels are on a racking system over a canal (Jenna 2015)).

Because of the challenges of wave action in open-water, floating solar is more common in inland applications. These can include lakes, reservoirs, retention ponds, water treatment ponds, or canals. The systems have anchoring systems in place, tethering the racking systems to land or the bed of the body of water, as shown in Figure 1. The structural design of the racking and tethering systems needs to be tailored to the specific location of the proposed installation, making the structural engineering slightly more complicated than typical ground mount or rooftop systems.

Other than the components that float, are anchored to the bed of the water body, or are suspended over the water body, a floating system is similar to typical land-based systems. Like traditional PV, floating solar can be designed with a fixed tilt or the PV can be installed on tracking systems that change the angle of the panels to follow the sun throughout the day. The systems are typically modular, so that once the system is designed it is easily deployed and scalable.

Estimated costs

The cost of floating solar has not yet been analyzed intensely in the technical literature. Some papers have proposed and studied cost structure for floating energy plants (Castro-Santos et al. 2016), including wave energy and wind energy, but not floating solar. Some internet sources provide cost references for the Asian market comparing traditional and floating solar, which go from almost equal to a 25% more expensive in the case of floating solar, but more research on this topic for the American market is required. Only the World Bank Group's floating solar market report provide references for costs and installed capacity in different countries in the world. This report defines total capital expenditures for turnkey floating PV installations in 2018 between \$0.8–\$1.2 per installed Watt depending on the location of the project, the depth of the water body, and variations in that depth for facilities in the 0.2 to 150 MW range. For instance, in 2018 a 150 MW floating solar plant built on top of an abandoned coal mine located in Anhui, China has come online with a budget around \$148 million dollars. But the costs of smaller systems in different regions could vary significantly (World Bank Group; ESMAP; SERIS 2018).

In the United States, the University of Arizona evaluated the feasibility of using floating solar to produce power and reduce evaporation in Arizona. The study found that a utility-scale floating solar project would have similar costs to a land-based

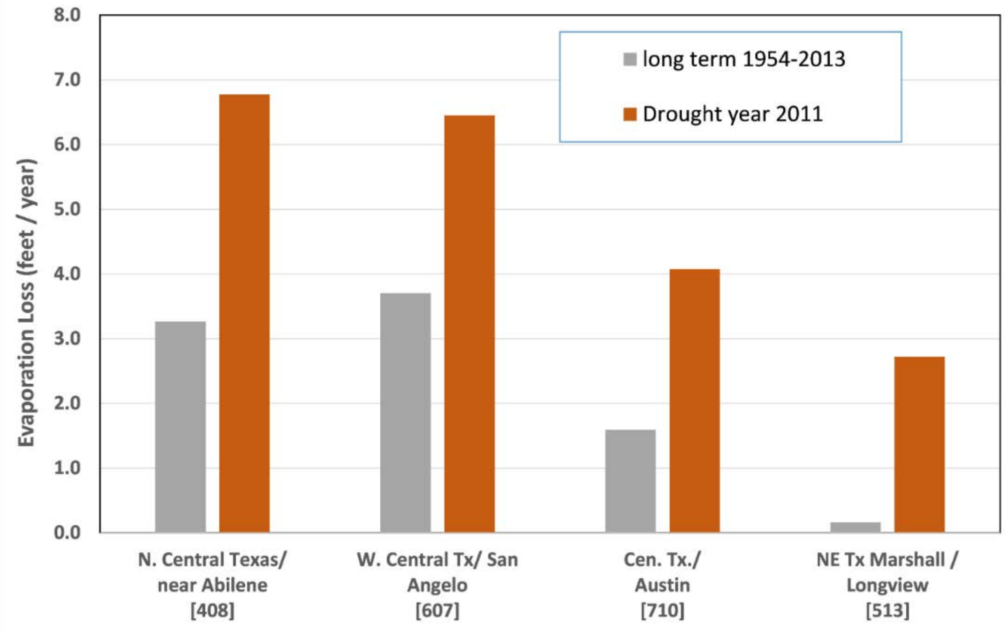

Figure 2. Evaporation loss (Johns 2014).

PV installation in the United States, and power production would be higher for the floating system than for a land-based system due to the lower temperatures that the panels reach. Based on the results of the review of the technology and applications, the researcher recommended a pilot-scale study to confirm the results of the research. The proposed pilot study would be located on the Lake Pleasant Reservoir, part of the Central Arizona Project. The researcher modeled production and costs and noted that while the lifetime costs per unit energy were higher than the current Central Arizona Project rates, the estimated costs did not include projected electricity price increases, savings from water conservation, or other benefits (Hartzell 2016). In addition, The U.S. Bureau of Reclamation completed a study in October 2015, "Fundamental Considerations Associated with Placing Solar Generation Structures at Central Arizona Project Canal," and concluded that placing panels over the canal would be approximately 24% more expensive than traditional land-mounted systems (U.S. Department of Interior 2015). The report further recommended additional research for "improved structural cost estimates, improved operating and maintenance cost estimates, improved impacts to operating and maintenance, impacts to the canal and canal lining, evaporation studies including evaporation with shading, viability of solar power over small canals (Pickerel 2016), and a robust design for solar panels to be installed in remote locations," (U.S. Department of Interior 2015).

Benefits and applications of floating solar

PV has benefits compared to other methods of electricity generation, and floating PV has several benefits over traditional terrestrial PV. Both PV systems are silent and do not consume water for the power generation process, a boon to the energy-water nexus. PV can also be easily deployed as a local power system, especially in locations where:

- the costs of extending transmission lines might be prohibitive;
- power quality is not good, or an additional layer of security is required for the power supply (i.e., extra resilience);
- current electricity prices are high; and
- there is a desire to minimize or offset emissions associated with power consumption.

Obstacles are easier to avoid in medium and large water bodies, thus floating solar has the potential added benefits of suffering fewer shading issues than traditional PV systems, while reducing water evaporation. Water quality can be improved too. Algae formation in the water bodies can be reduced by floating solar as the amount of sunlight in the water would decrease, reducing the photosynthesis process to produce less algae in water (Sharma et al. 2015).

Most of the annual rainfall in Texas occurs during rain storms, when a large amount of precipitation falls over a short period of time. Except for the subtropical humid climate of the eastern quarter of the state, evaporation exceeds precipitation—yielding a semiarid or steppe climate that becomes arid in far west Texas (TWDB 2012). Figure 2 presents evaporation losses for different areas in Texas. In most of these regions evaporation during a drought year might be twice the evaporation during a regular year.

The shading provided by floating solar panels can reduce evaporation in lakes, reservoirs, canals, and other surface water bodies, helping to increase the efficiency of water supply systems. Also, the proximity of the water has an evaporative cooling effect on the panels that increases their efficiency, resulting in a higher electricity production per panel. For example, a project in South Australia at a wastewater treatment basin is currently underway. In that hot, dry climate, the project developer is estimating that a floating PV system would be 50% more efficient than a land-based system and would reduce evaporation in the covered area by 90% (Doran 2014). That estimation seems high to these authors since typical power losses due to high temperature are around 16%, so saying a 50% efficiency increase might mean reducing temperature-based power losses by half. However, while this is the anticipated result, there is a need to conduct additional research to quantify the real-world effects on evaporation from this and other projects. This South Australian project may provide valuable data to evaluate whether this technology could benefit the regions of Texas that have a similar climate.

Like traditional PV, floating solar can provide electricity to where it is needed in remote areas. It may be integrated with equipment such as pumps, data loggers, sensors, and analyzers. For example, the City of Houston's Lake Houston SolarBee project uses solar-powered water circulators to improve water quality. The City of Houston uses the 11,000-acre water body as one of three sources of drinking water. Although the water quality is generally good, seasonal blue-green algae blooms and depleted oxygen levels at depth were resulting in odor and taste issues. Installed as a pilot program in 2006, the solar-powered circulators help oxygenate the lake, helping maintain a healthy ecosystem and reducing the need for chemical treatment. The three-year pilot program was successful and continues today (City of Houston; Green Houston Texas 2006; Bleth 2007; C40 Cities 2011).

Shading can also provide water quality benefits. When sunlight reacts with naturally-occurring bromide in the water, it creates bromate, which is a carcinogenic compound. The sunlight also promotes algae growth. Because floating solar also provides shading, it has the potential to offer similar benefits while concurrently producing power. Bacterial issues have been detected on some projects that tried to minimize water evaporation through shading, so more research on the materials to be used as standing structures for floating solar in water reservoirs for drinking water is needed (De Graaf 2015).

Floating solar projects can also provide shelter for fish from feeding birds, especially in water bodies used for aquaculture. Although these are consistent advantages, when developed in natural ecosystems such as natural lakes or the sea, the environmental impact of floating solar plants must be carefully studied in advanced.

Since floating solar is best suited to inland applications such as lakes, reservoirs, retention ponds, water treatment ponds, and canals, the ideal location has power needs suited to the size of the system and would benefit from reduced evaporation and shading. Therefore, wastewater treatment plants and surface water supply and transport systems, particularly those in hot, dry climates, can be well suited to the application of floating solar technology. Irrigation ponds, such as those used for agriculture, may also benefit. The authors provide examples of floating solar installations in the United States below.

Potential in Texas

Texas is well-positioned to take advantage of the benefits of floating solar. According to the Texas Water Development Board (2012), "Except for the wetter, eastern portion of the state, evaporation exceeds precipitation for most of Texas, yielding a semiarid climate that becomes arid in far west Texas. The El Niño Southern Oscillation affects Pacific moisture patterns and is responsible for long-term impacts on Texas precipitation, often leading to periods of moderate to severe drought." Because floating solar systems can prevent water evaporation, this helps to conserve water.

Texas has approximately 191,000 miles of streams and 196 major reservoirs, with a combined reservoir capacity of over 30 million acre-feet (TWDB 2016). These reservoirs along with wastewater treatment plants, power plant cooling water ponds, and irrigation ponds may all potentially benefit from not only the power production provided by floating solar but also the reduction in evaporation resulting from the shading. Irrigation ponds with floating solar can use the power to operate irrigation pumps, making it easier to maintain ponds that require aeration pumps in remote locations. Or, if the user prefers to irrigate at night when the sun is not shining, solar pumps could be used to pump the water into an elevated tank that could then be used to irrigate when the sun is not shining, or the energy could be stored in batteries and used at night.

Floating solar can also help places in Texas with persistent blue-green algae. Blue-green algae can cause taste and odor problems and produce toxins that are poisonous to fish and wildlife. According to the Texas Parks and Wildlife Department, "Fish kills have occurred in private stock ponds as a result of blue-green algal blooms and there have been a few reports of livestock dying from drinking water contaminated with blue-green toxins" (TPWD 2016). Blue-green algae can also compromise human health through both external exposure and ingestion (UNL 2019). Solar-powered floating mixing systems such as those used on Lake Houston might be helpful for these water bodies with persistent blue-green algae, blocking the sunlight that hits the water and the reducing the photosynthesis process to produce less algae (Sharma et al. 2015).

Figure 3. Ground-mounted and floating solar plants in Far Niente Winery, Oakville, California. Source: Google maps.

EXISTING FLOATING SOLAR EXAMPLES IN THE UNITED STATES

So far, no energy agency or government-related entity has published a database of the existing floating solar plants in the world. In January 2018, a list of the 70 top floating solar plants was published by the website Solarplaza (Mesbahi and Minamino 2018). Although it is not clear which is the criteria used to consider a plant as "top," the list presents some of the facts of the floating solar market, such as:

- Asia is the continent with the highest number of facilities deployed: Japan is probably the country in the world with the highest number of plants while China is the country with the biggest plants (by capacity).
- Floating solar plants have already been developed in almost every climatic area of the world where water bodies exist.
- Sizes range from less than 2 MW for commercial and small industrial facilities, to hundreds of MW for larger power plants.
- Owners and developers vary from commercial or industrial clients to public entities such as municipalities, water authorities, or electric companies.

There is no information about the business models adopted by these 70 plants in the cited website. Most of these 70 plants began operating from 2014 to 2016, reflecting how the global market has grown rapidly over the last five years, based on technological advances that enabled the deployment of PV technologies and the other components of floating platforms.

The foundations of the present floating solar technologies were established in the early 2000s, beginning in 2007, the year in which the annual number of patents on floating solar began ramping up. In February 2008, a winery in Oakville, California installed what was perhaps is the first commercial-scale floating solar plant in the United States: Far Niente Winery (Business Wire 2008). Other facilities have followed in the United States in different sectors, developed with different drivers and goals by different entities.

Far Niente Winery, Oakville, California

In 2008, Far Niente Winery installed a 175-kW floating solar plant in their irrigation pond. After looking at several configurations for the expansion of their existing solar array, all the alternatives involved taking out a significant amount of its vineyard. The idea of installing the panels in its irrigation pond came up during a meeting and the winery found a company with the right technology to develop the project. The floating array's positioning on the pond saved 3/4 of an acre of valuable Cabernet vines that would have been ripped out for a total land-mounted system, as seen in Figure 3. This is equivalent to about $150,000 dollars' worth of bottled Far Niente Cabernet annually. This expansion of the existing solar arrays helps the company with its goals to be annual net zero (to sell more electricity back into the grid than the energy purchased from the grid) and to reduce its electricity bills considerably (cost savings).

Figure 4. Panels at the Bordentown Avenue Water Treatment Facility. Source: www.wateronline.com.

Bordentown Avenue Water Treatment Plant Reservoir, Sayreville, New Jersey

Another large project that began construction in 2016 is the 4.1 MW floating solar array in Sayreville, New Jersey. The $12 million project is located on a reservoir for the Bordentown Avenue Water Treatment Plant. The array, shown in Figure 4, produces all the electricity required to operate the plant over the course of a year. While the plant is connected to the electrical grid, the expectation is that the plant will result in net zero annual energy consumption from the grid (Pickerel 2016).

Olivenhain Reservoir, San Diego County Water Authority, San Diego, California

San Diego County Water Authority is installing floating solar panels on a portion of the 200-acre Olivenhain Reservoir according to the layout presented in Figure 5, producing around 6 MW of peak capacity. Exploiting the additional potential of these facilities to generate power and to minimize water evaporation are some of the drivers of this project.

Figure 5. Olivenhain Reservoir and Dam in San Diego, California and floating solar plant layout in initial design. Source: Google Maps and San Diego County Water Authority.

Figure 6. Installation process of the Walden, Colorado Plant. Source: NREL.

Walden Municipality, Walden, Colorado

In 2018, the Colorado Energy Office supported the development of a 75-kW floating solar array in the town of Walden, as a part of an energy performance contract with the company Johnson Controls. NREL documented the installation process (Figure 6). The project is expected to generate approximately $10,000 in annual savings and to offset part of the municipal environmental emissions (Runyon 2018).

Salad Cosmo, Dixon, California

In Dixon, California, Salad Cosmo, a family-owned bean sprout producer, installed a 600-kW floating solar system as part of its environmental commitment. Placing a traditional solar system on its farm land would have harmed productivity. Floating solar enabled this company to utilize the surface area of the pond, as seen in Figure 7, saving money and reducing environmental emissions (Ciel & Terre 2018).

CONSIDERATIONS

Floating solar systems are finding new opportunities in the U.S. market. Depending mostly on geospatial factors such as location, size (economies of scale), and other factors such as how easy or complex the access to the body water is, floating solar may range from equal to more expensive per watt installation costs than ground-mounted systems. Among these factors, the extra engineering and design for the racking and tethering systems must be included, since floating solar is not yet as stan-

Figure 7. Aerial view of Salad Cosmo's pond and floating solar plant. Source: Google maps and Ciel & Terre.

dardized as ground-mounted PV. But these costs may be offset because the reflectivity of the water surface and the slight cooling effects on the panels can result in higher power production.

Additional research and case studies on existing installations will help quantify these potential benefits in different climate areas of the United States, such as the paper recently published by the company Solener and the University at Albany (Perez et al. 2018). In this paper, they analyze the potential of floating solar in the United States with some interesting findings such as:

- Deploying floating PV on the 128 largest U.S. reservoirs could supply firm, 24/7 electricity equivalent to 100% of U.S. electrical demand. Deployed on all the lakes considered for their study, floating PV would produce 10 times that amount.
- Floating solar requires a smaller footprint than a hydroelectric facility to produce an equivalent amount of energy. Perez et al. affirm that covering 1.2% of their surface with PV would generate as much electrical energy as hydropower currently generates. Although the value of the percentage might fluctuate a little, the idea can be easily validated. In 2006, out of a database of 245 hydro plants in operation in the world with at least 30 MW of installed capacity, the average power density was 2.95 W/m2 (UNFCCC 2006). On the other hand, in 2019, power density for solar panels in the market is around 180 W/m2. According to these numbers, a floating solar plant with a 180 W/m2 power density would require just 1.6% of the area required by a hydropower plant to generate the same power.
- Floating PV panels can generate water savings not only reducing evaporation in the water bodies they float on, but also replacing other water-intensive power generation technologies.
- While PV deployment may have a vast potential on reservoirs and lakes, it is far from the only deployment option for this technology.

These authors also mention among their conclusions that hydroelectric production via turbines could be reduced or eliminated as a reservoir management objective, especially at the end of the life cycle of the most critical technological components. An alternative would be to deploy floating PV on a small fraction of reservoir area, focusing the management on other goals, such as flood control and water supply.

The combination of both technologies (floating solar and hydro power) is an opportunity worth exploring since hydro power plants have all the components of a power plant already installed onsite. But this statement might not be correct, considering that sometimes these turbines do not only generate power but also provide regulation services for the bulk power system. Providing this kind of service with a renewable (non-dispatchable) energy source such as solar is more challenging from a technical and economic standpoint. In that regard, energy storage technologies are gaining traction in power system regulation markets and could be a practical alternative for that scenario to occur (floating solar plus battery storage providing regulation services for the power grid).

Additional factors to consider are the potential infrastructure savings (if in remote locations), the durability of the systems (e.g., from biofouling and corrosion), operation and maintenance costs, access, the value of surrounding land, and the economic impact the structure may have on the body of water. For example, if the structure would interfere with sport fishing, and/or recreation, it may have negative economic consequences. In addition, for non-grid connected systems, power production and demand loads should be evaluated and the costs of storage, if necessary, should be included. Finally, non-economic factors should be considered as well. For example, if a project is proposed on a reservoir, the design should take into consideration the potential effect on aquatic life from both the structure itself and the shading that will occur from the panels.

CONCLUSION

Texas is experiencing tremendous growth, which brings challenges at the energy-water nexus. Texas has been a leader in renewable energy and the PV sector is predicted to grow rapidly in the next five years. In a climate where much of the state is arid or semi-arid and the entire state is subject to drought, floating solar may be part of the solution. Texas reservoirs, water and wastewater treatment facilities, power plant cooling ponds, and irrigation ponds all have the opportunity to realize benefits from floating solar that could not be achieved with standard land-mounted PV installations. Additional data on economics, evaporative effects, and environmental effects would help support planners and designers in evaluating the potential for this technology in the Texas market. The types of contributions that would be most valuable at the current life stage of this technology include: demonstration projects, laboratory studies, case studies, economic studies, and modeling of the energy, water quantity, and water quality benefits of floating solar.

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