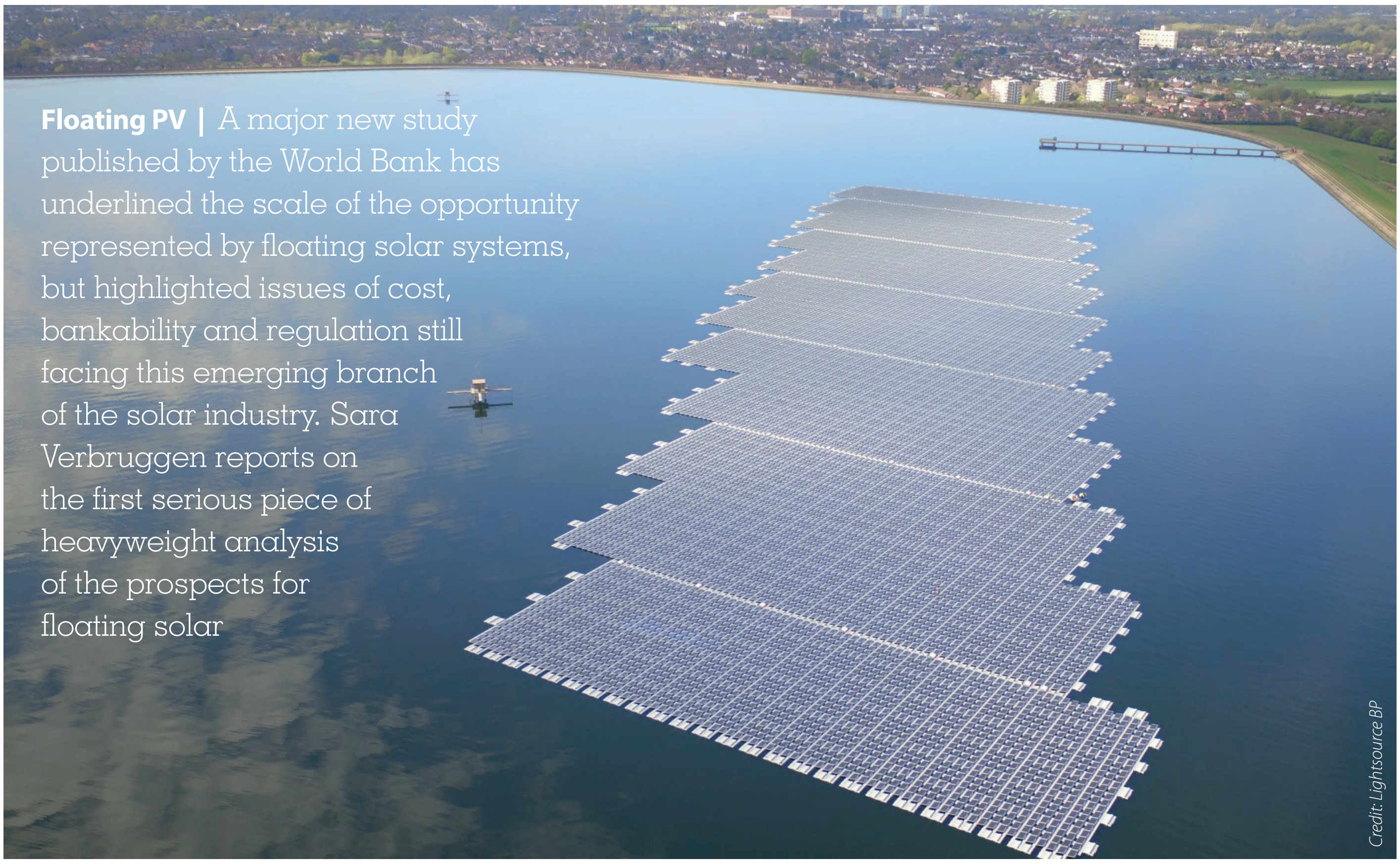
Crunching the numbers on floating solar

Floating PV | A major new study published by the World Bank has underlined the scale of the opportunity represented by floating solar systems, but highlighted issues of cost, bankability and regulation still facing this emerging branch of the solar industry. Sara Verbruggen reports on the first serious piece of heavyweight analysis of the prospects for floating solar



Credit: Lightsource BP

Floating solar has global potential, with cumulative installations exceeding 1GW today, according to an upcoming floating solar market report, 'Where Sun Meets Water', written by the Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore and published by the World Bank and the International Finance Corporation.

That said, investment costs are about US$0.10 per watt higher for floating solar projects, compared with equivalent ground-mounted plants, providing opportunities for collaboration between the solar industry and other sectors in order to bring down costs and deliver large-scale projects.

Demand outlook

According to the report,, a summary of which was published in early November as the first in a series planned by the World Bank and SERIS, a conservative estimate puts floating solar's overall global potential, based on available man-made water surfaces, in excess of 400GW. Since the first floating PV system was built in 2007 in Aichi, Japan, the market has grown with projects increasing in size and more countries installing these types of renewable energy plants.

Around 500MW was installed in 2017 and 2018, much of it in China by making use of flooded mine sites. Many floating solar projects are being developed or under feasibility studies in many different parts of the world.

SERIS' senior financial advisor Celine Paton says: "If they all materialise, then yes we could see such annual growth of 400-500MW taking place. However, the development and realisation of these projects also depends on many factors, which are not always controlled by the owners/developers: politics, environmental aspects, but also appetite from banks.

Floating solar capacity now exceeds 1GW worldwide, but has significantly greater potential if issues around cost and bankability can be surmounted

Therefore, this annual figure may not materialise immediately in 2018 or 2019, but is likely thereafter."

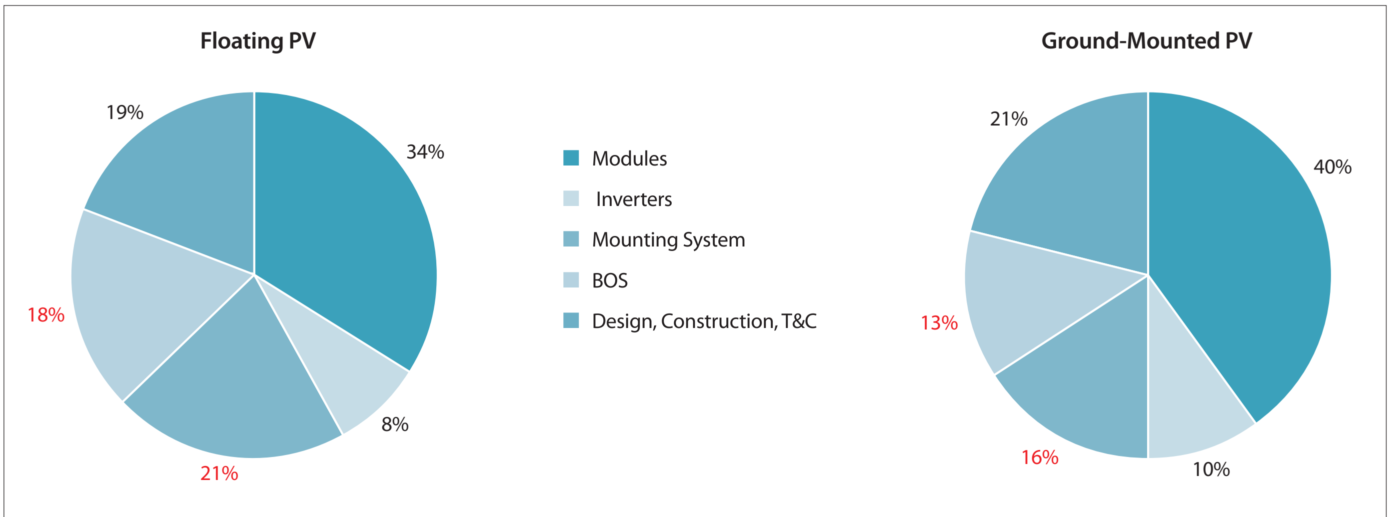
Costs and project structuring

Calculated on a pre-tax basis, the levelised cost of electricity (LCOE) for a generic 50MW floating PV system does not differ significantly from that of a ground-mounted system.

The higher initial capital expenditures of the floating system are balanced by a higher expected energy yield, from the cooling effects of the close proximity of cold water. This is conservatively estimated at 5%, but potentially could be as high as 10-15% in hot climates.

Capital expenditure (capex)

The main difference in investment costs when comparing floating PV with a ground-mounted PV plant of similar size is in the floating structure and the related



Source: Authors' compilation based on 2018 data received from industry. *Notes:* BOS = balance of system, T&C = testing and commissioning.

Credit World Bank/SERIS

Figure 1: Floating versus ground-mounted 50MW PV investment cost breakdown (numbers indicative only)

anchoring and mooring system. These are highly site-specific, according to the report's authors. At this early stage in the market's development, lack of experience as well as available data makes it very difficult to provide an "average" cost figure with confidence.

Cables, a balance of plant (BoP) element and cost for all types of PV installations, differ for floating solar projects. Using direct current (DC) – in some cases submarine – electric cables with additional insulation and shielding properties to protect against moisture degradation, potentially adds a premium to the capex of a floating solar plant compared with a ground-mounted PV system.

In capex cost modelling, the report's authors have tried to make reasonable assumptions in terms of crunching the numbers on the main average cost per component for a hypothetical 50MW floating PV system on a freshwater reservoir, based inland. In addition, the theoretical site presents no particular complexity. For instance, the maximum depth level is 10m and there is minimal water level variation.

The cost component assumptions used in the report's chapter on cost analysis are based on SERIS' experience, investigations and guidance from solar PV equipment suppliers, engineering, procurement and construction contractors and developers.

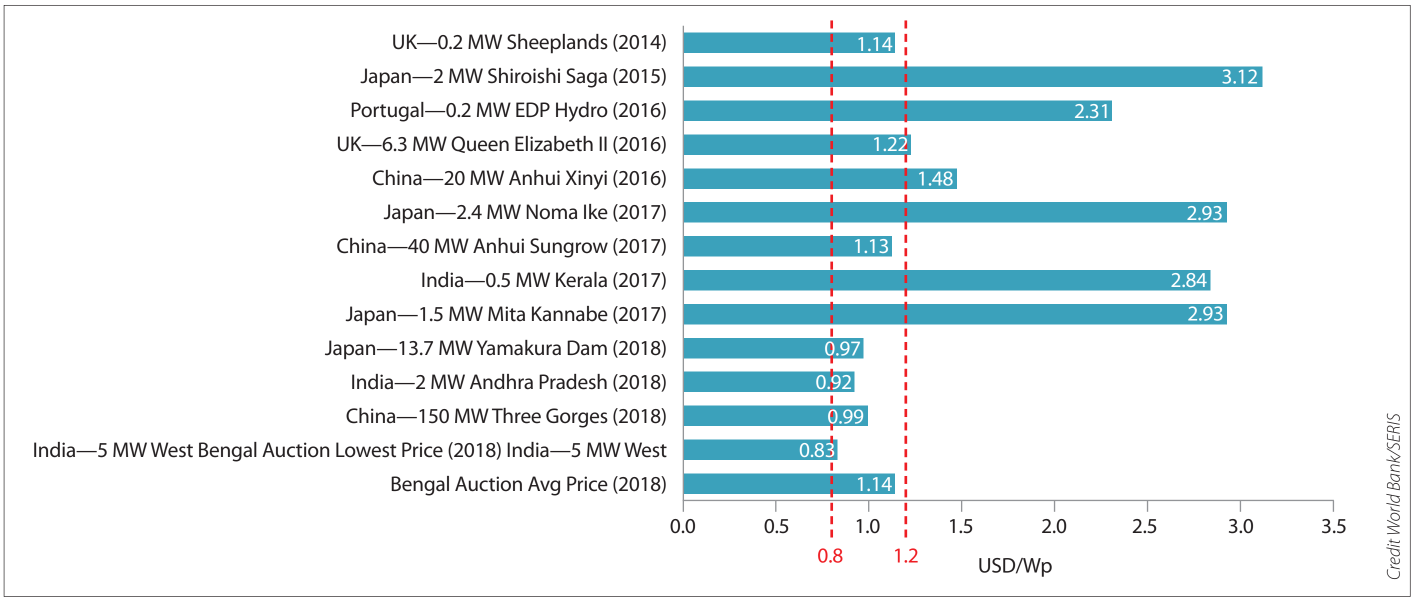
The authors stress the figures represent estimations and need to be adjusted once the design and location of a specific floating PV project is determined and as more cost figures become available from the completion of more and more large-scale floating PV systems across the world.

A breakdown of the main capex cost components assumed for a hypothetical 50MW solar PV installation, comparing floating to ground-mounted systems, both of which are fixed tilt, at the same location is shown in Figure 1.

Standard module and inverter costs are assumed identical for both technologies. Mounting system, including floating structure, anchoring and mooring for floating PV and BoP costs are significantly higher for floating solar projects as opposed to ground-mounted.

On a per watt-peak basis, industry experience has shown that floating PV capital expenditure to date tends to remain US$0.10 higher than ground-mounted PV projects under similar conditions.

Improved economies of scale and competition between vendors will begin to



Credit World Bank/SERIS

Figure 2. Investment costs of floating PV in 2014–2018 (realised and auction results)

Floating solar industry turns to Seaflex for its mooring expertise

Many investors, project managers, engineers, and product manufacturers are concerned with the longevity of individual components of floating PV systems. The LCOE generally revolves around a lifespan of 20-25 years for such floating PV projects. How does Seaflex tackle the challenge of longevity and make ownership cost effective?

Our approach to a 20-year-plus longevity for our mooring systems comes from several factors. First being that we have a 20-year warranty on our products and mooring solutions. We can offer this because we have over 30 years' experience designing and building marinas using the Seaflex mooring systems. We currently have Seaflex in marinas that are over 30 years old, so we know from real-life experience that our products, materials and designs last a long time.

We have adapted our range of Seaflex products and mooring designs to be utilised in the floating solar segment. We have numerous different mooring designs and products that can handle a wide variety of environmental factors such as water levels from zero meters to hundreds of meters deep. We also have existing floating solar projects that have survived typhoons without failure. So, we can say from real-world experience that Seaflex, installed on floating solar applications, can also withstand extreme wind conditions as well. Additionally, our mooring products are compatible with every floating solar panel float, which allows for seamless integration and helps to increase the lifespan of the floats and solar panels.

Since Seaflex products only require routine inspections and do not require maintenance, we provide a much lower cost of ownership over the lifespan of our applications.

What should designers and engineers be careful to consider when looking at mooring solutions for floating solar applications?

One misconception that many designers and engineers have when considering the mooring aspect of the floating solar application is the correlation between the size (in megawatts) of the system and how much in terms of cost and quantity of mooring is needed. Unfortunately, the relationship is not linear and is somewhat complex to describe.

There are many factors which can change the quantity, composition of materials and design of the mooring system. For example, different environmental conditions like water levels and wind from two identical 2.5 MW facilities can have very different designs and costs associated with the mooring. Another factor can be the proximity of the solar panels and floats to the shores of the water source. A system located in the middle of a body of water is moored differently than one where all four sides are close to the shores.

Factors such as these are why we caution designers and engineers not to guess about the mooring solution based on sizes or designs of other seemingly similar floating solar applications.

Why is using Seaflex versus other mooring technologies beneficial for floating solar applications?

The use of metal cable and chain in mooring floating solar projects is one type of solution that comes with many drawbacks and potential devastating failures. We have seen such real-life failures and therefore can comment on the design and material inadequacies.

Seaflex offers an elastic solution that unlike metal cable and chain provides a dampening effect that neutralises shocks (or peak load effect) to both the floats and solar panels from wave and wind forces. This is beneficial from both a safety and durability standpoint in that the possibility of potential damage over a 20-year period is minimised, saving material replacement and labour costs. It should also be said that the usage of piles as a mooring solution has the same risks as cables in that shocks and peak loads are not at all dampened and therefore can also create a total failure in storm conditions.

Additionally, Seaflex products utilise very little metal and even offer a titanium hybrid option to drastically limit corrosion and material degradation. Another benefit of our elastic mooring solution is that Seaflex can handle water level variations from very small to very large (+50 meters!) This would not be possible using the metal cable, chain or pile solutions.

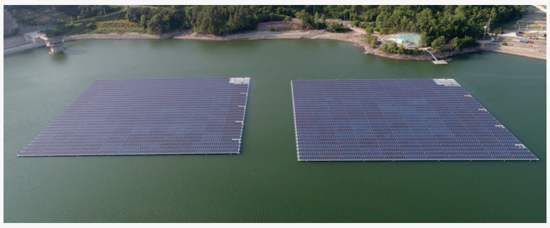
If you have questions about this article or other questions regarding floating solar applications, please do not hesitate to contact us at info@seaflex.net

For information on Seaflex products, services and reference material please visit our website at www.seaflex.net

Anchoring innovative floating applications is our passion!

SEAFLEX is the flexible mooring solution that has been securing floating applica - tions world-wide since 1981. The system can be used regardless of water depth, while handling large water level variations, strong currents and storm conditions.

We are thrilled to follow the development in the groundbreaking floating renewable energy sector. Anchoring such innovative applications couldn't be a better fit for us, since achieving longevity while taking environmental responsibility have always been cornerstones in the creation and development of the SEAFLEX mooring system.

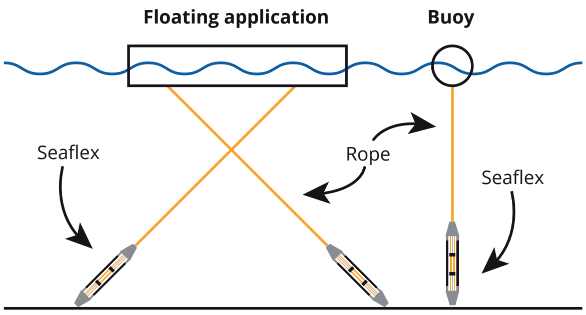


GEUMJEON, KOREA, Nemoeng Co.

This pictured 2MW floating solar power plant produces electricity that can be used by 660 households at the same time. SEAFLEX is used to secure both 110 x 100 m platforms.

KERALA, INDIA
Adtech Systems Limited
Shown above is a 0.5 MW floating solar park in India, the SEAFLEX holding it in place manages their 20+ meter water level variation.

How Seaflex mooring works



SEAFLEX is used whenever there is a need to anchor something floating, such as commercial marinas, wave attenuators, floating solar parks or wave energy converters. The system expands and retracts with each tide and wave, taking on and dampening the forces year after year.

Contact us
info@seaflex.net

See more at
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	Ground-mounted PV (fixed tilt)	Floating PV (fixed tilt)
Electricity produced (first year), GWh *Increase in performance from ground-mounted fixed tilt*	75.8	79.6 *5%*
LCOE (U.S. cents/kWh)		
at 7% discount rate (base case)	5.0	5.6
at 8% discount rate	5.2	5.7
at 10% discount rate	5.4	6.0

Credit: World Bank/SERIS

Source: Authors' compilation.
Note: GWh = gigawatt-hour; kWh = kilowatt-hour; LCOE = levelized cost of electricity; MWp = megawatt-peak; PV = photovoltaic

Comparing the levelised cost of electricity from a 50MWp floating with that from a ground-based PV system

System size (MWp)	Business model	Ownership	Financing structure
≤ 5	Self-generation	Commercial and industrial companies	Pure equity and/or corporate financing (or "on balance sheet" financing). Owner would typically be an energy-intensive commercial or industrial company with ponds, lakes, or reservoirs on its premises and willing to install a floating solar system for its own use.
>5	Power sold to the grid	Independent power producers and public utilities	Mix of debt and equity (typically 80:20); on balance sheet or non-recourse project finance. The latter is still rare, however, because such project finance structures make sense only for projects of a certain size (generally larger than 10 MWp). Future large projects will likely have financing structures similar to the ones used for utility-scale ground-mounted PV projects.

Credit World Bank/SERIS

Source: Authors' compilation.

Financing structure versus size of floating solar system

drive down float costs, lowering capex.

Module costs are a slightly smaller proportion of overall investment costs for a 50MW floating PV project, at 34%, versus 40% for a 50MW ground-mounted solar plant.

Design and construction costs and inverter costs see little variation, though are proportionally slightly less for a floating PV farm than for a ground-mount PV installation.

Together, mounting system, which include floats, and BoP costs are higher as a proportion of capex for a floating solar project, compared with a ground-mounted one. For floating PV, BoP and mounting system costs account for 39% of total capex investment, compared with 29% for ground-mounted PV.

Regionally floating PV capex varies just as it does for ground-mounted PV, market by market. As reflected in Figure 2, Japan remains a region with relatively high system prices, while China and India achieve much lower prices, a trend reflected in these countries' ground-mounted and rooftop solar system prices, in the context of the global average.

Levelised cost of energy (LCOE)

Data from across the world shows that floating PV systems have a higher energy yield compared with ground-mounted PV systems under similar conditions.

Irradiance level and ambient temperatures relating to the climate where a project is located are an even more sensitive variable for calculating the energy yield and, therefore, the LCOE of floating solar plants.

Preliminary results show that in hotter climates the energy yield gain of a floating PV plant when compared to ground-mounted technology is higher than in temperate climates thanks to the cooling effect on PV modules, improving their efficiency.

However, the authors advise that more studies should be done to verify this assertion and to more accurately quantify the correlation between energy yield gains and various climates.

In the report, representative 'average' P50 global horizontal irradiance and performance ratio figures for ground-mounted PV have been estimated for each climate zone. The performance ratio (PR) of floating PV systems under similar conditions is estimated to increase by 5% in the conservative scenario and 10% in the optimistic scenario.

In the conservative scenario (+5% PR), the LCoE of a floating PV system is 8-9% higher than the LCOE of a ground-mounted PV system. In the optimistic scenario (+10% PR), the floating PV LCOE is only 3-4% higher than the LCOE of a ground-mounted PV system.

In time, say the report's authors, this difference is likely to reduce, become zero, or may even reverse with an increasing installed base and anticipated cost reductions for floating PV installations as volumes go up. The installed capacity today is much smaller in relation to ground-mounted PV systems across the world.

Bankability

According to the report, from an investor's perspective, more traction needs to be gained in terms of bankability of floating solar systems, which will come over time, when durability and reliability have been proven in real-world installations.

In this early phase of the market, floating solar PV plants are deemed to have more risks than conventional land-based installations. They include a lack of experience with long-term reliability of system components, particularly modules, cables and inverters, under permanent high-humidity conditions. Paton says: "This remains one of the main barriers at this stage."

According to the report's authors, when banks are considering investing in projects, they are looking at the creditworthiness of every counterparty. This will stand in the favour of big, established solar developers and EPC companies. In many cases these types of businesses also have the funds for on-balance sheet financing that characterises how projects have tended to be financed and funded in the initial stages of the conventional, land-based, solar PV market's development.

"That said, we are seeing a mix of models at this stage, especially when systems are not too large and funded with equity or corporate – balance sheet – financing, or a mix of both, from the owner," Paton says.

Traditional solar developers with experience of developing large rooftop and ground-mounted PV projects are diversifying into floating PV. Examples include Lightsource BP, Canadian Solar, Sunseap and Cleantech Solar. Some of them are doing the EPC themselves or are outsourcing it to other companies.

According to Paton: "Most of the time the company providing the float structure will be involved in overall plant design, EPC and operations and maintenance (O&M) support; thereby 'training' the developer to gain skills in floating PV. The float supplier therefore has a key role to play in the development and construction of these plants."

In certain jurisdictions float suppliers are forming partnerships with developers, such as Ciel & Terre, a French company that has commercialised a floating PV mounting system and is working with developers and EPCs in France, the UK, the US, Columbia and other markets.

The market has also provided opportunities for new developers, which are defining their business or service as a one-stop shop floating PV solution provider. "This is in the case of maritime companies looking to bring their skills to floating offshore solar projects in marine or nearshore environments, which are more complicated to do than floating solar systems on reservoirs," Paton says.

According to the report, in order to design, build, commission and operate floating solar PV plants that are bankable and are able to produce competitive, clean electricity, collaboration is needed that aims to bring together relevant skillsets from a range of companies.

The adapted supply chain needed to deliver floating solar will span developers and EPCs experienced at developing, building and operating large-scale conventional solar plants, float manufacturers, such as chemicals producers, companies experienced in designing and developing floats for maritime applications, providers of mooring and anchoring equipment and hydropower plant operators.

Market support

Policy and regulatory framework needs to be adapted in some markets, the report adds. "As an example, in certain jurisdictions like in the Netherlands, the ownership of an asset, in this case a floating solar system, constructed above an immovable site owned by another party, in this case, a reservoir, can complicate how to enforce certain lenders' securities over the assets," says Paton.

On the other hand, floating solar projects can pose fewer development headaches, especially during the early permitting stages.

Oliver Knight at the World Bank's Energy Sector Management Assistance Programme (ESMAP) division says: "Floating solar is more straightforward to develop in many cases, since large bodies of manmade water tend to be under public or government ownership, such as hydropower dam reservoirs, for example. If you have one owner then the project is simpler to develop rather than dealing with several. In many cases the owners want these assets to be used."

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Both Paton and Knight agree that subsidy regimes for floating solar – though they do exist in some markets – are not usually necessary, as solar costs have already come down significantly.

Countries with subsidies for the technology include Taiwan, which has a specific feed-in tariff (FiT), and the US, where Massachusetts has a location-based compensation rate adder. A renewable energy certificate (REC) mechanism has also been implemented in South Korea, which favours floating solar over ground-mounted plants. In countries in Southeast Asia, such as Vietnam, floating PV projects benefit from the same FiT as ground-mounted PV, which was also the case in Japan, though FiTs have been removed for large projects.

What is needed, say the report's authors, are more empirical studies to determine the exact advantages of floating PV systems in various climates or how to create beneficial hybrid business models, with hydropower plants, for example.

"Floating PV is still a new application and there will be a need to address it specifically through regulations and policies, especially with regards to permitting, licensing and eventually minimum quality standards," says Paton.

Knight adds: "There may be a need for enhanced monitoring for a country's first few floating solar projects, particularly in terms of gathering evidence of the environmental impacts of such projects on fish and other aquatic life. This would be a good candidate for concessional or grant financing, for example using climate finance."

As the market is at an early stage the authors are cautious in their expectations. However, in future, in some locations and depending on the specifics of projects, such as design complexity and floating structure, the LCOE of floating PV installations could reduce to below that of ground-mounted PV, making them the cheapest form of solar generation. ■

Hybrid approach – hydropower and floating solar

The potential for building solar farms on hydropower water bodies could have unique advantages over other sites. Potentially capex costs could be streamlined as solar installations can piggyback on a hydropower plant's under-used grid connection.

Hybrid clean generation plants are being commercialised in all flavours, such as solar+wind, solar+wind+storage, around the world. In the case of floating solar PV and hydropower, especially in dry regions, the two resources are highly complementary. Installing solar can reduce over-reliance on hydropower for electricity generation. "Hosting floating solar farms that feed into the same grid connection means that in summer months solar takes care of demand for electricity that hydropower generation would usually supply, preserving the water resource during dry seasons and spells," says the World Bank's Oliver Knight.

Some hydropower resources have such large bodies of water that a solar array would only need to cover 1-2% to double their existing installed power capacity.

Some Asian countries are particularly interested in floating solar on hydropower reservoirs, including Vietnam, which has a lot of dams but limited available land. "Myanmar has initiated a floating solar study and there is similar interest in India also," says Knight.

In West Africa, where ESMAP is funding a number of studies on solar, floating PV plants on hydropower dams can bring different benefits as in many areas where grids are weak, hydro can firm up solar output, according to Knight.

Countries with floating solar on hydropower resources projects include Indonesia, with 200MW under development, Vietnam with 47.5MW under development, Thailand with a 45MW and 24MW project under development, Brazil and India with large-scale projects in development. Lithuania has a pilot project underway. According to SERIS there are likely to be others underway that they are not aware of.