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**Floating photovoltaic parks: A new frontier in solar energy**




# *Floating photovoltaic parks: A new frontier in solar energy*

*Abstract:*

*In recent years, floating photovoltaic solar energy has emerged as a promising technological alternative with great potential to support the global energy transition. This article presents a didactic and rigorous analysis of the functioning, advantages, challenges, and prospects of this technology, with a particular focus on the Spanish case within an international context. Updated data and verified sources are included to provide a broad and substantiated view of the subject.*

*Keywords:*

*Solar energy; floating photovoltaics; reservoirs; sustainability; energy transition.*

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## Introduction

Over the past five years, the global capacity of floating photovoltaic parks has approximately doubled every two years, surpassing 3 GW in 2023 according to the International Renewable Energy Agency (IRENA)[1]. Meanwhile, conventional land-based solar technologies face spatial limitations, positioning floating systems as an innovative and sustainable alternative for solar energy expansion. In fact, by the end of 2019, more than 300 floating solar installations had already been deployed across approximately 30 countries worldwide[2].

Solar energy is one of the most promising renewable sources for addressing the challenge of climate change. Why? Because it harnesses a clean, inexhaustible resource: sunlight. This technology has evolved significantly since its early days, when solar panels were inefficient and costly. Today, advancements have enabled new installation formats, such as floating photovoltaic parks—an innovation that blends technology with sustainability.

Floating photovoltaic parks consist of solar panels mounted on floating platforms installed on bodies of water such as reservoirs, lakes, or even at sea. These systems not only generate clean electricity but also solve several challenges faced by traditional land-based solar installations.

Spain, with more than 1,200 reservoirs and among the highest average solar irradiance levels in Europe, is well positioned to lead in the development of this technology. Furthermore, the recent adoption of Royal Decree 662/2024[3], has established a clear legal framework to promote the installation of floating photovoltaic parks, aligning with the European Union's energy transition goals.

This article seeks to answer key questions about floating photovoltaic parks: what they are, how they work, their advantages, the challenges they face, and how they are revolutionizing the energy landscape in Spain and around the world.

[1] International Renewable Energy Agency (IRENA). *Renewable Capacity Statistics* 2024. Global renewable capacity statistics, with data through 2023.
[2] *Environmental and Energy Study Institute* (EESI). "*Floating a New Solution for Solar Deployment*". Washington, DC, 2021. (Report indicating, among other data, a 5-15% performance increase in floating systems compared to terrestrial ones, and more than 300 floating projects installed through 2019.)
[3] Government of Spain - Official Bulletin. Royal Decree 662/2024, of July 25, regulating the installation of floating solar plants in the public hydraulic domain. Ministry for Ecological Transition, 2024.

## What is photovoltaic solar energy?

Photovoltaic solar energy is the process of converting solar radiation into electricity. This process requires three essential components: photovoltaic modules, which convert sunlight photons into electrical energy; inverters, which transform the direct current (DC) generated by the panels into alternating current (AC) suitable for consumption; and transformers, which increase voltage levels to minimize transmission losses.

Photovoltaic modules are composed of cells—typically made of silicon—that generate electric current when exposed to sunlight. This energy is clean, renewable, and does not produce polluting emissions during operation.

The capacity of photovoltaic panels and systems is measured in peak power, expressed in watt-peak (Wp). The Wp value represents the maximum power a solar panel or photovoltaic system can generate under standard test conditions. These standardized conditions allow for meaningful comparison of different solar panels' performance.

Why use Wp instead of simply W? The actual power output of a solar panel varies depending on factors such as solar irradiance, temperature, orientation, and atmospheric conditions. Therefore, Wp does not represent the power a panel will generate at all times, but rather its theoretical maximum performance under optimal conditions.

For instance, a solar panel rated at 300 Wp can produce 300 watts of electricity under ideal conditions; however, on a cloudy day or under high temperatures, the actual output may be significantly lower (this concept is extensively described in specialized literature[4]).

A typical residential solar panel has a capacity of 300–400 Wp, enough to power basic appliances like a refrigerator and home lighting. In contrast, a large-scale photovoltaic plant—whether land-based or floating—can range from 10 MWp to 500 MWp in capacity, sufficient to supply thousands of homes.

For example, the floating solar park in Huainan, China, has a capacity of 40 MWp, capable of meeting the energy needs of around 15,000 households.

[4] Dunlop, J. Photovoltaic Systems. American Technical Publishers, 2010. (Reference technical text on photovoltaic systems.)

It is important to distinguish between a solar park's capacity[5] and its annual production[6].

**What are floating photovoltaic parks?**

Since the 1970s, when solar panels began gaining popularity, photovoltaic technology has made significant strides, reducing costs and increasing efficiency. Today, photovoltaic plants can be installed on land, rooftops, or even floating on water.

A floating photovoltaic park is a solar power installation mounted on a water surface. These systems are typically deployed on reservoirs, lakes, ponds, or artificial basins designed specifically for this purpose. The floating structure supports the panels, while an anchoring system keeps them in place to prevent drifting due to wind or water currents.

The floating platform usually consists of modular floatation units (often made of high-density polyethylene, HDPE) that support the panels on the water's surface[7]. These modular floats are interlocked to form a stable platform and are anchored to the bottom using cables or elastic elements that maintain the system's position despite fluctuations in water levels or wave action.

Although this type of installation may seem like a recent innovation, the first floating solar parks were developed in Japan in 2007, as the country sought energy solutions due to limited available land. Since then, the technology has gained traction globally, with projects emerging in countries such as China, India, South Korea, the Netherlands, France, Portugal, and Spain.

**Advantages of floating photovoltaic parks**

Floating photovoltaic parks offer multiple advantages that make them an attractive alternative to land-based solar plants:

[5] Installed capacity: This value, normally in MWp, represents the maximum instantaneous power that the solar park can deliver at a given moment, under optimal conditions. That is, when there is full sun, no clouds, and the system functions perfectly.

[6] Annual production: This is the total energy produced in a year, reflecting the actual use of available solar resources. It is measured in gigawatt-hours (GWh), and reflects actual production taking into account that: (a) There is not always sunlight; (b) The sun does not shine with the same intensity all day, nor all year; (c) There are losses in the system (inverters, cables, maintenance, etc.).

[7] Ciel & Terre. "Floating Solar Technology Overview". White Paper, 2018. (Description of structural components of floating photovoltaics.)

- Efficient use of space: In countries where land is scarce or expensive, floating parks make use of underutilized water surfaces—such as reservoirs or lakes—thereby avoiding competition with productive land.
- Higher efficiency: Water acts as a natural thermal regulator, cooling the solar panels and enhancing their performance. On average, panel efficiency can increase by 5% to 15% compared to land-based installations[8].
- Reduced water evaporation: By partially covering the surface of a reservoir, solar panels help reduce evaporation—a key benefit in arid regions or areas affected by drought[9].
- Compatibility with existing infrastructure: Floating installations can be integrated into hydroelectric reservoirs, sharing infrastructure such as transmission lines and thereby reducing connection costs.
- Soil conservation: By avoiding the use of agricultural or natural land, these systems preserve those areas for other purposes such as farming or biodiversity conservation.
- Improved water quality: The shade cast by the panels can reduce algae growth and eutrophication[10], leading to better water quality in the reservoir.

| System Type | Average Cost (USD / Wp) |
|---|---|
| Ground-mounted solar | 0,85 |
| Floating solar | 1,00 |
| Hybrid system (floating + hydro) | 1,15 |

Figure 1: Average installation costs by system type (2023). *Source: Author's elaboration based on IRENA's 2023 report "Renewable Power Generation Costs."*

[8] Environmental and Energy Study Institute (EESI). "Floating a new solution for solar deployment". Washington, DC, 2021.
[9] World Bank Group, *Where sun meets water: Floating solar market report*, Washington, 2019.
[10] Eutrophication refers to the process by which nutrient levels—particularly nitrogen and phosphorus—increase in freshwater ecosystems such as lakes and reservoirs, resulting in the excessive growth of phytoplankton. These microscopic algae can reach such high concentrations that they significantly reduce water clarity and often form a dense, green surface layer, colloquially known as "green soup". This algal layer inhibits sunlight penetration into deeper waters, impairing the ability of submerged photosynthetic organisms to produce oxygen. In addition, the phytoplankton bloom stimulates a rapid increase in populations of other organisms, especially decomposers, which consume the organic matter and further deplete oxygen levels, potentially leading to hypoxic or anoxic conditions.

The figure compares estimated initial investment costs per installed watt for ground-mounted, floating, and hybrid photovoltaic systems. Floating systems are slightly more expensive due to flotation and anchoring infrastructure.

**Challenges of floating photovoltaic parks**

Despite their advantages, floating photovoltaic parks also face several challenges:

- Higher initial costs: Building floating structures and anchoring systems increases installation costs, although these are expected to decrease over time as the technology becomes more widespread.
- Local environmental impact: While floating plants may offer positive effects (such as reducing evaporation), it is essential to assess their impact on local aquatic flora and fauna to avoid ecological imbalances.
- More complex maintenance: Aquatic environments —such as exposure to saltwater or wave motion— can accelerate wear and tear on materials and components, requiring more specialized maintenance.
- Regulation and permitting: Installing floating parks on bodies of water requires specific regulatory frameworks that ensure a balance between energy use and the protection of water resources.

That said, although the upfront cost of a floating solar park can be 10% to 20% higher than that of an equivalent land-based installation, long-term savings in water conservation, increased panel efficiency, and compatibility with hydroelectric infrastructure can offset the investment. Moreover, floating systems do not occupy agricultural land, minimizing their impact on food production.

**Situation in Spain**

In Spain, the implementation of floating photovoltaic parks is still in its early stages but holds significant potential. Currently, the country's operational floating solar plants are located on reservoirs or artificial basins and are primarily used for self-consumption, particularly to power irrigation systems in the agricultural sector.

Spain is uniquely positioned within the European Union, with the highest number of suitable aquatic infrastructures for such projects (dams, reservoirs, and impoundments):

a total of 1,225, according to the Ministry for the Ecological Transition's inventory of dams and reservoirs (MITECO)[11].

Royal Decree 662/2024, approved last summer by MITECO, establishes a legal framework regulating this type of installation. According to this regulation, floating photovoltaic plants may occupy between 5% and 15% of a reservoir's usable surface area, depending on the characteristics of each water body.

Some of the most notable projects in Spain include:

- Sierra Brava reservoir (Cáceres): The country's first floating solar installation, with 3,000 solar panels covering a surface area of 12,000 m².
- Andévalo irrigation community – Pedro Arco dam (Huelva): A 369 kWp floating plant aimed at reducing energy costs for local irrigators.
- Segarra-Garrigues canal (Lleida): A project currently under development that uses technology from the French company Ciel & Terre to take advantage of the surface of an irrigation canal.



Figure 2: First solar PV plant connected to Spain's electrical grid, located in the Sierra Brava reservoir, Extremadura. *Source:* https://www.review-energy.com

[11] Ministry for Ecological Transition and Demographic Challenge (MITECO). Dam and reservoir inventory, 2021 edition. (Official database of hydraulic infrastructure in Spain.)

The National Integrated Energy and Climate Plan (PNIEC) establishes that by 2030 Spain must reach a total renewable energy capacity of 120 GW. From this goal, floating photovoltaic parks could play a significant role, especially if successful pilot projects like those at Sierra Brava and the Segarra-Garrigues canal are replicated on a larger scale.

These initiatives demonstrate the feasibility of the technology and could be expanded to other strategic reservoirs across the country. It is worth noting that the PNIEC explicitly acknowledges the expected contribution of photovoltaic energy—including floating systems—to the national energy mix[12].

**The international landscape**

The deployment of floating photovoltaic parks is a global phenomenon that is gaining momentum in numerous countries due to its many benefits. Although this technology still represents a small share of the global solar market, its annual growth is remarkable, driven by the need for sustainable energy solutions and more efficient land use.

- China - The global leader: China has established itself as the undisputed leader in floating photovoltaic installations as part of its broader energy diversification strategy and efficient use of water resources in densely populated areas. A standout example is the Huainan floating park, located on a lake formed over a former flooded coal mine. With a capacity of 40 MW, this project not only generates clean energy but also symbolizes the country's shift from a fossil-fuel-based energy model to a more sustainable one.
- India - An expanding market: With the ambitious goal of reaching 500 GW of renewable energy capacity by 2030, India has identified floating solar parks as a key component of its strategy. The country hosts several large-scale projects, including the 100 MW Ramagundam floating park in the state of Telangana—one of the largest in the world. The Indian government has launched multiple tenders to develop floating plants on reservoirs, which also help mitigate water scarcity in arid regions.
- Europe - Innovation and sustainability: Several European countries are investing in this technology. In Portugal, the Alqueva floating solar plant—installed on the namesake reservoir near the Spanish border—is one of the largest in Europe, with

[12] Government of Spain. National Integrated Energy and Climate Plan (PNIEC) 2021-2030. Renewable energy objectives and strategies in Spain.

around 12,000 panels and an estimated annual output of 7.5 GWh (enough to power about 1,500 households). The Netherlands is at the forefront of floating solar in Europe, leveraging its vast network of lakes and canals with projects like the 27 MWp Bomhofsplas solar park, designed with floating structures that allow light penetration to preserve aquatic ecosystems. In France, the Piolenc floating solar park (17 MWp) was built over a flooded former quarry. All these projects combine sustainability with advanced technology, positioning Europe as a leader in adopting innovative renewable energy solutions.

- Latin America - Emerging potential: In South America, the Aquasol project stands as the region's largest floating solar plant. Installed on the reservoir of the Urrá hydroelectric plant in Córdoba, Colombia, this 1.5 MWp pilot project—launched in 2023—combines hydroelectric and floating photovoltaic generation, enhancing the reliability and output of clean electricity in the region[13]. Brazil and Chile, for their part, have also begun demonstration projects on hydroelectric reservoirs, showing considerable promise due to their abundant water resources.

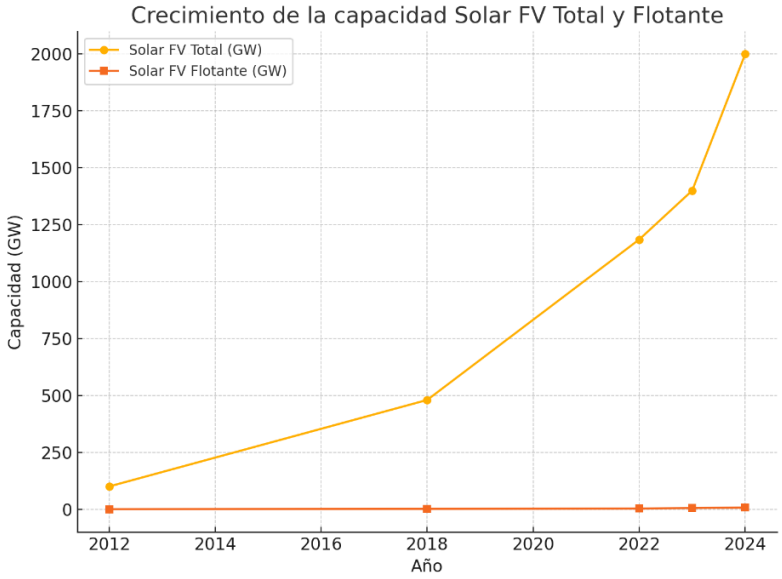



Figure 3. Comparative growth of total installed photovoltaic solar capacity (top yellow line) and floating capacity (bottom orange line) worldwide (2012-2024). *Source: Author's elaboration based on IRENA (2023) and Global Solar Council (2024) reports.*

[13] Ini, L. "Colombia will build the Yurubí floating solar plant, 2.8 MW". PV Magazine Latam, Nov 7, 2024. (includes details of the 1.5 MW Aquasol project in Córdoba, Colombia.)

The growth of total installed photovoltaic capacity worldwide has been exponential, surpassing 2 TW in 2024. While still in its infancy, floating photovoltaics are growing at a rate exceeding 30% annually, and their capacity is expected to increase tenfold over the next decade, with Asia at the epicenter of this expansion. Globally, according to IRENA, installed floating solar capacity has doubled every two years since 2015, reaching approximately 3 GW in 2023[14].

Although floating solar currently represents a small fraction compared to land-based installations, its technical potential is immense, especially in countries with high population density and limited land availability.

**Social impact and future**

The transition to renewable energy is measured not only by installed capacity or emission reductions but also by its broader social impact.

Floating photovoltaic parks are demonstrating positive effects across multiple dimensions:

- Local job creation: The construction, operation, and maintenance of floating solar parks generate both direct and indirect employment in local communities. From engineers and specialized technicians to workers involved in floatation system manufacturing, this sector stimulates local economies, especially in rural areas.
- Support for the energy transition: Floating solar parks are a key tool in reducing dependence on fossil fuels and diversifying energy sources. This strengthens national energy security and reduces costs related to fuel imports, freeing up resources for other economic and social priorities.
- Contribution to rural development: In many areas where floating parks are deployed, these projects have helped lower irrigation and electricity costs for farmers and irrigation communities (as in the previously mentioned Andévalo project in Huelva), promoting energy self-sufficiency and supporting vital economic activities such as agriculture[15].
- Educational impact: The installation of floating solar plants also plays a catalytic role in education and public awareness of renewable energy. These sites are frequently

[14] International Renewable Energy Agency (IRENA). Renewable Capacity Statistics 2024.
[15] Roca, R. "Huelva has a new floating solar plant for its irrigators". El Periódico de la Energía, September 19, 2022.

visited by students, researchers, and professionals, promoting broader understanding of clean technologies within the population.

Internationally, floating solar projects are also leaving a mark on local communities. In Colombia, as previously mentioned, the 1.5 MW Aquasol project has delivered clean and stable energy to rural areas by operating alongside a hydroelectric plant, improving the reliability of local energy supply[16]. In Asia, initiatives in countries like South Korea (the 41 MW Hapcheon floating plant) and Thailand (the 45 MW Sirindhorn dam project) have created jobs and new technological tourism attractions in their respective regions. In Europe, pioneering projects like Alqueva in Portugal have actively involved local communities in their management, and plants like Andévalo in Spain are already helping reduce energy costs for farmers and nearby residents[17].

**Future prospects**

The future of floating photovoltaic parks is highly promising. It is specifically estimated that the global technical potential of this technology exceeds 400 GW—enough to supply energy to millions of households[18]. Various market studies predict that this strong growth trend will continue over the next decade. For instance, a report by Solar Power Europe forecasts an annual growth rate exceeding 20%, projecting that the global market for floating plants could surpass 6 GW by 2030.

Several factors are driving this growth:

- Technological innovation: New materials and designs are being developed to enhance the durability and efficiency of floating structures, including bifacial panels (which capture light on both sides) and solar tracking systems adapted to aquatic environments to maximize light capture.
- Cost reduction: Although floating parks were initially more expensive than their land-based counterparts, advances in engineering and economies of scale in the production of specialized components are lowering costs, making the technology increasingly competitive.

[16] Ini, L. "Colombia will build the Yurubí floating solar plant, 2.8 MW". PV Magazine Latam, Nov 7, 2024.
[17] Roca, R. "Huelva has a new floating solar plant for its irrigators". El Periódico de la Energía, September 19, 2022.
[18] World Bank Group. Where sun meets water: Floating solar market report, 2019.

- Climate change adaptation: Reservoirs and lakes are experiencing higher evaporation rates due to rising temperatures. By reducing water loss, floating parks not only generate energy but also serve as an adaptation measure, preserving water resources in regions affected by drought.
- Public and private support: Many governments are promoting floating solar installations through subsidies, research programs, and public–private partnerships. At the same time, private investors are betting on this technology, attracted by its potential return on investment and alignment with sustainable investment criteria (ESG—Environmental, Social, and Governance). For example, South Korea plans to install 2.1 GW of floating photovoltaic capacity by 2030 in its reservoirs as part of its climate neutrality strategy[19].

Recent technical studies support these optimistic projections. Floating photovoltaic plants typically generate more energy than equivalent land-based installations under the same conditions, thanks to the cooling effect of water. Various analyses indicate gains of 5% to 15% in annual energy output for floating parks compared to ground-mounted ones[20]. Additionally, while total installed floating capacity remains small relative to conventional solar, its relative growth is accelerating (as shown in Figure 3).

In the long term, floating photovoltaic parks could be integrated with other clean technologies to create true “floating energy ecosystems.” For example, combining floating solar panels with offshore wind turbines or green hydrogen production facilities could maximize the use of available water surfaces and multiply clean energy output—offering a holistic approach to tackling global energy challenges more effectively.

## Conclusions

Floating photovoltaic parks represent an innovative and sustainable solution to the energy challenges of the 21st century. In Spain, with its abundance of reservoirs and high solar irradiance, this technology has the potential to transform the national energy landscape, contributing significantly to decarbonization and sustainability goals.

[19] Bellini, E. "South Korea's largest floating PV plant now online". PV Magazine International, Nov 25, 2021.
[20] Environmental and Energy Study Institute (EESI). "Floating a new solution for solar deployment". Washington, DC, 2021.

As the technology continues to evolve and costs decline, floating solar parks will solidify their role as a key option for harnessing solar power in an efficient and environmentally friendly way. Their development will not only support clean energy production but also promote local economic development and strengthen national energy security, as emphasized by energy strategy experts[21].

Moreover, from an energy security perspective, diversifying the electricity mix through innovative renewable technologies—such as floating solar—enhances countries' strategic autonomy and reduces their vulnerability to fluctuations in global fossil fuel markets[22].

**Epilogue**

Technological innovation is the driving force behind the global energy transition. From the integration of floating solar panels with offshore wind turbines to the development of hybrid systems that incorporate energy storage and green hydrogen, the future of renewable energy will depend on our ability to explore and harness new technological frontiers.

Floating solar energy, in this context, stands out as a clear example of how creativity and engineering can open pathways toward a cleaner, safer, and more sustainable energy system for future generations.

International collaboration and knowledge sharing will be crucial to accelerating the adoption of floating solutions across continents. Only through joint and coordinated efforts will we fully unlock the vast potential of floating solar energy on our planet.

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[21] Spanish Institute of Strategic Studies (IEEE). Energy and Geostrategy 2022.
[22] IEEE. Analysis Document 02/2023: Renewable energies and national security.