Comment

Floating solar power: evaluate trade-offs

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Covering 10% of the world's hydropower reservoirs with 'floatovoltaics' would install as much electrical capacity as is currently available for fossil-fuel power plants. But the environmental and social impacts must be assessed.

Solar panels need to be deployed over vast areas worldwide to decarbonize electricity. By 2050, the United States might need up to 61,000 square kilometres of solar panels — an area larger than the Netherlands[1]. Land-scarce nations such as Japan and South Korea might have to devote 5% of their land to solar farms[2].

The question of where to put these panels isn't trivial. There is fierce competition for land that is also needed for food production and biodiversity conservation. One emerging solution is to deploy floating solar panels ('floatovoltaics') on reservoirs.

The idea of floatovoltaics holds much promise, and there has been a rapid rise in installation and investments. But there are still many unknowns about the technology's environmental impacts, along with its social, technical and economic dimensions.

These knowledge gaps need to be filled as soon as possible to avoid overpromising on the benefits of this approach, or having its roll-out derailed by unforeseen roadblocks.

Location, location

Solar power is space-intensive, requiring at least 20 times more area than conventional fossil-fuel plants to produce one gigawatt (GW) of electricity[3]. Several environments have been proposed as locations for extensive installations, each with pros and cons.

Deserts have ample sunshine and don't have much competition for land use. But even here, there are trade-offs. For example, modelling indicates that in the Sahara, the dark colour of large swathes of solar panels would alter local temperatures and global airflow patterns in ways that could cause droughts in the Amazon, sea-ice loss in the Arctic and more[4]. Solar-energy developments in the Mojave Desert in the US southwest have reduced the cover of cacti that are culturally important to resident Native Americans[5]. And logistically, it can be hard to get energy from remote desert regions to where it is needed.

Agricultural fields are another promising possibility, but researchers are only starting to understand how pairing solar panels with crops in 'agrivoltaic' systems will affect food production[6]. Rooftops, car parks and highways are also good options, but are limited in scale.

Placing solar arrays on reservoirs could have many advantages. The arrays are simply conventional solar panels installed on floats that are anchored through mooring lines. Proximity to water tends to keep them cool, making floating panels about 5% more efficient than land-based ones[7]. Arrays shield the surface from the sun and might reduce evaporation, retaining water for hydropower, drinking and irrigation[8]. Hydropower reservoirs already have the grid infrastructure for conveying electricity to consumers, reducing transmission costs. Pairing solar with pumped-storage hydropower could address the twin challenges of providing energy when sunlight is weak and storing it as potential energy in reservoirs when solar-power production is high[9].

Floatovoltaics might also reduce the carbon intensity — emissions per unit of energy produced — of some hydropower operations. Many hydropower plants are as low-carbon as other renewables. But for some projects, so much methane — a potent greenhouse gas — is released from decaying submerged plant matter that they can emit as much carbon per unit energy as do fossil-fuel power plants[10]. For some

Reservoirs could offer alternatives to land for hosting solar panels.

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of those sites, putting solar panels over just 2% of the reservoir's surface could double the electricity production, thereby halving the carbon intensity — which is an important metric in climate policy (see Supplementary information).

For now, floatovoltaics make up a tiny part of the electricity picture. As of 2020, the global installed capacity of floating solar panels was just 3 GW[11], compared with more than 700 GW for land-based solar systems[12]. But the potential for expansion is considerable, given the vast number of reservoirs worldwide — with a total area roughly equivalent to that of France. Covering 10% of the world's hydropower reservoirs with floating solar panels would install nearly 4,000 GW of solar capacity[9] — equivalent to the electricity-generation capacity of all fossil-fuel plants in operation worldwide.

Floatovoltaics are currently more expensive than land-based ones, but not by much: despite the immaturity of this new market, the break-even cost of floating solar projects is only 4–8% higher than that of ground-mounted solar power[13]. The market is growing fast[14], with dozens of projects under way. One, scheduled to be completed by 2024 in Batam, Indonesia, plans to produce 2.2 GW by deploying solar panels over 16 km^2 of water, nearly doubling global floatovoltaic energy production.

Rapid scaling-up of any new energy technology can have unforeseen consequences. Wind turbines, for example, have harmed birds and bats, and their installation offshore can create noise pollution for marine life, interfere with whale migrations and pose complications for commercial fisheries.

Trade-offs between the expansion of floatovoltaics and environmental, social and economic goals remain largely unexplored in both concept and practice. Reservoirs are artificial ecosystems that have been critiqued for a wide range of undesirable socioenvironmental impacts. Yet, in many places, they also provide habitats for wildlife, and have an important role in fisheries and recreation. Reservoir management often serves many needs besides water supply, such as flood control and hydropower. Pressure on multiple uses of reservoirs will intensify under climate change.

Neglecting these trade-offs could increase public opposition to floatovoltaics, lengthen the environmental-impact approval process and deter private investors, thus hampering the decarbonization shift.

National potential

To explore the potential of floatovoltaics, we compared the solar-power potential of large reservoirs with projected national

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Workers fix a floater onto a solar panel to be deployed on Tengeh reservoir in Singapore.

demand for extra solar energy by 2050 (see 'Floatovoltaic potential' and Supplementary information).

We found that countries in the Americas and Africa could benefit most: even low coverage of reservoirs by floatovoltaics should generate all the solar energy needed to decarbonize their electricity sector. Brazil and Canada could be hotspots, each requiring only about 5% coverage of their plentiful reservoirs to satisfy their massive solar-energy needs. Last year, Brazil implemented regulatory changes to help the industry to develop (see 'Brazil's photovoltaic boom').

By contrast, island nations and much of Europe and the Middle East will find it harder to use floatovoltaics to meet their needs, owing to limited reservoir areas in small or arid nations and weaker sunlight at high latitudes. In some industrial nations, including China, mid-century demand for solar power will be so high that even covering all their reservoirs with floatovoltaics would not suffice; they will also require solar on land.

In places where floatovoltaics make sense, the question becomes one of how much of any given reservoir could be covered before downsides outweigh the advantages. More coverage could amplify logistical difficulties, social disruption and environmental side effects. Even 2% coverage of a mid-sized, 300 km^2 reservoir would still be a massive footprint — amounting to about one-tenth of the area of the world's largest land-based solar farm, India's 2,245-megawatt Bhadla Solar Park.

Environmental impacts

Climate change is warming water bodies around the world, with impacts such as harmful algal blooms[15]. Modellers have looked at whether floatovoltaics might counter these effects in lakes and other reservoirs, and found that they can, but only when more than half of the water surface is covered[16]. More needs to be learnt about the consequences for physical, chemical and biological processes, drinking-water quality, aquatic biota, terrestrial wildlife and downstream ecosystems.

Shading a large proportion of a reservoir could trigger cascading effects. Reduced light makes it harder for photosynthetic organisms such as aquatic plants and phytoplankton to flourish, and this might be beneficial in nutrient-polluted reservoirs where harmful algae proliferate. However, the reduced production of oxygen could harm fish and other animals. Extreme oxygen depletion would favour methane-producing bacteria, which could offset decarbonization benefits. If solar-panel coverage is low, these effects will probably be minor. But it's not known exactly how severe any particular type of impact will be, or how the impacts will vary with latitude, water quality and other factors.

Large-scale field studies are needed to evaluate the response of ecosystems to floatovoltaic coverage. Although several test sites have been deployed, such as the Tengeh Reservoir testbed in Singapore, most research efforts focus more on engineering feasibility than ecology.

Use conflicts

Societal uses of reservoirs might also be compromised by floatovoltaics. If a project interferes with a fishery, it could undermine the livelihoods of populations already affected by reservoir construction. For example, Lake Kariba, on the border between Zambia and Zimbabwe, is home to the world's most productive reservoir fishery, and the artisanal fishing gear used to harvest sardines there would be hard to deploy near or under large floatovoltaic arrays. It is also hard to predict how the food webs that support fisheries would respond to shading.

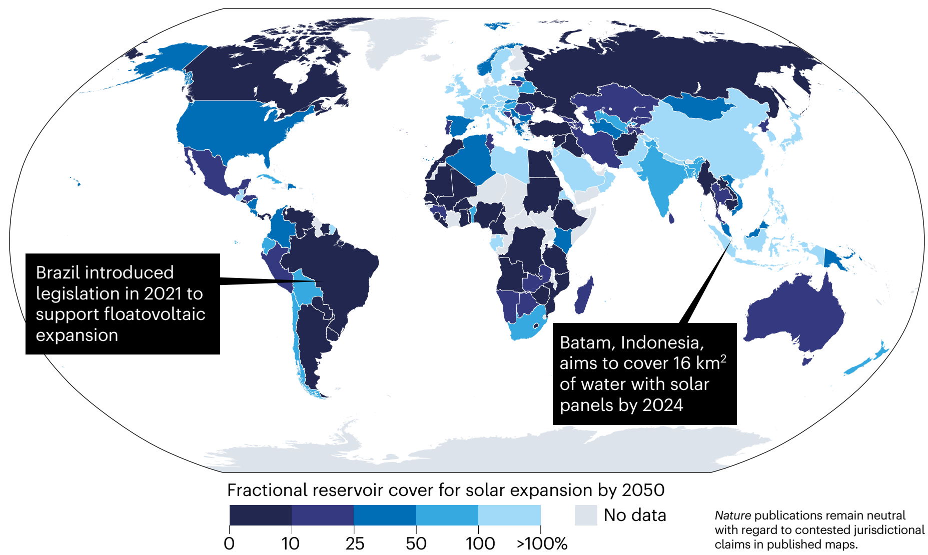
Floating solar arrays might mar the scenery and curb the recreational use of reservoirs, leading to falls in local property prices; floatovoltaic developers will thus probably face resistance from nearby landowners. Social scientists should catalogue such concerns and work out the conditions that would make floatovoltaic projects acceptable to the public.

Operational challenges

Technical challenges could increase costs for developers. Biofouling of panels by bird faeces and microbial biofilms is likely to be

FLOATOVOLTAIC POTENTIAL

Some countries, including Brazil and Canada, can meet their 2050 solar-energy demands by covering less than 10% of reservoir surfaces with floating solar panels. Others, mainly in Europe, the Middle East and Asia, cannot, and will also need land-based solar panels and other renewable sources.



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more problematic over water than land, and could reduce photovoltaic output. Frequent cleaning might be necessary, requiring easy and safe access to the panels.

Inclement weather is another factor. At high latitudes, the formation and break-up of ice cover creates large, unpredictable forces, leading to operational and maintenance challenges — as is the case with a floatovoltaic system built in northeast China's Heilongjiang province. In regions hit by tropical cyclones, high winds can create waves and cause damage. In 2019, for example, a typhoon hit a floatovoltaic project on the Yamakura Dam in Japan; the panels piled up in the wind and ignited a fire.

Variable water levels can also be a challenge. For example, lakes Mead and Powell are more than 40 metres below their full levels following persistent droughts in the southwestern United States. Such fluctuations could be exacerbated by climate change. Drinking-water supply and irrigation needs would probably override the desire to maintain stable water levels for floatovoltaics. Engineering solutions need to be developed and factored into project costs.

Plans to address these issues must be made public so that industry and society can move rapidly towards mutually acceptable practices and a realistic assessment of floatovoltaic potential. Transparency would also boost investor confidence. Researchers need to model costs given the conditions at each site, and document the outcomes after large projects go live.

Moving forwards

Beyond modelling, empirical field-based studies are needed. It is unrealistic to suppose that power companies would do all of this work themselves. Licensing agreements should require access for independent researchers and long-term monitoring. The sharing of lessons will be paramount as the industry and regulators refine guidance on best practices.

The floatovoltaic industry is poised to expand rapidly. Science and policy must move equally fast to ensure that this use of the world's reservoirs is sustainable and equitable.

Brazil's floatovoltaic boom

New regulations pave the way.

In November 2021, Brazil's National Electric Energy Agency approved a resolution regulating the joint operation of hydropower and floatovoltaic plants, with the energy generated by each source measured separately. The move should make Brazilian hydropower producers more likely to install floatovoltaics.

In Brazil, hydropower plants are remunerated according to their share of nationwide hydropower production, not the energy that they produce. This system, known as the Energy Relocation Mechanism, was designed as a hedge against hydrological risk. But it means that a plant installing floatovoltaics would share its gains with all hydropower producers in the country. The new resolution splits those energy markets.

Subsequently, Brazil's Congress enacted Federal Law 14300 in 2022, which authorizes small-scale floatovoltaics to operate in the decentralized generation market. Specific environmental regulations are still needed to maximize the sustainability of operations and gain the confidence of investors.

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