Renew. Energy Environ. Sustain. **6**, 4 (2021)
© V. Piana et al., Hosted by EDP Sciences, 2021
https://doi.org/10.1051/rees/2021002

Renewable Energy and Environmental Sustainability

Available online at:
www.rees-journal.org

RESEARCH ARTICLE OPEN ACCESS

Floating PV in mountain artificial lakes: a checklist for site assessment

Valentino Piana[1,*], Annelen Kahl[2], Cristina Saviozzi[3], and René Schumann[4]

[1] Institute of Sustainable Energy, HES-SO Valais/Wallis, Sierre, Switzerland
[2] WSL Institute for Snow and Avalanche Research SLF, Davos Dorf, Switzerland
[3] Institute of Tourism, HES-SO Valais/Wallis, Sierre, Switzerland
[4] Institute of Sustainable Energy, HES-SO Valais/Wallis, Sierre, Switzerland

Received: 28 November 2020 / Received in final form: 30 January 2021 / Accepted: 30 January 2021

Abstract. Floating photovoltaics is a emerging approach to deploy photovoltaics on water bodies. Thanks to its high overall global potential and the extensive experience gained (with more than 2 GWp installed and than 510 plants, up to 2020), it represents a promising venue for expanding renewable electricity production worldwide. However, a local assessment for sustainability is needed for this potential to be converted into specific projects attracting the attention of stakeholders. This paper provides an original and wide-ranging screening checklist that allows for site assessment, with a view of separating suitable from unsuitable sites and emphasising that appropriate design can solve difficulties linked to the site features. It offers an extensive list of activities that international, national and regional authorities, investors, solution providers, local communities and civic society, environmentalists and other stakeholders might undertake for a fruitful dialogue. It explores the possibility that art, architecture and industrial design may play a role in increasing the touristic value and the public acceptance of new plants. Although the checklist can be used in other conditions, a particular attention is paid to mountain artificial lakes used as reservoirs by hydro-power plants, since they have potential high synergies (and a global potential of over 3.0 TW) but also may encounter significant implementation issues.

1 Overview

The aim of the paper is to provide guidance on the choice of the location of a floating PV plant. Its originality stems from the wide range of issues highlighted for consideration. More specifically, we are the first to highlight the possibility that the plant becomes an element of land design, in connection with art and landscape-level architecture.

We present an overview of the current state of research on a specific renewable technology (floating photovoltaics), whose application in artificial lakes in mountain areas seems promising but also requiring a careful crafting in technical, economic, social and environmental terms. Floating photovoltaic panels over reservoirs may provide a relatively inexpensive and highly up-scalable increase of electricity supply, with synergies with existing hydro-plants (e.g. in transmission lines). Mountains have favorable conditions for solar energy but they have a high landscape value and several fragilities.

Thus, we extend the current research by providing a detailed checklist of factors and potential venues of remedial means that might, lake-by-lake, maximise the positive impacts and minimise the negative ones, including by highlighting factors that might prevent its use altogether in certain lakes. By this connection between site assessment and design philosophy, we contribute to ongoing regulatory and industry-led activities towards both experimentation and mainstreaming of good practices.

Moreover, we describe possible synergies across sites, in the logic of providing positive externalities to a managed socio-economic trajectory of diffusion of Floating PV in mountain areas across the globe. From all this, a balanced vision of desired energy futures of mountain regions emerges, where renewable energy production is integrated into broader sustainability goals and measures.

---

[*] e-mail: valentino.piana@hevs.ch

Throughout this paper, we shall be referring to Switzerland as case study of a country for which mountain artificial lakes are particularly important and shall be referring to it in many quantitative indicators. However, the check-list can be applied in any country.

It should be emphasised that this contribution has not a focus on engineering but rather it is the result of a critical multidisciplinary reflection on the potential of a new technology, having in mind the constraints that society posed to other technologies in the past (e.g. nuclear and wind energies), thus it is sensitive to the need of establishing a fruitful dialogue not only among legally entitled institutions but also across a broad range of stakeholders. Accordingly, we end our contribution with a large number of recommendations for the stakeholders' involvement in terms of regional authorities, hydropower plant operators, investors, municipalities, local communities and civic society, environmentalists and energy experts.

2 Background

In the IPCC Special Report on the reasons why and ways how to limit global warming to 1.5°, all scenarios that limit warming to 1.5° include very large shares of renewable energy integrated in the grid [1]. This can be enhanced by distributed storage [2].

In Switzerland, a largely mountainous high-income country, the national context is characterized by an Energy Law establishing a quantitative goal for renewable energy production, a very slow actual uptake of wind and photovoltaics systems, and the need to update and upgrade its Nationally Determined Contribution, in the light of art. 4 of the Paris Agreement and of the Katowice UNFCCC COP24 decisions.

The difficulties in finding non-yet-utilized large flat areas has prevented the establishment in Switzerland of utility-scale PV plants, the current lowest cost supply of electricity in the world [3]. In Switzerland less than 10% of installed PV is at utility scale [4]. Rooftop solar, which is considered in the literature as basically the only way to harvest solar irradiation in Switzerland for electricity purposes[1], has been incentivized but PV contributed in 2019 was only around 3.2% of electricity net production [8][2]. These conditions may be considered as particularly extreme, but many mountainous countries in the globe do have an interest in exploring ways to integrate more renewable sources in their grid.

3 Current state of research on the potential of floating photovoltaics, including in mountain artificial lakes

3.1 Technology overview

Floating photovoltaics, a family of technological design aimed at placing photovoltaic panels on the top of a floating structure over water, has been recently comprehensively assessed in several papers [9–17], also in comparison with other renewable technologies [18,19]. Its environmental impacts and co-benefits have been addressed [20–24].

Floating photovoltaics (FPV) is a field characterized both by innovative design and incremental innovations. Several alternative design co-exist, compete, and a dominant design is yet to emerge[3]. This means that data and analyses for FPV may come from both the academia and the industry.

Alternatives exist as for where to anchor the system, the type of floating structure, the type of modules to use (e.g. monofacial or bifacial[4], with or without sun tracking[5]). For instance, the systems are moored (or anchored) either to the bottom or to the shore. The solar panels are usually interconnected in parallel or series. The combiner boxes are connected to central or string inverters. The inverters, which transform the direct current (DC) generated by the modules into alternating current (AC), can be placed floating on the water or installed onshore. Using transformers, the current is converted to the correct voltage and either fed into the grid[6] or used for self-consumption.

Beyond this broad technical characterization, there exist many different possible design philosophies, including company-specific approaches. There are different systems and suppliers for segments of floating PV substructure systems on the market. The suppliers offer different solutions to deploy floating systems on water bodies. The first design is based on floating substructures where the individual floats (e.g. in HDPE) are connected to each other and either one or two floats carry the modules. Two examples of these modular systems can be seen in Figures 1 and 2.

The second segment of substructure suppliers offer pontoon solutions. These are single large floats carrying the arrays of modules (Fig. 3).

In the third design, no floats or pontoons are used. Instead, a substructure consisting of a non-permeable membrane carrying the modules is utilized [32], represented in Figure 4.

---

[1] See for example, Dujardin et al. [5], Kienast [6], Michellod [7].

[2] Everything we shall say in favour of floating PV should not be interpret as disadvantageous to rooftop PV. There is no competition between rooftop and floating PV, since they depend on non-overlapping investors' budget and span of control. They share the same panels and many electrics and electronics systems, thus key cost components.

[3] For a test bed allowing for comparing different designs see Hammoumi et al. [25].

[4] See Tina et al. [26].

[5] For a discussion on dual-axis tracking see Alktranee [27].

[6] This may happen at different voltages. In Switzerland, for instance, the grid is divided into maximum voltage (up to 380 kV), high voltage (50–150 kV), medium voltage (up to 35 kV), and low voltage (440 V) [28].

Fig. 1. An example of floating substructure modular design [29].

Fig. 2. A second example of floating substructure modular design [30].

Fig. 3. An example of pontoon-based design [31].

Fig. 4. Flat membrane design. Source: https://cleantechnica.com/2019/03/12/floating-solar-trampoline-by-ocean-sun-tested-by-statkraft/.

Fig. 5. Floating PV on ice.

To cope with a potentially difficult environment, a Japanese plant by Sungrow is testing the compatibility with ice in Fukushima prefecture [33], represented in Figure 5.

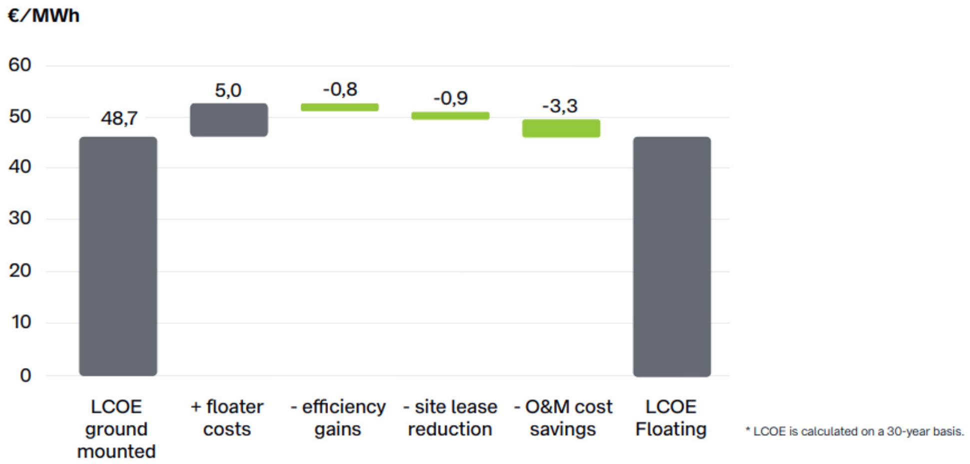
Many efforts for standardization and mainstreaming of good practices have been made[7] to rebalance the company-specific design innovations (and they relative pros and cons, which are not in the scope of this paper) and to take advantages of the lessons learned.

As indicated by the World Bank [33] "[t]he first floating PV system was built in 2007 in Aichi, Japan, followed by several other countries, including France, Italy, the Republic of Korea, Spain, and the United States, all of which have tested small-scale systems for research and demonstration purposes [...] The first plant larger than 10 MWp was installed in 2016, and in 2018 the world saw the first several plants larger than 100 MWp, the largest of which is 150 MWp. As of mid-2018, the cumulative installed capacity of floating solar was approaching 1.1 gigawatt-peak (GWp), the same milestone that ground-mounted PV reached in the year 2000. If the evolution of land-based PV is any indication, floating solar could advance at least as rapidly, profiting as it does from all the decreases in costs attained by land-based PV deployment. Most of the installations to-date are based on industrial basins, drinking water reservoirs, or irrigation ponds (not yet on solar ponds[8]), but the first combinations with

---

[7] Current efforts towards FPV standardization and knowledge sharing:
- World Bank's "When Sun Meets Water" series, including the "Handbook for FPV practitioners
- STOWA (Netherlands) "Guide for licensing of floating solar parks on water"
- South Korea and China (NB/T 10187-2019) have national requirements for floating solar HDPE structures
- IEC TC 82 is considering FPV in its agenda
- Working Group for Singapore-based technical reference (building on IEC TS 62738)
- TUV Rheinland's 2 PfG 2731/02.20 for Floating bodies
- DNV GL's Joint Industry Project to write a Floating Solar PV Recommended Practice (expected release: March 2021). Source: Michele Tagliapietra [34].

[8] For a review of solar ponds see Al-Musawi et al. [35].



* LCOE is calculated on a 30-year basis.

Fig. 6. Levelized cost of energy for floating PV. Source: Ortmann [60].

hydropower reservoirs, which bring the added benefits of better utilization of the existing transmission infrastructure and the opportunity to manage the solar variability through combined power output, have started to appear. In these installations, special attention needs to be paid to possible effects on the downstream flow regime from the reservoir, which is typically subject to restrictions related to water management (in case of cascading dams), agriculture, biodiversity, navigation, and livelihood or recreational uses".

Floating PV in artificial basins has been recognized as particularly promising [36]. The connection with hydropower plants has been extensively investigated [18,37–46][9].

3.2 Market potential

According to a 2018 report of the World Bank, "[t]he most conservative estimate of floating solar's overall global potential based on available man-made water surfaces exceeds 400 GWp, which is equal to the 2017 cumulative installed PV capacity globally" [33]. In one key nation, the National Renewable Energy Laboratory – a part of the US Department of Energy – found that almost 10% of U.S. energy supply could be met by siting solar projects on 24 419 man-made water bodies, if 27% of them would be covered by FPV systems [36]. If South Korea would fully utilize all its appropriate bodies of water for FPV systems, three terawatts could be generated as a result [58].

Lee et al. [45] estimate the global potential of Floating PV hybridized with hydropower ranging from 3.0 to 7.6 TW (4251 to 10 616 TWh annual generation). They take into consideration location, irradiation, dimension of the water body and many other technical factors. However, as Lee et al. [45] state, "these datasets do not capture the potential, local project-siting constraints to floating solar that reflect regulations for water body use (such as prohibitions on siting on recreational waterbodies) or waterbody conditions (potential freezing during winter months). This assessment does not capture finer, project-siting barriers that developers will eventually face. These siting constraints require local, often ground-verified data, as well as knowledge of local development regulations (such as colocation on reservoirs used for recreational purposes)". The checklist presented in this paper therefore provides a bottom-up answer to this signaled gap.

Another point is that the specific issue of high-altitude mountains' artificial basin used by hydropower plants has not yet been focalized in the scientific literature, which is why no specific site assessment criteria have yet been developed. This paper addresses this issue by providing a guideline for developers in those areas.

3.3 Economic assessment

In broad economic terms, utility-scale ground-mounted PV is significantly cheaper per kW than rooftop PV[10]. According to Ortmann [60], for floating PV plants the "same LCOE as for ground-mounted systems are achievable, if three conditions are met: a higher system efficiency, a lower site lease cost, a lower Operations & Maintenance cost" and it suggests approaches and site limitations to meet these conditions[11]. Figure 6 provides economic estimations according to Ortmann [60] for a generic plant.

---

[9] Other inland location types that have been assessed include (aquaculture) fish ponds [47], ash pond of a thermal power plant [48], mine pit lakes [49], irrigation dams and reservoirs [50,51], water treatment surfaces [52,53] or drinking water sites [54,55], quarry lakes and tailing ponds [9]. A separate strand of research and business pilot plants and operations is on the sea (near-shore and off-shore), with the corresponding issues of salinity and possibly of multi-national interconnectivity [15,56,57].

[10] See https://www.irena.org/costs. "Utility-scale solar PV's global weighted-average LCOE fell by a precipitous 82% between 2010 and 2019, from a value of USD 0.378/kWh in 2010 to USD 0.068/kWh in 2019. Residential and commercial sector rooftop solar PV typically have higher cost structures than utility-scale projects within a country the LCOE of residential PV systems by country and market declined from between USD 0.301/kWh and USD 0.455/kWh in 2010 to between USD 0.063/kWh and USD 0.265/kWh in 2019" (p. 15–16, [59]).

[11] To keep maintenance costs lower, for instance on dust removal [61], solution designs with good accessibility are relevant (for solar panel cleaning robots see [62]).

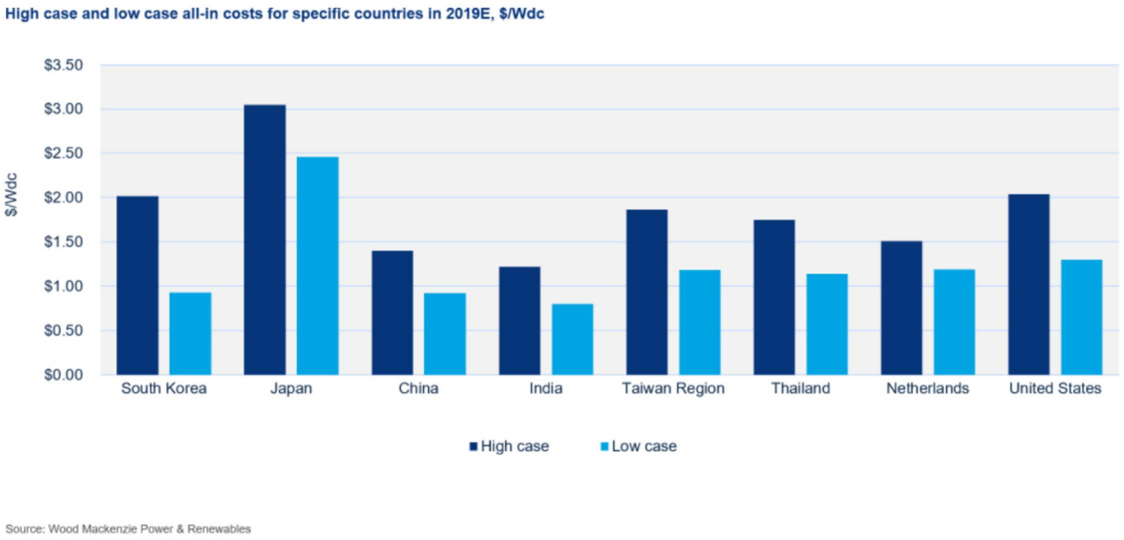


Fig. 7. Costs for floating PV plants.

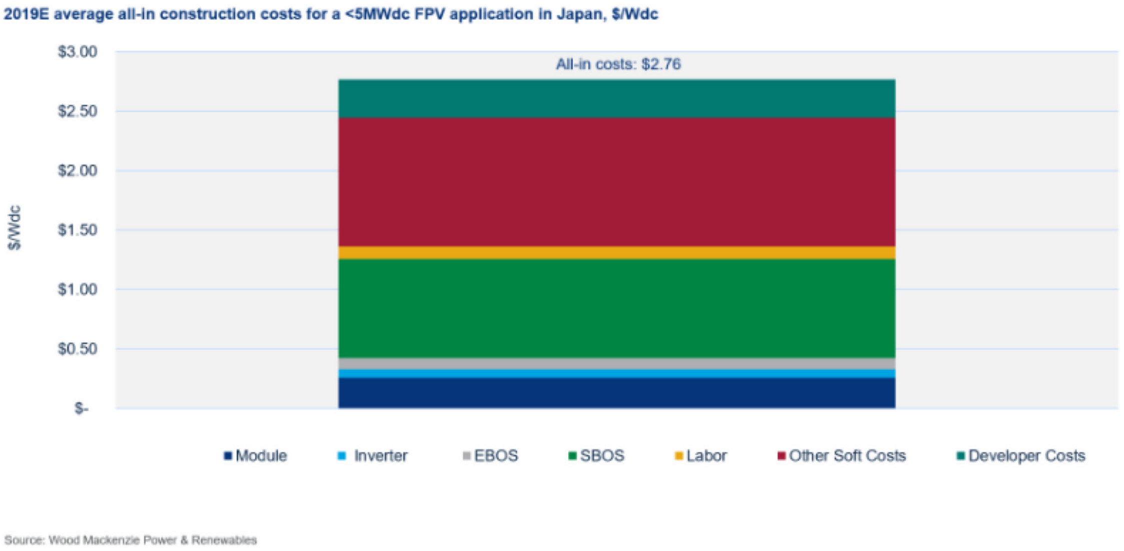


Fig. 8. Construction costs. Source: Wood Mackenzie [66].

In terms of evolution over time, improvements can be already detected. While the World Bank Group et al. [33] published an average capital investment price of 1.135USD per watt-peak (Wp) of installed capacity for floating solar projects, only a few months later World Bank et al. [63] highlighted an average capital investment price of 0.73US dollar per Wp (USD/Wp), indicating a decrease by 60%. This has to do with a strong price decline in modules, a slow price decline in inverters, as well as a decline in price for the floating substructures [63–65]. The latter is due to a more efficient use of materials through design improvements of the substructures during recent years [13]. However, this overall trend should not miss that the price for a floating solar farm depends on different factors such as the water body characteristic, distance from the grid, or anchoring complexity [63].

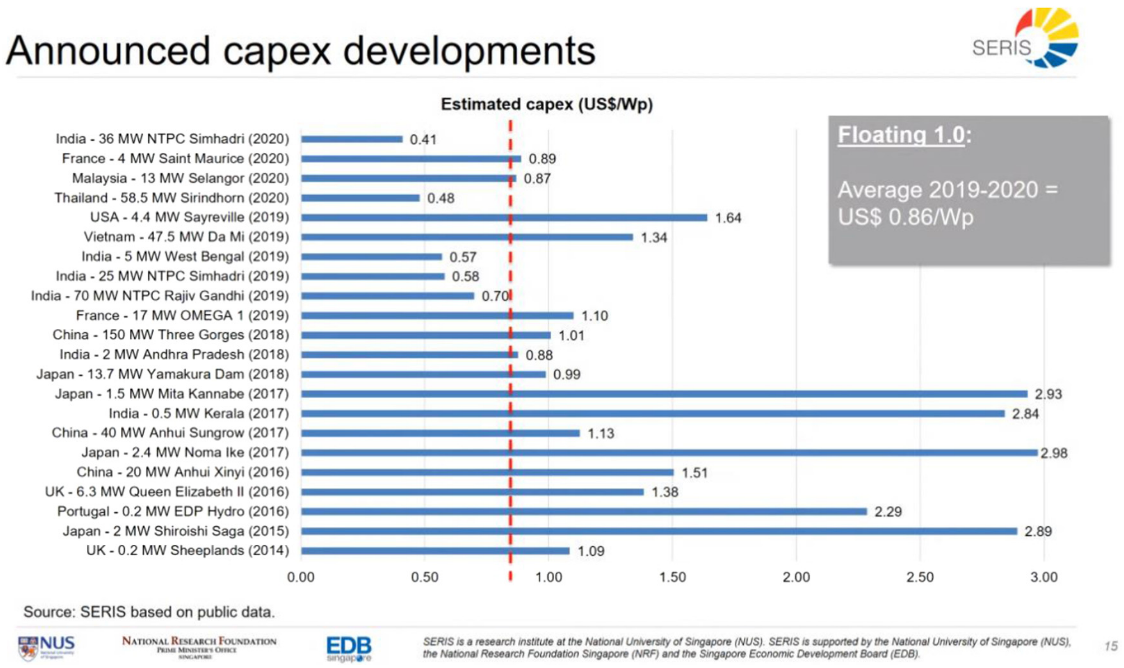
In terms of averages of actual projects, depending on size, design, location, and operator the cost per watt is depicted in Figure 7, for a few selected countries[12].

For instance in South Korea, the low case price is less than 1$ per Wp, with the high case is about 2$. If for Switzerland the nearest case were to be considered Japan (for the high labor cost and high sophistication of planning and technology sensitivity), the detailed full structure might be similar to the Figure 8.

Please note that soft costs include Design & Engineering, Permitting & Interconnection, Civil costs, Supply Chain, Logistics & Misc., Taxes, Overhead & Margin. The water acquisition costs are included in the Developer

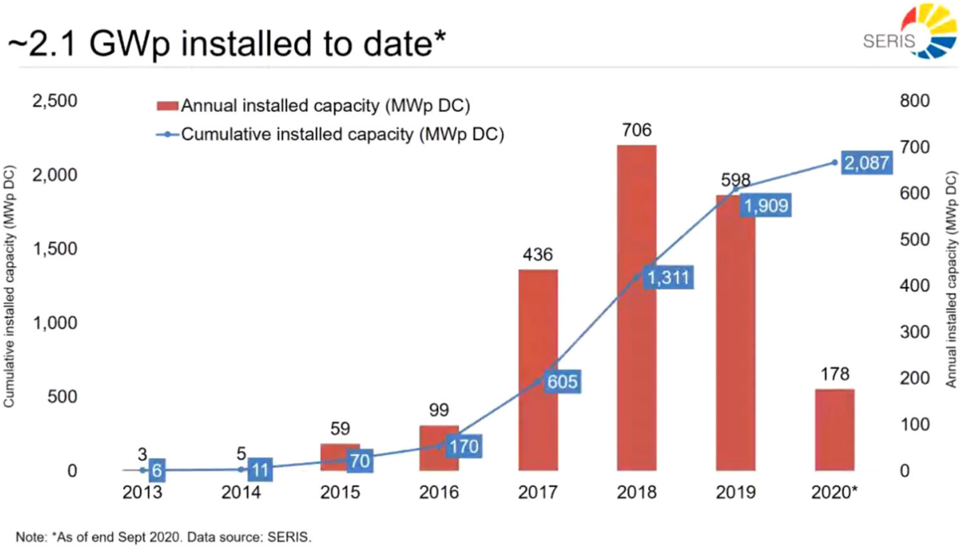
---

[12] Data of Figures 7 and 8 are from Wood Mackenzie [66], courtesy of Molly Cox (Wood Mackenzie, Power and Renewables).



Source: SERIS based on public data.

Fig. 9. Capital expenditure (US$ per Wp).



Note: *As of end Sept 2020. Data source: SERIS.

Fig. 10. Installed capacity 2013–2020.

Cost category. Keeping all these elements into account leads to a total of 2.76$ per Watt.

In Figure 9, a project-wise overview of capital expenditures (CAPEX) for specific FPV projects is given. It indicates that in Europe the estimated CAPEX cost are settled between 0.89$ per Wp and 2.2$ per Wp [67].

3.4 Business trends

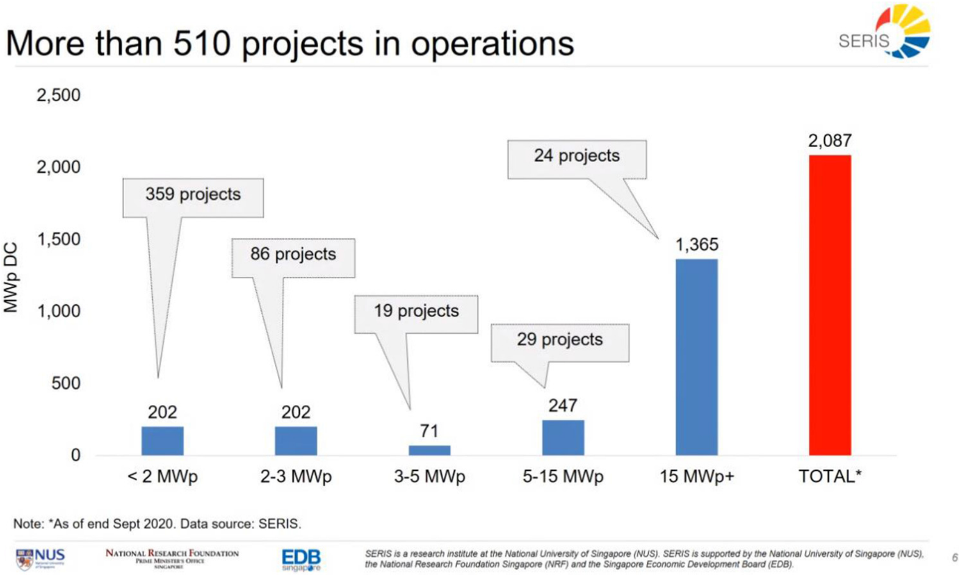
An overall positive technical and economic potential, in a moment in which there is a broader trend of success for photovoltaics in general – recently recognized by IEA as the cheapest source of electricity [3] – has led to the growing trend of floating photovoltaics represented in Figure 10[13].

The plant size distribution is quite dispersed, as shown in Figure 11[14].

---

[13] Source: Reindl and Paton [67]. For market forecasts see Merlet [68] and Cazzaniga and Rosa-Clot [16].

[14] Source: Reindl and Paton [67].

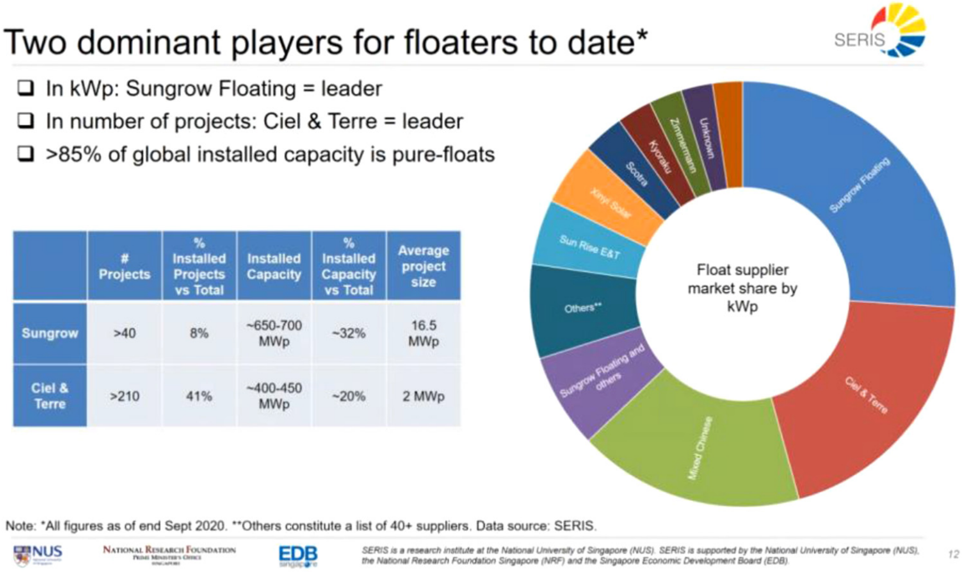


More than 510 projects in operations

Note: *As of end Sept 2020. Data source: SERIS.

SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by the National University of Singapore (NUS), the National Research Foundation Singapore (NRF) and the Singapore Economic Development Board (EDB).

Fig. 11. Plant size distribution.



Two dominant players for floaters to date*

- ☐ In kWp: Sungrow Floating = leader
- ☐ In number of projects: Ciel & Terre = leader
- ☐ >85% of global installed capacity is pure-floats

	# Projects	% Installed Projects vs Total	Installed Capacity	% Installed Capacity vs Total	Average project size
Sungrow	>40	8%	~650-700 MWp	~32%	16.5 MWp
Ciel & Terre	>210	41%	~400-450 MWp	~20%	2 MWp

Note: *All figures as of end Sept 2020. **Others constitute a list of 40+ suppliers. Data source: SERIS.

SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by the National University of Singapore (NUS), the National Research Foundation Singapore (NRF) and the Singapore Economic Development Board (EDB).

Fig. 12. Solution providers' market share.

The sector is worldwide dominated by two major players (the French Ciel & Terre and the Chinese Sungrow), but there are also many other floating suppliers in the field with their specific products, as evidenced in the Figure 12[15].

From the analysis of the proprietary database by SolarPlaza containing data about 242 plants, at the beginning of 2020, ten European countries have at least one FPV plant (in descending order of plants: The Netherlands, Spain, UK, Italy, France, Portugal, Belgium, Germany, Sweden), for a total of 46 plants.

A ranking of the operators with the largest market shares in Europe include Ciel et Terre, with 23 plants, the Spanish Isigenere with 8 installations, the Italian NRG Island with 7 installed plants. In terms of installed capacity, after Ciel & Terre, BayWa r.e. is second. These two companies have installed the 88% of the total European capacity. In synthesis, there is a remarkable market and expertise concentration amongst few floating solution providers[16].

---

[15] Source: Reindl and Paton [67].

[16] Source: Our elaboration based on data obtained in November 2020 from Solarplaza International BV by request.

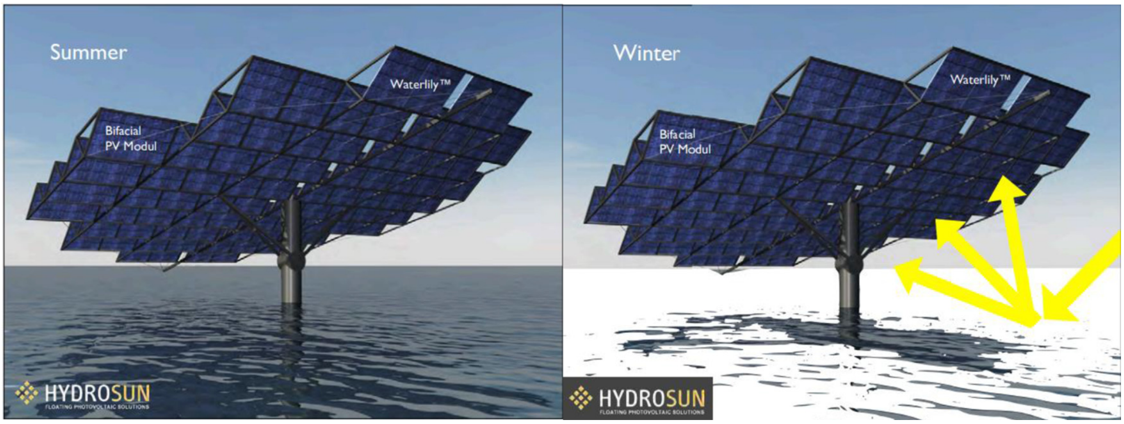


Fig. 13. Canopy design with bifacial modules. Source: [71].

3.5 The situation in Switzerland

Zooming from the international level to the case of the mountainous country that we specifically address in this paper, in Switzerland:

- there are 103 lakes larger than 0.3 hectares in the country, covering 2 180.75 km^2;
- the 45 artificial lakes cover 84.48 km^2;
- the 21 natural lakes are used as reservoir for dams, covering 28.63 km^2.

As a broad first approximation of production potential, according to Kahl et al. [69], about 60 km^2 of PV surface in cities would generate 12 TWh per year, value chosen by the authors because “[t]his amount would replace half of the current nuclear production”.

Kahl et al. [69] single out a number of very important additional points in favor of placing PV in mountains, with a tilted angle aimed at maximizing winter production, when prices are higher and the overall need, in case of nuclear phase out, larger. In a fully renewable Swiss electricity system, “the mismatch between demand and supply underscore the remarkable impact of moving PV production from urban to mountain environments: the seasonal energy gap is reduced by half” [69].

In mountains, thanks to lower number of cloudy days, higher irradiance, increased ground reflectance because of snow cover, and steeper panels, which would “suffer less from soiling, due to dust, dirt and other particles (assuming in particular vertical panels, ‘which rarely cumulate snow and would shed it very quickly’) the surface fully covered by PV that would replace half of the current nuclear production reduces to about 45 km^2, according to Kahl et al. [69].

In short, from a merely quantitative point of view, Floating PV can make a sizeable contribution to Switzerland’s overall electricity production, ranging from 3 to 5 times the current level of installed PV (which produced 2.178 TWh in 2019)[17] to a significant share of the total net (which in 2019 was 67.761 TWh)[18], depending on how many lakes would be involved, in which percentage they are covered and with which technology. For instance, a 60% coverage of all (but only) artificial lakes with the standard 10 m^2 per kWp (including the space for shading) utilised by Lee et al. [45], at an average of 1500 h a year equivalent to peak production, would generate 7.6 TWh.

In business project-wise terms, Switzerland was envisaging a floating PV plant as early as 2009 in a visionary paper laid down by [70], describing the advantages of FPV systems. Furthermore, it included a potential application on the Sihlsee, a lake close to Zurich, which hydropower plant is owned and operated by the Federal Railway Company of Switzerland, the SBB. The hydropower plant is powering the public transport system in the area of Zurich, which demand curve is similar to the production curve of PV during daytime. A 2014 presentation updated on the difficulties met and proposes some solutions, represented in Figure 13 [71].

In 2012, a testing floating plant at the Lac des Toules was installed by Romande Energie. The test over the years revealed how to overcome a number of difficulties related to floating systems, which prompted for a wider installation. From the press release “2240 m^2 of bifacial solar panels will soon produce more than 800 000 kilowatthours per year. If the results will be positive, more than 24 million kilowatthours will possibly be produced every year [by subsequent investments]. According to several studies, this innovative installation is characterized by a particularly high energy efficiency: it should produce up to 50% more energy than a park of equal dimensions localized in the plain” [72]. This result is expected, among other factors, because the strong reflection of the light by the snow, which increases the effectiveness of the solar panels. The project has attracted international interest, as testified by the slide by Reindl and Paton [67] presented in Figure 14.

4 The checklist for site assessment

In this paper we advocate a lake-by-lake approach in which a long checklist of different criteria for a lake to become subject to a more extensive and detailed feasibility study, possibly leading to an investment plan and the relative

---

[17] OFEN [8].

[18] Source: OFEN [8].

Alpine FPV in Switzerland

SERIS

Lac des Toules

- Capacity: 448 KWp
- Altitude: 1,800 metres
- Yield: expecting +50% (bifacial)
- Temperatures: -25°C to +30°C
- Wind: up to 120 km/h
- Water level variation: 50 metres
- Ice: up to 60 cm thickness
- Snow load: 50 cm

Pictures: © Romande Energie, Keystone

SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by the National University of Singapore (NUS), the National Research Foundation Singapore (NRF) and the Singapore Economic Development Board (EDB).

18

Fig. 14. Actual Swiss plant.

funding and implementation. In this way, benefits and risks, opportunities and limitations (including specific technological arrangements) are balanced at the micro (bottom-up) level, allowing for the identification of the most immediate stakeholders. Their consultation will be necessary, both for responding to the checklist and for the possible feasibility study. Special attention will be paid to cognitive and emotional biases that might characterize the stakeholders, replicating known effects of bounded rationality.

The list is an original contribution, derived from our reading of key issues. It is not an attempt to provide a ranking of different locations, thus it embeds a "sufficiency" orientation rather than an "optimization" orientation. It does not provide quantitative thresholds for the criteria to be met, since the evolution of prices and technological performances will lead to inevitable shifts in any of such thresholds. For instance, we do not establish in general a minimum number of hours of full irradiation for the project to be viable economically, since such indication necessary depends on the price of the panels, of the sold electricity and of the overall structure of the investment over time.

In comparison with the broader scope of the DNV GL's Joint Industry Project to write a Floating Solar PV Recommended Practice [34], the list is mainly concerned with site assessment, design philosophy, and environmental impact. The checklist does not enter into an assessment of energy yield[19], the electric layout and the different anchoring opportunities. It does not cover how to install, operate, monitor and maintain such systems. The structure of the list is such that its three main subjects (site assessment, design philosophy, and environmental impact), far from being independent, are co-evaluated. The specificities of the site might suggest a certain design, which in turn may need to be further refined in order to avoid any relevant environmental impact. Moreover, we consider that governance issues may impact the choice of the site to be submitted to assessment, depending on the subjective judgement and material interests of the promoter. Accordingly, we shall devote the Section 5 to governance issues.

In this Section 4, we present the nested structure of the checklist, broadly drawing on conflict maps as operationalized in Kienast et al. [6]. In general, a lake should be subject to a more detailed feasibility study if it passes all criteria (logical AND operator). In certain situations, after a difficulty or possible limitation occurs, the checklist includes potential (non-exhaustive) venues of remedial action, whose actual evaluation would require further steps. In other terms, the checklist contains raccomandations.

The checklist covers five broad areas particularly important of the site assessment:

A. Climate and atmospheric conditions
B. Lake accessibility
C. Lake shape, soil, and water features
D. Environment
E. Landscape services

Several items are contained into the five broad areas. For each item, two or more criteria are indicated, leading to three possible general outcomes: suitability, unsuitability or the need of a specific line of design philosophy coping with the difficulty. Instead of a simple dichotomy ("stop or go"), we introduce the possibility that appropriate design solutions are explored. By aggregating all items across the five areas, one gets a mapping of what is particularly favorable, what is problematic (with some, inevitably cursory, venues for solutions), and what would hint at avoiding to localize the floating PV plant on that lake. In general, one indication of unsuitability would suffice to discard the site. However, an overall evaluation of all

---

[19] For a contribution selecting sites mainly based on energy yields and economic parametres see Zubair et al. [73].

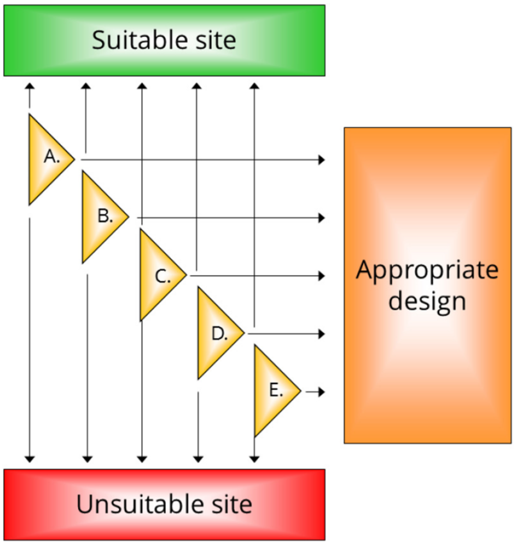


Fig. 15. For the five areas (A, ... ,E) of the checklist, their items may lead to three possible indications (suitability, unsuitability, exploration and choice of an appropriate design). Overall suitability requires in principle that all criteria are positively met or that appropriate design has been introduced.

reasons for unsuitability and the kind of advantages that a lake might have would impact on the final decision to undertake a full-fledged feasibility study.

A graphical representation of this scheme is in Figure 15. More in detail, the full list of criteria is the following:

A. Climate and atmospheric conditions
  A.1 Solar irradiation
  A.2 Shading from surrounding terrain
  A.3 Maximum wind speed
  A.4 Snow
  A.5 Ice
B. Lake accessibility
  B.1 Road accessibility for logistics
  B.2 Land availability for on-shore construction, storage and float assembly
  B.3 Electric grid accessibility
C. Lake shape, soil, and water features
  C.1 Geometrical/fractal shape of the lake
  C.2 Water depth
  C.3 Water level variation, leading to the variability of the dimension of the lake
  C.4 Bathymetry
  C.5 Soil composition
D. Environment
  D.1 Broad characterisation of the lake
  D.2 Presence of geological, biological and ecosystemic idiosyncrasies (e.g. unique endemic species)
  D.3 Potential chemical contamination of water by the PV plant
  D.4 Presence of flora and fauna in the lake
  D.5 Economic utilisation of flora and fauna in the lake
E. Landscape services
  E.1 Current landscape perception by local communities
  E.2 Current landscape perception by tourists

Needless to say, a checklist is a simplified way to look at issues. Once a real investment is envisaged, based on a detailed feasibility study and its technical annexes, during the phase of obtaining permits, constructing and operating the plant a transparent tracking of a broad range of qualitative and quantitative indicators is called for, including more specific environmental variables. In short, this checklist (and its evolution over time, including when new floating plants are actually built around the world) provides a simple, wide, non-technical tool for a first assessment of possible consideration for the implementation of a floating PV plant, to be followed, in case of positive evaluation, by stakeholders engagement and a full-fledged feasibility study.

In what follows you find the checklist and its articulation. Please note that for simplicity's sake every time the criterion is satisfied the site is declared suitable, obviously limitedly to the criterion itself.

A. Climate and atmospheric conditions

A.1. Solar irradiation

If solar irradiation is high or intermediate, then the site is suitable. If solar irradiation is low, then you need to take great care of the economic costs and potential revenues, designing solutions that achieve economic viability, irradiation notwithstanding. If viability turns out to be impossible, then the location is unsuitable.

A.2. Shading from surrounding terrain

If shading from surrounding terrain is none or minimal, then the site is suitable. If it is relevant, then you need to compute the path of the sun throughout the sky and its possible obstruction by the local topography (e.g. high mountains and steep slopes), especially for winter when the sun stays quite low. Check whether good conditions could characterize a part of the lake (where to concentrate a smaller plant) and whether this part might change over the years, leading to an exploration of towing the plant seasonally.

A.3. Maximum wind speed

If the maximum wind speed at the site in historical records and time series is well below storm level, then the site is suitable. If is at or above storm level, then the design should utilize a flexible yet robust mooring system and compute (analytically or numerically) simulations for damage dynamics, including domino effects. Such system should be in place already during construction. One could also verify the possibility of emergency modification of shape at a short notice. Conversely, if wind is often strong, due attention should be paid to the possibility of a wind power plant [74].

A.4. Snow

If the presence of snow is increasing the electric production, then the site is suitable. If the presence of snow is disturbing electric production, then one could choose a vertical tilt and a floating structure that passively (by shape) and actively (by electric-powered heating)[20] removes snow, while exploring further remedies. If the presence of snow will be burdening the physical structure, one should choose a robust enough structure, compatible with costs. If such costs are prohibitive, then the site is not suitable.

A.5. Ice

If the presence of ice is minimal, then the site is suitable. If the ice, in a certain season, is present in the coast but not at center of the lake, you can choose a suitable location and size of the plant in order to avoid ice. If the ice present across the lake, including any location of the plant, you need to verify if your default plant design can resist freezing, in which case, the site is suitable. If your default plant design cannot resist freezing, then choose a plant design that allows to float on ice and is pushed up while the water is undergoing freezing or choose a "canopy" design, where the panels do not float but are fixed to a structure above water, possibly with a bifacial design of the panels, along Nordmann [71]. You need to pay particular attention to the effect of ice on panels, electric cables and anchoring systems. If all (economically sustainable) designs fail, then the site is not suitable.

B. Lake accessibility

B.1. Road accessibility for logistics

If the site is easily accessible, then the site is suitable. If it is accessible with difficulties, then you need to verify the reason of the difficulty and whether other economic and human activities would call for a road infrastructure improvement. If unsurmountable, check for air or water access (and relative costs and technicalities). If nothing suitable can be found, the location is unsuitable[21].

B.2. Land availability for on-shore construction, storage and float assembly

If there is sufficient land availability, then the site is suitable. If there are constraints on the land availability, then you need to verify the possibility of a step-wise construction with successive modules attached to the main floating structure. If impossible, limit the size of the floating plant.

B.3. Electric grid accessibility

If the planned Floating PV plant is in the proximity of a grid node and possibly to a transmission line, then the site is suitable. It is located at a high distance from a grid node, you need to verify the possibility and the costs of grid connection. If it is inaccessible, the site is unsuitable. Please note that this feature is one of the arguments for co-localizing floating PV in dams for hydroelectric production.

C. Lake shape, soil, and water features

C.1. Geometrical/fractal shape of the lake

If the shape of the site is (if only approximately) of a rectangular shape, the location is suitable. If shape is highly irregular but the lake is overall large and the plant will occupy a minor part of the lake, the location continue to be suitable. If, by contrast, if the plant has to fill most of the lake to be economically sustainable and the lake is small, possibly with narrow points, the location is unsuitable.

C.2. Water depth

If the water is very shallow then you need verify a particular design and protection from land intrusion. If the water is deep, then the location is suitable.

C.3. Bathymetry

If the underwater soil has a regular shape, then the location is suitable. If it has a highly irregularly shape with risks for navigation and floating structure, you need to verify the possibility of anchoring in a safe place and with redundancies.

C.4. Soil composition

If the soil is hard and compact, then the location is suitable. If it is soft and irregular, you need to carefully choose the anchoring site and plan redundancies.

C.5. Water level variation, leading to variability of the dimension of the lake

If the water level variation is minimal, then the location is suitable. If it sizeable, you may take the lowest dimension over the year in order to decide the size of the PV plant. You may also explore the possibility of localizing the plant without water temporarily. Excessive water level variation in absence of remedial actions would make the site unsuitable.

D. Environment

D.1. Broad characterization of lakes

If the lake is artificial and with an active dam producing electricity, the location is suitable. If the lake is artificial without hydroelectric production, you need to verify the origin and current utilization of the lake for compatibility of the PV plant and cope with the issues that would be eased by the dam presence (e.g. transmission lines).

If the lake is natural, large or medium-sized, then you should consider a possible plant with low percentage coverage and high penetration of sunlight. If the lake is natural and small, the site is unsuitable.

---

[20] We thank Michael Lehning for this suggestion to the audience of the IMC 2019 Conference Workshop on Renewable Energy: Impacts on Mountain Environments and People.

[21] For a further discussion of the issue, see Pimentel Da Silva and Branco [22].

D.2. Presence of geological, biological and ecosystemic idiosyncrasies (e.g. unique endemic species)

If there are such idiosyncrasies, the site in unsuitable, the more so that is likely that, in this condition, an integral reserve has been established (or should have been established), forbidding any human settlement and activity.

D.3. Potential chemical contamination of the water by panels and/or the technological solution to sustain them

The location is only feasible if the technological solution cannot lead to such contamination[22].

D.4. Presence of flora and fauna in the lake

If in the lake there is flora and fauna, then you have to verify the potential impact (sun rays, biological reproduction, ecosystem unbalances, ...). If they are large and/or irreversible, then the location is unsuitable. Please note that many lakes used for hydropower generation do not have such conditions, so they are suitable.

D.5. Presence of flora and fauna in the surrounding areas of the lake and in downstream flow

If there is flora and fauna in the surrounding areas of the lake and in downstream flow, then you have to verify the potential impact (sun rays, biological reproduction, ecosystem unbalances, ...). If they are large and/or irreversible, then the location is unsuitable.

D.6. Economic utilization of flora and fauna in the lake

If there is no economic utilization of flora and fauna in the lake, then the location is suitable. If there is economic utilization then you need to quantify the number of people and companies operating on the lake, verify the declared profits and personal income from fishing, hunting and other kind of economic utilization, and compute in which measure the plant could diminish or augment such values. If the plant will be raising the activities' revenues, the site is suitable. If the plant would diminish them, then a stakeholder consultation should, in case of implementation of the project, include economic and symbolic compensation. Unless this is planned in a sufficient measure, the site is unsuitable.

E. Landscape services

E.1. Current landscape perception by local communities

If the lake is at the very margin of the perception by local communities, for instance because of the distance or of alternative sites, then the site is suitable. If the local communities have a sizeable visibility on the lake, the plant must be made aesthetically not intrusive. If the lake is a major local identity element then you need verify with the population if the proposed modification is compatible with their desired identity. If absolutely not, the site is unsuitable.

E.2. Current landscape perception by tourists

If the lake is not currently a tourist attraction, the site is suitable. You may even want to verify the possibility that the floating plant might become an attraction in itself, for the land-art shape of its panels, for the waterfront it might create for pedestrians and cyclists if connected to land with a proper transit connection[23].

If the lake attracts a sizeable amount of tourists, then the plant should at least be made aesthetically not intrusive, as you may verify with landscape and tourism experts and stakeholders. If the lake is surrounded by walk and bike lanes, you may add a safe and monitored transit through the plant and/or around the "solar island" for the tourists.

If the plant turns out to be intolerable from a landscape point of view (including being a potential object of conflict), the site is unsuitable.

If the lake is a major tourist attraction in itself, then the site is unsuitable.

5 Alternative governance structures and decision-making processes

There are a number of important questions regarding future investments for floating PV, for which no definitive answers exists today. These covers aspects like:

- Who might invest in Floating PV in mountain artificial lakes?
- How may someone be convinced to begin an exploratory decision-making approval and stakeholders involvement?
- How would stock exchange markets react to the news about a certain company carrying out a project?
- How a scenario of certainty could be built for financial markets to provide funds to the projects?

There is a lot of path-dependencies, geographical and historical vested interests, incumbents and industrial dynamics. But we begin to explore a few alternative possibilities and their potential constraints and advantages. This is done especially in order to anticipate possible developments and track actual projects and identifying which stakeholders need to be engaged.

By concentrating the attention to artificial lakes serving as reservoir for hydro-power plants, an obvious departing point would be the company operating that plant, usually under a regulated concession, with some degree of involvement of the municipalities and of the

---

[22] For instance, one need to avoid panels out of copper indium gallium selenide [75]. A major company in the field has obtained tested compliance with drinkable water standard BS 6920:2000 (source: https://www.ciel-et-terre.net/hydrelio-floating-solar-technology/hydrelio-products/).

[23] For a wider discussion on the possibility of attractive artistic composition in green energy plant, see the Appendix.

subnational regional authority (e.g. in Switzerland the cantons[24]).

Alternative governance structure could include: a Floating PV plant vertically integrated in the hydropower operator, in-house designed, funded, and operated:

- a Floating PV plant vertically integrated in the hydropower operator, outsourced as for the design and independently looking for funds, but operated according to the direction of the hydropower operator;
- a Floating PV plant designed, funded and installed by a specialized operator, in a contractual agreement with the hydropower operator, voluntarily based on mutual interests or under a certain regulatory scheme (which would mandates for instance the hydropower operator to let the PV plant to access proprietary transmission lines, charging not more than a reasonable, cost-based market price);
- a totally independent operators of the two plants, with little or no cooperation.

In terms of corporate structure and history, there are many settings, including possible spin-offs from the hydro-operator, two parallel companies in the same large holding group, etc.

In the decision to undertake a floating PV project, the specific company culture may play a role. In particular, certain cognitive and emotional biases could hinder a comprehensive analysis of the system, leading to a premature dismissal. If the managers and technicians at the hydro-power plant consider the photovoltaic technology a competitor, a negative confirmation bias might occur, with a negative opinion on the technology stemming from a perceived threat to business-as-usual. Moreover, under the operation of mental accounting [76] such stakeholder may judge the FPV plant by comparing with what is produced by the dam, often with particularly pessimistic assumptions about energy performance and the percentage of lake coverage. Indeed in some informal conversations, the Corresponding Author has met with contradicting objections to Floating PV. On one hand, some people quickly envisage the contribution of the PV plant as "too small". On the other hand, other people suggests that floating plant would be "too big" to be tolerated in a landscaping perspective.

Addressing the first argument ("too small"), one need to note that with a lake of a regular shape, fairly large, and high percentage of coverage, the installed capacity of the FPV can well match that of the hydro-plant. Secondly, as PV has achieved the status of the cheapest source of energy, such installation may well be more profitable that they hydro-plant, or at least complement its profitability. Third, a strong position of solar PV with respect to hydropower has been recently tracked back to "managerial flexibility" as opposed to "operative flexibility" in a very comprehensive analysis of the future of hydropower [78].

On the other possible objection about the environment, it's important to engage early the environmental organizations and institutions. It would be very important to jointly decide a number of tests and variables to be tracked, including the species and ecosystems living in the lake and surrounding it, so as to dispel doubts, take technical and behavioral measures to avoid any disruption and defining constraints to the project, including early termination in case there is a risk of hard conflict with no clear "winner".

Needless to say, the history of renewable energy and other technologies in Switzerland provides plenty of examples of positive and negative processes of consultation, thus further assessment of such cases and company-specific ways to handle the process may turn out to be decisive. As for specifically the landscaping services and the insertion of the plant in the overall landscape, the involvement of landscape experts is advisable.

One may expect that regional (cantonal) authorities develop an interest in the technology but also many questions. They may see it as an opportunity of jobs [79] and tax revenues (e.g. in Switzerland within the debate about water fees). They care about the landscape, while a general goal of increasing renewable may specifically be easier or more difficult in city centers, semi-peripheries and peripheries, rural and mountain areas, etc. A wider set to choose from is possibly welcomed but they look at the plan across many different points of view.

Their power, linked also to the "ownership" of the water resource, are extensive. A significant and timely dialogue is essential.

A possible way to cope with a situation of low interest by the hydropower operator and high interest by the cantonal power might be to link a reduction of the water fee on the former conditional on the presence of Floating PV in the artificial lake (not necessarily in a vertically integrated governance structure).

Moreover, the financial community should be made aware of the general features of utility-scale PV plants and of the specificities of Floating PV, so as to be able to interact with potential investors in a structured way. Also in this community, the novelty of the approach might raise a number of biases, with systematic over-estimation of risks, which might make the insurers weary of addressing this niche market. Conversely, if efforts of standardization succeed and a time series of comparable cases of plants can be constructed, pricing the risks become more feasible, introducing an element that might be very helpful.

In short, the process needs a pivot but requires the exchange of views across heterogeneous stakeholders, a lot of informal understanding but also some tentative calendar to implement both legal and material requirements.

6 Synergies and learning mechanisms for multi-lake activities

In a relatively young industry addressing a varied landscape of application, pioneers do often fail. But the lessons that can be learned both from failures and successes are key to the emergence of a "dominant design" [80].

This is sometimes embedded in certain companies quickly ramping up their activities, with "success breeding success". This is in part already happening in the Floating PV, with some companies clearly leading the way. This is

---

[24] For a different national context see Mdee et al. [77].

good but also challenging: there are few actors that are cumulating the knowhow and the credibility necessary for loans to be agreed and projects to be carried out.

Some new agents of change will come from the PV operators, others from the hydropower companies, other from engineering companies leading consortia, etc.

It would be important to cumulate the knowhow and to help new entrants in order to assure a competitive environment.

In this vein, academia can play a role in disseminating knowledge, providing a neutral testbed for competing design philosophies and implementations, helping distilling lessons, both in technical and socio-economic-environmental sustainability terms. In short, academia can be the catalyst of a better relation between different stakeholders.

On the financial side, it would be important that banks and other financial institution have a energy desk, with specialists of the different mainstream technologies but also with additional expertise in more experimental and pilot plants, whose financial conditions need to take into account the value of knowledge generation.

Some of the lessons learned and the guidelines issues should be brought not only at the national level or mountain-chain levels (Alps) but also across mountain chains (e.g. Andes, Himalaya, etc.). Floating technologies will develop in non-mountain hydro reservoirs conditions (e.g. Brazil and Portugal); such experiences, although not enough to solve certain specificities of the narrower context, will be precious in settling certain technological standards and operative routines.

In this respect, the Convention for the Alps and its institutional governance, as well as IRENA (the International Renewable Energies Association) and the International Hydropower Association may well establish platform to share experiences and operational tools. The UNFCCC official technology development and transfer institution (the Climate Technology Centre and Network) might be play a funding and matchmaking role, activated by the developing countries requests[25].

All this needs to foster not only the sustainable diffusion of the technology on the ground but also the international diffusion of supporting policies [81].

7 Towards stakeholders' involvement: suggestions for action

Our vision, reflected in the checklist but going beyond it, is a balanced one: we suggest to use the floating photovoltaics opportunity for a large scale production of zero emission electricity, while avoiding the missteps that hindered the development of other energy innovative technologies, anticipating and proactively solving societal conflicts and entrenched vested interests.

It would be undesirable to have conflicts about landscape and environment for a technology whose main systemic goal is foster an energy transition towards zero emission climate goals, in reducing the role of coal, nuclear and gas power in the overall interconnected energy system, while increasing the supply of electricity in a moment where electric mobility is taking off (e.g. for Switzerland: Piana [82]; for the world: Piana [83]).

From a regional development perspective, floating PV, by concentrating the infrastructural effect in an already anthropized area, can deliver jobs and revenues locally. Depending on the governance of the system, it could provide a new source of tax revenue, with the consequence of potentially combining high level of services with low personal and business taxation. It may help the profitability and economic sustainability of local energy producers and distributors.

This in turn depends on an effective take-off of larger Floating PV projects in a way that is channeled into generating positive externalities at regional and subregional scales.

This happens in the broader mountain evolution, in which not all municipalities enjoy high incomes, sustainably high tourist flows and other positive developments. In many areas, there is a risk of marginalization, due to a reduction in the tax base, ageing population requiring more services, difficulties in mountain agriculture due to globalization and climate change (which in term presents a host of specific challenges to such regions).

Accordingly, the proposal of floating photovoltaics should be carefully analyzed by authorities, companies, local communities and stakeholders.

In particular, national governments might:

- explore the potential of floating PV for their decarbonization and carbon neutrality strategies, including for the sake of the next wave of Nationally Determined Contribution under the Paris Agreement;
- provide facilitative conditions to pilot experiments that implement participatory approaches, such as grants and feed-in tariffs;
- once a few positive cases have been carried out nationally, with experience gained in the communities of project developer, regional authorities, and environmental organizations, if the promotion of renewable is based on auctions, allow floating PV plants to compete in auctions (or organize auctions explicitly for floating PV plants);
- foster national actors in the field;
- leverage financial and cooperative approaches for the international diffusion of clean technologies including floating PV.

Regional authorities:

- might operate a stakeholder dialogue platform on energy and regional development[26], a topics of which can well be the potential of floating photovoltaics;

---

[25] https://www.ctc-n.org/. For an overview of the role of CTC-N within the broader UNFCCC system, see https://unfccc.int/topics/climate-technology/the-big-picture/what-is-technology-development-and-transfer.

[26] This platform may be part of the processes leading to planning for carbon neutrality and high penetration of renewables or have other regulatory and strategic purposes.

- this platform may request a compilation of the above mentioned check-list (or any other one proposed by other entities) of one or more lakes of the region;
- might evaluate reasonable targets (e.g. number of projects under study, expected revenues and jobs, etc.) in conjunction with the constraints that current or emerging legislation and regulation might pose to such developments;
- in certain cases might suggest a participatory design process;
- might explore ways to incentivize investment, including by de-risking the regulatory framework;
- proactively enter into discussions with the national level on the subject;
- track and monitor projects at the different state of definition, so that experiences of failures and successes can be helpful within and outside the region.

Hydropower plant operators might:

- participate to discussion on the energy transition, including synergies across photovoltaics and hydropower;
- inform themselves about prices, strategic and operative aspects of photovoltaics, including Floating PV, its many designs and specificities;
- preliminary compile the checklist as for their knowledge of the reservoirs where they operate;
- highlight in early stages which main difficulties might the plant have in technical terms and explore alternative designs;
- conduct pilot studies, including by placing panels and inverters in different location on the dam and over the lake at different tilts, so to generate a time-series of data that are helpful not only to assess the technology and its revenues but also for bankability purposes and de-risking the investment;
- begin early to measure wind speeds, including in extreme events, so as to provide a time-series for evaluating risk mitigation designs and strategies, including providing a reference for insurance;
- utilize these data either to engage in possibly vertically integrated activities or third-party investors, developers, solution providers and operators, across the full value chain;
- initiate a stakeholder dialogue with possible conflicting interests so as to jointly discussing tests and criteria for a consensual experimentation;
- in case a positive decision about a feasibility study is taken, to carry out the study (internally and/or with external expertise);
- in case the feasibility study and the on-going consultation provide a positive assessment, to take a decision about the governance structure and the decision-making process leading to technical design, funding, investment and operations;
- actively participate to regional platform and other initiative surrounding the issue, including by informing about successes and failures.

Municipalities, local communities, civil society and environmentalists may:

- require information about different venues for renewable power to be generated locally;
- highlight their current and perspective use of the lake-related resources;
- participate to the compilation of the checklist, including by involving expertise, NGOs and academia;
- take part to stakeholder consultations and platform, including based on legal requirements;
- vote or express other ways of direct democracy on projects that are of particular significance for their territory, whose legal value will depend on legislation.

Floating solution providers may:

- map alternative sites and establish preliminary priorities;
- consolidate external knowledge and their own experience so as to offer plant design fitting the site;
- map the interests, powers and potential attitudes of national, regional and local stakeholders;
- elaborate an outline of a few potential alternatives in partnership and for plant high-level design;
- involve at a certain point insurer brokers and insurance companies, to cover some of the risks of the investments;
- share their experience, including on risk mitigation and risk management, so as to establish a baseline for risk assessment and insurance schemes.

Investors may:

- operate energy desks in which the recent development of Floating PV can be assessed in the light of investment criteria and priorities, as well as the deviation or concordance with other PV projects;
- verify the willingness of capital markets and specific interests (e.g. pension funds at regional, national or international levels) in funding different types of PV projects, including Floating PV;
- establish a framework for discussing Floating PV projects which in part may draw on the above mentioned checklist;
- provide seed money for pilot tests and experiments, if needed, as well as much larger funds at conventional rates and conditions for bigger projects.

Energy experts may want to:

- deepen the issues of photovoltaics and floating photovoltaics in particular;
- provide technical substance to different designs of the plant and its technologies;
- pool knowledge across different projects and technological trajectories;
- explore overall impacts of the diffusion of floating photovoltaics in the energy debate.

At the international level, it would be advisable that a global alliance of floating photovoltaics solution providers would be established. Ideally, to this alliance should take part also environmental organizations and other high-level stakeholders so as to foster a sustainable development of floating photovoltaics.

8 Limitations and next steps

The contribution is meant to be a non-technical non-engineering study, aimed at stimulating a discussion, without proposing a one-size-fits-all solution, and remaining open to the possibility that Floating PV would continue to play a marginal role in the energy transition, if stakeholders want so. We refer for more technical considerations to the ongoing efforts to mainstream good practices, both in institutions and by industry leadership.

Conversely, we hope that this checklist may be used and validated in real-world cases as well as modified by experience and other experts. Particularly promising is the perspective of computer simulating of the diffusion pathways across lakes of Floating PV and their overall contribution to energy future scenarios.

9 Implications and influences

This paper has highlighted the need to carefully craft the design of any floating PV plant in sensitive mountain areas. It will possibly lead to a better dialogue among stakeholders, after having contributed, in the broader scientific and business activities, to put the floating PV on the "mind map" of policymakers, investors and energy planners. The paper may influence the actual adoption and diffusion of floating PV plants, ex-ante reducing the attritions and the potential conflicts among stakeholders, including environmentalists, energy operators, and authorities.

Sitography (quoted in text)

https://cleantechnica.com/2019/03/12/floating-solar-trampoline-by-ocean-sun-tested-by-statkraft/

https://www.irena.org/costs

https://www.ciel-et-terre.net/hydrelio-floating-solar-technology/hydrelio-products

https://www.ctc-n.org

https://unfccc.int/topics/climate-technology/the-big-picture/what-is-technology-development-and-transfer

https://www.sccer-crest.ch/

https://landartgenerator.org

https://www.infobuildenergia.it/progetto-loto-il-fotovoltaico-diventa-galleggiante/

https://www.theguardian.com/environment/2014/sep/25/is-this-heart-shaped-solar-farm-the-worlds-most-beautiful-power-plant

https://www.vs.ch/web/sefh/strategie-energetique

http://www.air-art.ch/

Acknowledgements. This work arose in the strand of research generated by the Swiss Competence Center for Energy Research CREST (https://www.sccer-crest.ch/). The authors gratefully acknowledges the financial support by Innosuisse. Needless to say, the opinions expressed are of the authors only.

What was offered to the reader builds upon our contribution to the International Mountain Conference at the Workshop 3.1.E: Renewable Energy: Impacts on Mountain environments and people (September 2019). We grateful thanks for their suggestions the participant to that event as well as the participants (such as Esmée Walker – Solarif Risk Management) to the Floating Solar Conference 2020, organized by Solarplaza International BV, which kindly provided industry-specific data.

The Appendix builds upon the results of the HES-SO project "Analysis of tourism demand towards sustainable energy infrastructures" (Inter-institute HEG funding programme 2019, project n. 96864; collaborating entities: Institute of Business Informatics and Institute of Tourism under the leadership of Prof. René Schumann and Prof. Marc Schnyder). We grateful acknowledge the series of interviewees that collaborated to the project and especially Jean-Maurice Varone (Air & Art Foundation). The authors declare to have no conflict of interest. Valentino Piana provided the main idea, the first draft of the paper and the overall coordination. Annelen Kahl provided key inputs for the checklist. Cristina Saviozzi is author of the Appendix. René Schumann contributed to revisions and obtained the funds.

Appendix – Art, architecture and industrial design for improving the impact of floating PV structures on the landscape, which would be conducive to a broader public acceptance

Renewable energy plants can well be producing zero-carbon electricity, be sustainable and innovative on a range of issues and but still risk to conflict with landscape value [84]. Their practical implementation may turn out to be problematic and questioned due to their increasing size, shape and impact. It is then crucial in the design phase to start from the specificity of the territories concerned and from the sensitivities of the public, which in turn evolve depending on how iconic projects are designed [85]. Photovoltaics technologies can well enter into this general trend [86].

In this appendix, we make a general plea for a new alliance between the industry, local authorities, architects, designers and artists and provide a few examples in which they have committed themselves to enhancing these facilities to make them aesthetically attractive to visitors and tourists able to add value to the host territory of real "green landmarks". We recognize that there is still a long way to go for such a development.

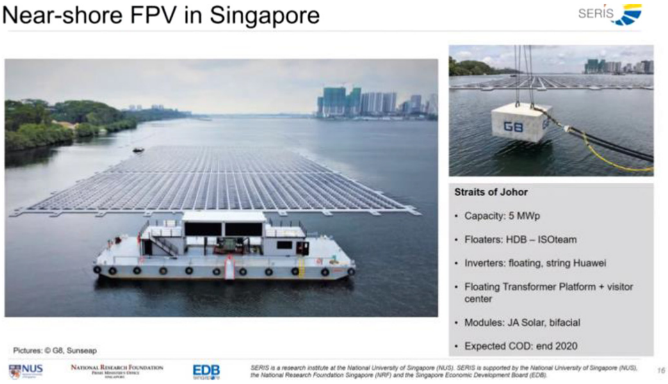
Still, by following this trend, the structures would not be exclusively useful to the economy, as they generate clean energy, but can be considered by visitors and tourists, attracted by sustainable tourist destinations, a niche "tourist" marker. Conversely, inhabitant may find a new pride, enhancing the attachment to their location [87] and young generation can find education and inspiration [88].

Floating PV designers should thoroughly explore such venues. They potentially represent the next frontier of "land art" – an artistic movement that in the second half of the XX Century has contrasted the art for the museums and called for free fruition of large-scale human-enhanced landscapes. Land Art has been committed in recent years to creating new points of view on renewables through the involvement of internationally renowned artists such as Christo, Adéagbo, Jata Castro, Michelangelo Pistoletto. In the same direction the international competition "Lagi" (Land art generation initiatives[27]), which aims to spread sustainable culture and a new awareness for designers and planners, called to develop innovative proposals that generate clean energy. The objective that they envision is to build Land art or environmental art installations that also produce clean energy.

---

[27] https://landartgenerator.org.

Fig. 16. Artistically pixelated real plant. Source: Philippart [89].



Near-shore FPV in Singapore

Straits of Johor

- Capacity: 5 MWp
- Floaters: HDB – ISOteam
- Inverters: floating, string Huawei
- Floating Transformer Platform + visitor center
- Modules: JA Solar, bifacial
- Expected COD: end 2020

Pictures: © G8, Sunseap

SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by the National University of Singapore (NUS), the National Research Foundation Singapore (NRF) and the Singapore Economic Development Board (EDB).

Fig. 17. Real plant with a visitor center. Source: Reindl and Paton [67].

Nonetheless, the possibility that the art produces clean energy is somehow new and would require sensitivity from the industry, the developer, and the regional authorities.

The technological potential is there, already with some simple pixelations, as shown in Figure 16.

In Italy, the shape of a floating plant has been inspired by nature and by the lotus flower in particular[28].

Energy infrastructure, especially if clean energy and with a strong profile of innovativeness, can well attract tourists, whose economic value may be not particularly relevant with respect to the total investment but whose attention provides potentially better understanding and higher public acceptance. This may be enhanced with an explicit "visitor center", as it has already been addressed in Singapore (see Fig. 17).

In China a floating photovoltaic plant has been created (represented in Fig. 18) which explicitly look for aesthetics in a figurative mold: the Panda Power Plant was built with an eye to raise awareness and bring young people closer to environmental issues.

Fig. 18. Panda Power Plant. Source: GettyImages, utilized under Fair Use clause.

Fig. 19. Heart of Voh. Source: The Guardian. https://www.theguardian.com/environment/2014/sep/25/is-this-heart-shaped-solar-farm-the-worlds-most-beautiful-power-plant.

In New Caledonia, a ground-mounted heart-shaped plant will be built with 7,888 panels and will be located in Grand Terre, the largest island in New Caledonia. The design is inspired by the "Coeur de Voh" ("Heart of Voh"), a mangrove forest on the island that has naturally taken the shape of a heart (Fig. 19).

In Switzerland the Valais canton, which has a strategy of 100% local renewable by 2050 (https://www.vs.ch/web/sefh/strategie-energetique) and where the Alpine plant represented in Figure 14 of the main text is located, the Air & Art Foundation aims to develop contemporary art projects in relation to the region[29]. It wishes to entrust international creators with portions of the landscape for monumental and permanent artistic interventions *in situ*, based on its history and identity. Starting from the Swiss Alps, the project aims to create works that will take place in different regions, so that over the years they will become several "stages" that will constitute a unique and remarkable open-air path in the Swiss and international cultural landscape. In particular, it has worked with Michael Heizer

---

[28] https://www.infobuildenergia.it/progetto-loto-il-fotovoltaico-diventa-galleggiante/.

[29] Air & Art Foundation http://www.air-art.ch/.

for a Tangential Circular Negative Line, in direction towards abstraction that sidesteps the figurative inspiration of the abovementioned works.

In synthesis, art, architecture and industrial design can play an important role in the design of renewables, improving their visual impact and their acceptance by the host communities. In order to support the green development of a territory it is not enough to locate a resource, but it is essential to integrate it with the context, working with community stakeholders to assess interests and needs. In the future, it will be relevant not only to establish the place where to place these structures to achieve greater energy efficiency, including in mountain settings, but also to find typological-structural solutions that fit the place and ensure profitable operations. However, this requires the involvement and open dialogue between all stakeholders, facilitating participatory design processes.

References

1. IPCC, Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (Eds.), In Press (2018)
2. D. Laslett, Can high levels of renewable energy be cost effective using battery storage? Cost of renewable energy scenarios for an isolated electric grid in Western Australia, Renew. Energy Environ. Sustain. **5**, 6 (2020)
3. IEA, World Energy Outlook 2020, October 2020
4. Solar Power Europe, Global Market Outlook for Solar Power/2019-2023, 2019. https://www.solarpowereurope.org/wp-content/uploads/2019/07/SolarPower-Europe_Global-Market-Outlook-2019-2023.pdf
5. J. Dujardin, A. Kahl, B. Kruyt, S. Bartlett, M. Lehning, Interplay between photovoltaic, wind energy and storage hydropower in a fully renewable Switzerland, Energy **135**, 513–525 (2017)
6. F. Kienast, N. Huber, R. Hergert, J. Bolliger, L. Segura Moran, A.M. Hersperger, Conflicts between decentralized renewable electricity production and landscape services – a spatially-explicit quantitative assessment for Switzerland, Renew. Energy Environ. Sustain. **67**, 397–407 (2017)
7. J. Michellod, Scénarios de décarbonisation complète du secteur énergétique en Suisse, Travail de diplôme HES-SO, Energie et techniques environnementales (2019)
8. OFEN, Statistique globale suisse de l'énergie (2019)
9. A. Sahu, N. Yadav, K. Sudhakar, Floating photovoltaic power plant: a review, Renew. Energy Environ. Sustain. **66**, 815–824 (2016)
10. M. Rosa-Clot, G.M. Tina, *Submerged and floating photovoltaic systems: modelling, design and case studies* (Academic Press, 2017)
11. R. Cazzaniga, M. Cicu, M. Rosa-Clot, P. Rosa-Clot, G.M. Tina, C. Ventura, Floating photovoltaic plants: performance analysis and design solutions, Renew. Energy Environ. Sustain. **81**, 1730–1741 (2018)
12. A. Dizier, *Techno-economic analysis of floating PV solar power plants using active cooling technique: a case study for Taiwan* (2018)
13. P. Ranjbaran, H. Yousefi, G.B. Gharehpetian, F.R. Astaraei, A review on floating photovoltaic (FPV) power generation units, Renew. Energy Environ. Sustain. **110**, 332–347 (2019)
14. D. Friel, M. Karimirad, T. Whittaker, J. Doran, E. Howlin, A review of floating photovoltaic design concepts and installed variations, 4th Int. In *Conf. Offshore Renew. Energy CORE2019 Proc. Glasg.* ASRANet Ltd UK Vol. 30 (2019)
15. S. Oliveira-Pinto, J. Stokkermans, Assessment of the potential of different floating solar technologies–overview and analysis of different case studies, Energy Convers. Manag. **211**, 112747 (2020)
16. R. Cazzaniga, M. Rosa-Clot, The booming of floating PV, Solar Energy (2020)
17. S. Gorjian, H. Sharon, H. Ebadi, K. Kant, F.B. Scavo, G.M. Tina, Recent technical advancements, economics and environmental impacts of floating photovoltaic solar energy conversion systems, J. Clean. Prod. 124285 (2020)
18. M. Perez, R. Perez, C.R. Ferguson, J. Schlemmer, Deploying effectively dispatchable PV on reservoirs: comparing Floating PV to other renewable technologies, Solar Energy **174**, 837–847 (2018)
19. REN21, Renewables 2020 Global Statu Report (2020), https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf
20. S. Casini, R. Cazzaniga, M. R. Clot, Floating PV plant and water chemistry, Res. Dev. Mater. Sci. (2018). DOI: 10.31031/RDMS.2018.07.000658
21. M.K. Hoffacker, M.F. Allen, R.R. Hernandez, Land-sparing opportunities for solar energy development in agricultural landscapes: a case study of the Great Central Valley, CA, United States, Environ. Sci. Technol. **51**, 14472–14482 (2017)
22. G.D. Pimentel Da Silva, D.A.C. Branco, Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts, Impact Assess. Proj. Apprais. **36**, 390–400 (2018)
23. M.P.C. Lopes, S. de Andrade Neto, D.A.C. Branco, M.A.V. de Freitas, N. da Silva Fidelis, Water-energy nexus: floating photovoltaic systems promoting water security and energy generation in the semiarid region of Brazil, J. Clean. Prod. **273**, 122010 (2020)
24. M. Tawalbeh, A. Al-Othman, F. Kafiah, E. Abdelsalam, F. Almomani, M. Alkasrawi, Environmental impacts of solar photovoltaic systems: a critical review of recent progress and future outlook, Sci. Total Environ. (2020)
25. A. El Hammoumi, A. Chalh, A. Allouhi, S. Motahhir, A. El Ghzizal, A. Derouich, Design and construction of a test bench to investigate the potential of floating PV systems. J. Clean. Prod. **278**, 123917 (2021)
26. G.M. Tina, F.B. Scavo, L. Merlo, F. Bizzarri, Comparative analysis of monofacial and bifacial photovoltaic modules for floating power plants, Appl. Energy **281**, 116084 (2021)
27. M.H. Alktranee, Q. Al-Yasiri, M.M. Sahib, Power output enhancement of grid-connected PV system using dual-axis tracking, Renew. Energy Environ. Sustain. **5**, 8 (2020)

28. Swiss Research Foundation for Electricity and Mobile Communication, Technik – Stromversorgung, 2020. Available from: https://www.emf.ethz.ch/de/emf-info/themen/technik/stromversorgung/infrastruktur/ (accessed July 13, 2020)
29. Isifloating, Isifloating is the most high quality and durable floating solar system, 2020. https://www.isifloating.com/en/wp-content/uploads/2020/06/Brochure-Technical-Data sheet-ENG-ISI200601.pdf (accessed July 13, 2020)
30. Ciel et Terre, Floating PV applications, 2020. https://www.ciel-et-terre.net/floating-pv-applications/ (accessed July 13, 2020)
31. Moss Maritime, A leader in maritime technology, 2018. http://www.mossww.com/ (accessed July 9, 2020)
32. Ocean Sun, Ocean Sun Products, 2020. https://oceansun.no/our-products/ (accessed July 9, 2020)
33. World Bank Group, ESMAP and SERIS, *Where sun meets water: floating solar market report* (World Bank, Washington, DC, 2019a)
34. M. Tagliapietra, Floating PV standardization as a driver for quality and trust, presented at the Floating Solar Conference (2020)
35. O.A. Al-Musawi, A.A. Khadom, H.B. Manhood, M.S. Mahdi, Solar pond as a low grade energy source for water desalination and power generation: a short review. Renew. Energy Environ. Sustain. **5**, 4 (2020)
36. R.S. Spencer, J. Macknick, A. Aznar, A. Warren, M.O. Reese, Floating photovoltaic systems: assessing the technical potential of photovoltaic systems on man-made water bodies in the continental United States, Environ. Sci. Technol. **53,** 1680–1689 (2019)
37. J. Farfan, C. Breyer, Combining floating solar photovoltaic power plants and hydropower reservoirs: a virtual battery of great global potential, Energy Procedia **155**, 403–411 (2018)
38. R. Cazzaniga, M. Rosa-Clot, P. Rosa-Clot, G.M. Tina, Integration of PV floating with hydroelectric power plants, Heliyon **5**, e01918 (2019)
39. L. Liu, Q. Sun, H. Li, H. Yin, X. Ren, R. Wennersten, Evaluating the benefits of integrating floating photovoltaic and pumped storage power system, Energy Convers. Manag. **194**, 173–185 (2019)
40. N. Mousavi, G. Kothapalli, D. Habibi, C.K. Das, A. Baniasadi, Modelling, design, and experimental validation of a grid-connected farmhouse comprising a photovoltaic and a pumped hydro storage system, Energy Convers. Manag. **210**, 112675 (2020)
41. H. Li, P. Liu, S. Guo, B. Ming, L. Cheng, Z. Yang, Long-term complementary operation of a large-scale hydro-photovoltaic hybrid power plant using explicit stochastic optimization, Appl. Energy **238**, 863–875 (2019)
42. Y. Zhou, F.J. Chang, L.C. Chang, W.D. Lee, A. Huang, C.Y. Xu, S. Guo, An advanced complementary scheme of floating photovoltaic and hydropower generation flourishing water-food-energy nexus synergies, Appl. Energy **275**, 115389 (2020)
43. M. Ates, O.S. Yilmaz, F. Gulgen, Using remote sensing to calculate floating photovoltaic technical potential of a dam's surface, Sustain. Energy Technol. Assess. **41**, 100799 (2020)
44. H. Rauf, M.S. Gull, N. Arshad, Complementing hydroelectric power with floating solar PV for daytime peak electricity demand, Renew. Energy **162**, 1227–1242 (2020)
45. N. Lee, U. Grunwald, E. Rosenlieb, H. Mirletz, A. Aznar, R. Spencer, S. Cox, Hybrid floating solar photovoltaics-hydropower systems: benefits and global assessment of technical potential, Renew. Energy **162**, 1415–1427 (2020)
46. J. Haas, J. Khalighi, A. de la Fuente, S.U. Gerbersdorf, W. Nowak, P.J. Chen, Floating photovoltaic plants: ecological impacts versus hydropower operation flexibility, Energy Convers. Manag. **206**, 112414 (2020)
47. P.A. Château, R.F. Wunderlich, T.W. Wang, H.T. Lai, C.C. Chen, F.J. Chang, Mathematical modeling suggests high potential for the deployment of floating photovoltaic on fish ponds, Sci. Total Environ. **687**, 654–666 (2019)
48. J.Y. Choi, S.T. Hwang, S.H. Kim, Evaluation of a 3.5-MW floating photovoltaic power generation system on a thermal power plant ash pond, *Sustainability* **12**, 2298 (2020)
49. J. Song, Y. Choi, Analysis of the potential for use of floating photovoltaic systems on mine pit lakes: case study at the ssangyong open-pit limestone mine in Korea, Energies **9**, 102 (2016)
50. M.R. Santafe, P.S.F. Gisbert, F.J.S. Romero, J.B.T. Soler, J.J.F. Gozalvez, C.M.F. Gisbert, Implementation of a photovoltaic floating cover for irrigation reservoirs, J. Clean. Prod. **66**, 568–570 (2014)
51. H. Nebey, B.Z. Taye, T.G. Workineh, GIS-based irrigation dams potential assessment of floating solar PV system, J. Energy (2020)
52. M. Rosa-Clot, G.M. Tina, S. Nizetic, Floating photovoltaic plants and wastewater basins: an Australian project, Energy Procedia **134**, 664–674 (2017)
53. E. Cagle, A. Armstrong, G. Exley, S.M. Grodsky, J. Macknick, J. Sherwin, R.R. Hernandez, The land sparing, water surface use efficiency, and water surface transformation of floating photovoltaic solar energy installations, Sustainability **12**, 8154 (2020)
54. C. Gamarra, J.J. Ronk, Floating solar: an emerging opportunity at the energy-water nexus, Texas Water J. **10**, 32–45 (2019)
55. D. Mathijssen, B. Hofs, E. Spierenburg-Sack, R. van Asperen, B. van der Wal, J. Vreeburg, H. Ketelaars, Potential impact of floating solar panels on water quality in reservoirs; pathogens and leaching, Water Pract. Technol. (2020)
56. T. Hooper, A. Armstrong, B. Vlaswinkel, Environmental impacts and benefits of marine floating solar, Solar Energy (2020)
57. S.Z. Golroodbari, W. van Sark, Simulation of performance differences between offshore and land-based photovoltaic systems, Prog. Photovoltaics: Res. Appl. (2020)
58. S.-M. Kim, M. Oh, H.-D. Park, Analysis and prioritization of the floating photovoltaic system potential for reservoirs in Korea, Appl. Sci. **9**, 395 (2019)
59. IRENA, Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi (2020)
60. B. Ortmann, The future of floating PV is already here; markets, merits, cost comparisons and lessons learned so far, presented at *Floating Solar Conference*, November 2020
61. M.T. Chaichan, H.A. Kazem, A.H. Al-Waeli, K. Sopian, The effect of dust components and contaminants on the performance of photovoltaic for the four regions in Iraq: a practical study, Renew. Energy Environ. Sustain. **5**, 3 (2020)
62. SolarCleano, Robot solutions for solar panel cleaning, 2020. www.solarcleano.com/gallery

63. World Bank Group, ESMAP and SERIS, *Where sun meets water: floating solar handbook for practitioners* (World Bank, Washington, DC, 2019b)
64. Bellini, EU to help anchor lower price for floating solar power, 2019. https://www.pv-magazine.com/2019/11/14/eu-to-help-anchor-lower-price-for-floating-solar-power/ (accessed July 25, 2020)
65. S. Enkhardt, Deutsche Braunkohle-Tagebauseen bieten wirtschaftliches Potenzial für knapp 3 Gigawatt schwimmende Photovoltaik-Anlagen, 2020. https://www.pv-magazine.de/2020/02/03/deutsche-braunkohle-tagebauseen-bieten-wirtschaftliches-potenzial-fuer-knapp-3-gigawatt-schwimmende-photovoltaik-anlagen/ (accessed October 16, 2020)
66. Wood Mackenzie, *Floating Solar Landscape* 2019
67. T. Reindl, C. Paton, Where sun meets water: global market status, project database and economics, presented at the *Floating Solar Conference* (November 2020)
68. S. Merlet, Floating PV: global market and perspectives, 2018. https://www.norwep.com/content/download/34428/253399/version/1/file/Stanislas+Merlet.pdf
69. A. Kahl, J. Dujardin, M. Lehning, The bright side of PV production in snow-covered mountains, PNAS **116**, 1162–1167 (2019)
70. T. Nordmann, T. Vontobel, L. Clavadetscher, T. Boström, H.T. Remlo, Large Scale Hybrid PV Hydro Electricity Production in Floating Devices on Water, In 24th European Photovoltaic Solar Energy Conference, Hamburg (2009)
71. T. Nordmann, Photovoltaics and the Lacustrine Landscape Large Scale Photovoltaik Hydro Electric on Water, PVSEC Amsterdam (2014)
72. Romande Energie, Press release on the Lac de Toules plant, 2019. https://www.romande-energie.ch/espace-presse/communiques-de-presse/innovation-energetique-mondiale
73. M. Zubair, A. Bilal Awan, S. Ghuffar, A.D. Butt, M. Farhan, Analysis and selection criteria of lakes and dams of Pakistan for floating photovoltaic capabilities, J. Solar Energy Eng. **142** (2020)
74. A.S. Darwish, R. Al-Dabbagh, Wind energy state of the art: present and future technology advancements, Renew. Energy Environ. Sustain. **5**, 7 (2020)
75. N.R. Brun, B. Wehrli, K. Fent, Ecotoxicological assessment of solar cell leachates: copper indium gallium selenide (CIGS) cells show higher activity than organic photovoltaic (OPV) cells, Sci. Total Environ. **543**, 703–714 (2016)
76. U. Hahnel, G. Chatelain, B. Conte, V. Piana, T. Brosch, Mental accounting of energy behavior, Nat. Energy (2020)
77. O.J. Mdee, T.K. Nielsen, C.Z. Kimambo, J. Kihedu, Assessment of hydropower resources in Tanzania. A review article, Renew. Energy Environ. Sustain. **3**, 3 (2018)
78. M. Barry, R. Betz, S. Fuchs, L. Gaudard, T. Geissmann, G. Giuliani, W. Hediger, M. Herter, M. Kosch, F. Romerio, M. Schillinger, L. Schlange, C. Schule, R. Schumann, G. Voegeli, H. Weigt, The Future of Swiss Hydropower Realities, Options and Open Questions (2019). https://fonew.unibas.ch/fileadmin/user_upload/fonew/Reports/Report_HPFuture_Final.pdf
79. C. Malamatenios, Renewable energy sources: jobs created, skills required (and identified gaps), education and training, Renew. Energy Environ. Sustain. **1**, 23 (2016)
80. J.M. Utterback, *Mastering the dynamics of innovation* (Harvard Business School Press, Cambridge, MA, (1994)
81. V. Piana, *Innovative economic policies for climate change mitigation* (EWI, 2009)
82. V. Piana, *Implementing Paris: which more ambitious Nationally Determined Contributions can promote innovation in the transport system with sufficient urgency to contribute to 1.5°C-consistent global greenhouse gas emission pathways*, University of Oxford Conference “1.5 Degrees: Meeting the challenges of the Paris Agreement” (2016)
83. V. Piana, *Towards 1.5°C-consistent next Paris NDCs: a comparison between Italian and Swiss transport decarbonization perspectives* (SISC, 2018)
84. W. Brücher, Geography of energy, in: N.J. Smelser, P.B. Baltes (Eds.), *International encyclopedia of the social & behavioral science*, Gale-Cengage, Detroit, MI 2001, pp. 4520–4523
85. M. Pasqualetti, Reading the changing energy landscape, in: S. Stremke, A. Van Den Dobbelsteen (Eds.), *Sustainable energy landscapes: designing, planning, and development*, CRC Press, Boca Raton, FL 2012, pp. 11–44
86. E. Michalena, Y. Tripanagnostopoulos, Contribution of the solar energy in the sustainable tourism development of the Mediterranean islands, Renew. Energy **35**, 667–673 (2010)
87. J.F. Rodriguez, Hydropower landscapes and tourism development in the Pyrenees. From natural resource to cultural heritage, Journal of Alpine Research Revue de geography alpine **100**, 2–15 (2012)
88. I. Msengi, R. Doe, T. Wilson, D. Fowler, C. Wigginton, S. Olorunyomi, I. Banks, R. Morel, Assessment of knowledge and awareness of “sustainability” initiatives among college students, Renew. Energy Environ. Sustain. **4**, 6 (2019)
89. O. Philippart, Lessons learnt from a pioneer in the market, Ciel & Terre International, presented at the *Floating Solar Conference* (November, 2020)

Cite this article as: Valentino Piana, Annelen Kahl, Cristina Saviozzi, René Schumann, Floating PV in mountain artificial lakes: a checklist for site assessment, Renew. Energy Environ. Sustain. **6**, 4 (2021)