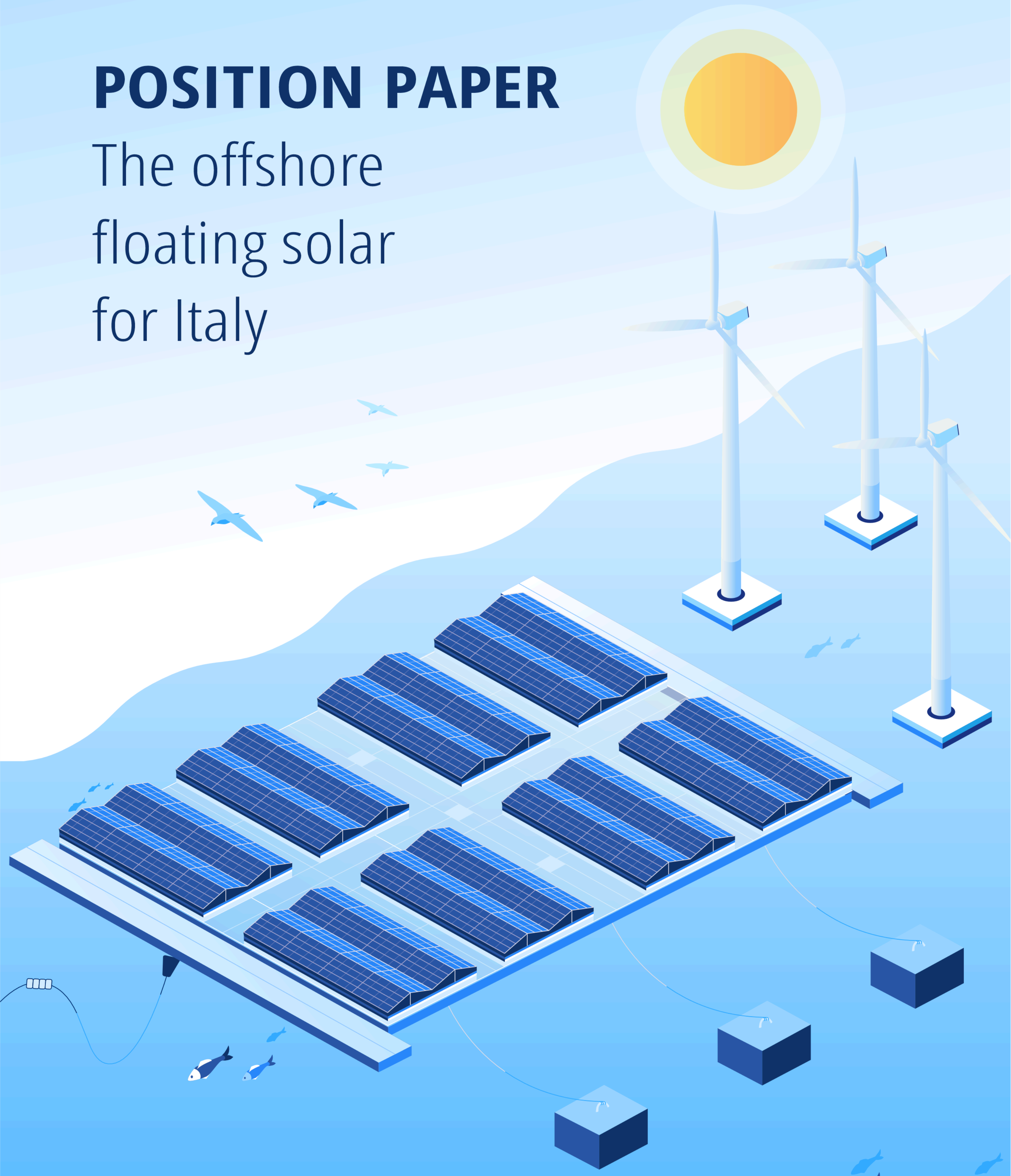
POSITION PAPER

The offshore floating solar for Italy



Citations

AERO (2025), Position Paper: The Offshore Floating Solar For Italy, Associazione delle Energie Rinnovabili Offshore, Rome.
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For information: segreteria@assoaero.it

About AERO

The Association of Offshore Renewable Energy, founded in April 2023, brings together the leading companies in the strategic and energy sectors related to the sea. It promotes the use of offshore renewable energy sources in a manner that is compatible and eco-sustainable with the landscape, the marine environment, and traditional activities such as fishing. The Association is committed to developing a national value chain and strengthening the country's energy independence, in line with the European goals of the National Recovery and Resilience Plan (PNRR) and RePower EU, while also fostering the progress of the blue economy to create tangible benefits for local economies.

Acknowledgments

The Position Paper was conceived by Agnes Holding and drafted by the "Offshore Floating Solar" Working Group. The coordination was provided by Agnes Holding (Gian Luca Vaglio, Francesco Melandri, Pietro Solaroli, Elisa Checcaroni, and Carlotta Marconi), with support from Tonucci & Partners (Stefano Lucarini, Teresa Di Mario, and Piergiuseppe Venturella), OWEMES (Alessandro Corsini and Marco Nazzarri), Fred. Olsen Renewables Italy (Lorenzo Longo and Massimo Caporaso), and Techfem (Luca Mendicino and Mario Giorgio Lagazzo). Translated from Italian by Anna Rossi (Agnes Holding). Special thanks to AERO (Fulvio Mamone Capria and Caterina Bagli). Graphic design by Outcrowd.

Disclaimer

**Floating solar is an innovative technology destined to make Italy a leader in the industry.
It will contribute not only to the transition to a low-emission future, but also to the growth of a strong national value chain.**

Fulvio Mamone Capria
Presidente, AERO

Endorsment

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The achievement of climate goals is closely linked to the advancement of renewable energy, including offshore sources. This is one of the most relevant challenges of our time. The objective is strategic: to move forward with the decarbonization process, strengthen Italy's energy security, and foster development through clean energy technologies. The real opportunity lies in seizing this crucial moment to accelerate the growth of innovative solutions that can guide us towards a more sustainable future and strengthen our country's clean energy industry. In this context, floating solar emerges as one of the most promising responses to the environmental challenges ahead. We must actively support the evolution of these technologies, which have significant growth potential.
It is our responsibility not to let this opportunity slip away.

Gilberto Pichetto Frattin
Minister of the Environment and Energy Security

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The growing number of positive outcomes in the state permitting process for environmental impact assessments is very promising. It is essential to continue this work with commitment and collaboration among the system, institutions, and industry, to enable our country to achieve an energy transition that ensures a sustainable future for generations to come. The adoption of innovative technologies, such as floating solar, could play a pivotal role in accelerating this transformation.

Massimiliano Atelli
President of the VIA-VAS and PNRR-PNIEC Commissions

*An image of **North Sea 2**, the world's first offshore solar system, installed in 2019 by **Oceans of Energy**, 4+ years of operations including during 10+ "named" storms*

The potential of offshore floating solar

In a world defined by the growing need for clean and sustainable energy, it is crucial to develop solutions that can address both environmental and economic challenges, in order to build a greener and more resilient future for all.

In this context, floating solar emerges as a promising technology with extraordinary potential in the renewable energy sector. When combined with other clean sources, such as offshore wind, it has the potential to strengthen sustainable energy production in our country, while also encouraging the development of a national supply chain and stimulating both local and national economies. The benefits are evident across several areas: from reducing greenhouse gas emissions and creating new jobs to strengthening logistical and port infrastructure.

Through this document, our Association aims to actively promote the adoption of these technologies, with the goal of ensuring that future generations live in a world where access to clean and renewable resources improves quality of life and creates new opportunities for growth. We aim to foster a reality in which development and protection of the planet can coexist.

Italy now has the opportunity to establish itself as a global leader in the implementation of floating solar technology, creating a replicable international model and enhancing its market competitiveness. In this way, our country will be able to make a meaningful contribution to the global energy transition, reinforcing its role in the fight against climate change and generating significant environmental, social, and economic benefits.

Fulvio Mamone Capria
President, AERO

Objectives of the Position Paper on offshore floating solar

This Position Paper has been drafted by the "Offshore Floating Solar" Working Group of AERO and aims to provide a clear and complete overview of these systems, which represent an emerging and strategic sector for the energy transition in our country, through a technical, regulatory, environmental and socio-economic analysis. The intention is to sensitize and involve key stakeholders, outlining the benefits, challenges, and opportunities associated with the development of this technology in the marine environment.

Thanks to its unique characteristics, Italy can play a leading role in the adoption of these systems. However, not only is there a gap in widespread knowledge about offshore floating solar, but there is also a lack of both unified and strategic planning.

The objectives of the Position Paper are as follows.

1. To Inform and sensitize

Raise awarness of the potential of offshore floating solar among key players of Italian energy sector, defining the technological, economic, and environmental features, and highlighting their contribution to energy diversification and decarbonization.

2. To Promote dialogue among stakeholders

Foster constructive debates among developers, institutions, industry associations, suppliers, investors, and local communities. This Position Paper aims to inspire the creation of a collaborative ecosystem that supports the implementation of projects in Italy.

3. To provide strategic recommendations

Provide guidelines and concrete proposals to overcome regulatory, technical, and financial barriers to the development of offshore floating solar. These recommendations will be mainly aimed at policymakers and industry operators to accelerate the integration of these technologies into the market.

4. To improve national planning

Integrate this technology as a key component of national renewable energy strategies, contributing to the achievement of climate goals set by the PNIEC (Integrated National Energy and Climate Plan) and the European Green Deal.

In Italy, some projects are already taking shape, with businesses increasingly embracing the integration of floating solar with wind farms to stabilize energy production. Leveraging the Mediterranean's favorable solar irradiation and Italy's renowned engineering expertise, the goal is to lead the way in scaling this innovative technology on an industrial level.

AERO encourages its members to work in a coordinated way to define the best strategies that simplify energy transition with the support of various offshore technologies. Only through positive and effective collaboration will we overcome the challenge of a sustainable development in Italy, guiding us toward the necessary decarbonization, which involves us from now until 2030 and beyond, up to 2050.

Why this technology is important for our country

1. The abundance of solar energy convertible into electricity in our seas creates great opportunities for faster decarbonization

According to AERO's estimates, up to 1 GW of offshore PV capacity could be installed in our seas over the next five years, enough to supply electricity to around half a million households annually, contributing to the achievement of Italy's ambitious sustainability targets.

2. Mitigating the landscape impact is crucial in a country with an immense cultural and natural heritage

Considering the modest height above sea level for floating solar systems and their position beyond 10 kilometers, the curvature of the Earth ensures that these structures become invisible to an observer on the coastline, excluding other mitigating factors.

3. We are a peninsula, surrounded by the sea: our coastline is longer than Brazil's. The future of renewable energy also lies offshore

With 7,600 km of coastline and abundant maritime space, our country has the possibility to harness marine resources in a synergistic and efficient way. Land-use issues are neutralized by the construction of large-scale plants far from the coast.

4. Italy's manufacturing and industrial tradition, combined with know-how in the Oil & Gas, positions us as an international leader

Italy has long been a landmark for hydrocarbon production in the Mediterranean, thanks to its unique engineering and industrial expertise. Today, many businesses have already begun an ecological transition, shifting their focus to support the growth of offshore renewable energy.

5. The ambitious targets for offshore wind farm installations present great opportunities for coexistence with floating solar

AERO's goal is to promote the implementation of 1 GW of offshore wind farms up to 2030. The installation of floating solar panels among the wind turbines will optimize the use of maritime space and improve grid stability by providing more complementary energy production.

What is offshore floating solar?

Offshore floating solar (referred to as “offshore FPV”) is a technology that involves the installations of solar panels on floating platforms that are anchored in open sea or coastal waters. This solution harness marine surfaces to generate electricity from solar energy.

Floating solar (FPV) installations can be classified into three main categories: solutions for inland, coastal, and offshore environments. Each category presents unique opportunities and challenges, which are reflected in distinct planning and structural approaches.

Inland FPV, typically installed on lakes, inactive mines, or quarries, is the most widespread due to its ease of implementation. This is simplified by the reduced exposure to environmental factors such as wind and waves. However, the limited surface area available in these locations and their distance from the electrical grid can present significant challenges for large-scale deployment.

Coastal FPV, situated in port waters or near the shore, offers a balanced compromise with more moderate waves and wind conditions. With the right technologies, these systems can be installed efficiently and cost-effectively, making them an attractive option for large-scale projects. It’s no coincidence that in recent years there has been a notable increase in utility-scale developments of this kind.

On the other hand, **Offshore FPV** offers vast spaces and enormous potential for the development of large-scale projects, thanks to the availability of untapped areas and the absence of land-use conflicts. However, it faces challenging environmental conditions, such as strong wind and waves, along with high installation and maintenance costs, which currently limit its widespread adoption. With technological progress and costs reduction, offshore FPV could become a key solution to meet the growing demand for renewable energy.

This Position Paper will focus exclusively on nearshore and offshore systems. For simplicity, the term "offshore" will be used to refer to both solutions.

Main Features

- Floating platforms: the panels are installed on structures designed to withstand marine conditions, including waves, currents, wind, and saltwater.
- Mooring and stability: mooring systems keep the platforms stable and ensure their proper positioning.
- Energy efficiency: the marine environment helps cool the panels, improving their efficiency. Additionally, water acts as a moderate reflective surface, which can increase energy production when using bifacial panels.

Opportunities

- Reduction of land use, freeing up terrestrial areas for other purposes, such as agriculture.
- Use of marine areas unsuitable for wind power for renewable energy installations, or, on the contrary, creating synergies with it.
- Access to abudant solar resources thanks to a continuous exposure to sunlight in open sea, without shading effects.

Obstacles

- Higher construction and maintenance costs compared to land-based or inland FPV systems.
- Creation of a value chain capable of designing and manufacturing components that can withstand offshore environments
- More extreme weather conditions than those encountered on land, such as waves, currents, tides, and high salinity.
- Potential environmental effects on the marine ecosystem are yet to be confirmed and evaluated following in-depth monitoring after the systems are operational.

This technology is seen as a promising solution to support the global energy transition, especially in countries where land availability is limited but marine areas are plentiful. For instance, in the Maldives, Malta, Singapore, and other islands or high-populated nations, the only viable option for reducing their energy dependence on foreign markets is to generate electricity from renewable sources in sea waters.

Italy, for its part, is a peninsula with a significant coastline, even longer than the one of Brazil's (CIA, 2025). Thanks to abundant solar energy and vast marine surfaces, Italy has the potential to produce large amounts of low-emission electricity and contribute to decarbonizing its energy mix.

Clearly, it will be necessary to create the right conditions for this technology to mature enough and attract private investment, while also working to reduce the LCOE, which currently remains high and does not always ensure the sustainability of initiatives.

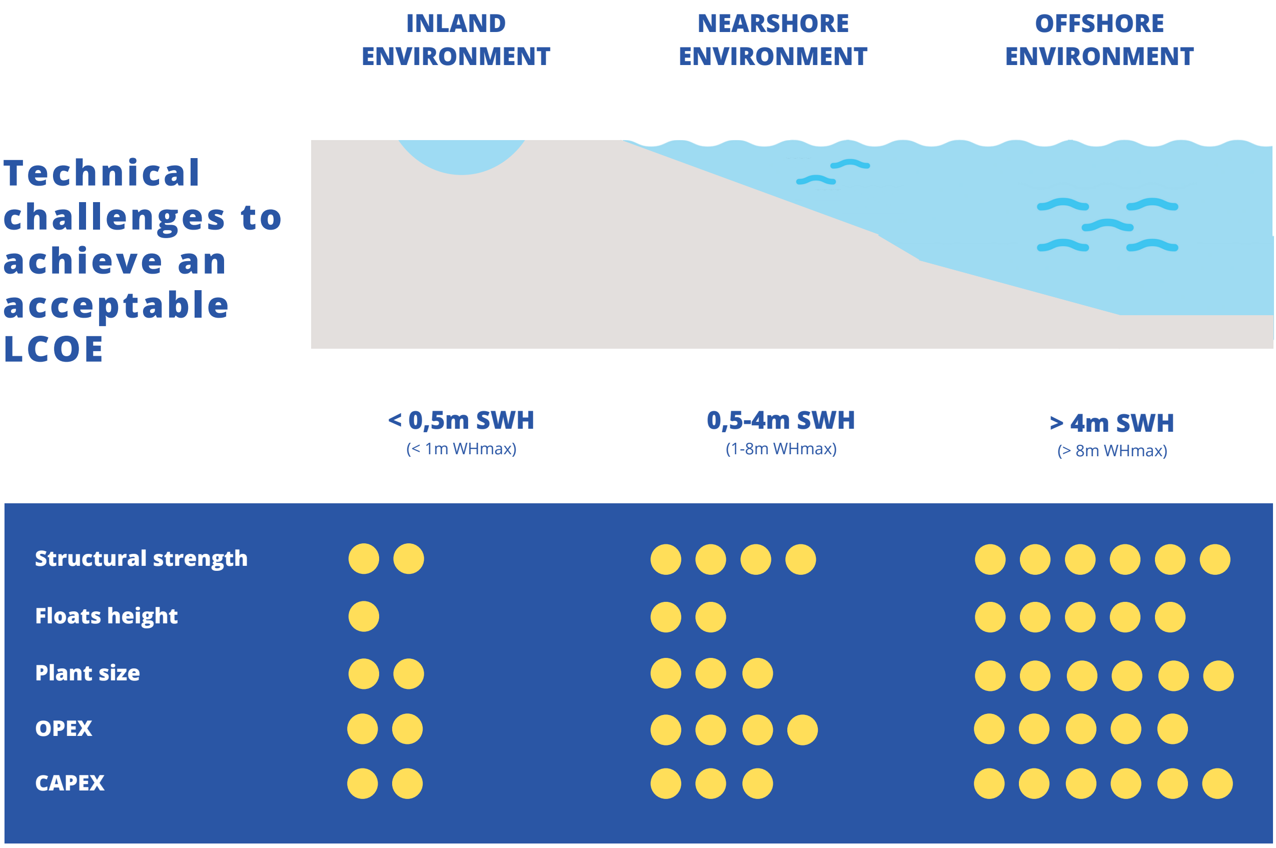


Figure 1 - The challenges for the various types of floating solar

Growth potential, markets, state of the art, and developments

In 2020, the LCOE for inland FPV ranged from 25 to 51 €/MWh, while offshore applications reached 354 €/MWh. However, a significant reduction is expected for offshore systems, with estimates predicting a drop to as low as 40 €/MWh by 2050. Moreover, the theoretical energy potential of offshore floating solar is estimated to range between 220,000 and 1,000,000 TWh per year (Wu et al., 2024), providing a concrete solution to meet the growing global energy demand, which is projected to increase by 50% between 2020 and 2050, according to EIA (Ramanan et al., 2024).

Looking at the broader trend in solar energy growth, there has been substantial expansion in the last years. In 2022, global installed capacity increased by 192 GW, marking a 22% rise compared to the previous year (IRENA, 2024), as shown in Chart 1.

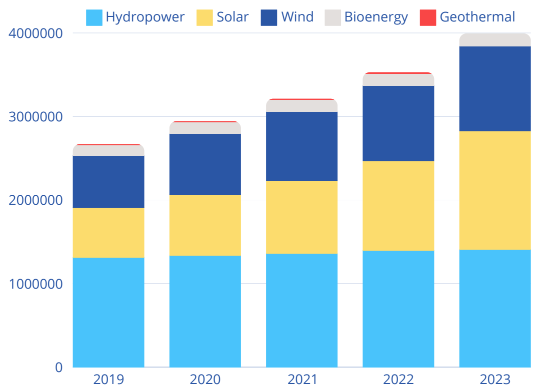


Chart 1 - Growth of renewable energy (values in MW)

These growth figures highlight the increasingly central role of solar power in clean energy production, alongside wind power. However, it is important to note that solar systems require a significant amount of surface area, equal to about 10 m² per installed kW (Djalab et al., 2024).

Focusing on Europe, projections indicate that between 140 and 222 GW of solar capacity will be installed from now until 2030, meaning an annual transformation of 280 to 440 km² of surface area into solar installations. This huge land conversion raises significant concerns about ecosystems and biodiversity, while also intensifying competition for land among agricolture, industries, and urbanization. Such challenges are particularly pressing in countries characterized by high population densities and spatial constraints.

To address these issues, the development of floating solar (FPV) technologies becomes increasingly important, as they allow the use of different surfaces, such as watersheds and marine areas (Djalab *et al.*, 2024).

By the end of 2023, the installed capacity of offshore wind energy in the European Union reached around 19.4 GW. However, to be in line with EU climate objectives, a substantial increase in capacity is required. In 2024, 15 GW of new wind capacity were installed, which is less than half of the amount needed annually to meet the objectives set for 2030.

The European targets for offshore renewable energy include reaching around 88 GW by 2030 and 360 GW by 2050. Achieving these goals will require the introduction of a variety of technologies. In Europe, several offshore floating solar solutions and initiatives are emerging, from the first installed prototypes to signed agreements for future projects, as well as bids launched by EU member states to further encourage and develop these solutions.

The following map shows the current state of offshore floating solar development across Europe. It is evident that the North Sea is currently the geographical area where solutions have already been designed and installed, although in prototype or pilote stages.

For this reasons, the North Sea is presented as a global leader in offshore FPV development. Notably, the Netherlands has included offshore FPV as an integral part of its decarbonization strategy. Although the ambitious target of 3 GW by 2030 has been recently suspended pending further market developments, the first utility-scale solutions are expected within the next five years, integrated with ongoing offshore wind projects (Crosswind, 2025).

In contrast, the Mediterranean Sea, thanks to its excellent weather conditions, is considered one of the most promising market for floating solar.

In Italy, several developer initiatives are underway for projects involving hundreds of MW, even if there is still a lack of an appropriate planning policy. In other countries, strong support from authorities is evident, as seen in the recent round of Expression of Interest launched by the Maltese or Greek governments.

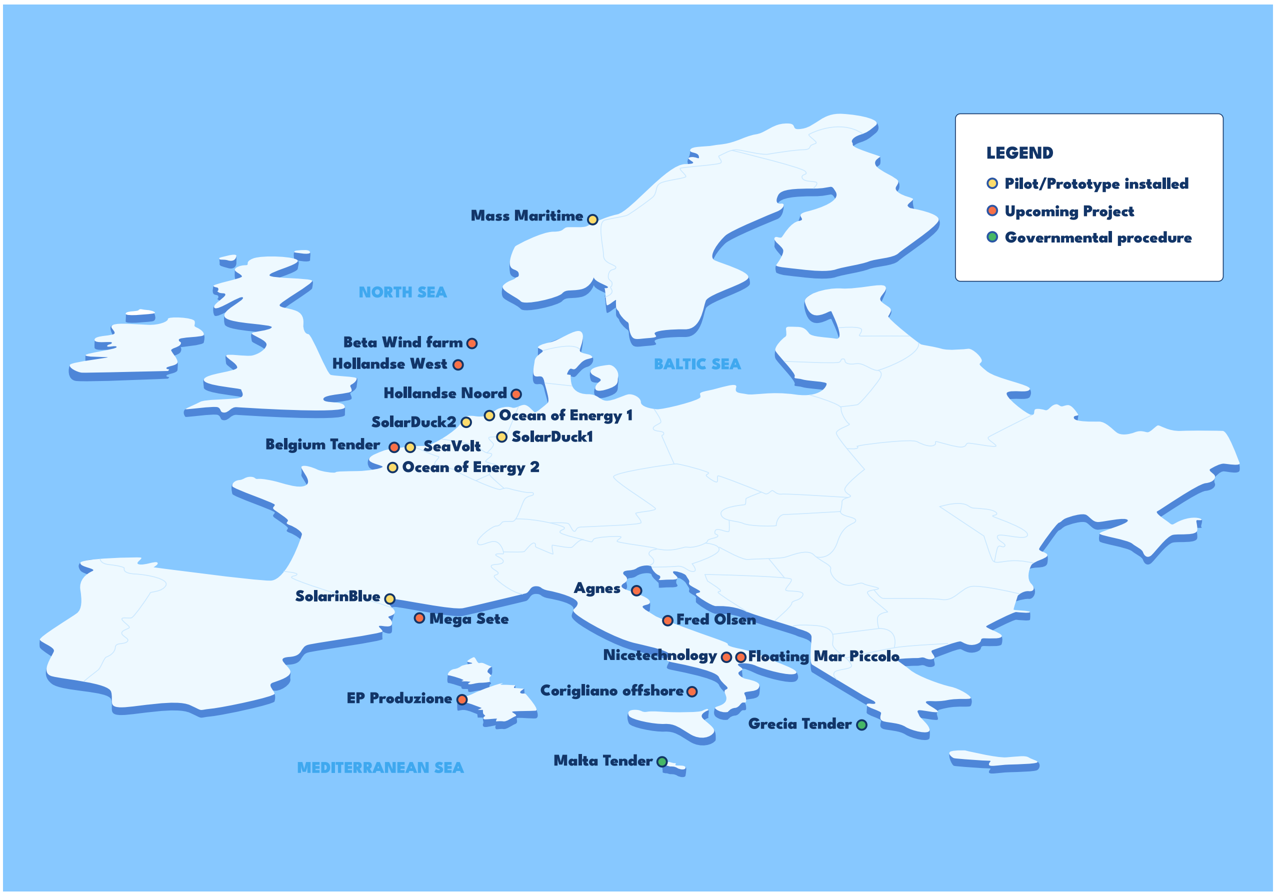


Figure 2 - Map of the principal initiatives of offshore FPV in Europe

Environmental impacts and synergies with the blue economy

The marine environment is often surrounded by a complex network of anthropogenic activities, which should be taken into account when designing any offshore system. Effective planning should ensure the integration of the installation into the maritime context, minimizing its impact on both natural and existing anthropogenic systems. However, any unavoidable disruptions can be mitigated by new perspectives on co-use of the maritime space.

On the one hand, the installation of infrastructures at sea can actually interfere with stakeholders engaged in offshore activities. On the other hand, it offers the opportunity to create synergies between the energy and blue economy sectors, promoting new collaborations and sustainable development.

The most promising sectors for activating synergies include especially fishery, aquaculture, tourism, and research. Below are some potential collaboration opportunities that can be envisioned as of today.

Fishery and Aquaculture

A first positive interaction is related to fish repopulation. Given that floating structures are interconnected and anchored via cables and catenaries, areas occupied by the plant will prohibit ordinary navigation and fishing activities, creating a safe zone that provides habitat favourable to some marine species and promotes fish repopulation with a potential *spillover* effect, where fishery resources migrate towards areas outside the project scope.
Moroever, some studies have highlighted the importance of shaded areas or refuges for preserving fishery associations, both beneath drifting materials and Fish Aggregating Devices (FADs). In this case, the floating solar structure could act as a FAD, encouraging the aggregation of fish species beneath the structure (Rountree, 1989; Dempster & Taquet, 2004; Prinsloo, 2019), thereby indirectly increasing resources and biodiversity in the project area.

To conclude, the presence of an offshore floating structure cluster can be leveraged to support various aquaculture initiatives, such as the farming of shellfish, fish, or algae. Aquaculture installations could benefit from several advantages both from a technical and an economic perspective, such as:

- Possibility to share mooring systems.
- Significant cost optimizations for offshore operations, combining OFPV maintenance with aquaculture facility operations.
- Ability to provide on-site energy for oxygenation systems in aquaculture nets.
- Improvement of environmental conditions for certain farmed species due to shading from floating structures (e.g., oysters, mussels).
- Opportunity to experiment with integrated multi-trophic aquaculture systems, combining fish farming with the cultivation of filter-feeding organisms.
- Use of a marine area already restricted to navigation, without taking up additional maritime space.

Tourism

The offshore floating solar system, especially when combined with a wind farm, can be promoted as a tourist destination focused on environmental sustainability, the blue economy, and energy innovation.

The presence of offshore FPV systems can indeed align with the growing trend toward more sustainable forms of tourism. Eco-tourism, as defined by the United Nations World Tourism Organization (UNWTO), is a responsible form of tourism that considers the economic, social, and environmental characteristics of the destination. It is characterized by a low negative impact from tourist activities, and, on the contrary, creates opportunities for the local socio-ecological system.

Among the potential activities that could be developed near a wind farm, previous studies have highlighted:

- Visitor centers and theme parks aimed at showcasing the installations of the system and providing information and knowledge about renewable energy.
- Visits to the offshore FPV system (and possibly the offshore wind farm) via dedicated boats.
- Other specific installations located near the facilities, such as observation points, possibly even submerged.
- Opportunities for collaboration with the local hospitality sector to promote "green" tourist packages that include visits to the system, in line with the sustainable tourism concept described above.

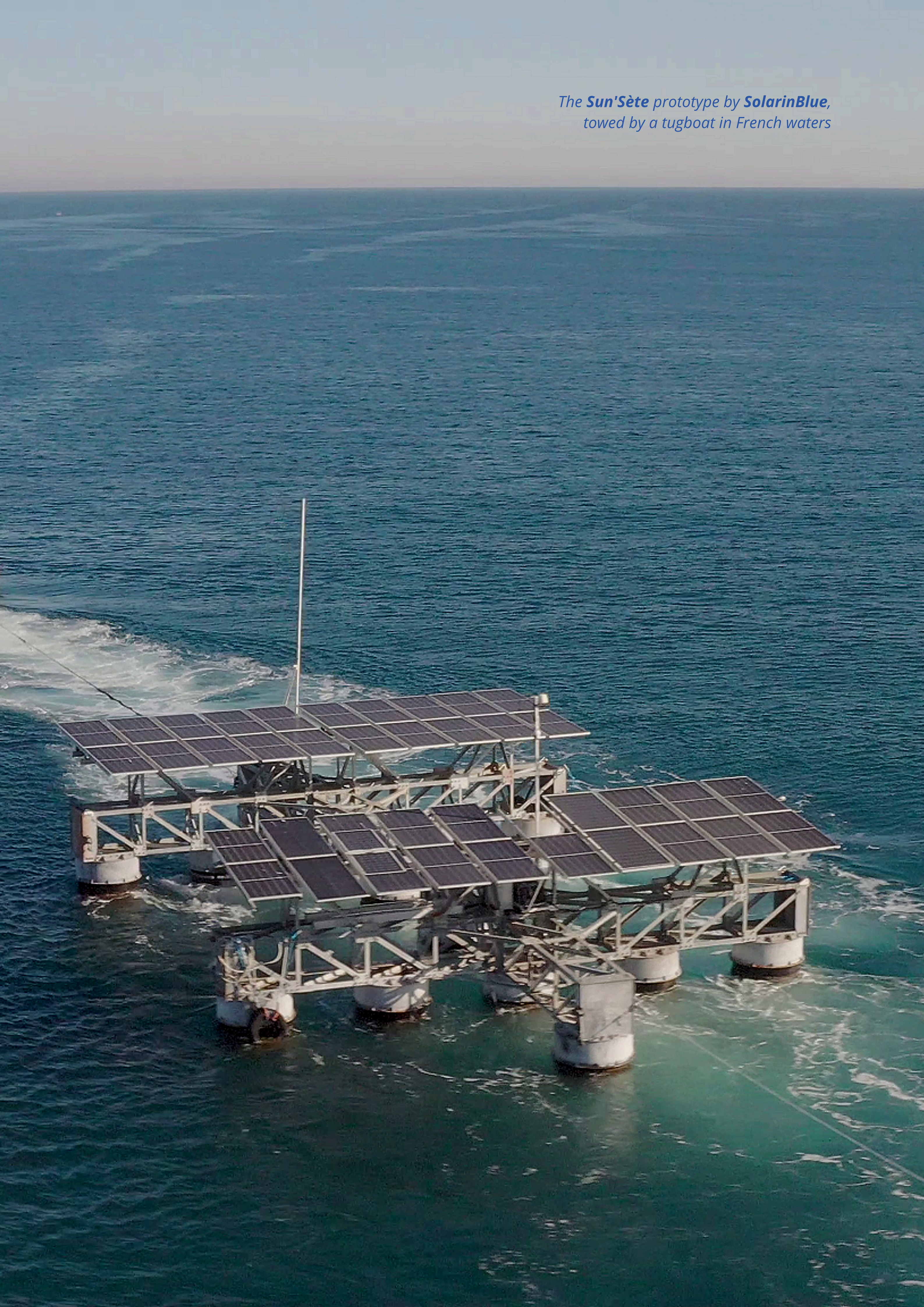
Research

Any artificial structure in open seas can potentially serve as a true outpost for marine and meteorological-oceanographic research, facilitating various activities that contribute to a deeper understanding of the sea. The potential activities are discussed below.

- Environmental monitoring: floating platforms offer an exceptional opportunity for monitoring various environmental and meteorological parameters. By integrating specific sensors, the system can function as a wave and current buoy, as well as a probe for measuring seawater quality, temperature, salinity, and other important chemical-physical parameters for climate change research and beyond.
- Biodiversity monitoring: similar to chemical-physical components, the offshore structure is also well-suited for monitoring local biodiversity, serving as an observatory for the development of pelagic and benthic communities, as well as for studying the impact of the structure on the ecosystem.
- Technological development: as an emerging industry, offshore FPV systems provide the opportunity to test innovative technologies, such as more efficient materials for photovoltaic panels and structural elements adapted to the offshore environment, as well as advanced maintenance solutions for the systems.

Offshore FPV systems can have environmental and social impacts related to both the technology and their location. As an emerging technology, research and monitoring are essential. Below is a brief summary of the most critical aspects identified so far.

- The systems can obstruct shipping routes, increasing costs and travel times. Designated corridors may help mitigate this issue, but fishing is restricted due to the presence of anchors and cables. However, reduced fishing pressure could potentially lead to an increase in local fish stocks.
- Metallic anchors can damage the seabed and disturb marine fauna through acoustic emissions, and can pose an obstacle to certain migratory species, such as cetaceans and sea turtles.
- Membrane systems installed near the surface may reduce gas exchanges and block sunlight, negatively affecting the food chain and the underlying ecosystem.



The ***Sun'Sète*** *prototype by* ***SolarinBlue****,*
towed by a tugboat in French waters

Operating principles and system components

Offshore FPV operates similarly to terrestrial systems, but with the panels installed on floating platforms in marine areas, often located far from the coast.

The energy generated in direct current (DC) is converted into alternating current (AC) through inverters and then transmitted to transformers, which step up the voltage (typically to 33 kV or 66 kV) to minimize transmission losses. In offshore environments, the long distances to the connection point make this process critical.

The connection to the mainland grid is made through a dynamic cable that reaches the seabed, where it is buried to ensure protection and reduce environmental impact. The cable is designed to withstand both marine currents and the mechanical stresses typical of underwater environment.

The various offshore floating solar solutions emerging in the global energy landscape are characterized by different design choices in terms of form and materials. These technologies can be classified into two main categories: (i) elevated structures and (ii) pontoon and membrane structures.

Elevated structures

These solutions use robust and sophisticated structures, made with metallic supports, primarily aluminum, and floats designed to keep the panels several meters above sea level. The design ensures optimal protection against large waves and harsh marine conditions. Despite the high construction cost, these solutions are capable of adapting to extreme meteorological and marine conditions, being conceived to withstand waves up to around 15 meters and winds up to 120 km/h.

Pontoon and Membrane Structures

These systems involve the installation of solar panels just at few centimeters above water's surface, supported by floating modules or membranes, often made from plastic materials. These modules are interconnected to form a structure that follows the movement of the waves, ensuring both flexibility and stability. While more cost-effective than the elevated structures, this technology requires annual maintenance due to the increased exposure of the panels and electrical components to saltwater.

Figure 3 - Elevated structure (Moss Maritime)

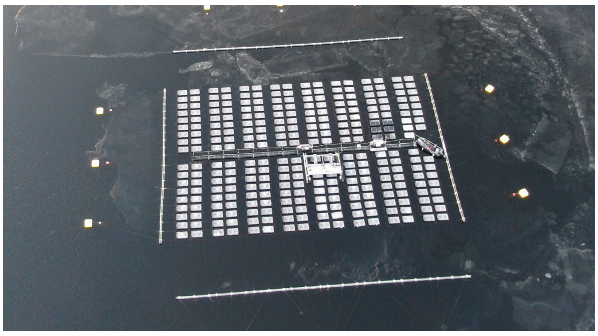


Figure 4 - Pontoon structure (Fred. Olsen 1848)

Mooring systems

The stability of floating solar platforms in marine environments is primarily ensured by a mooring system that uses ropes, chains, and anchors, typically made of steel or metallic materials, renowned for their reliability in the offshore industry. However, steel presents high costs and vulnerability to corrosion when exposed to the harsh marine environment. As a result, it is necessary to explore alternative solutions or materials that can not only reduce costs but also enhance the long-term performance of these systems.

From a structural perspective, there are four main mooring methods, as illustrated in Figure 5 (Wu et al., 2024).

The elements that come into direct contact with the seabed may consist of anchors or dead weight, such as concrete blocks.

These systems can be classified into the following categories.

A. Catenary

A system that uses the weight of chains or cables to provide flexibility and stability to the floating structure, adapting to waves and currents.

B. Taut Mooring

Tensioned cables that are nearly vertical, reducing horizontal movements and using elastic materials to lower loads. Ideal for deep waters due to the shorter length of the cables.

C. Compliant Mooring

It integrates weights and floats into the cables to enhance stability and adapt to marine conditions, reducing stresses.

D. Rigid Mooring

Suitable for shallow seabeds, such as lagoon areas, but not particularly suitable for offshore installations in deep waters.

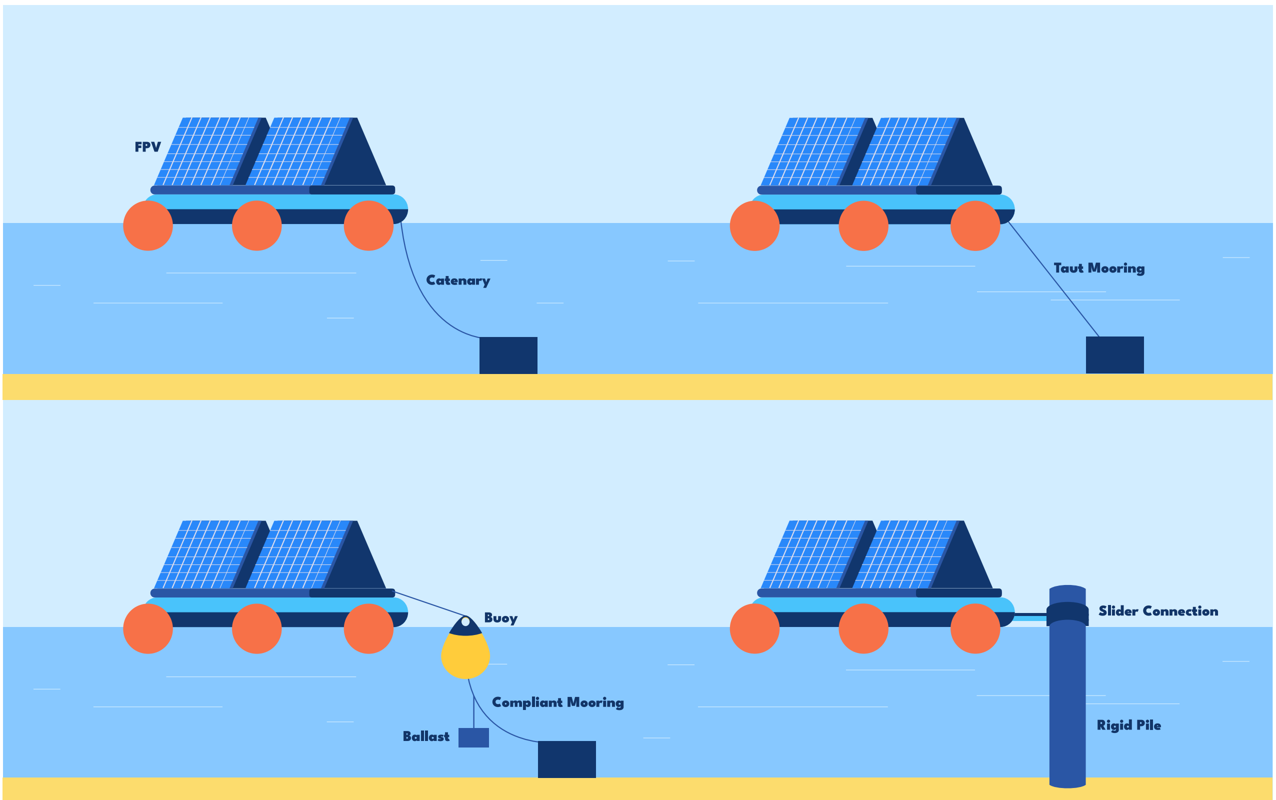


Figure 5 - Various types of mooring

How is an offshore floating solar system installed?

All of the technologies presented earlier are highly modular: platforms can be interconnected through semi-mobile joints, forming configurable "solar islands" that can be sized and arranged according to the project requirements. The scalability is indeed a great advantage of this technology.

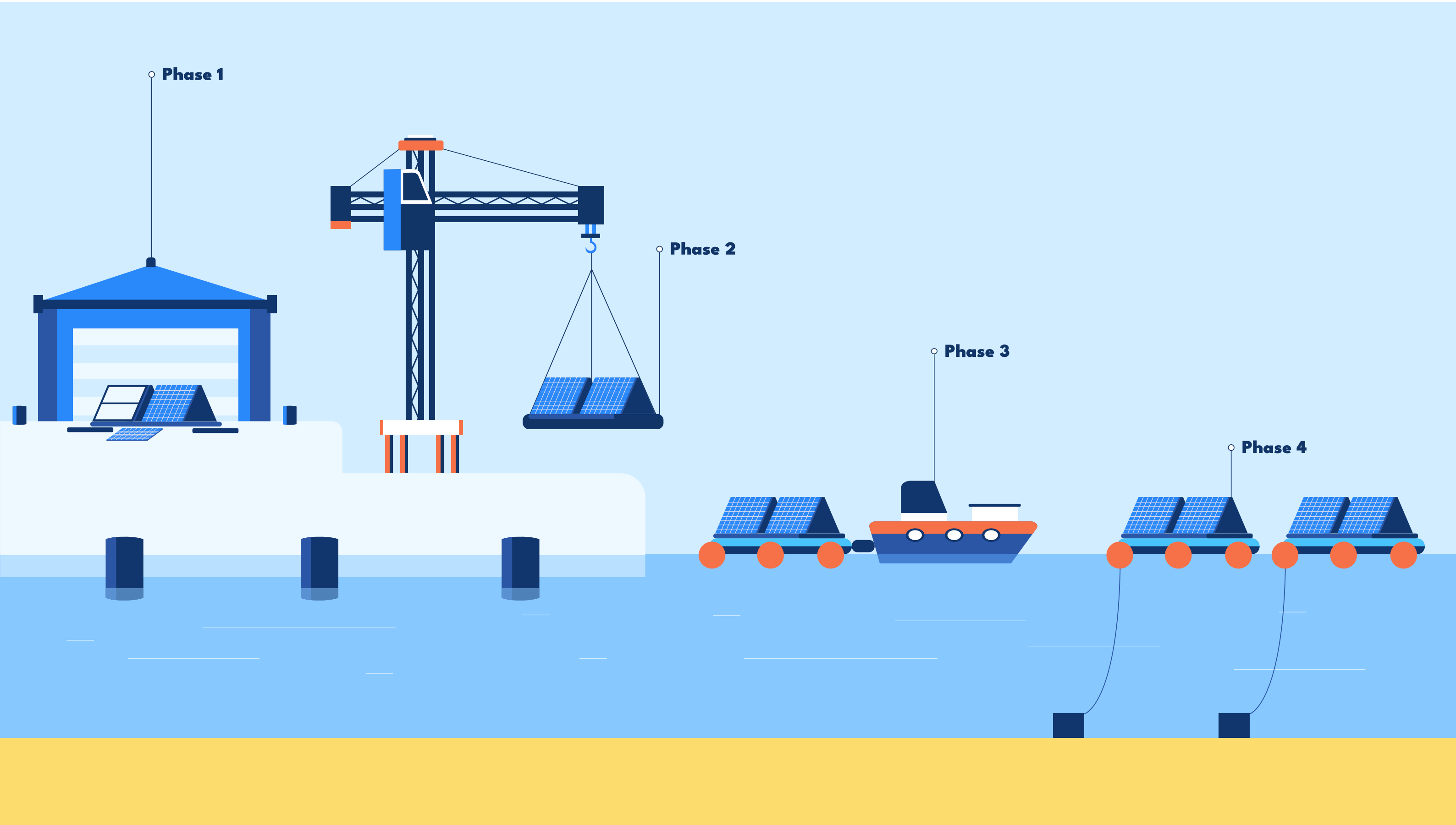
In simplified terms, the main installation phases can be summarized as follows.

Phase 1. The structure, floats, solar panels, and electrical components are assembled at temporary yards located in the nearest port. The solutions are designed to allow for quick and easy assembly, without the need for specialized equipment.

Phase 2. Once completed, the platform is lowered into the water using a crane with a modest lifting capacity. Multiple platforms can be connected together before being transported to the installation site.

Phase 3. The transportation of the platforms does not require specialized vessels. Two tugboats are sufficient to tow one or more platforms to the site.

Phase 4. Upon arrival, the platforms are secured to the pre-positioned ropes. This process is repeated until the entire solar island is assembled. Finally, the electrical connections between the platforms are made. In parallel, the export cable system is installed.



Design philosophies: integrated or stand-alone systems

Integrated systems with wind farms

The integrated solution involves connecting the solar system with a offshore wind farm: the cable exiting the photovoltaic platform will go directly to the existing transformer. Therefore, the connection cable of the wind turbines to the offshore substation will also allow for the transmission of solar energy.

Integrating with an existing wind farm could significantly reduce the solar CAPEX, while also creating synergies and optimizations both in construction and operation terms between wind and solar power.

A synergy arises from the complementary nature of the two systems, as their production peaks generally occur at different times of the year: wind power tends to generate more in the evening hours and during the winter months, while solar power in the summer.

Several studies have analyzed this topic, showing that the percentage of curtailment (i.e., the need to limit power due to excessive combined production from both systems) is minimal. This demonstrates that it is not necessary to oversize the interconnection cables between the turbines.

For this reason, even existing and operational wind farms could host floating solar, without making radical changes to the shared infrastructure. Moreover, the more sensitive electrical components of the solar system could be transferred directly to the turbine, offering clear benefits in terms of durability and maintenance.

In addition, by taking advantage of concession fees and navigation-restricted areas, floating solar offers a solution to maximize space utilization and mitigate these limitations.

To conclude, combined maintenance could reduce OPEX, which currently represent some of the highest costs in offshore environments. These are just some of the advantages that help reduce costs, not only for solar power but for the entire system.

Stand-alone systems

The stand-alone solution involves the installation of an autonomous offshore solar power plant, designed to generate energy independently. This configuration requires a dedicated infrastructure for energy conversion and transmission, but allows a greater independence compared to integrated solutions.

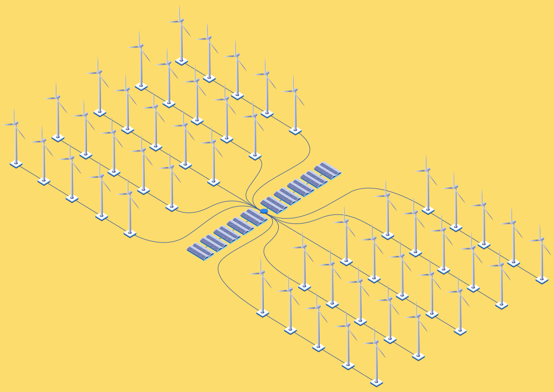
Stand-alone systems, which can be located closer to the coast to reduce connection costs, present a floating solar field with a reticular mooring system that ensures operational stability. These structures, almost invisibles from the coast even at close distances, represent a significant development opportunity for Italy.

While they do not benefit from the cost amortization of an adjacent wind farm's construction and maintenance, stand-alone systems offer a replicable alternative that can be implemented in nearly any marine area of Italy, including those with challenging seabed depths.

Offshore wind power and floating solar: a winning pair

This hypothetical case study illustrates **the benefits of integrating a floating solar system with an existing or planned offshore wind farm**, in terms of curtailment and energy yield per square meter.

Geographical location	Central Italy
Wind farm total capacity	500 MW
Wind turbine capacity	10 MW
Solar farm total capacity	100 MW
Solar module capacity	10 MW
Average wind speed	6.3 m/s
Global horizontal radiation	1,615.4 kWh/m²
Type of export cables	Al 3x2,000 mm²
Ampacity of export cables	2,100 A
Wind power production	2,905 h
Solar power production	1,484 h
Total area of the systems	138 km²



A hypothetical offshore wind farm in Central Italy, representative of average wind conditions, has an energy density of 3.6 MW/km². The integration of offshore FPV, without altering the electrical infrastructures, increases the density to 4.3 MW/km². **Therefore, for the same occupied area, the installed power is increased by approximately 20%**.

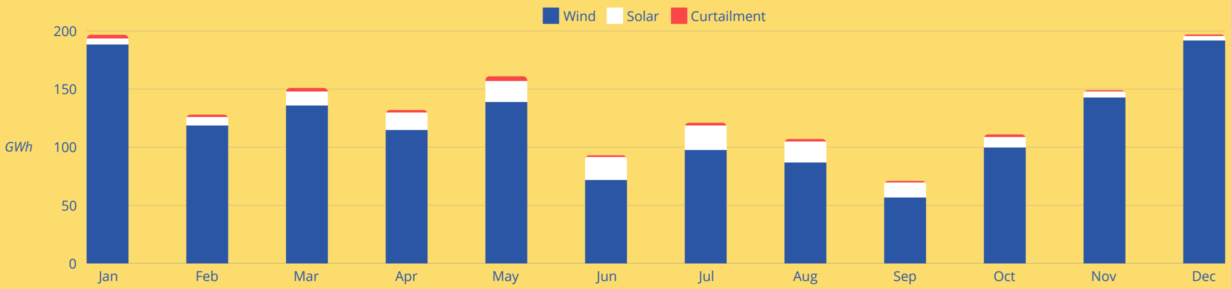


Chart 2 - Monthly production in a typical year for an integrated system, with curtailment indication (WindPro; PVSyst)

In terms of energy yield, a purely wind-based system would generate 10,500 MWh/km², whereas an integrated layout would produce 11,550 MWh/km². Without occupying additional maritime space, **this results in an approximate 10% increase in total energy production**.

The above calculation excludes **curtailment** (i.e., power cuts), which in this case is limited to just 1.4%, demonstrating the feasibility of **integrating solar energy without altering the electrical connection system** designed for the wind farm. This is due to the modest capacity factor of solar energy and the complementary nature of the two systems: **wind power generates more in winter, while solar power in summer**.

Specificities and legal gaps of offshore floating solar

Despite its promising potential and the pioneering role that Italy played over a decade ago, the national regulatory framework — at least until the very recent adoption of the T.U. FER (Unified Renewable Energy Law) — has long been characterized by significant gaps and inconsistencies that have severely hindered the development of these projects.

Over the past decade, there has been a clear imbalance between the rapid pace of technological development and the slow adaptation of the regulatory framework, similar to the challenges faced by offshore wind.

The current regulatory framework

Over the past decade, there has been a clear impulse from the European legislator towards the development of innovative technologies, such as offshore wind and FPV systems. A key example is the provisions of the RED II Directive (EU Directive 2018/2001), which recognized floating solar as a promising technology to accelerate Europe's energy transition.

As for Italy, in the update of the PNIEC (National Integrated Energy and Climate Plan), the inclusion of FPV technology, along with other unconventional technologies and surfaces, has been noted as part of the technologies to be promoted in order to achieve the set targets.

The new PNIEC text indeed stipulates that "*among the innovative technologies, the development of floating solar systems, both on inland waters and offshore, will be supported*", and that "*a rapid and sustainable expansion of solar capacity also requires actions for the development of floating solar*".

This represents, therefore, a manifestation of renewed legislative interest in this promising technology. Prior to the update of the PNIEC and the entry into force of Legislative Decree 190/2024 ("T.U. FER"), Italy's focus on floating solar projects had been primarily directed towards the regulation of so-called onshore FPV, while offshore development was largely neglected.

Compared to onshore FPV, the now repealed Article 9-ter of Decree-Law 34/2022 (by the T.U. FER) included "*simplifications for the installation of floating solar systems*", recognizing the possibility of authorizing onshore FPV projects in PAS (Simplified Authorization Procedure) for capacities up to 10 MW.

This regulation marked a first recognition of the strategic importance of onshore FPV, not only in terms of managing land consumption but also in addressing the growing water crisis that increasingly affects Southern Italy.

Regarding the legal framework, the development of offshore renewable technologies in Italy has certainly been delayed due to incomplete regulations — particularly concerning projects beyond the 12-mile limit — as a result of the lack of national agreements for defining the Exclusive Economic Zone (EEZ), as well as the delayed implementation of Maritime Spatial Planning.

In relation to the definition of Italy's EEZ, the United Nations Convention on the Law of the

Sea (UNCLOS), signed in Montego Bay on December 10, 1982, and ratified by Italy through Law No. 689 of December 2, 1994, was the first to define the Exclusive Economic Zone and the applicable legal regime within that area. In detail, the EEZ cannot extend beyond 200 miles from the baseline from which the breadth of the territorial sea is measured (188 miles from the territorial sea). Unlike the continental shelf, for an EEZ to be effective, it must be formally declared. Additionally, in cases where states have adjacent or opposite coastlines separated by a distance of less than 400 miles, the declaration must occur through international agreements between the bordering states.

Article 56 of the Montego Bay Convention specifies that in the EEZ the coastal State enjoys sovereign rights for the purpose of exploring, exploiting, conserving, and managing natural resources, as well as, among other things, for the economic exploitation of the area. This includes activities related to the production of renewable energy, such as offshore wind and FPV projects.

Italy established its Exclusive Economic Zone (EEZ) under Article 55 of the Convention only in 2021, with Law No. 91/21. However, this law only *authorized the establishment* of the EEZ without actually defining its boundaries, due to the proximity of Italy's coasts to those of other neighboring States, such as Croatia, Malta, and France. As a result, it is not possible to declare an EEZ extending 200 miles from the baseline without overlapping with the EEZs of the neighbouring countries.

Therefore, in order to fully and efficiently develop offshore technologies, it will be necessary to accelerate the process of negotiating the boundaries of Italy's EEZ. This will also enable a clearer definition of the applicable authorization regime for such projects, when developed in international waters.

In addition to defining the Exclusive Economic Zone, Spatial Planning Plans are increasingly playing a central role.

Following a lengthy process, Ministerial Decree No. 237 of September 25, 2024, was adopted, which approves the Maritime Spatial Planning. Among the objectives, it reiterates the goal of promoting the energy transition towards renewable and low-emission sources, through the production of offshore renewable energy, as well as supporting the experimentation and development of technologies and systems for generating energy from renewable marine sources, both in coastal sub-areas and in offshore areas, in accordance with current environmental and landscape protection policies and requirements.

Among the relevant measures identified in the Plans, it is worth noting the recommendation to develop National Guidelines for the identification of suitable sites for offshore renewable energy (wind, solar, waves, and currents) and for the assessment of the environmental and landscape-cultural impacts, both individual and cumulative. This should consider potential impact factors during the phases of construction, operation, and decommissioning, as well as the infrastructural elements for the transmission of the produced energy to the mainland.

These Guidelines will enable: i) refining spatial planning, ii) guiding the design of installations, and iii) facilitating the permitting stages.

Moreover, it will be necessary to develop a Decision Support Tool (DST), dynamically linked to the National Marine Portal and also fed by data derived from pre-construction and post-construction monitoring and investigation activities for offshore renewable energy production systems.

The approach expressed by the Legislator in the approval of the Maritime Spatial Planning is consistent with the renewed awareness regarding the development of offshore FPV technology.

As noted in the update of the PNIEC, *"to achieve these challenging goals, it will be important to use the various available renewable technologies, including offshore (also floating) ones, in order to exploit additional windy and sunny areas while minimizing land consumption and landscape impact."*

In conclusion, although within a fragmented and not yet fully defined regulatory framework, offshore FPV systems now play a central role in achieving the PNIEC objectives. In this regard, Italy must reach a renewable energy capacity of 131 gigawatts by 2030.

This central role is now even more evident from the analysis of Article 23 of Legislative Decree No. 199/2021, which deals with simplifications and suitable areas for the development of offshore wind and solar systems, as well as from the innovations introduced by the recently adopted T.U. FER, which came into force on December 30, 2024. This act governs the administrative regimes for the production of energy from renewable sources, in implementation of Law No. 118 of August 5, 2022.

In particular, when defining the new permitting schemes for renewable energy projects, the T.U. FER finally establishes a clear regulatory framework regarding the authorization procedures for floating solar systems.

Among the main innovations introduced, attention should be drawn to the provision in Annex B, which implements Article 8 of the T.U. FER. This includes, as part of the interventions eligible under the Simplified Authorization Procedure (PAS), floating solar systems with a capacity of less than 10 MW, located on bodies of water in reservoirs or water basins, both public and state-owned, including those situated in abandoned or still operational quarries. This provision largely mirrors the content of the repealed Article 9-ter of Decree-Law No. 34/2022.

Regarding the installations to be authorized under the Single Authorization procedure, attention should be drawn to the provisions of Annex C, which implements Article 9 of the T.U. FER. According to this provision, the single authorization procedure applies to offshore (wind and solar) and floating solar systems located on reservoirs created by dams not included in Article 1 of Decree-Law No. 507 of August 8, 1994 (i.e., so-called "retaining dams" or "weirs" that exceed 15 meters in height or generate a reservoir volume larger than one million cubic meters).

However, there remains a significant regulatory lacuna regarding the actual regulation of authorization regimes.

In fact, the absence of the implementation of the final paragraph of the aforementioned Article 23 of Legislative Decree No. 199/2021 is notable, which pertains to the so-called *Vademecum*.

The adoption of the *Vademecum* could indeed help define with greater certainty the regulatory framework for offshore FPV, resolving uncertainties related to the relationship between the authorization procedures and the request and granting of the state concession. This would also address, beyond 12 miles, some of the issues arising from Article 10 of the T.U. FER concerning the regime for granting public land concessions, in cases where the concession of public surfaces and, if necessary, public resources, is required.

This recent regulation imposes the obligation to first obtain the concession and then—within the following thirty days—strictly initiate the authorization process. As a result, there is insufficient time for completing the necessary activities of analysis, verification, and design, which are typically very lengthy and complex for this type of technology. As indicated, these potential issues could be mitigated by the Vademecum, which is expected to be adopted in accordance with paragraph 6 of the aforementioned Article 23 of Legislative Decree No. 199/2021.

The obstacles of the current State concession fee

An innovative and distinctive aspect in the field of floating systems certainly concerns the acquisition of areas intended for the construction of such facilities. This is especially true in the case of offshore systems, as these areas are public property and, as such, can only be granted to private parties by the State through the payment of an annual concession fee.

As is well known, under the current regulations, the amount of the concession fee is primarily governed by the Navigation Code and subsequent adjustment (Royal Decree No. 327/1942 and its amendments) and interpretation (MIT Circulars). In Law No. 296/2006 (the 2007 Financial Law), Articles 1, paragraphs 251-257, outline the criteria for calculating the fees, specifying the distinction between tourism-recreational uses and other uses. Following the reform of Title V of the Constitution, Regions have competence in managing the maritime domain, leading to the issuance of regional laws that complement national criteria. Most recently, with the Ministry of Infrastructure and Transport (MIT) Decree of December 17, 2023 (published in the Official Journal on January 25, 2024, No. 20), the adjustment of the fees for maritime public concessions for the year 2024 was established.

According to Circular No. 22/2009, the following distinctions are made:

- **Unbuilt area**, which refers to *"an area where there are no buildings that develop usable or accessible volume"*.
- **Area occupied with easily removable installations**, which refers to *"an area whose structures can be built with isolated or distributed foundations, and can be relocated elsewhere without the removal causing their partial or total destruction"*.
- **Area occupied with difficult-to-remove installations**, which refers to *"an area whose structures are built with deep foundations, either isolated or distributed, connected to the ground, and whose removal would result in the destruction or alteration of the structure"*.

Circular No. 40/2012 introduced a specific paragraph to regulate offshore wind farms, recognizing the possibility of identifying specific calculation methods due to their technological particularities. This effectively moves beyond the usual approach regarding the occupied area as a whole. As stated in the Circular, *"for this type of installation, the surface area can be defined by the area of the circle generated by the movement of the blade projected onto the water surface, with a radius equal to the length of the blade plus an additional 0.50 meters"*, as an alternative to the standard method, which consists of *"the entire water surface encompassing the whole wind farm and the maritime state area affected by the infrastructure for connection to the electrical grid"*.

This approach, with regard to offshore wind energy, results in the definition of a fee that is generally about twice as high as what the market expresses for an equivalent land-based surface right for onshore systems. Specifically, it amounts to around €6,000/MW/year, and this does not take into account the cable ducts and connection infrastructure, but only the turbines.

The absence of a specific regulation for FPV systems, and the need to consider the entire surface area occupied by the modules and connection infrastructure, would inevitably lead to considering the investment as unsustainable.

In fact, if the fee applicable to offshore wind farms were analogously applied (which in 2023 amounts to €2.34058/m²/year), the annual cost per hectare would be €23,405.80. On the other hand, if the areas occupied were considered as "easily removable installations" and the updated 2023 fee of €4.38855/m²/year were applied, the annual cost per hectare would be as high as €43,885.50.

To better understand the scenario outlined here, assuming an average land occupation of about 1 hectares per 1 MWp of FPV, the concession fee would approach €45,000/MW/year. Aside from being unsustainable in itself, the enormity of this value would be difficult to justify from any perspective, even when compared with equivalent technologies. In fact, it would be approximately 7 times higher than what is applied to offshore wind installations. If we consider agricultural land for the installation of onshore solar systems, the annual rental fee ranges from €1,500 to €4,500 per hectare (CREA, 2025), which is at least 1/10 of the cost that offshore solar systems incur.

It is therefore essential that the legislator introduces a new category specifically for offshore floating solar, which ensures a fair and sustainable compensation for the public property subject to concession. Among the possible calculation methodologies to be pursued are:

- *Benchmarking in relation to land costs for terrestrial PV*
- *Benchmarking in relation to offshore wind concession fees*
- *Benchmarking in relation to the Levelized Cost of Energy for this type of systems*

While the first two methodologies could risk aligning the offshore floating solar fees with technologies that differ in both capacity factors and construction/operating costs, potentially creating distorting effects, the third methodology, despite involving more complex calculations, would allow for a much fairer and more appropriate quantification of the concession fee.

In addition to the purely economic aspect, offshore FPV introduces another issue of no easy resolution, namely the availability of areas for these systems.

In fact, while the concession of maritime areas within territorial waters can certainly refer to the provisions set out in Article 36 et seq. of the Navigation Code, as well as the recently adopted provisions of the T.U. FER, specifically Article 10, some concerns arise regarding the legal regime applicable to offshore FPV projects developed beyond 12 miles from the coast, that is, outside territorial waters.

In this context, the definition of Exclusive Economic Zones and Marine Spatial Planning, as previously mentioned, becomes increasingly important and central. Additionally, the adoption of specific, ad hoc legislation is necessary to define the methods for acquiring access to these areas, particularly when they are located beyond territorial waters.

Inadequacy of the support schemes: the issues of FER 2

The FER 2 Decree marks a significant advancement in the regulatory framework aimed at encouraging the use of renewable energy in Italy, with a focus on emerging technologies and offshore environments. Enacted on August 13, 2024, it promotes the development of innovative renewable energy systems or those with high operating costs, including both offshore and inland FPV systems, through a CFD mechanism. Operators submit the minimum price (strike price) at which they are willing to sell energy. If they qualify in the ranking, the difference between the market price and the strike price is calculated. When the market price is lower than the strike price, the operator receives a compensation payment; conversely, the operator must repay the difference.

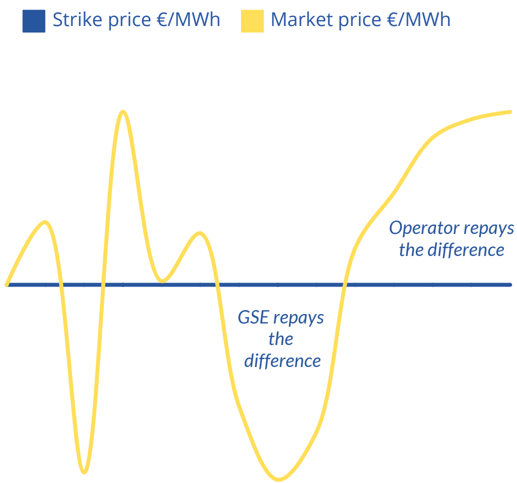


Chart 3 - Contract For Difference mechanism

The measure, effective until December 31, 2028, aims to install a total capacity of 4.6 GW by 2028. However, the following issues within the decree currently pose challenges to the effective development of offshore floating solar systems.

Undersized available quota

The available quotas are limited to just 50 MWp for onshore FPV and 200 MWp for offshore FPV, which are also competing with projects for "*tidal, wave, and other forms of marine energy*". This creates significant uncertainty for developers in securing the benefit.

In any case, the 200 MW cap for offshore floating solar is modest in relation to Italy's potential, which boasts extensive coastlines and favorable marine areas. AERO estimates this potential could reach 1 GW by 2030.

Challenging timelines for COD

Furthermore, the Ministerial Decree FER 2 requires that offshore floating solar systems ranking favorably in the relevant tenders must be commissioned within 43 months of receiving the incentives.

This timeline for the realization of highly innovative projects could be challenging, especially considering the current state of the offshore renewable energy value chain. It risks discouraging both Italian and foreign investors from financing ambitious projects, potentially leading to a preference for less innovative but faster-to-deploy solutions.

A technology that is still in its developmental stages and must be installed in deep waters requires longer timelines for the successful realization of pre-commercial or commercial-scale projects.

Insufficient incentives

Finally, the financial support outlined in the Ministerial Decree FER 2 cannot satisfy operators. In fact, the reference tariff set for offshore FPV systems is 105 €/MWh, which is even lower than the expected LCOE for this technology until 2030, which is unlikely to fall below 150 €/MWh (Iglesias & Martinez, 2024). This LCOE could be more achievable for large-scale projects (on the order of hundreds of MW), but this would contradict the limited 200 MW quota discussed earlier. The complexities associated with the marine environment, combined with the partial maturity of offshore floating solar, result in a cost structure that is undoubtedly more challenging than land-based solar systems, which the legislator does not seem to have fully considered. As a result, no offshore FPV projects in Italy can currently reach the so-called Final Investment Decision with the incentive levels proposed.

The Ministerial Decree FER 2 is a promising start for the development of offshore floating solar in Italy, but its real impact will depend on the ability of authorities to address the inherent challenges of this technology.

Drawing on international experience, a proper structuring and planning of auctions is essential for developing a sector in the domestic market and avoiding delays in decarbonization.

For instance, the UK's AR5 auction in September 2023 and Denmark's auction in April 2024 both failed.

It is therefore essential to establish a constructive dialogue between private operators, industry associations, and authorities to find the right balance in the incentive levels, ensuring both the feasibility of undertaking these complex infrastructure projects and a fair energy procurement cost for the State.

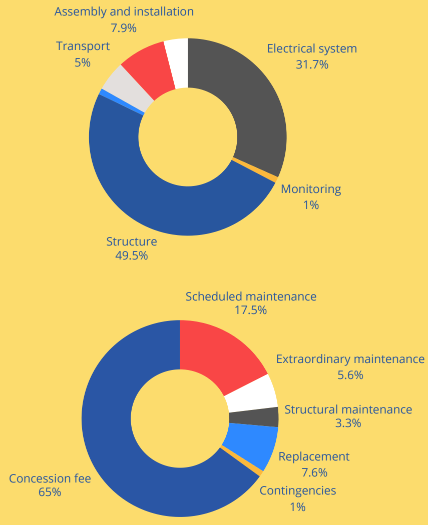
It is hoped that a future revision of the decree will expand the available quotas, adjust the incentive contributions to more appropriate levels, and consider the role of public-private dialogue in accelerating the development of this technology.

Figure 6 - Prototype of Solar Duck

Limits and potential of offshore floating solar

This use case illustrates the financial performance of a hypothetical stand-alone offshore floating solar system located in Central Italy, set to be implemented in 2030. It highlights its limitations and offers recommendations to authorities for making the investment more sustainable.

Geographical location	Central Italy
Type of system	Stand-alone
Solar panel orientation	East-west
System total capacity	200 MW
Type of export cables	Al 4x(3x630) mm²
CAPEX	1,500,000 €/MW
OPEX	17,500 €/MW/year
DECEX	150,000 €/MW
Horizontal global irradiation	1,615 kWh/m²
Electricity produced in the 1st year	296,800 MWh
Equivalent hours of operation	1,485 h
Total area of the system	1.6 km²
Average annual inflation	2%
Construction phase duration	1 year
Operational phase duration	28 years
Concession fee	4.39 €/m²/year
FER2 auction base price	105.00 €/MWh
FER2 auction awarded price	102.90 €/MWh



Charts 4 and 5 - Distribution of CAPEX and OPEX

The proposed hypothetical project, according to its key characteristics, presents unsatisfactory returns:

- **Unlevered IRR < 3%**
- **Payback period > 20 years**

In addition to the still high costs for this technology, the reasons are mainly two:
1. **The concession fee is excessively high**, representing about 65% of the OPEX.
2. **The proposed tariff is too low**, even lower than the project's LCOE.

To make offshore FPV projects sustainable in Italy, it would be enough to adjust the two variables discussed above. Below is a **sensitivity analysis of the industrial IRR**, demonstrating how the investment return can become satisfactory. The figures presented here are purely indicative and for illustrative purposes.

		Concession fee		
		3.50 €/m²	2.50 €/m²	1.00 €/m²
Tariff	130 €/MWh	4%	5%	5%
Tariff	160 €/MWh	6%	6%	7%
Tariff	190 €/MWh	7%	8%	8%

Next steps...

Floating solar represents an innovative technology with significant global development potential, particularly in offshore applications. The growing interest in this technology is driven by key benefits such as land conservation, reduced water evaporation, and improved PV panels efficiency, enhanced by the natural cooling effect provided by the water surface. However, both globally and in Italy, several challenges still remain to be overcome.

Firstly, there is still a notable technological immaturity, with a lack of commercial plants in the operational phase.

From an economic perspective, floating solar on inland waters involve significantly higher capital costs (CAPEX) compared to traditional land-based systems. Offshore installations face even greater costs due to the harsh environmental conditions typical of marine settings, such as strong winds, high salinity that accelerates corrosion, and wave motion that compromises the stability of the structures. These challenges require floating platforms and panels to be meticulously designed to withstand extreme weather events, including typhoons, high waves, and intense wind gusts. Without proper technical solutions, such forces could lead to irreparable damage, including the risk of capsizing. Additionally, maintenance costs tend to be higher than those for traditional solar systems.

Given these technological and environmental complexities, there is an urgent need for a targeted incentive framework that is tailored to the unique characteristics of a technology still in its maturation phase. Applying support measures designed for traditional renewable technologies, which are more established and lower-cost, is inadequate.

It is essential to provide dedicated incentives that make the development of floating solar economically viable, while encouraging investment from industry players.

Only through a well-structured incentive system and a solid regulatory framework will it be possible to fully unlock the potential of a technology that, in addition to revolutionizing the renewable energy sector, will make a significant contribution to achieving decarbonization goals.

The "Offshore Floating Solar" Working Group of AERO proposes the following actions.

- **Introducing a tailored concession fee for floating solar systems located in territorial waters**, ensuring a fair cost that reflects the specificities of this technology.
- **Adjusting the floating solar tariff set in the FER2 decree** to accurately reflect the real investment and maintenance costs.
- **Properly sizing the allocation of support mechanisms** to account for all initiatives currently in development, both for the short and medium term.
- Developing strategies to ensure the **growth of a national supply chain**, with companies specializing in project development, component manufacturing, and the patenting of new designs and technologies.
- Establishing a **clear and comprehensive regulatory and legislative framework** to support not only floating solar but all offshore installations.

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Piazza Madama, 9 - 00186 Roma (RM)
C.F. 96564570586
E-mail: segreteria@assoaero.org