Floating PV in mountain artificial lakes: a sustainable contribution?

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Overview

In this contribution, we present an overview of the current state of research on a specific renewable technology (floating photovoltaics), whose application in artificial lakes in mountains seems promising but also requiring a careful crafting in technical, economic, social and environmental terms. Floating photovoltaic panels over dam reservoirs may provide a relatively inexpensive, as recent data highlight, as well as a highly upscalable increase of electricity supply, with synergies with existing hydro-plants (e.g. in transmission lines). Mountains have favourable 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 minimize the negative ones, including by highlighting factors that might prevent its use altogether in certain lakes.
We describe possible synergies across lakes, in the logic of providing positive externalities to a managed socio-economic trajectory of diffusion of Floating PV in mountains across the globe, with innovation arising as solutions to the bottlenecks. The potential contribution to landscape services and tourist attractivity is taken into account into the main text, while referring to an appendix for a broader coverage.

From all this, it emerges a balanced vision of desired energy futures of mountain regions, where renewable energy production is integrated into broader sustainability goals and measures.

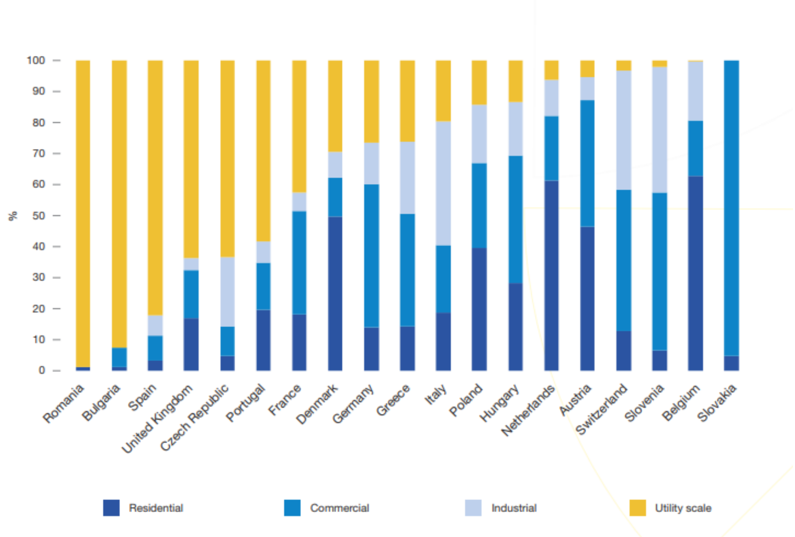
It should be emphasised that this contribution is not a narrow engineering exercise - nor certain technical issues are treated the depth expected if it were - but rather represents a critical reflection of the potential of a new technology, having in mind the contraints that society posed to other technologies in the the past, thus it is sensitive to the need of establishing a fruitful dialogue, since the very beginning, not only among legally entitled institutions but also across a broad range of stakeholders. Accordingly, we end our contribution with a number of recommendations to regional authorities, hydropower plant operators, investors, municipalities, local communities and civic society, and energy experts.

Background

Before entering the specific analysis of the topics at hand, we need to remind the reader of the international context of energy transition, on which we stress the needs of a very radical cuts in emission by expansion of renewables and clean technology at an unprecedented scale and speed, as underlined by the recent IPCC Special Report on reasons why and ways how to limit global warming to 1.5 degrees, of which the current Author was one of the reviewers.
In Switzerland, a largely mountaneous high-income country, the national context is characterised, in a nutshell, by an Energy Law establishing a quantitative goal for non-water renewable energy production, a very slow actual uptake of wind and photovoltaics systems, and the need to update and upgrade the Nationally determined contributions, in the light of art. 4 of the Paris Agreement and of the Katowice UNFCCC COP24 decisions.

The difficulties of finding non-yet-utilized large flat areas has prevented the establishment in Switzerland of utility-scale PV plants, one of the current lowest cost supply of electricity in the world, thanks to the steep fall in prices panels, electric and electronics components and systems and thanks to improved bankability, with an extensive investment experience which led to falling risk premiums on financial instruments backing the new plants[1].

FIGURE 27 EUROPEAN SOLAR PV TOTAL CAPACITY UNTIL 2017 FOR SELECTED COUNTRIES



Source: Solar Power Europe (2018) - available at
http://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf

Rooftop solar, which the literature tends to consider as the only way to harvest solar irradiation in Switzerland for electricity purposes[2], has been incentivised, for households, by direct subsidies in proportion to costs, which international comparison of experiences tend to consider a pretty expensive and ineffective way to operate, in comparison to feed-in tariffs and auctions [Sovacool and Jacobs, 2010; IRENA and CEM, 2015; Fowlie M. 2017]. Indeed the current around 1% of electricity production with PV lags way behind several EU countries[3].

1. Current state of research on the potential of Floating Photovoltaics, including in mountain artificial lakes ("What is possible?")

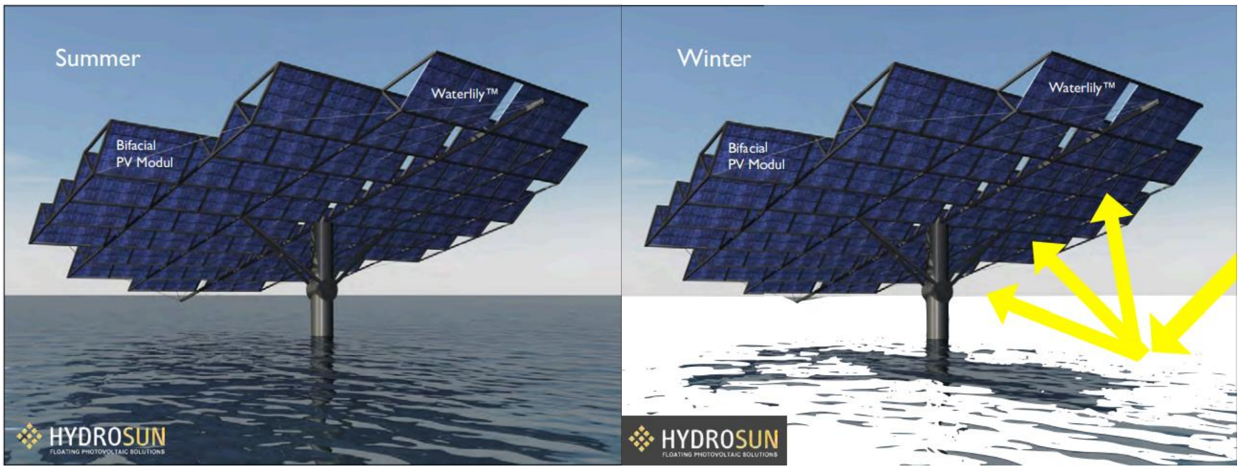
Floating photovoltaics is an area of recent assessment [Farfan et al., 2018; Cazzaniga et al., 2018], also in comparison with other renewable technologies [Perez et al., 2018]. There are several technological design for the plant, differing for instance as for the degree the water is covered, where the inverters and the cables connecting to further devices are, whether the plant is actually floating or it is above waters, etc.

As indicated by a 2018 report by World Bank "[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,

1 See https://www.irena.org/costs.
2 See e.g. Dujardin et al. (2017) and Kienast (2017).
3 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. On a more subjective tone, the author has been active in research and implementation field of eco-neighbourhoods, urban regeneration and complex projects that included rooftop application, green job creation and social inclusion. We recognize the important results of the research in the field and underline that an entire SCCCER (the Swiss Competence Center for Energy Research on Future Energy Efficient Buildings & Districts - SCCER FEEB&D) is devoted to energy savings and active renewables in buildings and urban areas.

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, but the first combinations with 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”.

Switzerland was envisaging such a plant as early as 2009 in a visionary paper laid down by (Nordmann and others, 2009), describing the advantages of the system and a potential application to the Sihlsee, a lake the city of Zurich, whose hydro power plant is owned and operated by the Federal Railway Company of Switzerland, the SBB, mainly for powering the public transport system in the area of Zurich, whose demand curve similar to the production curve of PV during daytime. A 2014 presentation updates on the difficulties met and proposes some solutions (Nordmann, 2014).



In 2012, a test at the Lac des Toules was begun under the aegis of Romande Energie by a team led by Guillaume Fuchs. The test over the years demonstrated how to overcome a number of difficulties, which prompts for a wider installation, foreseen for automn 2019. From the press release: “2'240 m² of bifacial solar panels will produce then more than 800 000 kilowatthours per year. If the results will be positive, more than 24 million kilowatthours will be possibly be produced every year [by subsequent investments]. According studies already carried out, this innovative installation is characterised by a particularly high energy efficiency: it should produce up to 50% more energy than a park of equal dimensions localised in the plain. This excellent result is explained, among other factors, by the strong reflection of the light by the snow, which increases the effectiveness of the solar panels”.

All this happens while a number of pieces of news appears, demonstrating specific cases of utilization, price level or difficulties of Floating PV :

- The actual connection to the grid of 70 MW from a plant on a former coal-mining area at Anhui Province of China, part of the 150MW plant already mentioned by WB;

Ciel et Terre project in Anhui Province (Source: https://www.pv-magazine.com/2019/03/20/ciel-terre-completes-worlds-biggest-floating-pv-array-in-china/)

- The Chilean project on a tailings pond, generating up to 153MWh a year, with the technical achievement of anchoring lines' adaptability to a water level variation up to 25 m;

- The utilization of a trampoline-style floating solar array, with horizontally tilted panels and no shading, in principle suitable to ocean high wave fluctuations thanks to a large area surrounding the panels, in a reservoir in Albania (for a total 2 MWp at a cost of 2.3 million Euro);

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

- The installation of Floating PV on top of a rain harvesting reservoir for agriculture uses, where plastics covers all the water, to sharply reduce algae formation, that in this context is detrimental to water quality, as described in Haarburger (2018);
- A Swiss project aimed at anchoring three “radeaux gonfiable” of 25 m of diameter in the Lake of Neuchatel a few dozens of meters from the shore, has been temporarily blocked by the Tribunal, following a request by fishermen;
- A Japanese plant by SunGrow is testing the compatibility with ice in Fukushima prefecture

- Google is installing a 10-megawatt solar array in Tainan City, Taiwan, possibly with solar panels at the top of poles above fishing ponds[4], a concept known as a "canopy" system. The project design could result in improvement in fishing yields because elevated panels provide optimal room for fish while also providing them with shade. That finding was based on an experiment conducted by the Fisheries Research Institute (COA) unit of the Taiwan Council of Agriculture.

A ranking of the main operators in Europe includes the French Ciel et Terre, with 17 out of 30 largest plants, the Italian NRG Island, with 5 installations, the Spanish ISIFLOATING with 6 and the Hollender Sunfloat. There is a remarkable market and expertise concentration in few operators. The panels themselves do come, however, from a broader range of companies (Sunfloat, JA Solar, Trina Solar, Suntech, REC, PEIMAR, Byd)[5].

Queen Elizabeth II Reservoir (image: Lightsource BP), available at Solarplaza International BV

In summary, in the international scale, according to the same study of 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”.

The National Renewable Energy Laboratory (NREL) - a part of the US Department of Energy - found that almost 10 percent of U.S. energy supply could be met by siting solar projects on 24,419 man-made waterbodies, representing 27% of the number and 12% of the area of man-made waterbodies in the contiguous United States, identified as being suitable for such generation.

4 https://www.cnbc.com/2019/02/15/google-is-building-a-solar-power-project-above-fishing-ponds-in-taiwan.html
5 Our elaboration based on December 2018 data obtained from International Solarplaza BV by request (labs.thefuturegrid.com), where it was originally published.

All this need to be scaled down to Swiss lakes, and to Swiss artificial lakes in particular. As a reminder to the reader:

* there are 103 lakes larger than 0.3 hectars in the country, covering 2 180.75 km²;
* the 45 artificial lakes covers 84.48 km²;
* the 21 natural lakes are used as reservoir for dams, covering 28.63 km².

As a broad first approximation of production potential, according to Kahl et al. (2018), about 60 km² 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”.

In mountains[6], 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”) this surface reduces to about 45 km².

To this, one should add the additional efficiency of panels in direct contact to water, to the effect of heating dissipation and better temperature, that in other climate conditions has been computed as high as 10% or even 15%.

In short, from a merely quantitative point of view, Floating PV can make a sizeable contribution to overall electricity production, ranging from 3-5 times the current level of installed PV (which produced 0.420 TWh between 1 Jan 2017 and 1 Jan 2018)[7] to large share of the total demand (which in 2017 was 58.500 TWh)[8], depending on how many lakes are involved, in which percentage they are covered and with which technology.

For instance a 60% coverage of all (but only) artificial lakes with a pretty conservative 16 m² per kWp (including the space for shading), at an average of 1500 hours a year equivalent to peak production, would generate 4.752 TWh.

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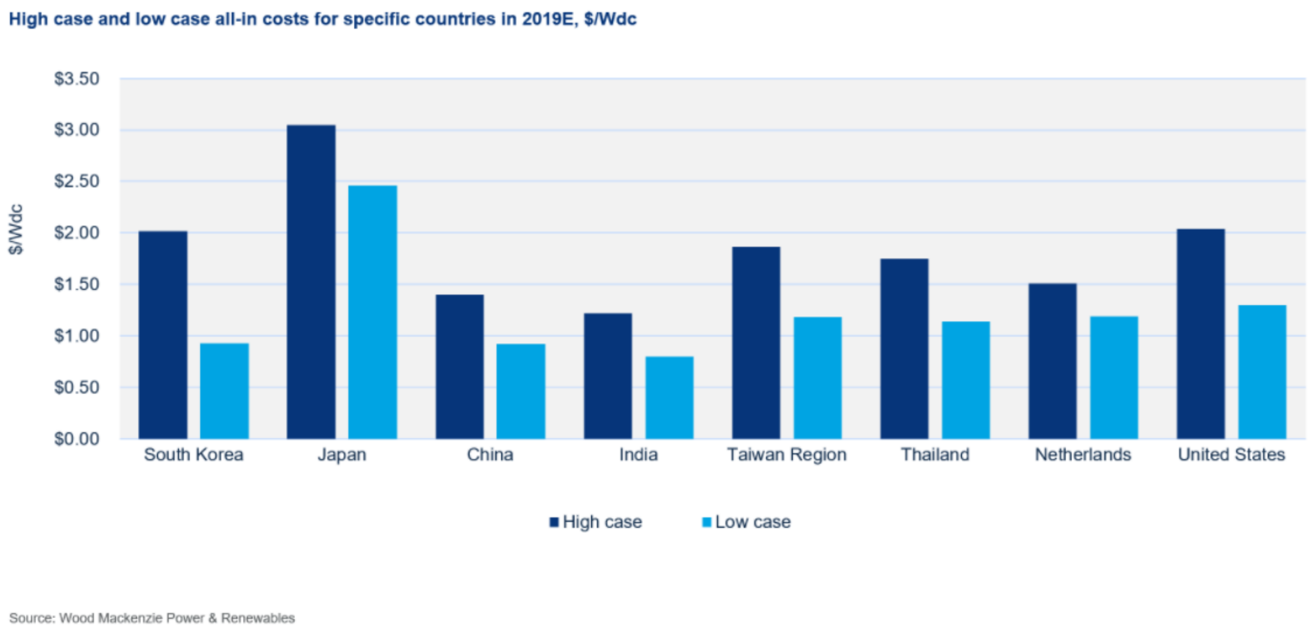
6 This recent paper makes a number of very important additional points in favour of placing PV in mountains, with a tilted angle aimed at maximising winter production, when prices are higher and the overall need, in case of nuclear phase out, larger. In a fully renewable Swiss electricity system, “the mismatch between demand and supply underscore the remarkable impact of moving PV production from urban to mountain enviorments: the seasonal energy gap is reduced by half”.

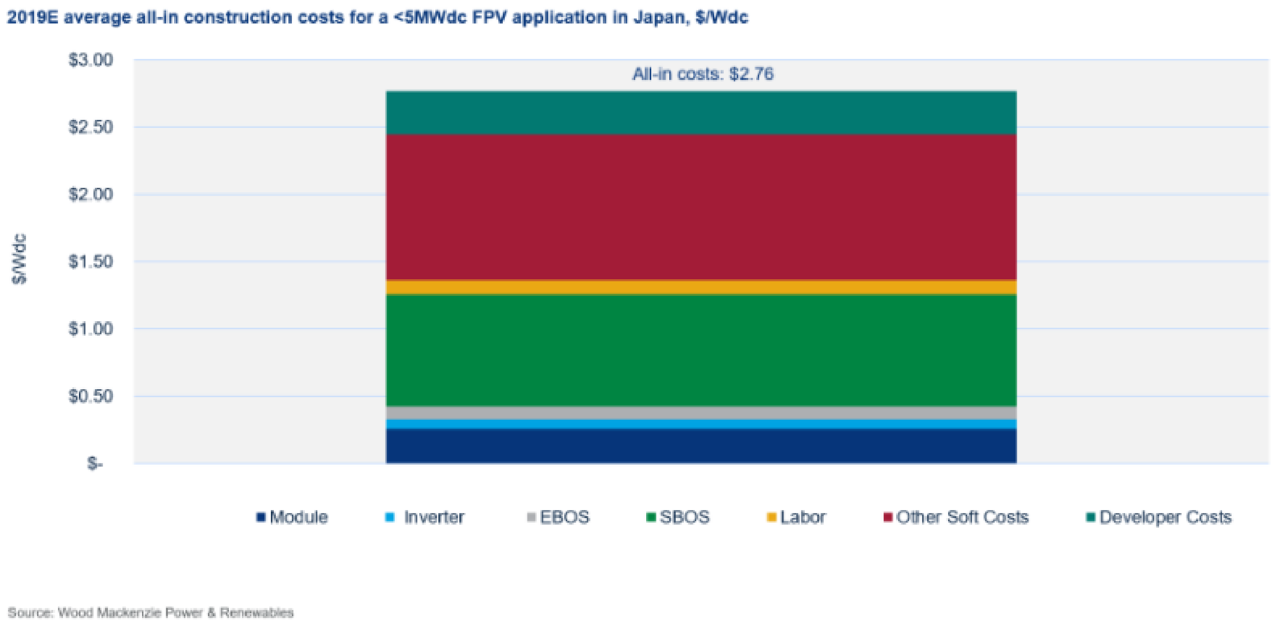
7 Our computation from Ensoe data, available from https://transparency.entsoe.eu/generation/r2/actualGenerationPerProductionType/show.

8 Source: Communication de l'Office Federal de l'Energie, Electric Yearbook 2018.

In economic terms, floating PV is significantly cheaper than rooftop PV, since it shares many of the advantages of ground-mounted utility-scale plants. Depending on size, design, location, and operator the cost per watt is the following, for selected countries:



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 labour cost and high sofistication of planning and technology sensitivity), the detailed full structure might be similar to the following, which indeed has been computed for that country:



The cost of the module is below 0.5$ per W; Electric Balance of Systems includes wiring and other electric components, SBOS stands for Structural Balance of Systems (the floating structure itself and racking equipment for the modules, along with the Mooring and Anchoring materials).

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

All data are from August 2019, courtesy of Molly Cox (Wood Mackenzie, Power and Renewables) from their Report: “Floating Solar Landscape 2019”.

2. The benefits as well as anticipated risks and environmental impacts of expanding mountains' role as "power stations" by the diffusion of Floating PV

In this paper we advocate a lake-by-lake approach in which a long checklist of different criteria to be filled in order for a lake to become subject to a more extensive and detailed feasibility study, possibly leading to an investment plan and the relative funding and implementation. In this way, benefits and risks, opportunities and limitations (including of specific technological arrangements) are balanced at the micro (bottom-up) level, allowing for the identification of the most immediate stakeholders, whose consultation will be necessary, both while responding to the checklist and for the possible feasibility study. Special attention will be paid to cognitive and emotional biases that might characterise the stakeholders.
After presenting this list in 2.1., alternative governance structures and decision-making processes are envisaged in 2.2. In sub-chapter 2.3. we shall be laying down synergies and learning mechanisms for multi-lake activities so that a real diffusion of Floating PV takes place, building upon - but also going beyond - pioneering activities.

2.1. A checklist for Floating PV making a sustainable contribution to energy and regional systems

In this sub-chapter we present the nested structure of the checklist, broadly drawing on conflict maps as operationalized in Kienast et al. (2017). In general, a lake should be subject to a more detailed feasibility study if it pass all criteria (logical AND operator). In certain situation, after a difficulty or possible limitation occurs, the checklist includes potential (non-exhaustive) venues of remedial action, whose actual evaluation would require further steps.

Needless to say, a check-list 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 for environmental variables[9].

In order to read the table, the following common structure is utilized:

Name of the criterium

<table>
<tr><td>IF…</td><td colspan="2">THEN….</td></tr>
<tr><td rowspan="3">IF…</td><td colspan="2">sub-criterium</td></tr>
<tr><td>IF…</td><td>THEN…</td></tr>
<tr><td>IF…</td><td>THEN…</td></tr>
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9 See for instance http://www.rhone-geneve.ch/seujet.html for such a monitoring and reporting system of a hydropower plant, including the level of the lake each 10 min, etc., activated in part as response to explicit constraints put by the regulators.

1. Environment

1.1.Broad characterisation of the lake

Artificial (with an active dam producing electricity at the end)	Go (to the other criteria)	
Artificial (without hydroelectric production)	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)	
Natural	Dimension of the lake	
	Large	Consider a possible plant with low percentage coverage, high penetration of sunlight
	Medium	Stop unless other criteria might be particularly positive
	Small	Stop
Natural but utilized as reservoir for a dam	Variability of the water level	
	Low	Consider a possible plant with low percentage coverage, high penetration of sunlight
	Medium	Stop
	Large	Stop

1.2. Presence of geological, biological and ecosystemic idiosyncracies (e.g. unique species, pristine conditions)

No	Go (to the other criteria)
Yes	Stop

1.3. Potential chemical contamination of the water by panels and/or the tecnological solution to sustain them

No	Go (to the other criteria)
Yes	Change technological solution[10]; if the problem persists, stop.

10 For instance, one need to avoid panels out of copper indium gallium selenide (CIGS) (Brun, N. R., Wehrli, B., & Fent, K. (2016). *Ecotoxicological assessment of solar cell leachates: copper indium gallium selenide (CIGS) cells show higher activity than organic photovoltaic (OPV) cells*. Science of the Total Environment, 543, 703-714. https://doi.org/10.1016/j.scitotenv.2015.11.074)

1.4. Presence of flora and fauna in the lake

No	Go (to the other criteria)
Yes	Verify the potential impact (sun rays, biological reproduction, ecosystem unbalances,...). If large and/or irreversible, then stop.

1.5. ***Presence of flora and fauna in the surrounding areas of the lake and in downstream flow***

No	Go (to the other criteria)
Yes	Verify the potential impact. If large and/or irreversible, then stop.

1.6. ***Economic utilization of flora and fauna in the lake***

None	Go (to the other criteria)
Yes	1. Quantify the number of people and companies operating on the business 2. Verify the declared profits and personal income from fishing, hunting and other kind of economic utilization; 3. Broadly estimate the share of the activities in the lake to the total activities by the people and companies 4. compute in which measure the plant could diminish or augment such values If criteria 4 is for augment, go. If criteria 4 is for diminish, then a stakholder consultation should, in case of implementation of the project, include economic and symbolic compensation. Unless this is planned in a sufficient measure, stop.

2. *Climate and technical issues*

2.1. Variability of the dimension of the lake

Certain lakes have large differences in size according to the season and actual use and refillment dynamics[11]. This also impact on the water level variability.

Minimal	Go		
Sizeable	Take the lowest dimension over the year in order to decide the size of the PV plant		
	Verify the possibility of localizing the plant without water	The lake floor is artificial (e.g. cement)	Verify the steepness, whether laying on the ground in absence of the water is feasible, rethink the type of floating structure (for instance by not floating but staying fixed above water). If not, stop.
		The floor is natural	Verify shape and consistency for any structure to be deposited on it. If no solution, stop.
Extreme (with period without water in the lake)	Verify the possibility of localizing the plant without water	The lake floor is artificial (e.g. cement)	Verify the steepness, whether laying on the ground in absence of

11 "Les trois plus hauts barrages valaisans que sont les barrages de la Grande-Dixence, Mauvoisin et Tseuzier. Le mois de septembre est en moyenne le mois où les retenues sont remplies au maximum tandis que cela est le contraire le mois d'avril où la retenue peut être remplie qu'à 10% de sa capacité. Encore au printemps l'accès n'est pas forcément idéal en raison de la neige toujours présente et de la retenue d'eau pratiquement vide. Les barrages en plaine comme ceux de Rossens ou Schieffenen ont un volume de remplissage qui varie beaucoup moins et sont bien entendu accessible toute l'année. Les barrages produisent principalement de l'électricité en hiver et au début du printemps tandis qu'ils se remplissent en eau le reste de l'année". https://torpille.ch/hydroelectricite-en-suisse-romande/

			the water is feasible, rethink the type of floating structure (for instance by not floating but staying fixed above water). If not, stop.
		The floor is natural	Verify shape and consistency for any structure to be deposited on it. If no solution, stop.
		The floor is not available for any structure on it	Verify the possibility to take out the structure over this period on adjacent land/mountain. If not, stop.

2.2. Snow

Presence increasing the electric production	Go
Presence disturbing electric production	Choose a vertical tilt, a floating structure that passively (by shape) and actively (by heating)[12] removes snow, further remedies
Presence burdening the physical structure	Choose a robust enough structure, compatible with costs

[12] 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.

3. ***Ice***

Minimal	Go	
Present in the coast but not at center of the lake	Choose location and size of the plant in order to avoid ice.	
Possibly present across the lake, including any location of the plant	Verify if your default plant design can resist icing	If yes, go.
	Choose a plant design that allows to float on ice (e.g. the) and is pushed up while the water is undergoing freezing	Check the strength of wind. If excessive, verify the possibility of making an eolic plant instead (or an hybrid where the wind mills stabilize the pv plant). If not excessive, go.
	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	Check costs and resistance to icing of the structure
	Verify the cable track (whether underwater - thus under ice - or above water)	If cables and other electric devices cannot be defended from ice, stop.
	If none of the above works, verify whether the structure can be delocalised on the shore or nearby before the icying season.	If not (and all of the above did not work), stop. If some of the technical solutions worked but was expensive, recompute the business plan and verify economic feasibility.

3. Landscape services

3.2 *Current landscape perception by local communities*

Minimal	Go
Sizeable	The plant must be made aesthetically not intrusive
The lake is a major local identity element	Verify with the population if the proposed modification is compatible with their desired identity. If absolutely not, stop.

3.2 *Current landscape perception by tourists*

Minimal (including cases where the reservoir is unattainable for many months due to winter conditions)	Go	
	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 pedestrian and cyclists if connected to land with a proper transit connection[13].	
Sizeable	The plant can be made aesthetically not intrusive	Verify with landscape and tourism experts and stakeholders. Involve land-artists (e.g. in a architectural / landscaping competition).
	The lake has walk and bike lanes around	Add a transit through the plan and/or around the “solar island” for the tourists
	The plant turns out to be untolerable from a landscape point of view (including being a potential object of conflict)	Stop
The lake is a major tourist attraction	Stop	

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 assessement of possible consideration of the lake for a Floating PV plant (in any design, including canopy).

13 For a wider discussion on the possibility of attractive artistic composition in green energy plant, see the appendix.

2.2. Alternative governance structures and decision-making processes

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 market to provide funds to the projects?

We at this stage do not have answers to these key questions. There is a lot of path-dependency, 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 would be stakeholders 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 of the Canton, with some degree of involvement of the municipalities and of the Confederation.

Accordingly alternative governance structure could include:

- a Floating PV plant vertically intergrated in the hydropower operator, in-house designed, funded, and operated;
- a Floating PV plant vertically intergrated 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.

Needless to say, there are many further settings, including possible spin-offs from the hydro-operator, two parallel companies in the same large holding group, etc.

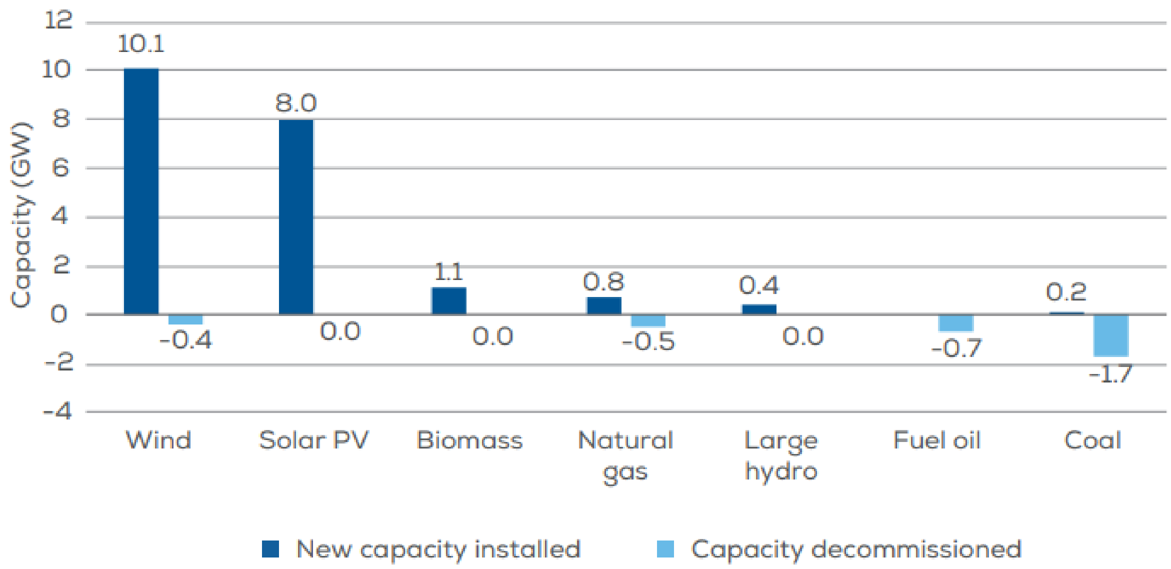
In this the specific company culture may play a role. In particular, certain cognitive and emotional biases could obstacle a comprehensive analysis of the system, leading to a premature dismissal.

Indeed in some informal conversation, the Author has met with contradicting objections to Floating PV . On one hand, some people quickly envisage as “too small” the contribution that the PV plant may do. On the othe hand, other people suggests that floating plant would be “too big” to be tolerated in a landscaping perspective.

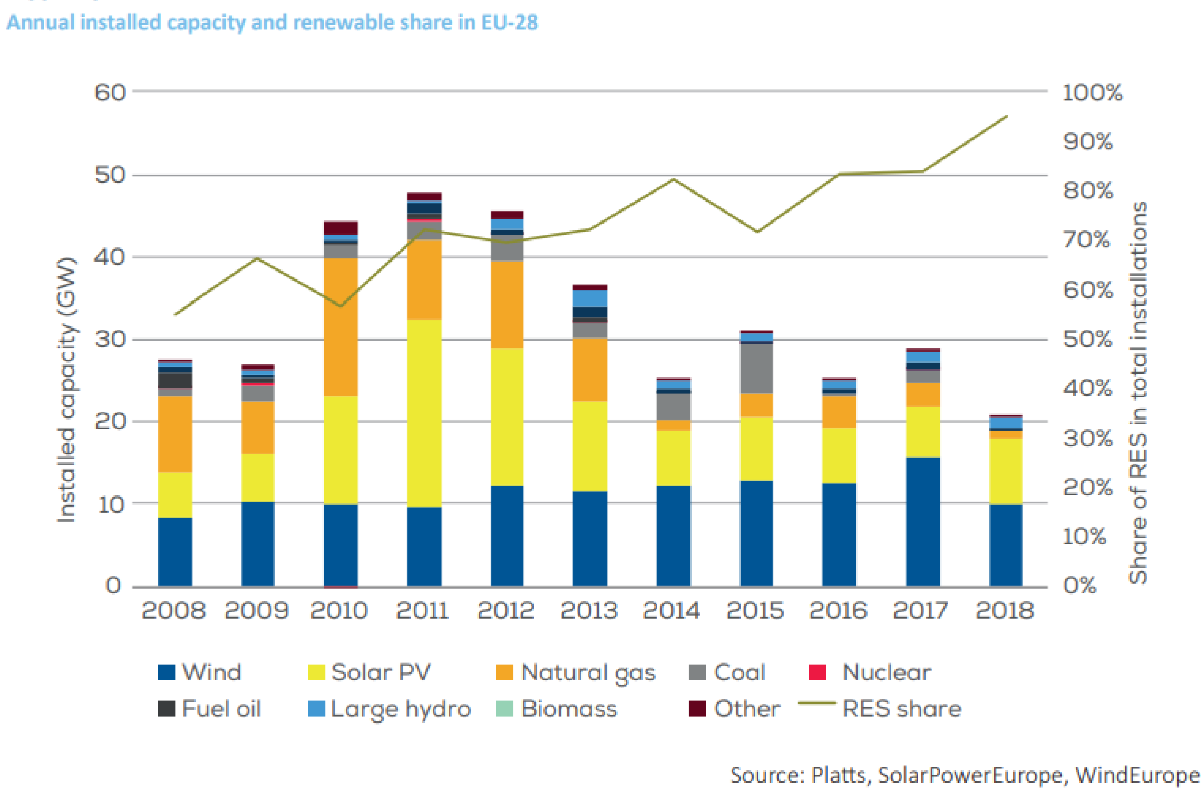
Let’s look to the first issue (“too small”). Hydropower is an industry where there are both rational and emotional reason for preferring large scale plants, with pride in a structure proportional to its size[14]. In this vein, a typical bias of “looking at the tree and missing the forest” occurs.

14 It is possible that also the span of control and the salaries are higher in larger plants / companies, so there is a material interest of the respondent in larger sized plants (including with a Baumol’ian understanding of the goals of companies as turn-over maximisers with profits as constraints, in opposition to the neoclassical assumption of profit maximisation without interference from the managerial structure).

The single panel may seems to be a small thing, but in Europe in 2018, this was the composition of new installations[15]:



Solar PV installed 20 times more than large hydro. This is not the first year in which solar and wind dominates new installations:



Including small hydro leads to a much better situation, with 2845 MW installed in 2017 in 28-EU[16], thus about 2445 MW in small hydro only. But this is hardly an argument for an emphasis on size, and dismissal of relatively smaller plants.

15 Source: https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf

16 Source: our elaboration from International Hydropower Association, 2017 and 2018 Hydropower Status Reports. According to the same source, Switzerland did not add new MW in hydropower in 2017.

This 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 (Barry, Hannes, Schumann and others, 2019),.

In general a comparison between what the two plants produce is like comparing the turnover of the activity in a building and the economic production of the PV on the roof of the building. It does not really have a meaning, even when the latter turns out to be small (except perhaps in this case by leading the governance structure towards outsourcing and with a third-party doing the investment, simply paying a fee for the surface).

In special cases, however, such comparison might be worth pursuing, for instance where the Floating PV plant is used to pump up the water to the lake. A literature estimates of a 23% efficiency loss in the process means that pumping is profitable to the extent the difference in price is higher than that. With cheap and integrated source of electricity[17], pumping would become profitable even with smaller differences.

On the other possible objection about the environment, it's important to engage early, with good specific arguments, results of testing the environmental organizations and institutions, 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 behavioural 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 assessement 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, with more detailed consideration included in the Appendix as how to maximise the positive contribution of a "beautiful" plant.

One may expect that cantonal autorities expresses an interest in the technology but also many questions. They may see as an opportunity of jobs and tax revenues, in a moment in which water fees are under discussion. They care about the landscape, while a general goal of increasing renewable may specifically be easier or more difficult in city centres, semi-peripheries and periferies, rural and mountain areas, etc. A wider set to choose from is possiby 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 for 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 intergrated 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.

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17 In which the plant is vertically integrated and the sales between the two units is not linked to the market, with the PV plant being profitable out of selling outside but giving the electricity "for free" to the hydroplant.

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 implementing both legal and material requirements.

2.3. 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" (Utterback, 1997).

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

Some agents 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 somehow help also new entrants, including Swiss and cantonal companies, to assure a competitive environment.

In this respect, academia can play a role in disseminating knowledge.

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.

All this is true not only at national level or mountain-chain levels (Alps) but also across mountain chains (e.g. Andes, Himalaya, etc.). Floating technologies will mainly develop in non-mountain non-hydro reservoirs conditions; such experiences, although not enough to solve certain specificities of the narrower context, will be precious in settling certain technogical 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) may well establish platform to share experiences and operational tools.

3. The role of Floating PV in the desired energy futures of mountain regions

Our vision is a balanced one: we suggest to use the floating photovoltaincs 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.

From a regional development perspective, this technology, while 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 and larger Floating PV projects in a way that is channeled into generating positive externalities at regional and sub-regional 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, aging 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 analysed by authorities, companies, local communities and stakeholders.

In particular, national governments might:

- provide facilitative conditions to pilot experiments that implement participatory approaches;
- explore the potential of floating PV for their decarbonization / carbon neutrality strategies, including for the sake of the next wave of Nationally Determined Contribution under the Paris Agreement;
- 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, a topics of which can well be the potential of floating photovoltaics;
- this platform may request a compilation of the abovementioned 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 conjuction 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;
- preliminary compile the checklist as for their knowledge of the reservoirs where they operate;
- highlight in early stages which main diffiulties 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 timeseries of data** that are helpful not only to assess the technology and its revenues but also for **bankability** purposes and de-risking the investment;
- utilize these data either to engage in possibly vertically integrated activities or third-party investors and operators;
- 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 (inernally 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 decisionmaking 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 and civil society 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 experties, 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.

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 sized of pv projects, including Floating PV ;
- establish a framework for discussing Floating PV projects which in part may draw on the abovementioned 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 diffent 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.

4. Limitations and next steps

What was offered to the reader is our contribution to the International Mountain Conference (Workshop 3.1.E: Renewable Energy: Impacts on Mountain environments and people) due to occur in September 2019. In the weeks ahead we plan to share and discuss with scholars and stakeholders it, including its appendix on “Landscape impact of clean energy structures: a positive contribution from arts to tourism” by Cristina Saviozzi (ITO – HES-SO Valais/Wallis).

The contribution will continue to be a non-technical non-engineering excercise, 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.

In another vein, it might be possible to implement the checklist in real-world cases as well as simulating diffusion pathways across lakes of Floating PV and their oveall contribution to energy future in the medium to long term (e.g. 2050).

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Appendix

Landscape impact of clean energy structures: a positive contribution from arts to tourism

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The increased awareness of the depletion of natural resources, as input to the socio-economic system, and of the deepening environmental deterioration and climate crisis, as output of the system, makes it necessary to use green, sustainable, zero emission sources for energy production.
At world level, the demand for renewable energy is rapidly increasing and must so to meet the growing energy needs of communities and enterprises.
It is hoped that the use of the such systems will have a positive impact on sustainable development and will respect the natural and human heritage. However, the practical implementation of these artifacts is often problematic and questioned, due to their increasing size, shape, and impact.
Although useful and innovative, these structures may be perceived by communities as out of context and dysfunctional to the landscape heritage and services. The need, therefore, arises to guarantee not only energy efficiency and effectiveness, but also harmony and integration with the territory.
Some authors have responded to this question, e.g. Angelucci 2008 states: "*by adopting visual impact mitigation measures, which improve the perception of the surrounding landscape, so that they do not affect the quality of the view ... the structures are after some time accepted as elements of built landscape… Not all structures or implants must, however, have a negative impact on the territory a negative impact on the territory, but they can become an element of enhancement*".
Moving beyond simple mitigation, cultural tourism, which can well be a generator of development, is increasingly sensitive to the theme of sustainability, including with the aim of promoting a tourism that is attentive and respectful of the history and the future potential of the destinations.
In the last few years, the same tourists have demosntrated a growing interest on the part to fully experience the places and to discover them in their specificity and authenticity, to integrate with the real life of the community and its local production processes (e.g. agriculture and food), enriching themselves with new values, while respecting the environment and the territory.
In Europe, there are energy parks and paths dedicated to renewable energy issues. They offer the possibility to know and understand this theme in areas where the latest energy technologies are combined with the architectural heritage and other activities, such as nature excursions. This contributes to attract tourists and enrich their participatory experiences.
A project that moves in this direction is the "Clean Energy Tour", in Egadina, where visitors can take routes to discover the production of green energy and immerse themselves in breathtaking views. Secondly, Enertour, a technology park in Trentino Alto Adige, was created in Italy, offering a wide range of experiences including guided tours of green energy systems.
This form of "energy tourism" could make visitors and citizens themselves acquire a more conscious behavior.

Renewables and design

Art and design can play an important role in the conception of renewable energy structures with enhanced visual impact. Architects, designers and artists have been active and have contributed with inspiration and creativity to create various projects to create structures, less impactful and aesthetically pleasing. Creating models capable of reconciling effectiveness and technological efficiency and costs in harmony with the landscape and the environment. The design has been exploring and reinterpreting structures such as photovoltaic panels, making them pleasing to the eye without affecting their essential functionality.
Promoting the design of visually and aesthetically pleasing structures, integrated with the environment and able to add value to the host territory is a task for local and national stakeholders, so that the structures turn out to be not only useful to the community, as they generate clean energy, but becoming part of the reasons for being proud of the place of living and to attract this niche "tourist" market.

Artworks and solar energy

Art works, installations and prototypes have been designed not only to integrate the natural environment but also to upgrade public spaces, including with the additional benefit of movement, thanks to solar energy. The work "Dancing Solar Flowers" created by the artist Alexandre Dang is a forest where every colorful flower moves thanks to the sun exposure: the more intense the light, the faster the movement. In Serbia, inside the

Tašmajdan Park, the sculptor Miloš Milivojevic created a black steel structure in the shape of a tree. Its branches capture sunlight, which is then used by visitors to recharge their devices. Larger systems with an attractive design can be found in China, where a company opted for the creation of the panda-shaped plant, the symbol of the country, to make young people curious and discover solar energy. In New Caledonia, a photovoltaic plant was designed with a heart shape to convey a positive image for the fascinating spread of renewable energy in the world.

Floating PV Systems

In Japan, one of the largest floating photovoltaic systems was designed based on several hexagonal units, equipped with LED lights, which help the growth of phytoplankton.

Inspired by nature and the characteristic of the place is "LOTO" made in Solarolo in Italy. About 25 meters long and located on a lake, it has been designed to have a high degree of environmental integration, without taking away space from the cultivations and by reducing evaporation of the water.

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.

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