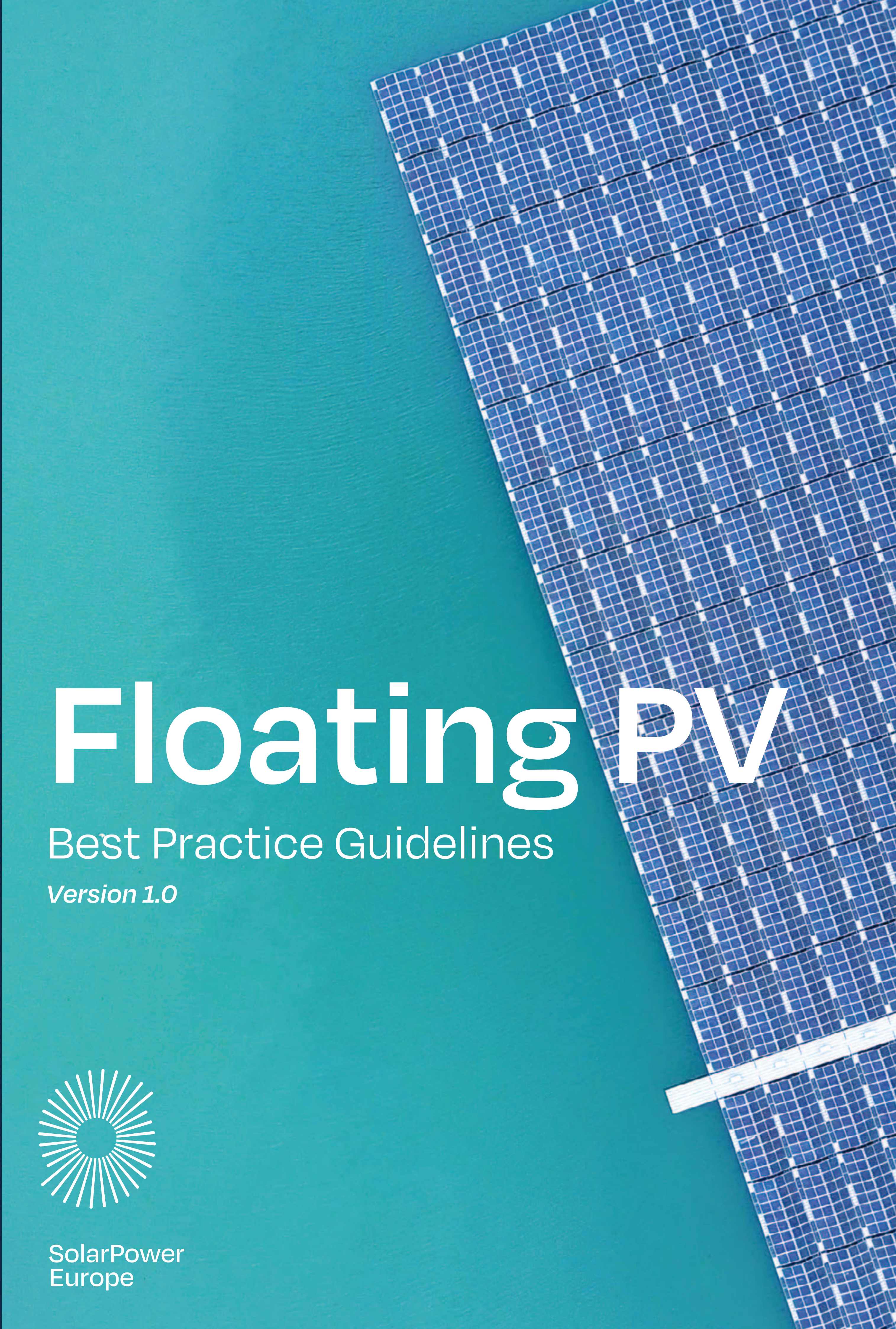

Floating PV

Best Practice Guidelines

Version 1.0

SolarPower Europe

www.solarpowereurope.org

Foreword

Floating PV is beginning to emerge worldwide. In Asia and Europe, the first projects have already been online for several years. Meanwhile, Europe, and the world, face combined and interrelated climate, energy and water scarcity crises, all in the context of increasing competition for land. Solar is stepping up as a rapidly growing energy solution to decarbonise economies, with Europe targetting 750 GWdc (600 GWac) total solar by 2030, from just over 200 GW^{dc} today.

It follows that developers are increasingly turning to the land-use efficiency and water-positive potential of onshore and marine floating solar technology too. As floating PV now sits on the horizon of mainstream expansion, the sector has decided to codify the best practice and expertise gained from these first projects.

It is clear that the energy transition requires significant investment, which depends on confidence in the technology at hand. Investors must be assured by the viability of projects, both economically and ecologically according to the green taxonomy, Sustainable Finance Reporting Directive (SFRD), and Corporate Sustainable Reporting Directive (CSRD) obligations.

Therefore, it is important to develop expertise on project design, best practices, and operation and maintenance guidelines in floating PV project development and implementation. All stakeholders, down to local level, should have access to knowledge, learnings, and case studies, including public bodies but also NGO, associations, and the finance community. This publication serves as a first handbook to drive high-quality floating PV projects, by creating and strengthening floating PV knowledge sharing.

Developing solar projects on water, both onshore and marine, require technical adjustments in design and operation in comparison to land based projects. Within this report, over 30 experts from SolarPower Europe's Land Use and Permitting workstream have illustrated their knowledge of floating PV best practices through technical guidance and real-world examples.

Building on this collaborative approach, we hope this report supports solar's journey to new shores and supports the sustainable development of floating PV in Europe and beyond.

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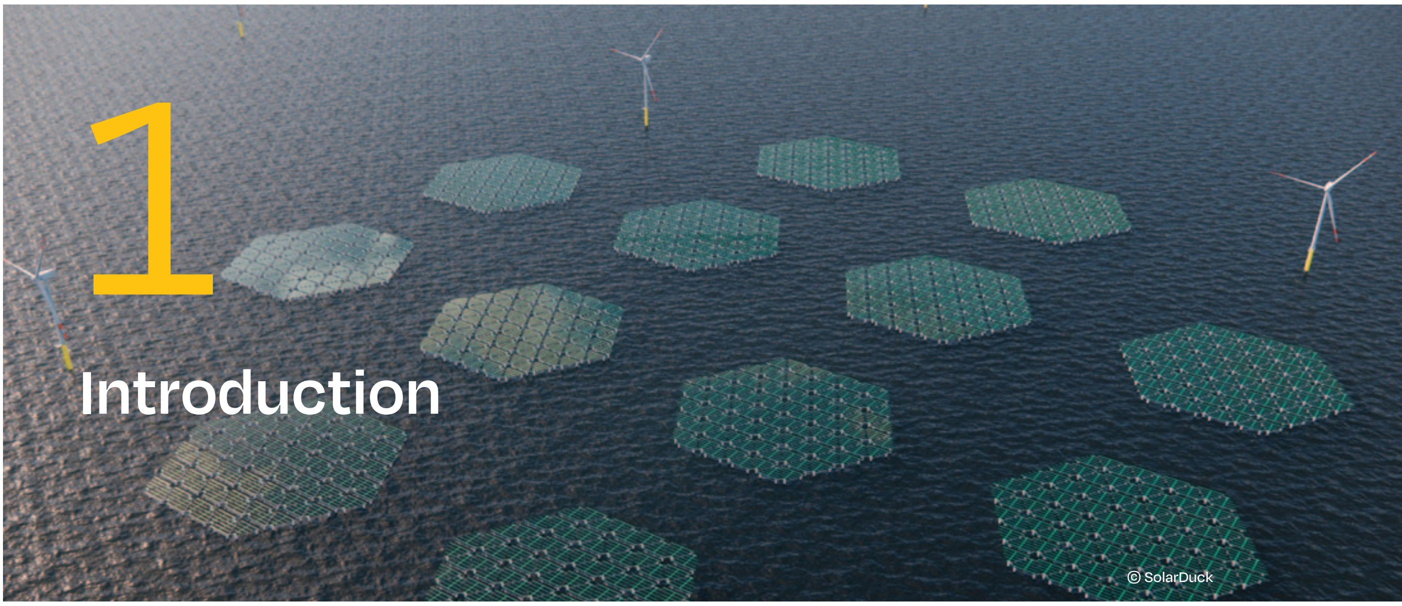
Abbreviations

AC	Alternating current
CO_2	Carbon dioxide
DC	Direct current
EU	European Union
GW	Gigawatt
HDPE	High density polyethylene
H&S	Health and safety
MW	Megawatt
MWh	Megawatt hours
O&M	Operation and maintenance
TW	Terawatt
TWh	Terawatt hours
UK	United Kingdom



1 Introduction

Climate change is the greatest challenge we face today, driven by human activities. Rising global temperatures as a result of the climate crisis, is causing substantial damage and loss to nature, society, and our economy. The changing climate puts all areas of the world at risk, resulting in rising sea levels, melting ice caps, and burning forests. According to the Intergovernmental Panel on Climate Change (IPCC) report[2] published in March 2023, human-induced activities are warming the climate at an alarming rate: global surface temperature has risen by 1.1°C compared to the pre-industrial period. Under all emission scenarios, the IPCC estimates that global warming will reach 1.5°C by the early 2030s.

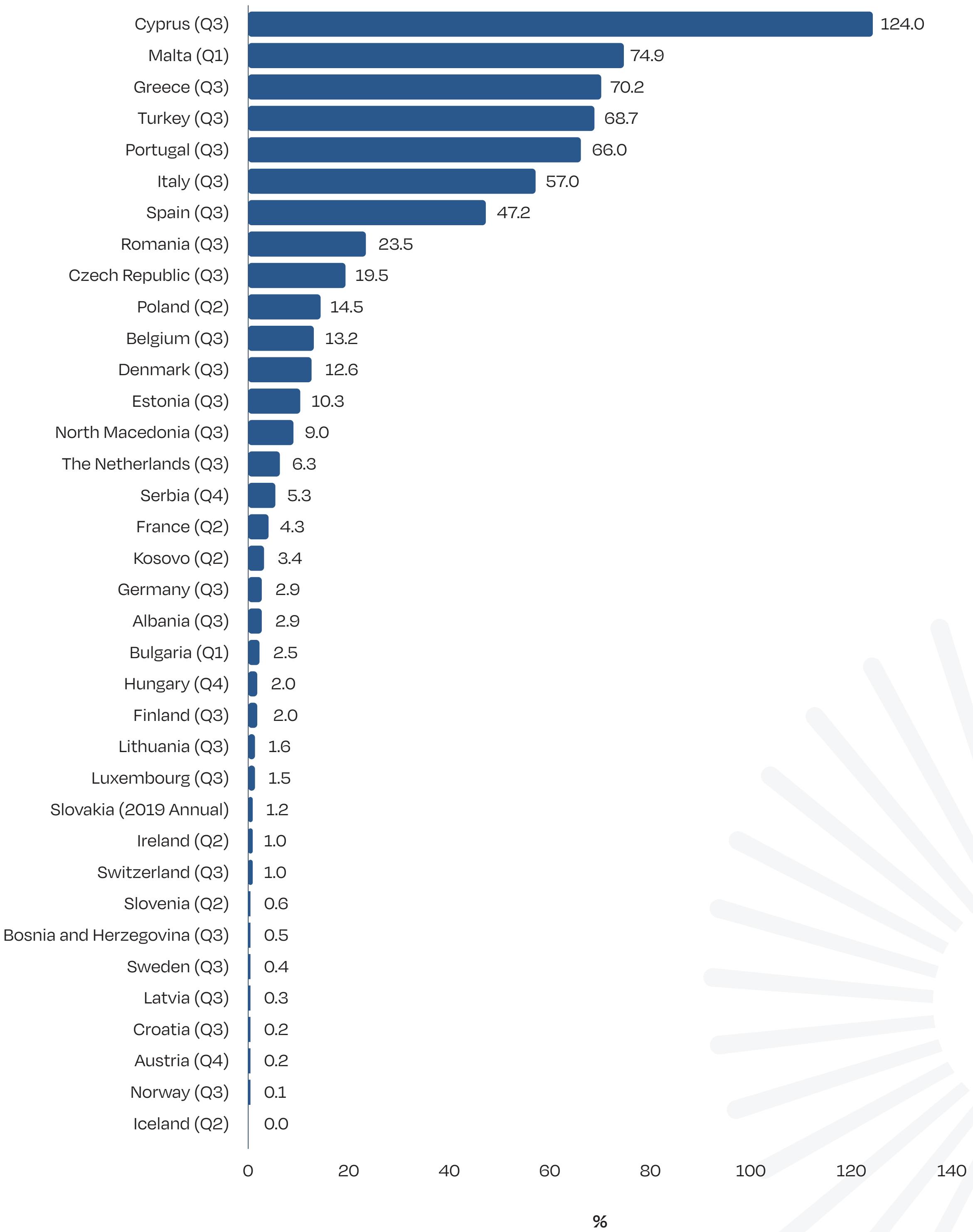
Water and climate change are intricately linked. According to United Nation Water: "Climate change affects the world's water in complex ways. From unpredictable rainfall patterns to shrinking ice sheets, rising sea levels, floods and droughts – most impacts of climate change come down to water."[3] Global warming increases risks related to water scarcity and water-related hazards, such as flooding and droughts due to disruptions in precipitation patterns and water cycles. An increase in scarce water supplies will impact our society, economy, and environment. Rising temperatures will continue to increase the frequency of heavy rainfalls, and at the same time, escalate extreme drought across regions. Based on the World Meteorological Organization's data, only 0.5% of Earth's water is usable and available freshwater. However, rising temperatures will negatively affect the freshwater supplies.[4] Moreover, raising concerns with water scarcity and climate change will inevitably affect water-dependent sectors such as agriculture. According to the Food and Agriculture Organization report, around 70% of the world's freshwater is used for agriculture, and will therefore impact food supply in future.[5]

Water scarcity and water-related hazards also impact the European continent, see Figure 1. As indicated by the European Commission, 38% of the EU population and 29% of EU territory was affected by water scarcity in 2019.[6] In general, water scarcity is more likely to occur in southern Europe, extending to western Europe where high water abstraction can impact water availability. In southern Europe, the largest use of freshwater comes from the agriculture sector. Further temperature rises will continue to reduce accessibility of freshwater resources in Europe, and increase the natural fluctuation in water availability throughout seasons, impacting water-dependent sectors such as the food sector. As a result of this, the frequency, intensity, and impacts of drought will accelerate over the coming years.

As a response to this crisis, and to minimise the risk induced by global temperature rise, in 2019 the European Commission adopted its EU Green Deal package in line with the 1.5°C target of the Paris Agreement. This package unveiled a roadmap for Europe to become a climate-neutral continent by 2050. One of the objectives of the EU Green Deal is the 2030 target set out in the 'Fit for 55' package. The revised package proposes to target the EU's greenhouse gas (GHG) emissions reduction, and renewable energy deployment. The aim is to reduce GHG emissions by 55% and increase the share of renewables in the final

2 Source.
3 Source.
4 Source.
5 Source.
6 Source.

FIGURE 1 EUROPEAN COUNTRIES WITH WORST SEASONAL WATER SCARCITY CONDITIONS



energy mix to 45% by 2030.[7] In March 2023, the EU provisionally adopted stricter legislation to accelerate the deployment of renewables, raising the EU's binding renewable energy target to 42.5% by 2030, with the ambition of reaching 45%.[8]

In parallel with the climate crisis and following Russia's invasion of Ukraine, the world has faced an unprecedented energy crisis causing spikes in energy prices, and disrupting energy trade flows.[9] In 2022, energy prices in Europe and beyond have skyrocketed, hitting a record high since 2008. As estimated by the International Energy Agency, 90% of the increase in energy prices was driven by high fossil fuel prices in 2022.[10] This has impacted all energy- consuming sectors.

As a result of Russia's illegal invasion of Ukraine, the European Commission put forward the REPowerEU plan. Under the REPowerEU strategy, the Commission presented a plan to save and diversify the energy supply, produce clean energy, and end Europe's dependence on Russian fossil fuels.

The REPowerEU package included a first-of-its-kind EU Solar Strategy, increasing solar ambition in Europe by 43%, and uncovering several steps to speed up solar deployment. The unprecedented EU Solar Strategy provides the right framework to accelerate solar PV energy deployment in Europe and sets out an EU solar target of 400 GW^{dc} by 2025, and 750 GW^{dc} by 2030. Based on future energy deployment scenarios, Europe can surpass its set ambition, and reach the TW-level milestone by the end of the decade, five times the capacity installed today. For this reason, the solar sector is central to the European energy transition. Europe's ambitious objectives will require the mobilisation of all existing surfaces suitable for PV panels, and the development of new uses of spaces suitable for solar installations.

Aside from global challenges of today, land scarcity is becoming an important topic to tackle. Land scarcity is rapidly increasing driven by complex multi-sector dynamics. The impacts of land scarcity on society, economy and environment are multi-dimensional and deep-rooted. With the world's population rising, demand for food, water and energy increases; this inevitably leads to increased land usage from different sectors. Aside from the land conversion driven by various sectors, soil erosion, desertification and salinisation are other drivers that can reduce the quality of soil, and impact the availability of the land.

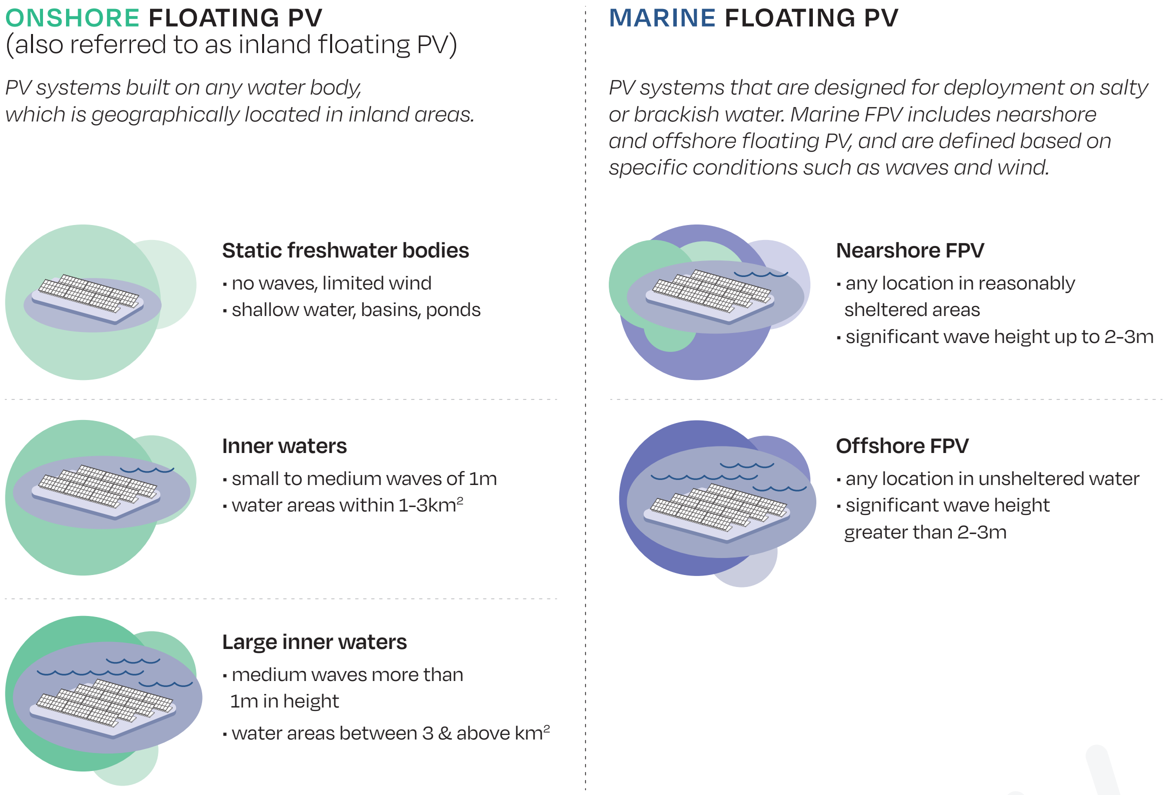
Solar can be part of the solution to tackle climate change, provide clean energy, and reduce land scarcity issues. Firstly, solar takes up a relatively small area of land. The data shows that powering current EU energy demand with solar, would require mobilising 0.26% of EU land.[11] Currently, agriculture takes up around 38% of EU land. However, some countries and regions might face challenges when mobilising land or rooftops for solar deployment. Countries with small land area, high latitudes, or countries with highly populated and dense areas might be restricted to the availability of land for solar deployment. Dual land-use can play a crucial role in providing solutions not only to generate clean energy, but to also minimise the pressure put on land availability. One such solution is floating PV (FPV). Floating PV can be defined as solar panels installed on a floating system or structure, on a water body, which can offer solutions for energy generation and water conservation.

Floating PV is a rather novel technology experiencing rapid growth over the last couple of years. Floating PV's forecasted annual growth rate is 22%; using 10% of the world's reservoirs could provide 23.317 GW capacity.[12] The global floating PV market is anticipated to surpass the 6 GW threshold by 2031.[13] This showcases the likely uptake of this technology worldwide. Moreover, Floating PV holds a great potential in addressing the global climate and energy crisis, and supporting the European Union in reaching climate neutrality targets.

Floating PV can also minimise any land scarcity risks. Utilising applicable water surfaces such as reservoirs, ponds, and lakes will in turn reduce land competition across different sectors, and help conserve valuable land resources while contributing to overall socio-economic and environmental benefits. FPV can not only improve land efficiency, but also provide water conservation benefits, improve or preserve water quality, reduce environmental impact, and where appropriate, provide the right conditions for wildlife to thrive. In addition, Floating PV can boost the local economy, and improve the livelihoods of local citizens by providing energy security, job opportunities, and educational opportunities.

7 Source.
8 Source.
9 Source.
10 Source.
11 Source: SolarPower Europe.
12 Source.
13 Source.

FIGURE 2 PLACEHOLDER FOR GRAPHS COMPARING ONSHORE, OFFSHORE AND NEARSHORE FPV



Floating PV can be categorised as:

1. Onshore Floating PV (also referred to as inland floating PV): *PV systems built on any water body, which is geographically located in inland areas.*

It can be classified further as following:

- Static freshwater bodies:
  - no waves, limited wind
  - shallow water, basins, ponds
- Inner waters:
  - small to medium waves of 1 m
  - water areas within 1-3 km^2
- Large inner waters:
  - medium waves more than 1 m in height
  - water areas between 3 and above km^2

2. Marine Floating PV: *PV systems that are designed for deployment on salty or brackish water. Marine FPV includes nearshore and offshore floating PV, and are defined based on specific conditions such as waves and wind.*

- Nearshore FPV: any location in reasonably sheltered areas with significant wave height up to 2-3m.
- Offshore FPV: any location in unsheltered water with significant wave height greater than 2-3m.

There are different types of artificial water bodies that can be utilised to deploy onshore floating PV technology. These types include but are not limited to:

i. Industrial basins

ii. Drinking water reservoirs (raw water reservoirs and water intended reservoirs)

iii. Irrigation ponds

iv. Sand or gravel extraction ponds

v. Hydroelectric dam reservoirs and pumped storage reservoirs

vi. Flooded quarries and flooded open cast mines

vii. Fishponds

viii. Aquatic food production

ix. Water treatment plants

Other areas such as natural lakes and rivers can also be considered for floating PV deployment. However, these areas should undergo specific considerations such as environmental aspects, grid accessibility, and other socio-economic aspects to determine the compatibility of deploying floating PV on such water bodies. It's important to highlight that any type of a water body (artificial lakes or natural lakes) might need to undergo environmental impact assessment to determine their suitability for floating PV development. Therefore, different national and regional regulations will be applied and will need to be complied with prior to getting permits for building floating PV.

Water areas used for recreational purposes might also be considered as appropriate areas for deploying floating PV. However, certain factors such as water surface availability, grid connections, social acceptance, and other construction and interface aspects should be considered on a case-by-case basis.

Onshore floating PV systems consists of a number of elements:

- A floating structure

  This is the part of the system that ensures buoyancy, and supports all of the electrical components installed to generate and transport electricity. There are different layouts available in the market and different types of materials used, ranging from pure HDPE floating systems, to rafted HDPE+Steel systems, and ring-shaped membranes.

- An anchoring and mooring system (station-keeping)

  Generally it is composed of anchors and mooring lines, to keep the floating structure in the intended position throughout the lifetime of the project. Anchors can generally be placed onshore, near the shore, or on the bottom of the reservoir, but other solutions (e.g. piles) can be adopted depending on the site conditions. In most cases, a mooring line, composed of one or more elements, is connected to the anchor on one end, and to the floating structure on the other end.

- PV modules

  As in other PV applications, PV modules are the key component to generate electricity from the irradiance received. Generally, products used in Floating PV, are similar to those use in ground-mounted PV systems; it is normally advised to use glass-glass PV modules for better protection against moisture and water ingress.

- Electric components (cables, inverters among others)

  Transporting the energy produced by the PV modules to the grid, or to the loads, requires a set of electrical components (EBoS: Electrical Balance of System), such as DC cables, AC cables, inverters, transformers, as well as all auxiliary components necessary for a smooth operation of the system, such as monitoring, earthing, etc.

The design of floating PV systems can be altered to suit specific water body parameters and applications. It can be adapted through variations, beginning with floating system materials, module type, orientation of the modules, and surface coverage.

FPV Market Outlook

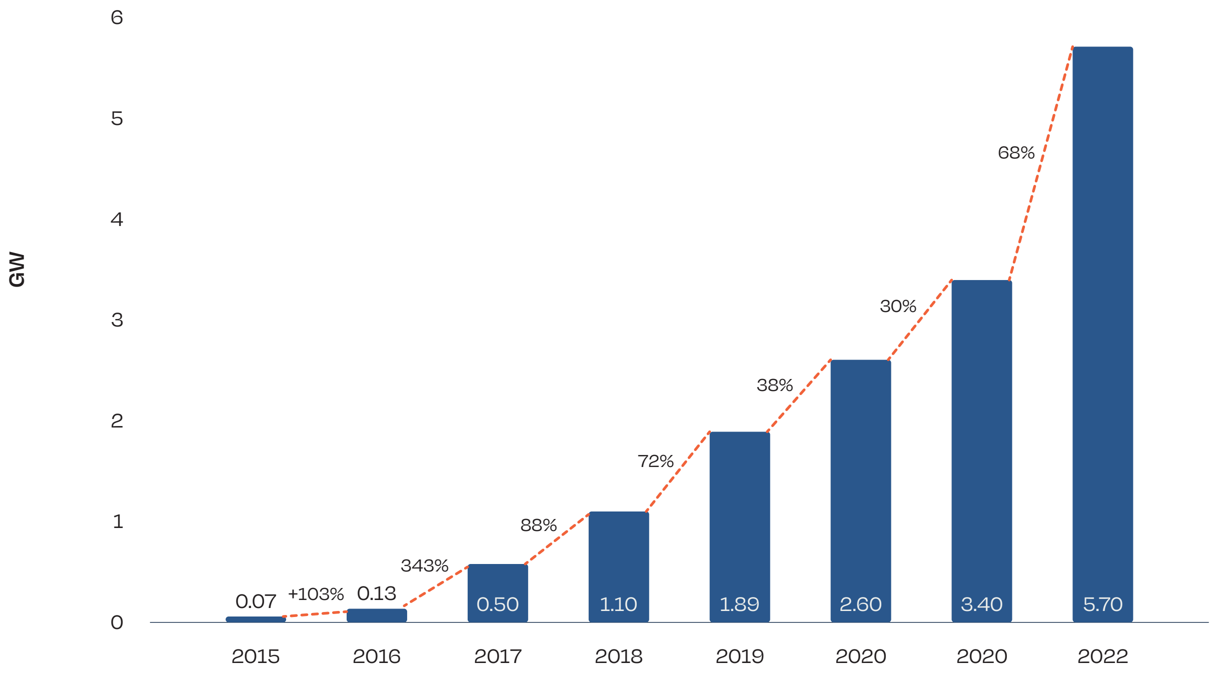
Global floating PV market

The first floating PV (FPV) system was built in 2007 in Japan, followed by other countries including France, the Republic of Korea, and the United States. All of these countries tested micro-FPV installations for research and demonstration ends. Finally, the first commercial FPV plant was a 175 kW system built in California in 2008.[14] In 2022, the world's largest floating solar array was grid-connected in China (Shandong), with an operating capacity of 320 MW.[15] The Dezhou Dingzhuang FPV farm is also connected to 8 MWh of battery storage, and a 100 MW wind farm.

In 2015, the FPV market (both on and offshore) was considered a niche segment, as installation levels remained below 100 MW worldwide (see Figure 2). However, the emergence of new markets in Southeast Asia, and the unlocking of flooded mining sites in China,

14 World Bank (2018): Where Sun Meets Water.
15 5 Largest Floating Solar Farms in the World in 2022 | YSG Solar | YSG Solar.

FIGURE 3 GLOBAL CUMULATIVE FPV CAPACITY BETWEEN 2015 AND 2022



Source: SolarPower Europe.

unleashed the exponential spirit of floating solar. From 2015 to 2017, the cumulative installed capacity of FPV grew by 743%, from 70 MW to almost 600 MW. As of September 2018, that figure had grown more than 100-fold to 1.1 GW, experiencing a nearly doubling of capacity relative to 2017 (+88%). Following this steep upward trajectory, the world's solar floating fleet expanded at a compound annual growth rate (CAGR) of 51% from 2019, until the end of 2022. This highlights the significant average year-on-year increase in installations. In 2022 alone, 2.3 GW was installed globally, reaching 5.7 GW of cumulative capacity (+68% relative to 2021).

The world's largest FPV market is in China, with approximately 70% of the total capacity (approaching 4 GW in 2022), and the rest is credited to Japan and Korea, closely followed by Europe. For the future, the global FPV fleet is expected to grow at a steady rate as land scarcity and increasing costs of land for ground-mounted projects continue to power demand.

To reliably determine the true prospects of floating solar, several studies have calculated its "technical capacity," which indicates the tremendous deployment potential of the technology on reservoirs and natural water bodies. The determined technical capacity ultimately depends on factors such as the geographical area, coverage ratio, cost constraints, or environmental and land use limitations.

The World Bank estimated in 2018 that the global technical potential for FPV is slightly over 4 TW, if 10% of the total surface of freshwater man-made reservoirs was utilised.[16] More recent research indicates that close to 4.5 TW could be globally installed in hydropower plants alone, assuming a 25% coverage ratio.[17] Other studies identify a global potential that ranges from 3 TW to 7 TW depending on the modelling assumptions.[18] However, experts from the IEA PVPS only foresee a cumulative capacity of over 60 GW by 2030,[19] which highlights the need to strengthen policy and market support for floating solar if its true potential is to be harnessed.

16 World Bank (2018): Where Sun Meets Water.
17 International Hydropower Association (2021): Hydropower Status Report.
18 Lee et al. (2020): Hybrid floating solar photovoltaics-hydropower systems: Benefits and global assessment of technical potential.
19 IEA PVPS (2023): Trends in photovoltaic applications.

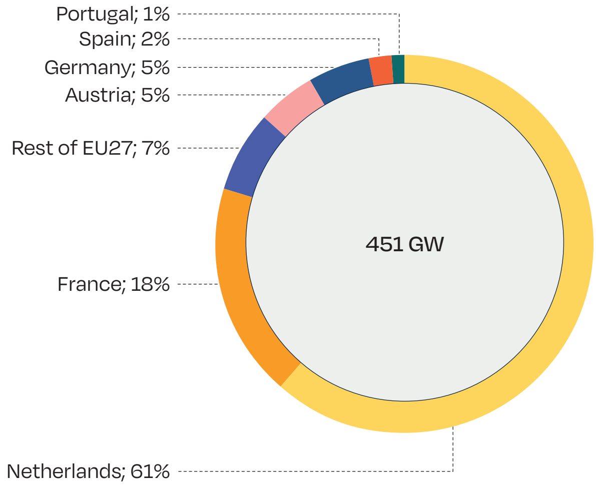
In offshore waters, floating solar is still in its infancy. Consistently, the technology keeps developing, with around 25 projects around the globe in the experimental phase, mostly located in Europe, and totalling an estimated capacity of 20 MW. Despite facing more challenges than its floating counterpart inland, offshore floating panels could provide a large component of the energy mix for countries with access to calm equatorial seas. For instance, research suggests that Indonesia's seascape offers a technical potential generation of about 35,000 TWh of solar energy per year, which is just about the current global electricity production.[20] Experts in the field reveal that industrial-scale offshore floating solar generation could become a reality before the end of this decade.

The FPV market in the EU27

FPV represents a nascent technology in the European Union, but it presents positive signs of rapid growth. FPV solar power systems on reservoirs and quarry lakes are gaining traction in Europe and offer vast potential. Currently, there are around 451 MW of grid-connected floating solar (see Figure 3), mostly located in the Netherlands (280 MW). The country's FPV capacity could grow even larger if its massive 2 GW pipeline materialises over the coming years. Additionally, the two largest FPV parks in the EU27 have been commissioned by BayWa r.e. in the Netherlands, with a total installed capacity of nearly 71 MW.[21] France ranks second with 80 MW of installed capacity, followed by Austria (25 MW), Germany (25 MW), Spain (10 MW) and Portugal (6.2 MW).

The rollout of FPV systems in the EU, despite a promising start, is still facing several challenges that should be addressed to release the full potential of the technology. Among those hurdles, a lack of strong policy support, long permitting processes, and social acceptance are the most prevalent. Developing and installing FPV plants often requires navigating complex non-standardised bureaucratic procedures, that can lead to delays and uncertainties in the approval process. Moreover, public perception of the environmental and visual impact of FPV systems can negatively affect social acceptance of floating solar, and hinder its expansion. Actively engaging with local communities and stakeholders to solidify support is crucial for the successful finalisation of FPV projects.

FIGURE 4 REGIONAL DISTRIBUTION OF FPV CAPACITY PER 27 MEMBER STATES IN 2022



Source: SolarPower Europe.

20 Silalahi and Blakers (2023): Global Atlas of Marine Floating Solar PV Potential.
21 Source.

Once the remaining barriers are removed, research sheds light on the enormous potential for floating solar in the EU. A recent study provides an estimation of the electricity output and installed capacity potential in existing hydropower reservoirs in the EU-27, depending on the assumed coverage ratio.[22] The most realistic scenario assumes a 10% coverage ratio of the total reservoir surface, which could produce a total of 157 GW of installed FPV capacity. This capacity would produce up to 6% of the yearly power consumption in the EU (137 TWh per year). Interestingly, the study presents a scenario where the FPV system would have the same installed capacity as the hydropower plant. This scenario would result in 42 TWh of electricity generation per year, and a total installed capacity of nearly 50 GW, covering only 2.3% of the examined reservoir surfaces. Overall, across all scenarios from the study, Sweden, Finland, and Spain are among the top 5 countries with higher FPV potential due to their vast size of reservoirs available. Idle-flooded coal mines are also excellent locations for floating PV. The Fraunhofer Institute for Solar Energy Systems (ISE) has calculated that the artificial lakes at former brown coal mines in Germany alone open up a technical potential of 44 GW.[23]

Rationale and scope

A dual land-use approach supports the simultaneous enhancement of renewable energy production, while using the land area for other purposes. Deploying floating PV on water bodies allows the normal usage of the water body, while also generating green energy. Additionally, floating PV not only can play a role in reaching climate neutrality, but it can also provide social, economic and environmental benefits. The aim of this report is to provide guidance and knowledge-sharing to PV developers, regulators, and other stakeholders about floating PV potential and benefits, as well as best practices in Europe and beyond.

The report includes an overview of sustainability aspects, guidance for the project development phase, and best practice examples for onshore floating PV. Furthermore, it focuses on best practices on a global scale, and outlines the key benefits and challenges of offshore floating PV technology.

Bomhofplas, Netherlands. © BayWa. r.e.

22 Kakoulaki et al. (2023): Benefits of pairing floating solar photovoltaics with hydropower reservoirs in Europe.

23 Source.

2.2. Introduction

Floating PV can provide multiple benefits to the climate, energy, and environment. Deploying floating PV systems can support the decarbonisation of the energy sector, and contribute towards the EU's energy and climate goals. It also reduces land-use issues, and minimises the impact put on the land by selecting and using appropriate water sites. Appropriately designed and sited floating PV projects can also contribute towards nature protection and biodiversity enhancement. Due to the shading of floating PV panels, there is a potential to decrease water evaporation, reduce toxic algal growth in water bodies, and in some cases, increase the underwater biodiversity. There is also growing evidence that floating PV systems does not impact water quality, and in some cases, provides water quality improvements.

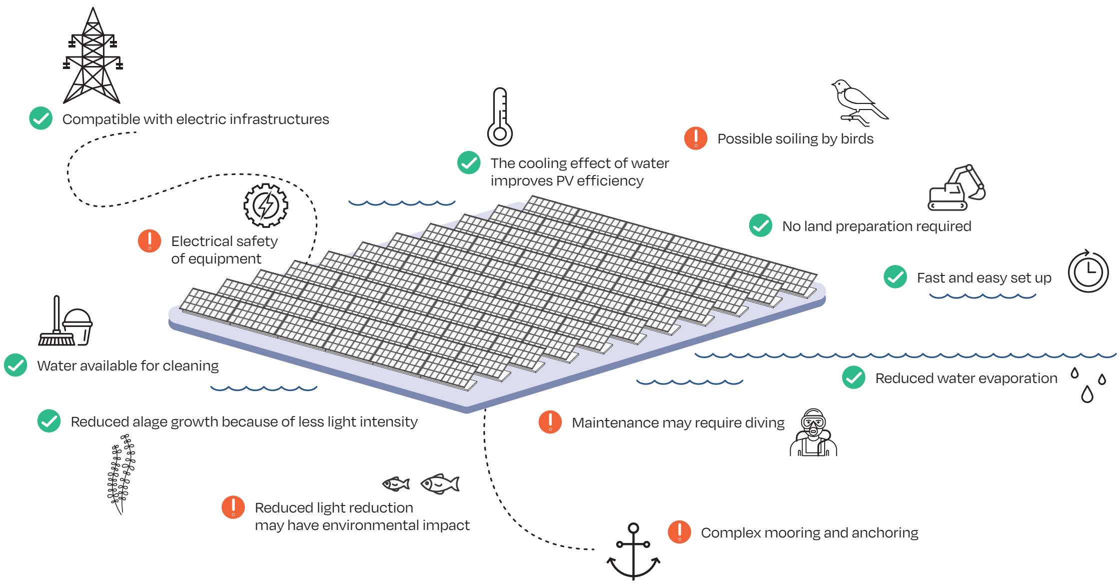
Floating PV can facilitate additional socio-economic benefits. For instance, due to the water-cooling effect, floating PV can generate higher electricity efficiencies in comparison to ground-mounted solar systems. However, when making comparisons between ground-mounted and floating PV systems, the tilt angle needs to be considered. Besides creating the cooling effect on the water surface, it also reduces the water evaporation.[24] This is especially critical in drought-prone areas, or areas where water is scarce.

Lastly, combining floating PV with existing energy generating facilities, can offer additional benefits, such as, optimising energy efficiency; offsetting the potential shortfall of the two power plants; use of existing grids and grid connection infrastructure; and minimise environmental impacts. Figure 1 showcases some these floating PV advantages.

This section will provide an overview of the environmental and socio-economic benefits of floating PV. Specifically, it will look at land efficiency, environmental benefits such as water use efficiency, wildlife enhancement, and improvements related to the water quality. The section will also provide an overview of the co-habitation of floating PV with other existing energy generating facilities, such as wind, hydroelectric dams, and storage facilities.

24 The process of a liquid changing to a gas, especially by heating (source).

FIGURE 5 OVERVIEW OF SOME OF THE BENEFITS AND POTENTIAL CHALLENGES OF FLOATING PV INSTALLATION



SOURCE: https://www.sciencedirect.com/science/article/pii/S2589004222015255

2.2. Land efficiency

Floating PV helps to reduce land scarcity issues by deploying PV systems on water. Europe has one of the most intensively used land surfaces globally. On the continent, around 80% of land surface area is used for man-made activities, including urbanisation, industrialisation, or for agricultural areas. Human-induced activities and the use of natural resources on land, are one of the main drivers for environmental degradation and climate change. In addition, the land-take trend is increasing every year, adding additional pressure to our ecosystems. According to the European Environment Agency, the artificial surface uptake has increased by over 6% in recent years.[25]

Using artificial water bodies or other appropriate water sites for PV installations can benefit land-scarce countries or highly populated countries. For instance, countries like Japan, which has limited land capacity, is home to more than 70 floating PV plants.[26] Floating PV can also provide leverage for countries or regions with high land prices by mitigating the land competition.

Based on a calculated data, in a 'business as usual' scenario, solar installations in Europe could reach 672 GW by 2030.[27] Assuming a solar generation can on average achieve 0.1 GW peak/km^2, this implies that land area equivalent to >4000 km^2 would need to be mobilised between 2023 and the end of the decade. This would be equivalent to the increase in urban land taken in the EU and UK from 2012-2018 for all purposes. Deploying multiple land-usage, like Floating PV, can minimise land competition and provide additional advantages. Converting unused and artificial water bodies into environmentally sound, socially inclusive, and profitable floating PV sites can benefit local communities, local agricultural sectors, and other incentives.

25 Source.
26 Source.
27 Source.
28 Source.

2.3. Environmental aspects

Water quality

Even though many megawatt-scale FPV plants are currently in service around the world, the effect of FPV on the water body's water quality needs to be studied in more detail. Consequently, several studies have recently been initiated to explore environmental impacts in more detail.

Prototypes and modeling

Different FPV prototypes and their influence on water quality, and ecology were analysed in a study conducted by Ziar et al. They indicated that anoxic conditions were not favoured below FPV, whereas hypoxic conditions, classified here at concentrations < 6 mg/l dissolved oxygen, occurred about 80% more frequently. Furthermore, a threefold lower biomass accumulation of submerged macrophytes below the FPV plant was detected at the studied lake in the Netherlands (Ziar et al., 2020). However, the study observed the prototypes in a very shallow lake. Most of the commercial FPV plants are located in the open water, with high water depths. Therefore, the above-mentioned results would not be expected for most the commercial power plants. Other authors simulated the installation of a FPV system in Windermere, England. They were using the MyLake model to simulate how a potential FPV facility will affect the lake's water temperature. It was simulated that at high FPV occupancies, surface water temperature reductions of up to 8 °C, as well as a stratification period reduced by up to 200 days can occur. However, they made the assumption that the simulated FPV blocks all irradiance and wind, which is not the case for most of the FPV systems (Exley et al., 2021). In another study by the same authors, they found that FPV generally promotes slow phytoplankton[29] growth. A less favourable mixing regime with FPV coverage, can also lead to substantial phytoplankton biomass reductions, even with only a small percentage of a reservoir covered by FPV. FPV deployment also changes phytoplankton community composition, but any negative consequences were negated by the considerable reductions in total biomass, diminishing hypothesised water quality concerns of a switch to undesirable species.

Measurements at commercial FPV systems

In a study by de Lima et al. (2021), the effects of FPV on the water quality were investigated at the Bomhofsplas PV park (27.4 MWp, Netherlands). Here, measurements of water temperature and dissolved oxygen were carried out using an underwater drone. In winter, an average of 1.1 mg/l lower oxygen concentrations could be measured under FPV, while these were 1.7 mg/l lower in summer.

Another commercial power plant was investigated by Ilgen et al. (2023). The 750 kWp system is located at a 70 m deep quarry lake in Germany. The monitoring showed a significant reduction in surface water temperatures, particularly on hot summer days. At night and in colder periods, the water was warmer compared to the open water. By using a hydrodynamic model, they simulated scenarios of different FPV occupancies and changing climatic conditions. They observed that a lake coverage with FPV results in a more unstable and shorter thermal stratification during summer, which could mitigate the effects of climate change. Significant reduction in oxygen concentrations could not be observed.

The studies on water quality show that there is still a great need for research in this area. However, it is also clear that FPV can have both positive and negative effects on water quality. This is largely dependent on parameters such as the system design, power plant size, but also site-specific conditions. Further research in this area will contribute to making the system designs even more eco-friendly, and to enhancing the beneficial effects of FPV on water quality.

Evaporation reduction

Studies have shown that deploying floating PV on water surfaces can reduce water evaporation, and increase water efficiency. Reducing water evaporation can bring substantial benefits to drought-prone areas and regions, by saving substantial amounts of water. In the study conducted by G. Kakoulaki *et al.*[30] it is shown that minimising evaporation, can provide yearly water savings of between 7,000 – 10,000 m^3 per installed MWp of floating PV.

29 Phytoplankton, also known as microalgae, are similar to terrestrial plants in that they contain chlorophyll and require sunlight in order to live and grow (source).

30 Source.

The main reasons behind evaporation reduction are based on two physical phenomena. Firstly, the irradiance is being blocked from reaching the water due to panel shading. This means lower energy and heat is stored in the water. The water temperature is a variable impacting the evaporation rate; therefore, keeping lower energy and heat will facilitate the evaporation reduction. Secondly, by physically occupying the surface of water, FPV impedes evaporation by reducing the open water subject to the evaporation phenomena itself. It blocks the wind from reaching the water surface, and sweeps away water vapour particles, minimising the evaporation.

Several studies have investigated evaporation in the context of FPV. Most of these studies are based on experimental designs or modelling. In modelling, there is often insufficient empirical measurement data available to include in the model, leading to results that are subject to uncertainties. However, nearly all studies demonstrate that FPV has the potential to significantly reduce evaporation and improve water balance. This effect is especially important in arid regions. The studies demonstrate that evaporation can be significantly reduced, by up to 70%, through the implementation of FPV systems (Abdelal, 2021; Bontempo Scavo *et al.*, 2021; Ferrar *et al.*, 2022; Sanchez *et al.*, 2021; Santos *et al.*, 2022). For instance, Abdelal (2021) observed a 60% reduction of evaporation in an experimental setup in Jordan. In another Jordanian case study, Ferrar et al. (2022) utilised different FPV system designs for an irrigation reservoir, and estimated a 42% reduction of evaporation with the most suitable design. The transferability of the results from both studies to commercial power plants is uncertain. However, irrigation reservoirs offer a promising location for water conservation through FPV, even from an economic perspective. According to Bontempo Scavo et al. (2021), covering just 30% of a basin's surface can lead to a reduction in evaporation of up to 49%. In this study, various system designs were examined, including modules on floats, buoyancy system anchored modules, canal top systems, and flexible floats. Santos et al. (2022) employed diverse empirical techniques to calculate the evaporation rate at the Passaúna Reservoir in Brazil. In addition to the empirical methods, measurements of evaporation were conducted and compared. Using the Penman-Monteith method, they estimated that there was an 60% efficiency water-use efficiency, with the reduced evaporation of the deployed FPV system. This could result in water savings of up to 743 million cubic meters per year.

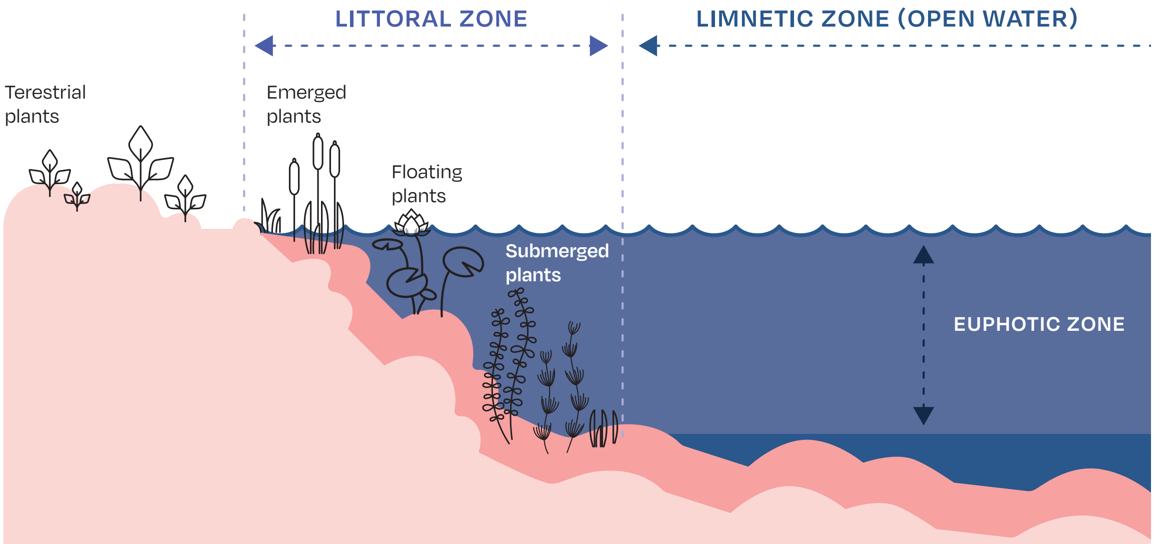
6.3 MW floating solar installation on the Queen Elizabeth II reservoir. © Lightsource bp

Wildlife and biodiversity enhancement

Floating PV can provide a multitude of environmental benefits, especially when looking at underwater marine biodiversity. Creating the right conditions such as sheltered areas and shaded areas under the FPV system, can provide spawning opportunities to aquatic species close to the surface of water. This area of water is also called a "limnetic area," where normally aquatic life is not so present due to the depth of the water, and the lack of shelters and substrates close to the surface, as opposed to the "littoral zone". This is a near shore zone, where sunlight penetrates the sediment, and allows aquatic plants to grow, see Figure 4.

One example is the *Bomhofsplas* Floating PV project, which was built on a sandpit near Zwolle, in the Netherlands. To achieve a biodiversity net gain in the artificial lake, and further understand the impact on the water ecosystem, 20 biohuts were installed at the edges of the floating plant in 2020. Biohuts are nurseries that provide protection for small fish from predators, and habitats as well as spawning grounds for fishes, micro-organisms, and invertebrates. The colonisation of marine organisms was monitored for three years. The three-year monitoring results showed a positive trend in the colonisation and growth of the species over time under the floating PV system. The abundance and number of species of mobile fauna observed in 2022 was higher than in 2021. In 2023, species number has stabilised. In this specific floating PV plant, the introduction of biohuts contributed to the establishment and the increase of aquatic organisms, therefore contributing positively to the ecological state of an artificial lake. For more information, see chapter Best practice examples in Europe, *Case study 5: Groenleven: Bomhofsplas Floating PV plant*.

FIGURE 6 DIFFERENT TYPES OF LAKE ZONES AND BIOLOGICAL COMMUNITIES FOUND IN THESE ZONES



SOURCE: https://www.waterontheweb.org/under/lakeecology/10_biological_lakezones.html

Reduction in algal blooming

Algal bloom, or excessive algae growth in water bodies, can be harmful and be detrimental to the surrounding environment. Certain types of algae (blue-green algae, cyanobacteria, and more), are types of algae that can be harmful to humans, aquatic ecosystems, including animals and plants, and impact the local economy, as they can produce dangerous toxins, create dead zones or low-oxygen areas in water bodies, and impact quality and cost for treating drinking water. According to report published by J. Richardson *et al.*,[31] European water lakes might face an increase in algal growth as a result of global temperature increases.[32]

Floating PV, when deployed on water reservoirs, can address the growing concern of algal blooms. Floating PV systems, in particular, when deployed on water reservoirs, can help in reducing the growth of algae, by decreasing the sunlight infiltration through water surfaces, while also reducing the overall temperature of the water. Algal blooming favours warm climates,[33] and direct sunlight that stimulates the process of photosynthesis[34] in water bodies. Floating PV structures can provide shade mitigating algal proliferation, and improving water quality. Floating PV installations' impact on the reduction of algal growth, can vary depending on the type of water body, water characteristics such as nutrient availability, and more. That said, evidence shows that floating PV can minimise the photosynthesis of algae, as a result decreasing the algal blooming and limiting their negative effects.

According to the Haas *et al.* study,[35] it was showcased that water coverage between 40-60% could greatly minimise algal blooms due to the shade provided by floating PV structures, which reduce the amount of sunlight reaching the water. The study indicates that: "a more extensive deployment of FPVs could potentially eradicate algal blooms, which could affect the entire water body ecosystem."[36] However, an excessive reduction in algal growth may be detrimental to the biodiversity of the water body, as algae represents an important food source for many aquatic species. Therefore, further research, with a higher coverage of water surfaces, is required.

2.4. Visual impacts

Certain aspects such as the visual impacts of floating PV systems can also play a role in the overall sustainability of FPV, especially when assessing social aspects. The visual impacts of FPVs compared with the more common PV systems are significantly less as they are located on the water surface. However, before any installation takes place, it is important to assess the integration of FPV into the landscape on both an aesthetic and practical level. Floating-PV arrays do not have a high visual impact as they are more likely to merge into the water surface, and reduce the overall visual impact. In addition to that, the aesthetic integration into the landscape, and providing compensation measures onshore, and on the platform can be helpful. Various types of actions can facilitate the better integration of floating PV systems into the local surroundings. Providing green fencing (such as planting trees and bushes), around the shore can provide additional visual protection. Other parts of FPV systems such as E-W systems, transformers and inverters, have a minimal visual impact as they have a homogeneous appearance.

2.5. Combination floating PV with other energy generating systems

Co-location with Hydroelectric dam power plants

Hydropower plays a crucial role in the decarbonisation of the energy sector, reaching a total installed global capacity of 1,330 GW[37] in 2022, with estimates demonstrating that the hydropower sector is responsible for 16% production of the total global electricity in 2018. However, hydropower is a sector dependent on the hydrological cycles, that can vary across climates and regions. Energy generated by hydropower is estimated to decrease over the coming years because of climate change, temperature increases, longer periods of drought, and other adverse climate events. These adverse climate events impact overall water resources, and its availability, and increase

31 Source.
32 Source.
33 Note: Algal blooming can occur in all reservoirs and can depend on the nutrient loading.
34 Photosynthesis is the process plants, algae and some bacteria use to turn sunlight, carbon dioxide and water into sugar and oxygen (source).
35 Source.
36 Source.
37 Source.

the evaporation from hydro reservoirs affecting the electricity generation from these power plants. Studies have shown the benefits of optimising the use of hydroelectric dams in combination with floating PV systems. The results indicate the gains related to optimised energy efficiency and improved system reliability; this includes sharing existing infrastructure for transmission extensions/grid connections, and minimising time and costs constraints. Combining hydroelectric reservoirs and floating PV has other synergies, for instance, in utilising already existing grid connections. Moreover, floating PV can increase hydropower efficiency due to PV panel shading, which can minimise water evaporation. FPV on hydropower lakes can also preserve water by limiting the use for hydropower, and saving water usage. This water can subsequently be used for drinking water or irrigation purposes, while still producing sufficient power over the hydropower electrical connection.

According to G. Kakoulaki *et al.*,[38] evaporation corresponds to a great loss factor for managed water resources on a global scale. Data shows that up to 40% of the total volume of water storage can be lost due to evaporation. The study states that: "coupling FPV with hydropower could prevent up to 74 bcm of global water evaporation, and support hydropower production—adding an estimated 142.5 TWh of generation from FPV systems on hydropower reservoirs ".[39]

CASE STUDY 1 BANJA FLOATING SOLAR PLANT, ALBANIA; (STATKRAFT)

Banja floating solar plant is an innovative project implemented in the reservoir of Statkraft's Banja hydropower plant. The pilot project of the Banja floating solar plant started implementation in 2020, and was completed in early 2023.

The solar plant is comprised of four floating units of 0.5 MW each, with a total installed capacity of 2 MW. The floating units are anchored on the Banja reservoir, near the dam of the Banja hydropower plant. Each floating unit is 70 metres in diameter, and is comprised of a floating polyethylene ring pipe and an impermeable membrane, in which the solar panels are mounted. The generated electricity is injected into Albanian national electricity grid.

The project is being implemented in cooperation with the Norwegian company Ocean Sun, and with Albanian local contractors. In addition to generating renewable energy, this R&D project will also serve as a learning opportunity to properly assess the potential benefits of this technology.

Albania - Banja Powerhouse, dam, reservoir Statkraft. © Statkraft

38 Source.
39 Source.

Retrofitting hydroelectric dams, and allowing the co-location with solar PV panels, could increase the output of hydropower plants and reduce evaporation potential. Synergising the FPV and hydroelectric dams can also provide benefits to the water-food-energy nexus. Nonetheless, further studies on the technical risks and environmental impacts need to be carried out.

Co-location with wind power plants

The hybridisation of onshore wind and solar is considered attractive as the two energy types have complimentary generation profiles. In Europe this is both seasonal, with solar producing more power in summer, and wind in winter,[40] and over shorter durations with some anti-correlation between dry clear weather with good solar production, and cloudy windy weather suitable for wind power. In addition, the duration of events where no power is being produced is shorter, and they can be expected to occur less frequently as there are two independent possible sources of generation.

In a study in Portugal using data on an hourly basis, the percentage of the time when at least 20% of the peak capacity was being generated increased from <70% of the time to >85% of the time for 8 sites studied.[41] The time 40% of the peak capacity was being generated increased from <50% of the time to >60% of the time. Curtailment due to production exceeding 100% of the installed wind capacity occurred only <15% of the time. When considered on a daily basis, at least 20% of the capacity was available >95% of the days; this is compared to <75% using wind only.

This provides a more consistent energy supply and increases the utilisation of the site's energy export route, reduces the need for storage (see below), and allows any attached load to be operated under a wider variety of weather conditions.

From a space usage perspective, wind installations need to have significant space in between turbines to reduce losses to wakes from one turbine impinging on another. This leaves unused space between the turbines that can be utilised for PV systems.

Offshore, the costs of energy export cables increase, and so improving the utilisation of this expensive asset with a single hybrid plant can be considered preferable to installing two separate floating solar and offshore wind installations, and balancing their contributions via the electricity grid. However, different technical challenges, possible curtailments, and costs need to be further addressed. This is also true where capital intensive hydrogen generation is considered as the energy export route, as is being considered for some far offshore installations.

Finally, some offshore installations or even high load remote shore installations, cannot feasibly be connected to the onshore energy grid, and in these cases decarbonising their energy use may rely on a stable supply of renewable energy in the form of a micro-grid combining local wind and solar resources.

What constitutes an optimal mix of floating solar and wind (or other renewable energy and storage resources), depends on the details of the site, but also the parameters that are to be optimised. For example, the aim of maximising the revenue generated by a particular installation for a given cost might call for a different balance than a system which prioritises availability of a certain minimum energy supply. The extent of this anti-correlation between solar and wind profiles, the time between them, and the statistical likelihood and duration of time periods of low or zero production, all need to be evaluated for the specific site conditions.

In cases where floating or offshore solar is being added to an existing installation, costs for the wind farm and export lines are 'sunk' and are no longer considered in the calculation. The optimisation of how much solar capacity to add is likely constrained by existing export, storage, and backup generation capacities due to the costs of redesigning, permitting, and constructing additional facilities.

Co-location with storage

As per any other renewable energy installation, such as wind and ground-mounted solar PV, co-location and integration with energy storage, either behind-the-metre or front-of-the-metre, can provide benefits such as peak shaving, time-shifting, and reduced strain on grid connection capacities.

40 Portuguese examples: Source; Belgian example: Source; UK example: Source; German example: Source.
41 Source.

2.6. Socio-economic benefits

Apart from the environmental benefits, FPV systems offer several social-economic benefits, contributing to sustainable development and addressing various societal challenges. Some of the social benefits of FPV include:

- Job creation: developing floating PV projects can facilitate new job opportunities and stimulate the local economy in the local communities. The planning, installation, and maintenance of FPV systems can create opportunities in various sectors such as engineering, construction, maintenance, etc.
- Energy sharing: new renewable energy projects can also bring additional economic benefits. Some of these advantages include financial benefits from project shares.
- Energy access: local communities can benefit from the use of the renewable energy generated in their local areas. Moreover, FPV can be developed in remote areas and provide opportunities for off-grid and remote communities to access green electricity.
- Improving air quality: replacing fossil-fuel based energy sources can improve the air quality and reduce pollution, providing direct positive impacts on public health.

CASE STUDY 2 BATTERY CO-LOCATION WITH FLOATING PV, THE NETHERLANDS; (BAYWA R.E.)

Co-location of FPV with energy storage is not common in Europe yet, but recently BayWa r.e., with its subsidiary GroenLeven in the Netherlands, has installed the first battery project co-located with the largest already operational Floating-PV project, the Sellingen floating solar PV park. The eight batteries together have a capacity of 15 MW, and capacity of 30 MW hours, marking a success in the energy transition, and will help solve issues associated with the overflow of grid capacity. The batteries offer the possibility to store solar energy during the off-peak times when the sun is not shining. It also provides benefits of stabilising the grid and providing a continuous and reliable power supply.

Floating PV site co-located with battery storage. © BayWa r.e.

In general, FPV projects can bring a number of advantages and opportunities to local communities and citizens. FPV project developments can enhance energy security, stimulate local economies, and improve the livelihoods of local communities. It can also contribute to the development of skilled workforces, and provide information about renewable energy sources for all citizens.

2.7. Technological advantages

Cooling effect

Based on numerous studies, it has been stated that floating PV can outperform ground-mounted solar PV systems (when the same tilt angle is considered), by delivering higher energy yields due to the cooling effect from the water. Solar cell temperature is essential for the electrical performance of the PV panel. Generally, solar PV modules perform better when they have a lower operating temperature. PV modules' operating temperature can be determined by factors such as incident solar radiation,[42] ambient temperature, wind speed, wind direction, and properties of the cell material and assembly.[43] Air temperature can vary depending on where PV modules are installed: near water bodies, on land or on rooftops. There are several mechanisms that allow the cooling effect to take place. First, as the water is transparent, incoming solar radiation is transmitted through the water surface allowing the water surface to remain cooler, therefore impacting the PV panel temperature. Secondly, the net radiation[44] on water is used for evaporation, whereas on land or on rooftops, net radiation is used for heat transfer to its surroundings. Thirdly, water can easily circulate and subsequently, allows the surface layer that has been heated up, to mix with lower water layers making the surface water cooler. Lastly, the ambient temperature[45] of the the above water surface is naturally lower than that of land or roofs; this results in a lower temperature of the PV panel installed on the water surface.

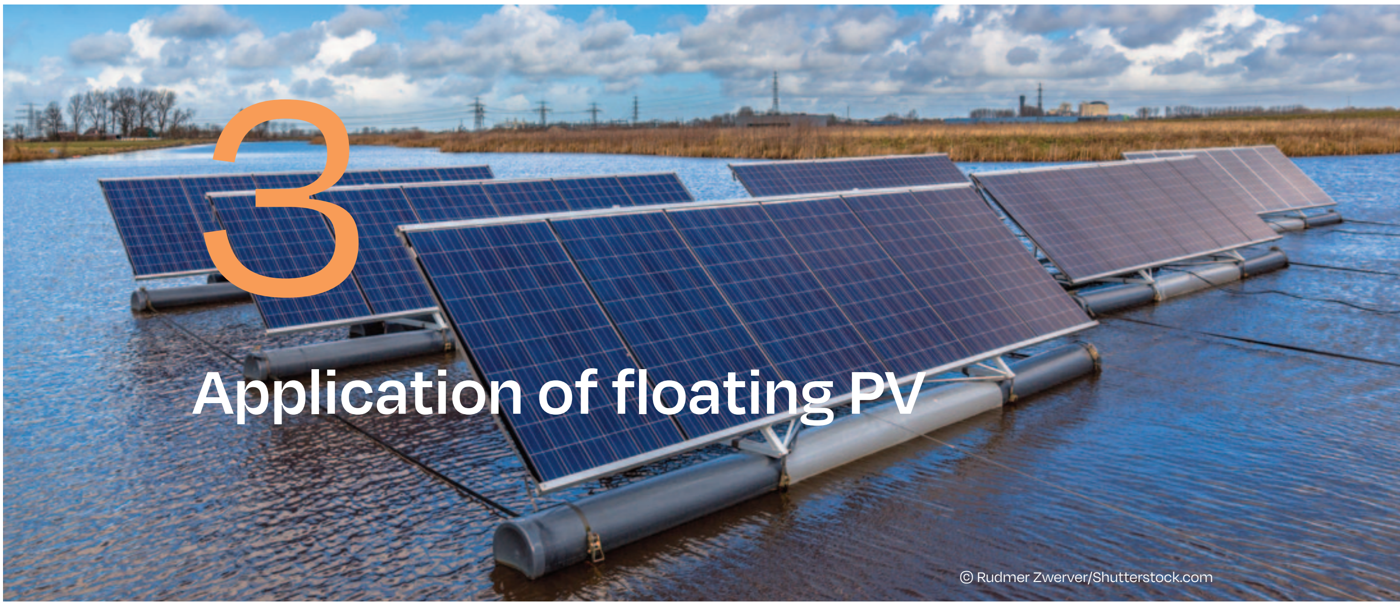
According to M. Dorenkamper, *et al.*[46] study, two field tests were developed in two different climate zones i.e. in the Netherlands and Singapore, to assess and monitor the impacts on the water-cooling effect by floating PV installations. These two tests were compared to reference systems, i.e. on the land and on the rooftop. The results showcased an energy yield gain from the cooling effect of floating PV systems of up to 3% and 6%, in the Netherlands and in Singapore respectively.

However, there are different variables that influence the cooling effect. Aspects such as the type of floating PV system, layout, different site conditions, wind, irradiance, water temperature, ambient temperature, and a number of other factors can affect the yield gain. Therefore, it is difficult to draw general conclusions for all floating PV projects and the impact on energy yield. These types of analysis would need to be assessed on a case-by-case basis. In addition, bird soiling should also be evaluated as it might impact each project site differently. Even though a lot of research has been conducted showcasing the multiple benefits that FPV can bring, conducting further studies will produce additional evidence on the impacts of FPV. For instance, data on the potential negative effects on marine flora and fauna should be researched. In particular, research on floating PV components and its impact on wildlife can be helpful to further understand its interaction. Assessing the impacts on the blocking light, disturbance from the mooring systems and cables on the seabed, fauna entanglement in mooring lines, electromagnetic field emittance from cables, and bird collision, could provide valuable information for developers, authorities and other relevant actors.

Additionally, large-scale supplies of raw materials for manufacturing FPV may have an environmental impact. Similarly, the end-of-life phase of the used materials must be considered in the early-stages of technology developments.

42 A radiant solar energy that hits the earth's surface (Source).
43 Source.
44 The difference between absorbed and emitted radiation (Source).
45 Ambient temperature is the temperature of the air surrounding a component (Source).
46 Source.

3 Application of floating PV



This chapter will provide an overview of the main aspects that need to be considered when developing and implementing floating PV projects. It will specifically highlight the process of permit granting, and include examples from Germany, and the Alqueva project in Portugal. The section will also provide insights into social acceptance and include best practices for O&M.

3.1. Development and implementation of projects

Permits and permit granting procedures

Special permits/concessions are regularly required for FPV installations. However, permit granting procedures can vary from country to country, and across regions. National permit or concession regimes may provide for regulations and limitations that can either promote or hamper the deployment of FPV. Also, the lack of specific permitting regulations for FPV can create a barrier; since it leads to legal uncertainties for investors, who need to know what permits are required, and what documentation needs to be prepared to successfully obtain the permits, and for national authorities that need to assess the permit requirements. Such barriers or shortcomings often result in a limited socio-political and market acceptance (see also section *Acceptance*).

Several laws and sectors of regulation must be considered in the FPV project development and implementation. For more information on regulatory initiatives and policies, please see Chapter 4.

Building law (building codes and spatial planning): Since most of the FPV are fixed to the water ground or water slides (banks) by using anchoring and mooring systems, national construction/buildings laws are usually applicable. Therefore, it is debatable if the installation of FPV is in line with spatial planning and land use designation regulations (zoning plans). In general, the construction permit grants the right to construct the building facility in accordance with the building application and building conditions, imposed by the competent building authority. In order to obtain a construction permit, the FPV project needs to be in line with the technical building regulations (which regularly address building statics, product safety and design aspects), and applicable spatial planning, as well as land use/zoning regulations. In some EU Member States, energy generation installations are exempted from the building regulations, and governed by an alternative regime (e.g., water, mining and/or energy law).

Water specific regulations: FPV are PV systems located on the surface of different water types (e.g., lakes, rivers, sea). Therefore, FPV projects have to be developed in respect to water specific regulations (e.g., water protection law, water use acts). In almost all EU Member States assessed, water related authorities need to be included in the permitting process, and must give their approval for installing FPV. In this context, what is mainly relevant is the type of water body selected for the FPV project.

Potential environmental impact and nature protection regulations: Nature protection laws are typically rather strict when it comes to interferences with (natural) water bodies. This aspect is essential for the deployment of FPV. In this context, it is particularly relevant to consider what type of water body is used for FPV plants (natural or artificial waters, public or private waters). Artificial water bodies are generally subject to less strict nature protection restrictions than natural water bodies, and less stringent rules may apply to privately owned water bodies compared to public ones. Operators and/or investors usually face FPV-project rejection by public authorities or additional permit conditions and measures, and in general, a lengthy permitting process, if an FPV plant is located on a public and/or natural water body.

Permit-granting procedure in Germany - Example

The permit granting procedures differs quite a lot from country to country, therefore it is only possible to present some exemplary procedures. In order to shed more light on the legal aspects surrounding approval, Fraunhofer ISE elaborated a process model for FPV in Germany (which is different from many other EU member states). The model is based on data received from an analysis of legal documents and interviews with approval authorities and project developers of six floating PV projects in five federal states: Bavaria, Baden-Württemberg, North Rhine-Westphalia, Brandenburg and Rhineland-Palatinate. This was conducted as part of the "PV2Float" research project. The water categories were an active quartz sand excavation lake, three active gravel excavation lakes, a former sand excavation lake, and an open-cast lignite mining lake.

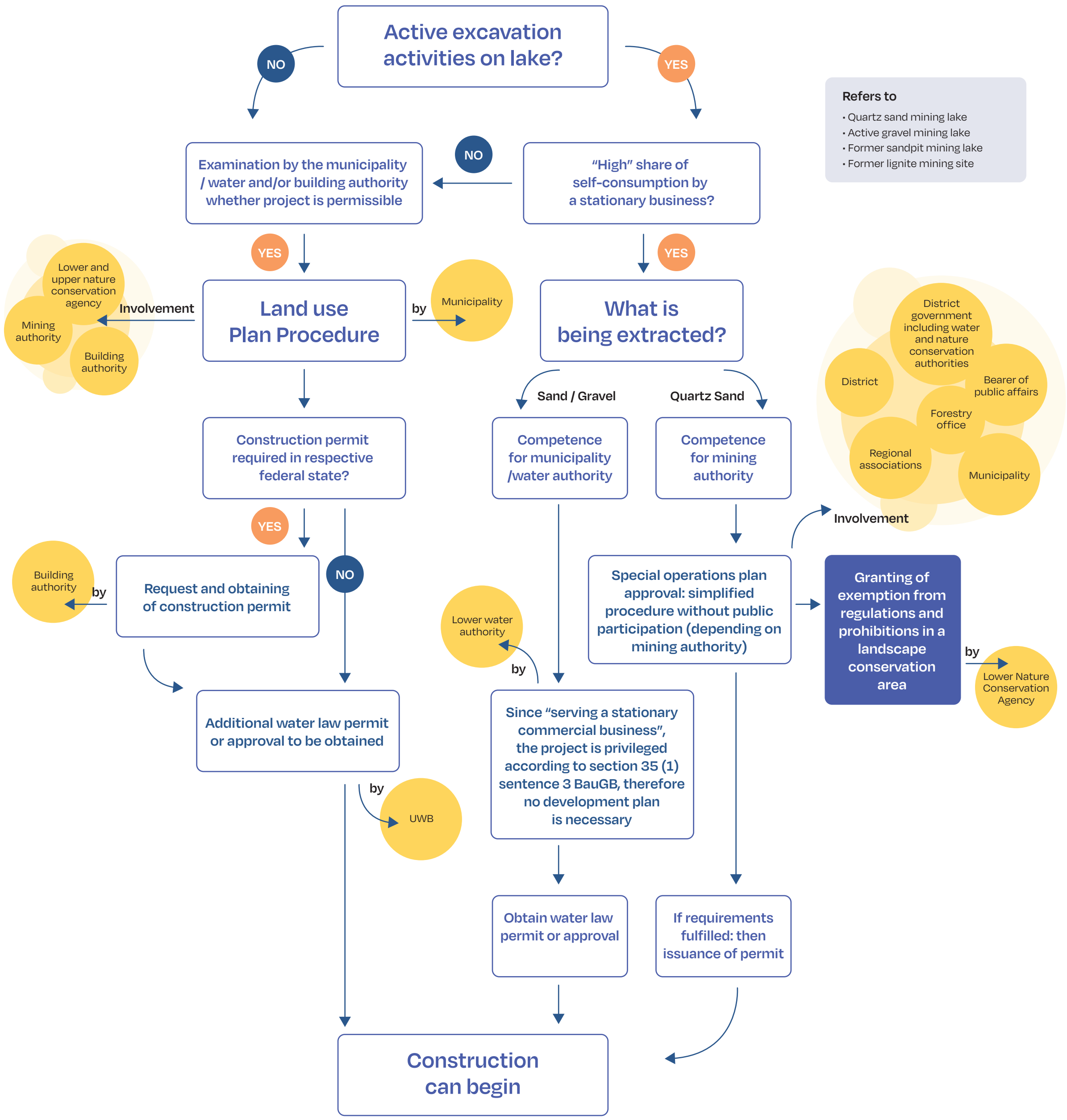
Based on the interview statements and further research, Fraunhofer ISE drew up a flow chart for approval processes (Figure 4), which is briefly described below. The central question which is decisive for the choice of the respective approval path is the following: *Is there a predominant self-consumption of the electricity produced by a local commercial operation?*

If this could be affirmed, the floating PV system was treated as a privileged project in the outdoor area in accordance with Section 35 (1) sentence 3 BauGB[47] ([...] serves a local commercial operation), and only required a permit under water law and a building permit (right, middle path in Figure 6). The lengthy urban land-use planning procedure could therefore be avoided. This approval path applies to active sand and gravel excavation lakes, for which the building and lower water authorities are responsible. In projects involving active quartz sand mining, the responsibility lies with the mining authority, at least in North Rhine-Westphalia. An additional decisive factor for this responsibility was the fact that self- consumption took place that served a mining facility, namely the local quartz plant. In this case, a special operating permit could be granted as a simplified procedure without public participation (far right path in Figure 6).

However, land-use planning cannot be circumvented if there is no self-consumption or the system is so large that only a small proportion of the electricity is consumed by an adjacent business, and the rest is fed into the grid. According to the project developers, it was initially difficult to get the project through the approval process. Lakes where excavation activities have been completed are usually subject to a renaturation plan. The lake must therefore be renaturalised, and this requirement cannot easily be combined with a commercial activity such as electricity generation. In most cases, the local authorities also have other plans, such as using the lake for tourism purposes. In the case of the Brandenburg floating PV project, a 150 MW plant was initially planned in a former lignite mining area, which would have taken up around 5% of the lake's surface area. However, as the lake was reserved for tourism in accordance with the lignite plan, the regional planning authorities had reservations. The project developers therefore scaled back the project considerably, so that less than 1% of the lake area would be covered. The regional planning authority approved the floating PV plant with an output of 21 MW. However, in order for this project to be approved, the urban land-use planning procedure had to be chosen (left-hand path in Figure 6).

47 Source.

FIGURE 7 PERMITTING PROCEDURE MODEL FOR FPV IN GERMANY



SOURCE: Zuber; B. 2022.

CASE STUDY 3 ALQUEVA - PERMIT GRANTING PROCEDURE WITH EIA; (EPD RENEWABLES)

Location and size of project

The Alqueva dam is the largest artificial lake in Europe, located in Alentejo, Portugal. Following a 2021/2022 competitive procedure (auction) for the allocation of electricity injection capacity into the electrical grid, development began on a floating project in Alqueva. In the auction EDP Renewables was awarded the 70 MVA grid connection capacity in the 400 kV substation of Alqueva, as well as the rights of use for an area of approximately 100 ha in the Alqueva water plan. The project will also have a wind component, which will be characterised as a hybrid project (solar and wind sources), with over-equipment, the size of which is still in the final study phase. An estimated installed capacity of 154 MW is expected, divided between floating solar and wind.

Commissioning of project

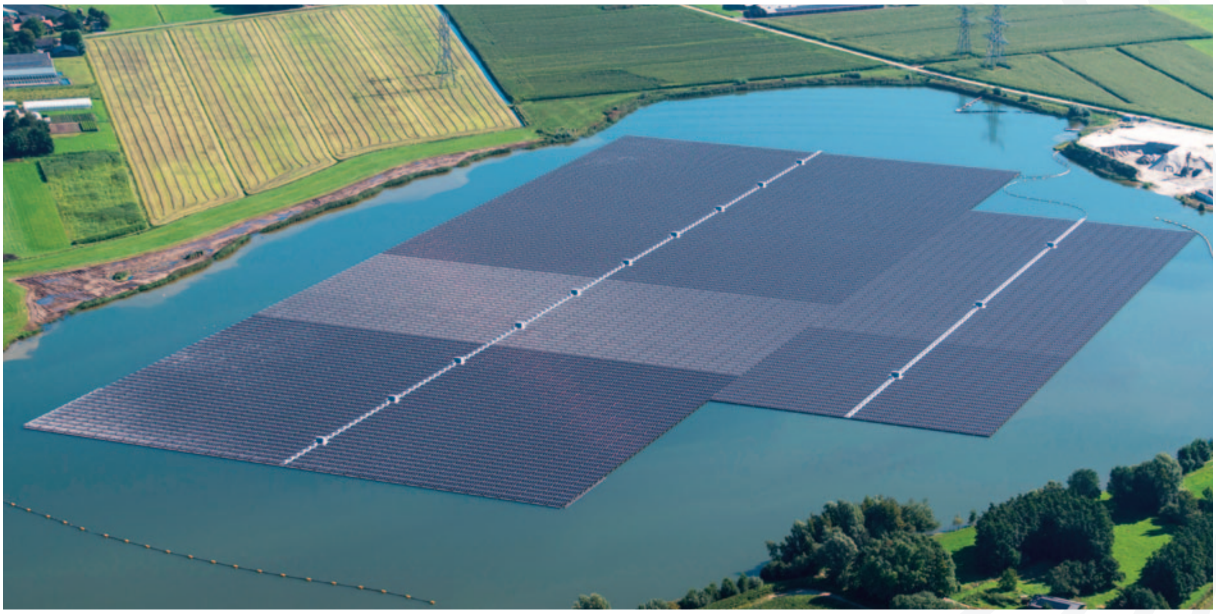
The commissioning of the project is estimated to happen in 2025, due to grid availability.

Existing results of the PV plants

The project is still in the Environmental Impact Study phase, but the monitoring of birdlife, archaeological prospecting work, and water quality is already underway. All these activities are being conducted in coordination with public entities that oversee the different areas/specifications.

After being completed, the study will be sent to the Portuguese Environment Agency (APA), and a rigorous conditioning plan will be created by the promoter, for a better compatibility between the different uses, current and future, of the multiple activities existing in the Alqueva reservoir, as well as in the vicinity of the project.

During the Environmental Impact Assessment and permitting phase of the project, the resulting decisions will be accommodated, making them compatible with the technical characteristics of the project, naturally involving local communities.



Zwolle, Holland. 72.000 solarpanels float in the water of Bomhofsplas.

3.2. Acceptance

In the debate on floating PV, the concept of acceptance is used very differently and sometimes very broadly. In general, the term appears whenever a project encounters local resistance. The (feared) lack of acceptance appears to lie with the population and the actors involved. This ignores the fact that barriers to acceptance can also lie in structures or procedures. Examples of this include bureaucratic hurdles for private operators of solar PV systems, inconsistent political guidelines, and the prevention of renewable energy expansion through bureaucracy, or a lack of resources at municipal level in the approval authorities.

The acceptance concept used in this paper is based on the differentiation made by Wüstenhagen et al. who distinguish between three facets of acceptance:

- Socio-political acceptance
- Local acceptance
- Market acceptance

Socio-political acceptance describes the overarching acceptance of society as a whole, i.e. the support or endorsement of the overall implementation of floating PV. Local acceptance refers to the acceptance of specific installations of FPV by the affected residents or local decision-makers. Market acceptance describes the adaptation of market players, and the adoption of FPV.

The five most expected issues for the local acceptance of FPV are seen in:

- If residents rate the (1) local economic benefits; and the (2) energy transition as positive overall; this has a positive effect on local acceptance. In addition, (3) trust in the process and the actors involved in the planning process; (4) the expectation of negative impacts on nature and people; and (5) the opinions of others in the area (social norm) are relevant.

Especially, any negative impact issues are crucial in the FPV permit-granting process. In general, several acceptance issues are not addressed by the permit-granting process. This can lead to a low acceptance or objection to FPV.

- **Local economic benefits:** Most projects are implemented by non-local project developers. Their main business cases are the sales of electricity from FPV through direct power purchase agreements, to industrial customers, or through sales to the grid based on national feed-in tariffs. In both cases, a direct economic benefit is very limited for the neighbouring municipalities. Concepts like financial participation in the FPV project by the municipalities or citizens, could provide an additional source of income for them through their share on the economic profit.

  Another option for local economic benefits could result from a local company (or local cooperative) which also pays tax to the relevant municipality. A last option would be project development through a citizen cooperative, which takes the profit for their members, pays tax at local administrations, and could even sell the electricity to their members or other local customers (i.e. as an energy community). Such projects do not have the same margins as commercial projects, and as a result, are not yet associated with FPV.

- **Energy transition as positive attitude:** Depending on the existing experiences with renewable energy projects in their local surroundings, a positive attitude can be high or rather low. From research, there is strong evidence that people that have encountered similar renewable energy systems previously, generally have a more positive attitude.

- **Expectation of negative impacts on nature and people:** Besides the environmental impacts through FPV, negative impacts with FPV are especially seen in the visual impacts on the landscape (i.e. visual impact on the water body) and in the hindering, limiting or even exclusion of other uses of the water body (recreational use, fishery, water sports etc.). Please see Chapter Sustainability, for more information on visual impacts).

Other aspects such as fire risk assessment, mitigation measures, management of the projects, and more, are also assessed during the development of the FPV projects. However, this section will not be detailed in this report.

3.3. O&M

Challenges

While FPV is a growing segment, there are a number of complexities associated with the operation and maintenance of floating solar plants. This section will look at the main challenges associated with floating solar installations.

Anchoring & Mooring

During the installation phase, there are significant challenges related to anchoring and mooring floating PV systems in place, accounting for possible water level variations, the reservoir's bed type and depth, and extreme weather situations such as high winds and waves. However, maintaining water integrity of the reservoir during the installation process is the highest priority. This is especially relevant to the drinking water reservoirs, where appropriate anchoring systems must be selected to ensure that no damage occurs.

The higher costs of floating PV installations, compared to ground-mounted solar systems, are attributed to the anchoring and floating structure.

Cleaning

Due to the negative impacts of dust, soil and dirt on the efficiency of PV panels, cleaning PV panels is crucial from both an economic and performance perspective. Furthermore, nesting birds prefer sheltered areas and minimal disturbance from humans. Solar panels and the floats between rows of panels, provide these desired conditions;. birds can rest and nest without disturbance. The result might be heavy soiling from bird droppings from day one of the installation, see Photo 1. Bird droppings can pose a risk in terms of direct energy loss due to shading from the droppings, and theo danger of hotspots in the modules. The performance of a PV module decreases because of surface soiling blocking sunlight. PV power loss reduces with the increased soil quantities on the PV module. The amount of dust and soiling rate varies by geographic region, and by the level of bird activity in the area, which generally needs to be evaluated in each specific project location. Therfore, there is no universal suggested cleaning regime and frequency for PV panels. Each cleaning technique has its own pros and cons, and may be more suitable for either dust or soiling as bird soiling may require a more extensive technique than dust. The optimal cleaning frequency mainly depends on the environmental conditions of the specific floating PV installation site, such as humidity, rain, snow, wind velocity, particle type, soiling rate, bird presence, etc. It has been suggested that PV panels should be cleaned at least once a week in moderately dusty places,[48] and that all equipment should be cleaned after a dust storm to maintain operating efficiency. Seasonality of bird presence and consequent bird droppings, should be incorporated when relevant, in the definition of the cleaning routine. Cleaning techniques for floating PV installations include manual cleaning, robotic cleaning, and anti-soiling panel coating among other approaches.

Module mismatch

The uneven yield of energy production due to soiling covering some panels surfaces, is referred to as 'module mismatch'. A certain level of module mismatches is unavoidable in any PV installation. However, in FPV systems this is particularly prominent due to various environmental effects, such as the

Bird soiling - in white - can be seen on the PV panels. © SolarEdge

48 Source.

constant movement of the water, bird droppings, fluctuating temperatures, and potentially induced degradation of PV modules. Furthermore, when using bifacial PV modules, module mismatches increase even more. To maximise energy production and return on investment, mitigating module mismatch related production loss is imperative.

Module mismatch can also occur due to the movement, and instantaneous difference in orientation of PV modules, which is generally more severe in floating systems that allow relative movement between modules, rather than systems in which modules are more rigidly connected and aligned. Module mismatch, due to relative movement, occurs when modules within the same string have different orientation in terms of tilt and/or azimuth, which can occur in case of movement due to waves, depending on the structure response to waves.

Module mismatch results in high energy loss due to:

- Low power producing modules are fully bypassed or partially bypassed (sub-string bypass); all power is lost from such modules (even if low power).
- Slightly lower power modules may still produce power, but they limit the string current. This forces lower operation powerpoint to clean modules which can operate at a higher power.

Power optimisers or Module-Level-Power-Electronics is an effective way to deal with module mismatches since they allow module level MPPT, extracting the max power from each individual module, without impacting the performance of the string. This ultimately results in high energy yields, which translates to higher returns on investment for developers.

Electrical Safety

Floating PV installations are potentially more prone to safety hazards, because they are installed on water. Ions and impurities turn water into a good electricity conductor.[49] Water bodies are also in constant movement, interacting with their surrounding environments, and are affected by external forces . It is therefore important to take precautionary measures to prevent short circuiting and minimise the risk of electrocution.

Electric voltage is produced by solar panels from the moment they are exposed to sunlight. Since each panel produces around 40 volts (on average), a string of connected panels produces high voltage of about

Omega 1 project. © Akuo

49 Source.

400 volts to 1500 volts (depending on the type of solar inverter, and the lengths of the strings). This voltage is created by the mere exposure of the solar panels to the sun's radiation. Turning off the solar inverter, or disconnecting the device from the grid, does turn off the current passing through the system circuit. However, it does not lower the voltage produced by the exposure of panels to the sun, called DC voltage). High voltage may pose a safety risk to the installer of the system, and people working in adjacent areas. To lower the DC voltage, a function that reduces the voltage on a panel level is needed.

An electric arc is created as a result of discontinuation of a conductor or connector. In a solar system consisting of many connection points and cables, an electric arc can be created if the cable is not connected as required, or if damaged. Electric arcs have several prominent features: strong light and very high heat. As such, electric arcs are a common cause of ignition and fire in any electrical installation, especially a solar installation. Electric arcs can also 'electrify' the system including the construction, and endanger anyone who encounters it. The older the system, the greater the risk of arcing as a result of the ageing of the wiring, and the loosening of the connections.

In early 2022, a 17-MW FPV system in the south of France experienced a fire accident, attributed to the FPVs exposure to several days of strong winds. In January 2022, the body of water where the installation is located was exposed for several days to violent winds blowing up to 80km/h in gusts. Under the effect of the swell and repeated friction, the cables connecting the modules to the junction boxes became bare, causing a short circuit on one of the three-panel floaters of the power plant. The affected inverters were shut-off, but three floats ignited.

An investigation which was conducted after the incident revealed the friction of the cables and traces of wear on the cables that connect the modules to the transmission terminals had been observed.[50]

This event shows the effects of weather and movement on cable wear. If the fire spreads on FPVs, the combination of electricity, fire, and water makes tackling the blaze challenging.

Similarly, in 2019, a typhoon hit Japan and wreaked havoc at the country's largest floating PV project. The wind tore several modules off the project, and stacked them. That contact between loose panels and those that remained moored to mounting structures, overheated the modules, creating the conditions for a fire.

Such accidents and potential risks should first be mitigated by an accurate design, sound engineering, and by considering the components limits and requirements within an integrated system.

Afterwards, risks could be addressed by introducing new supporting policies, in order to enforce safety standards. It is of vital importance to integrate safety features which reduce electrocution risk on water, in order to protect people, assets and the surrounding ecosystem.

In addition to this, maintenance activities on electrical equipment can be more challenging than onshore PV, i.e associated to dynamic cables, or electrical equipment repairment or replacement offshore, and should be carefully addressed.

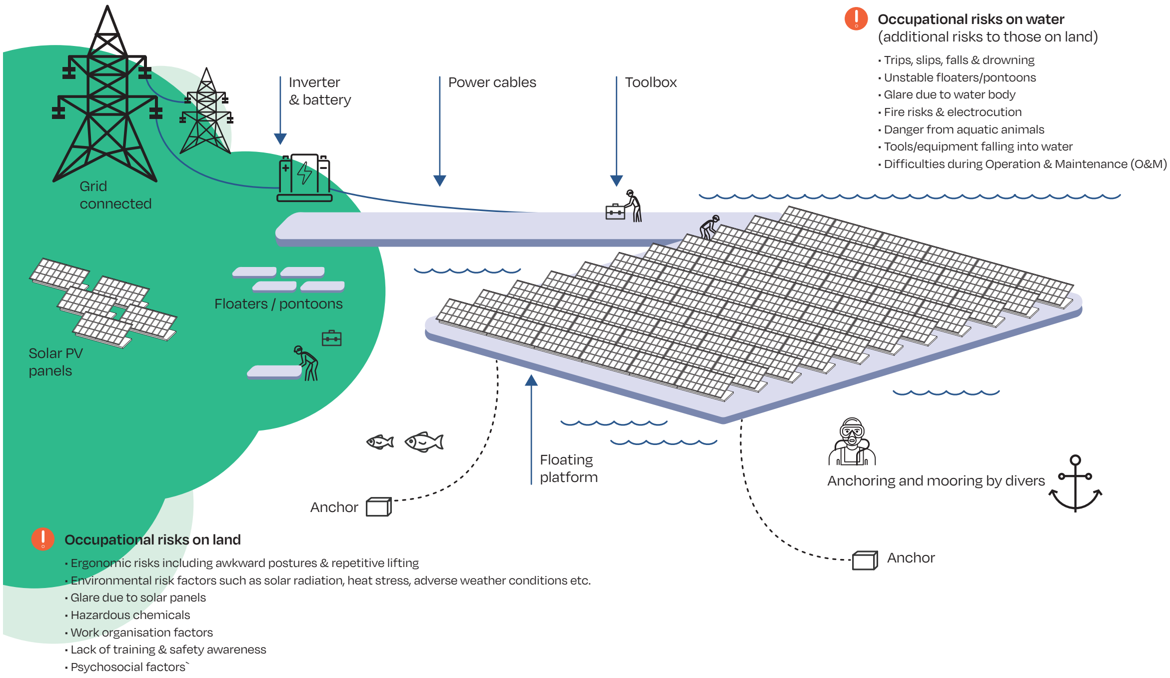
Occupational Safety & Health

All stakeholders involved in the installation, operation, and maintenance of FPV plants, must be aware of associated risks and safety considerations. Since FPV is an evolving segment requiring new skill sets, most workers are likely to be inexperienced and untrained. These factors can also lead to human errors, which might result in injuries. Therefore, all personnel should be trained and educated on routine safety measures. Some health and safety best practices from similar industries, could be used to transfer knowledge and learning for the solar sector.

A significant portion of the installation and maintenance of FPV projects, involves manual work on both land and water. The occupational risks on land and water associated with a typical floating solar PV project are depicted in Figure 6. Even with walkways, the additional water safety hazard requires additional health and safety considerations, equipment, and training specific to water hazards. In some scenarios the FPV systems can be far from the shore, and occupy large areas, requiring access via boat; the transfer of

50 Source.

FIGURE 8 OVERVIEW OF OCCUPATIONAL RISKS ASSOCIATED WITH FLOATING PV PROJECT DEVELOPMENT[51]



SOURCE: Risk Manag Health Policy.

personnel and tools should be considered in this situation. In such cases, especially with the scale being considered, thinking of numerous installation and O&M personnel that will be moving on these platforms, the durability of access arrangements, and reinforced berthing locations for boats, should be added to the design. These health and safety risks can be minimised through the design of walkways, and access to the structures, or by introducing safe boats or floating barges to access the sites.

Remote monitoring

Operation and maintenance poses a greater challenge in FPV systems, compared to ground-mounted solar or solar rooftop PV systems, because they require access by boat. Sending O&M crews by boat each time there is a performance issue in order to detect a faulty string or module, can become a significant operating expenditure. Since these power plants are located on water, the high voltage could also pose a safety risk for O&M crews.

Pinpointed automatic system alerts, and remote troubleshooting, are critical for floating PV systems where physical access is difficult. Module-Level-Power-Electronics easily detects the faulty module (rather than the entire string) and reduces site visits and time spent onsite during each visit in a cost-effective and efficient manner.

51 Source: Sen A, Mohankar AS, Khamaj A, Karmakar S. Emerging OSH Issues in Installation and Maintenance of Floating Solar Photovoltaic Projects and Their Link with Sustainable Development Goals. Risk Manag Health Policy. 2021 May 13;14:1939-1957. doi: 10.2147/RMHP.S304732. PMID: 34012306; PMCID: PMC8128445.

This specific project is a hybrid power plant developed in Montpezat d'Agenais, France, composed of a ground-mounted solar PV system on 2 ha of land, and a floating PV plant on a 3 ha of water surface; the project has a total installed capacity of 4.8 MW. The water body used for this project is a former quarry. This FPV plant will subsequently save 250 tonnes of CO_2 every year.

Planning phase

The key dates of this project are:

- Building permit submission in February 2018, which integrated all environmental studies and technical analysis;
- Building permit authorisation in May 2019;
- Construction phase started in April 2022, and finished in April 2023;
- Commissioning in April 2023.

Involvement of stakeholders

In order to develop this kind of project, the relevant communication and integration of key stakeholders during the project development is essential. The key stakeholders that were engaged in this project are as follows:

- Mayor and municipal council, which permits Amarenco to obtain urban planning compliance and local political support;
- Intercommunal council for local and political support;
- Administration (regional and departmental levels) in order to facilitate the project's approval process. In fact, consultation is required during the development phase with the Service Administration, allowing for the consideration of environmental and societal acceptance of the project. French regulations are strict; therefore, a well-defined project is necessary;

In addition, a local economy company (semi-public company), helped Amarenco to develop the project. Having a knowledge of the local context (network, political, etc.) and local consultants, is a plus for this kind of project.

Permits and permit granting procedure

This kind of project requires a specific process, notably environmental authorisation. Therefore, the building permit with environmental authorisation has to integrate this evaluation. It follows the same procedures as a ground-mounted solar PV project. This means, project developers need an environmental impact study with ecological inventories conducted over a full year.

This site is a former quarry, not a nautical base or a natural lake. Therefore, it does not pose a significant ecological or human activity impact. In addition, the developers did not encounter any problems with acceptance or reclassification programmes. This lake is classified as a degraded site, which is why the solar plant is favoured.

Technical challenges

The main challenges lie in the final design, aimed at maximising capacity, and the design of the anchoring system. The inclusion of these anchoring systems and knowledge of the water environment (tidal range, possible floodings, etc.) is important to define the executive layout.

During the construction phase, the presence of aquatic animals, specifically coypus, has raised some concerns, particularly regarding cable protection. Amarenco has addressed this issue to protect both the animals and the equipment.

Amarenco's Floating PV site in Montpezat, France. © Amarenco

4

Best practice examples in Europe

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This chapter will focus on outlining different best practice examples of floating PV projects across Europe. The scope of this section is to provide examples of operational FPV projects and showcase the benefits that FPV can bring.

CASE STUDY 5 GROENLEVEN: BOMHOFSPLAS FLOATING PV PLANT, THE NETHERLANDS; (BAYWA R.E)

The Bomhofsplas Floating PV project, built on a sandpit near Zwolle, Netherlands, was commissioned in March 2020 by Groenleven, a Dutch subsidiary branch of BayWa r.e.. The size of the plant is similar to more than 25 football fields and has aninstalled capacity of 27.4 MWp. The floating PV installation covers 25% of the lake's surface and the energy production of the plant is sufficient to meet the energy demands of approximately 7,800 Dutch households.

To achieve a Biodiversity Net Gain at the artificial lake, and evaluate the influence of the floating PV plant on the water ecosystem, 20 Biohuts were installed at the floating plant's edges in 2020 in collaboration with Ecocean, a French business that takes innovative actionin favor of aquatic biodiversity. The objective of the project was to improve habitat functions beneath a floating solar platform installed in a sandpit, as well as to evaluate Biohut's ecological advantage for the park in this environment.

Bomhofsplas Floating solar park landscape. © BayWa r.e.

The Biohuts have been monitored and observed for three years. Between 2020-2023, ecological monitoring of mobile fauna and juvenile fish was performed. The findings indicate that the Biohut ecosystem successfully adapted and the new species also integrated well into the habitat under the floating PV.

The first two monitorings showed a rapid growth in abundance of mobile fauna which stabilised in 2023 during the third monitoring. The wide range of species at the bottom of the food chain, such as daphnia and gammarids, suggests that the Biohut ecosystem is well-balanced and functioning to nourish aquatic life. Observed small arthropods are important because they serve as prey for other fish species and larger animals in the food chain. Their abundance suggests a favorable environment for an increase in diverse fauna, which is critical for the ecosystem's overall health and stability. These findings are highly encouraging and emphasise the Biohut's value as a positive artificial structure for aquatic biodiversity, as well as indicating that well implemented floating PV plants are not hindering biodiversity in water bodies, but can actually foster the thriving of different species by providing additional shelter and shaded areas. The integration of Biohuts into Bomhofsplas' Floating PV plant promoted the establishment and growth of aquatic species, positively improving the ecological state of the lake.

CASE STUDY 6 SEKDOORN CASE STUDY, THE NETHERLANDS; (BAYWA R.E.)

Sekdoorn Floating PV Park was developed and realised in Zwolle, Netherlands by BayWa r.e.'s Dutch subsidiary Groenleven in October 2019. The installed capacity of the project is 14.5 MW, covering 28% of the lake's surface.

BayWa r.e., together with its Dutch subsidiary GroenLeven, set as a target for this installation to lower the CO_2 emissions as much as possible during the construction phase. In order to achieve that, the floating PV park needed green power supply directly on-site.

After accurate evaluation of components and engineering processes, it was decided to only use electric vehicles, tools and appliances on site, and to install a temporary solar-powered battery to kickstart the project without having to resort to fossil fuels, ornecessary inputs from grid connection or generators.

CO_2 emissions were significantly reduced throughout the project. At Sekdoorn, over 10 tonnes of CO_2 were saved by avoiding the use of approximately 4,000 litres of diesel that would have been necessary for conventional construction procedures. Another beneficial side effect is that this also saved over €10,000 which would have been spent on bulky, now unnecessary equipment, without any impact on the efficiency and speed of the construction procedures; the Sekdoorn plant was built in just six weeks.

Looking ahead, this project was a proof of concept to minimise emissions during construction phase, improving sustainability and overall environmental impact of floating PV projects.

Sekdoorn CO_2 neutral construction site.

CASE STUDY 7 O'MEGA 1 & O'MEGA 1BIS, FRANCE; (AKUO)

The O'MEGA 1 power plant is the first Akuo project based on floating PV technology (Hydrelio® by Ciel et Terre floating structure). Located in the city of Piolenc, in south-eastern France, this plant is to date the largest floating PV power plant in France. When it was commissioned in 2019, it was the first FPV in France and largest in Europe. Its extension O'MEGA 1bis was commissioned in 2022.

O'MEGA 1 is a 17 MW power plant, and its extension O'MEGA 1bis increases the overall capacity by 5 MW. With an annual injected power of 30 GWh, this plant provides 5,700 households with clean energy. This plant uses a site that had been artificialised by years of use as a material extraction quarry. The quarry operator and Akuo worked together to rehabilitate the site in order to allow its transition from one activity to the other, as well as the site's ecological restoration.

This floating PV plant is made by a raft of HDPE floats on which the PV modules are placed. The system is mounted on the banks of the lake, then installed on anchor cables connected to moorings placed on the waterbed.

Concerning environmental impacts, the floating PV plant takes into consideration the results of the impact assessment carried out prior to the project, especially with a coverage limited to 45% of the pond's surface. The surrounding biodiversity has been studied since 2020, with annual monitoring of birds, bats, fish, and water quality. The power plant offers quietness on the site, since access is only allowed to authorised personnel. Biodiversity has been thriving since the monitoring started. The number of bird species went from 41 before the project, to 59 in 2021 and 77 in 2022, including 26 breeding on site - in particular in the riparian vegetation and the reedbed growing around the pond. Likewise, the number of bat species recorded on the site rose from 9 in 2018 (before construction) to 16 in 2022. There are no particular signs of degradation in water quality noted (especially on aspects such as metals and hydrocarbons levels).

Furthermore, BioHuts were attached to the floats in 2022, which pose as an artificial nursery for aquatic life, providing larvae with food and shelter from predators. The first survey was carried out in May 2023, showing a quick settlement of the BioHuts by fish, crustaceans and insects' larvae.

O'MEGA 1 & O'MEGA 1BIS location.

© Akuo

CASE STUDY 7 O'MEGA 1 & O'MEGA 1BIS, FRANCE; (AKUO) *CONTINUED*

Finally, the project involved the local community through the creation of educational displays with school children, and the financing of an innovative agricultural project on 6 hectares of wasteland close to the lake.

Omega 1 & O'mega 1 Bis, France. © Akuo

CASE STUDY 8 THE FIELDLAB: FLOATING PV RESEARCH, THE NETHERLANDS; (TNO)

TNO operates a field lab for innovative floating PV system designs under wave category 2 conditions, at the North-East side of the Lake Oostvoorne. Significant wave heights can be up to 1m high. The water of the lake is brackish. The lab is equipped with measuring equipment, a grid connection, and a floating walkway. A reference PV system can be installed on land to do a direct performance comparison with the Floating PV systems.

In 2019, a consortium led by TNO started a first pilot research project on the FieldLab with the aim to investigate three innovative system designs with different configurations on the following aspects:

- Wave and wind resistance of the floating PV system
- Electrical and mechanical reliability
- Cost and electricity yield
- Circularity and ecological design

Partners in this project included: petrochemical company SABIC; Norwegian energy company, Equinor; and the municipality of Westvoorne. Three companies SolarisFloat (Portugal), Isifloating by Isigenere (Spain), and SolarFloat (The Netherlands) were selected to design and construct an innovative Floating PV system of 50 kW. The three systems are shown in Figure 1. From December 2020 until March 2023, the systems were quantitatively monitored and assessed for their electrical performance and structural mechanical behaviour by TNO and MARIN respectively, while the effects of the floating PV islands on the water quality were investigated by the HZ university of applied sciences.

CASE STUDY 8 THE FIELDLAB: FLOATING PV RESEARCH, THE NETHERLANDS; (TNO) *CONTINUED*

The most important findings and reflections of this pilot study are listed below:

Electrically

- Important insights have been gained on the thermal behaviour ("cooling effect") of different floating PV system configurations and their influence on the electrical yield. Based on the collected data, so-called heat loss coefficients could be derived reflecting the thermal behaviour of the FPV system. For all the investigated FPV systems relatively high heat loss coefficients were observed. We found that for a correct interpretation and modelling of the data, it is very important to take wind conditions and direction dependence into account. PV predictive modelling tools to calculate annual yields have been further developed and applied for this specific application including loss factors caused by thermal effects, self-shading, reflection, and non-ideal tracking.
- An important attention point for Floating PV is adequate electrical design, long-term reliability, and safety. Improper cable management may lead to isolation failures causing system downtime or even fire incidents.

Mechanically

- Properly designed systems can withstand harsh conditions, but problems due to fatigue may arise in the longer term, especially for more rigidly designed systems. This implies that long term field tests are preferred to predict the mechanical failure modes.

Water quality/ecology

- No effect on the water quality was found for the three investigated islands. We concluded that the size of the pilot systems was too small compared to the lake area for generating any noticeable effect.
- Bird droppings is a serious point of attention – more vertically tilted systems show however less coverage of bird droppings.
- Underwater growth can be severe and poses challenges, for example when it comes to tracking or maintenance.

Corrosion

- Corrosion of specific components occurs under the brackish water conditions of the field lab. This caused minor issues, but the problems were not catastrophic during the time scale of the pilot project.

FieldLab 3 FPV systems located North-East side of Lake Oostvoorne. © TNO

The floating solar photovoltaic (FPV) market globally is rapidly expanding with global cumulative FPV capacity reaching 5.7 GW. One of the continents that are driving the FPV deployment is Asia. The market growth is driven by a variety of factors that make it a particularly attractive option for many countries in the region. This chapter will provide an overview of key markets in Asia that work towards developing and driving FPV projects. In addition to that, this chapter will also provide an overview of existing policy frameworks across Asian countries.

5.1. Overview of existing initiatives and policy frameworks

Taiwan is another Asian country making strides in FPV. The central government has set an ambitious target of installing 20 GW of solar power by 2025. To achieve this, the government is actively promoting FPV projects through capacity tenders under the Feed-in Tariff (FiT) regime. Water agencies are collaborating with local and central energy authorities to organise these tenders. Some FPV projects are being developed on privately owned land and water bodies, such as former fishing ponds or the Taiwan Sugar Corporation water retention basins. These projects have specific constraints, like not reducing fish production by more than 30%.

a. **Estimation of Yield:** Accurate energy yield estimation is crucial in the planning phase of FPV projects. Unlike ground-mounted systems, FPVs have unique variables like water body conditions and float stability that can affect energy yield.

b. **Quality Control:** The entire supply chain, from manufacturing to installation, needs stringent quality control. Third-party testing and certification of floats are essential for ensuring system reliability.

c. **Standardisation:** Standardising the scope of independent engineer (IE) reviews can improve FPV system reliability. This is particularly important for new components that are unique to FPVs and have yet to benefit from economies of scale.

d. **Environmental and Social Management:** Projects like the Da Mi project in Vietnam have specific FPV-related elements in their Environmental and Social Management Plan (ESMP). These include noise and vibration management during float manufacturing and measures to maintain aquatic habitat functionality.

e. **Technical Risks:** Four key factors must be considered to manage technical risks effectively: estimation of yield in the planning phase, responsibilities of EPC and O&M contractors versus floating solution providers, manufacturing and transport of floats, and standardisation.

f. **Cost-Benefit Analysis:** Early in the development phase, a cost-benefit analysis should be conducted to assess whether the FPV project meets certain minimum investment criteria like economic and financial rate of return, return on equity, and payback period.

g. **Ownership and Site Control:** The ownership of the water body and nearby land can significantly impact the project's economics. For instance, privately-owned sites are generally used for self-consumption with excess power potentially exported to the grid.

h. **Interconnection and Infrastructure:** Synergy with existing transmission infrastructure is crucial for power evacuation. The level of interconnection (high, medium, or low voltage) and related regulations can also impact project economics.

i. **Risk Mitigation for Bankability:** Measures required for bankability and/or credit enhancement need to be identified. This includes understanding and managing technical risks to ensure compliance with project requirements and expected payback levels.

j. **Regulatory Environment:** The time required to secure all authorisations can vary widely depending on the country's regulatory environment. For example, in Singapore, it took Sunseap about 2.5 years to secure the necessary clearances from 13 public agencies for their FPV project.

5.2. Country examples

General Trends

It's worth noting that the time required to move from the initiation phase to the "shovel-ready" milestone for FPV projects can vary widely. This period is expected to shorten as agencies in more regions gain experience with FPV projects. The ownership of the water body, nearby land, and existing transmission infrastructure are some of the key factors that influence the development timeline.

TABLE 1 FLOATING PV GLOBAL COUNTRY EXAMPLES

Country	Description
Singapore	In Singapore, Sunseap, a clean energy solutions provider, has developed the world's first large-scale (5 MW) near-shore FPV project in the Straits of Johor. Given Singapore's densely populated shoreline and the presence of strategic industries like utilities and semiconductor factories, the project faced a complex regulatory environment. It took Sunseap about 2.5 years to obtain the necessary clearances, involving consultations with 13 public agencies. One of the key agencies, the Economic Development Board (EDB), played a key role in securing clearances from other agencies involved, such as the Building and Construction Authority, Singapore Police Force, and Maritime and Port Authority.
Vietnam	Vietnam is another Asian country making significant strides in FPV. The Da Nhim–Ham Thuan Da Mi Hydropower Joint Stock Company (DHD) is developing a 47.5 MW FPV power plant on the reservoir of its existing 175 MW Da Mi hydropower plant. This project is supported by the Asian Development Bank (ADB) and aims to adhere to ADB's Safeguard Policy Statement. The project's Environmental and Social Management Plan (ESMP) includes specific measures for noise and vibration management during float manufacturing and focuses on maintaining aquatic habitat functionality during both construction and operation.
Taiwan	In Taiwan, the central government has set an ambitious target of installing 20 GW of solar power by 2025. To achieve this, the government is actively promoting FPV projects through capacity tenders under the Feed-in Tariff (FiT) regime. Water agencies are collaborating with local and central energy authorities to organise these tenders. Some FPV projects are being developed on privately owned land and water bodies, such as former fishing ponds or the Taiwan Sugar Corporation water retention basins.
Cambodia	In Cambodia, Cleantech Solar has developed a 2.8 MW FPV project on the CMIC cement pond. This project serves as an example of a privately-owned site where the FPV system is used for self-consumption, with excess power potentially exported to the grid.

5.3. Best practice examples globally

CASE STUDY 9 FLOATING PV PROJECT IN THAILAND; (BAYWA R.E.)

A great example of double use of a water surface in a sustainable away is the deployment of Floating PV for self-consumption of existing energy-consuming activities. In the case of BayWa r.e.'s first Floating PV project in APAC, this combination was achieved thanks to the collaboration with Ubon Bio Ethanol PCL (UBE), one of Thailand's leading manufacturers and distributors of processed cassava products.

The project, located in Ubon Ratchathani, about 615km northeast of Bangkok, Thailand, is installed within the premises of UBE's bio-ethanol production facility, on two adjacent water ponds containing water used as part of the cooling processes in production. The floating PV plant, which has an installed capacity of 2.83 MW, commissioned at the end of 2021, is split into two separate floating islands, each in a different pond. The plant is expected to generate about 4,440 MWh of energy in the first year of operation alone, used entirely for self-consumption and providing green energy for UBE's processes, satisfying around 20% of the energy needs of the facility.

Two different floating structure technologies have been deployed over the two ponds, with one using a pure pontoon technology and the other deployed with a pontoon and metal support structure floating technology, supporting a total of 6,900 bifacial PV Modules.

It is an example of how existing water ponds, which already had a productive use, can provide added value thanks to floating PV, generating green energy to decarbonise the energy demands of production facilities, in this case for bio-fuel production.

BayWa`s Floating PV site in Thailand,.

CASE STUDY 10 FLOATING PV PROJECT IN WINDSOR, CALIFORNIA; (LAKETRICITY)

Around every two years, the city of Windsor measures its greenhouse gas emissions and analyses them with the aim of reducing them. In 2017, it was established that 38% of the city's carbon footprint was due to wastewater treatment facilities.

To mitigate the impact of the water treatment plant, the city of Windsor aimed to install solar panels to make the facilities almost energy self-sufficient (at 95%), and thereby reduce the city's carbon footprint. However, it faced a dilemma: there was a lack of available land in Windsor to install an adequate number of solar panels.

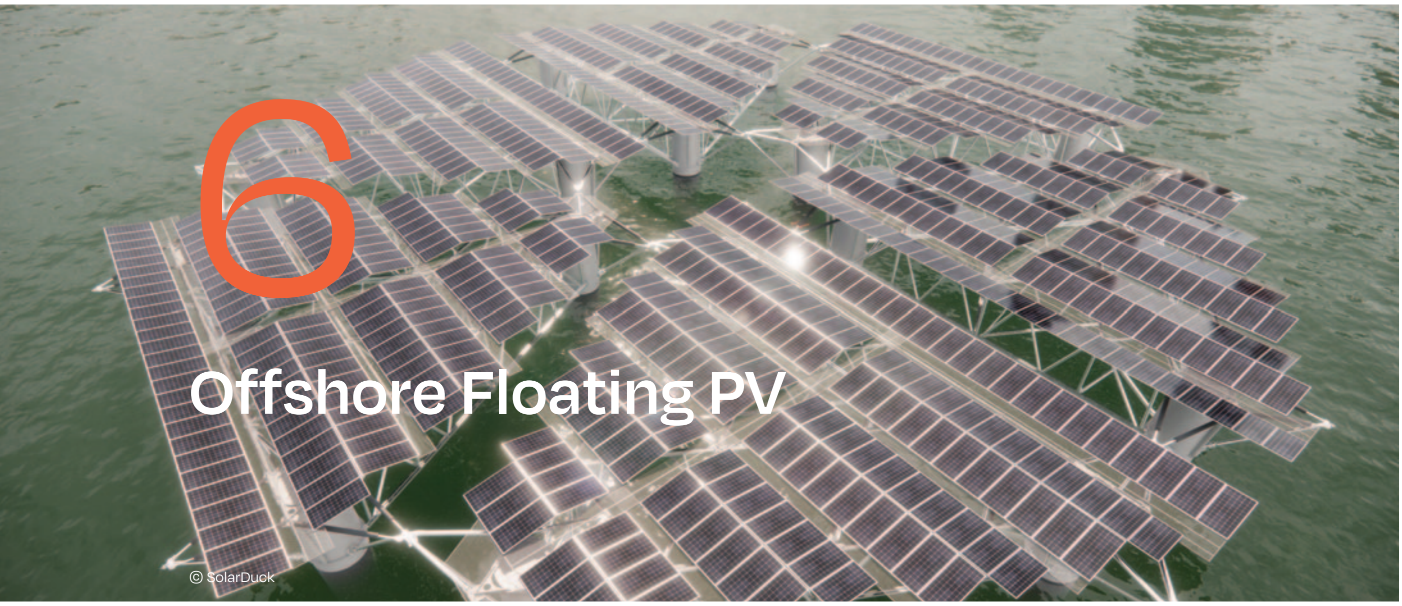
On the other hand, the water treatment pond, which collects the treated, filtered, and disinfected water, offered an available surface area to accommodate floating solar PV panels. The journey with Ciel & Terre and Laketricity could begin. After two years of project development, construction, and installation, the floating solar panels were able to generate electricity for the water treatment plant. This 1.8 MW power plant is the first mega-scale floating PV farm deployed in California. As a trailblazer municipality, the town received the esteemed 2021 Helen Putnam Awards for Excellence in Public Works, Infrastructure, Transportation for the floating PV system. The Windsor project has generated over 2 million kWh per year of renewable energy, equating to more than $210,000 worth of electricity for the town.

The floating PV system was provided by Ciel & Terre. The floating solar company delivered the power plant using Hydrelio® Classic Comfort. The system can help to reduce water evaporation, regulate temperature, and reduce algae growth by covering part of the water surface. The main idea is to benefit from the available water space by adding solar as a second source of energy, while saving water resources to produce at night.

Windsor plant is anchored with percussive driven earth anchors; the anchoring solution has been designed to optimise the space required for landing the plant.

Floating PV site in Windsor. © BayWa r.e.

6 Offshore Floating PV



© SolarDuck

As discussed in the previous chapter, efforts to limit global temperature increase to less than 1.5°C call for a steep change in investments in renewable energy generation. Due to the increase in global warming, which put the 1.5-degree limit at risk, solutions to steer away from fossil-fuel based energy need to be developed. As part of the Paris climate agreement, efforts to limit global temperature increases to less than 1.5°C and reach the global net-zero target by 2050, need to be pursued.[52]

Wind and solar PV are the best positioned technologies to drive the acceleration of renewable energy. The cumulative global solar PV capacity, in particular, is expected to triple between 2022 and 2027 surpassing coal, and is set become the world's largest installed power capacity.[53]

However, growing population and urbanisation pose limits to the widespread adoption of renewable energy. By 2050, it is estimated that the world's population will reach 9.7 billion.[54] In the same timeframe, it is forecasted 2.5 billion more people will live in cities, accounting for up to two thirds of the world's population.[55] This is in comparison to 57% in 2022.[56]

As a consequence, increasing competition for human activity on ever more limited land space, plus growing concerns about deployment of renewable energy infrastructure in built environments (NIMBY effect), call for new solutions to the deployment of renewable energy. The oceans represent a unique opportunity to open a new frontier for solar PV, providing an opportunity to install solar PV in a way which limits competition with other human activity, while remaining close to demand centres and opening up the possibility to co-locate with other infrastructure at sea, such as offshore wind.

The development and deployment of sustainable, reliable, affordable, and modern energy is crucial to ensuring that we meet our global sustainability targets. Offshore floating PV, provides a solution to a number of these challenges.

6.1. New technologies emerging

Despite the fact that Solar PV panels have been floating in inland waters for quite some time, the emergence of offshore floating PV represents a new family of technologies which are distinct from its inland predecessors, despite some similarities in the basic overall architecture.

This includes the panels and inverters which are mounted on floating substructures such as rigid metal frames with floaters, pontoons or foils. These are then anchored to the seabed with mooring lines. However, due to the harsher offshore environments, the substructure design and material selection differ significantly from inland floating solutions. Components have to be designed to withstand the more corrosive environment, and increased wind, waves and currents.

52 Source.
53 Source.
54 Source.
55 Source.
56 Source..

There are 3 main typologies of offshore floating PV technology:

- Flat Pontoon concept - floating pontoons, with PV-panels mounted on top, that are coupled into a modular floating array that is moored to the seabed. The technology is designed to use buoyancy for maintaining the systems very close to the sea surface, this enabling self-cleaning capabilities and additional cooling from sea temperature, whilst preventing exposure to wind forces.
- Elevated Truss concept - platform with solar panels placed on a truss structure, supported by semi-submersible buoyancy elements and moored to the seabed. Waves can move underneath the structure due to elevated design. The system is designed to keep PV panels and other electrical elements beyond the reach of "green water" (sea water from higher wave conditions).
- Foil or membrane concept - very flexible structure following the movements of the waves. Solar panels are mounted on a floating body and must be able to follow the deformation of the floater. During the higher waves' conditions, part of the structure may directly be washed over by waves.

Critical aspects for offshore floating PV include the solar resource measured in irradiation, wave conditions, in particular: the height and the steepness of the waves, and the distance to a grid connection point (such as an offshore wind farm substation or a substation on land). Water depths are preferably in the range of 20-200m, although deep sea mooring is technically feasible and considered more economic than within floating wind industries.

Currently there are around 10 European technology developers of offshore floating PV systems that already have a pilot plant installed or under development (Table 2), although most are installed on protected or inland waters.

TABLE 2 A HIGH-LEVEL OVERVIEW OF THE OFFSHORE FLOATING PV TECHNOLOGY DESIGNERS WHICH CURRENTLY HAVE PILOT PROJECTS INSTALLED OR UNDER DEVELOPMENT

Country	Name	**Description**
Netherlands	Bluewater & Genap	Foil concept/flexible pontoon concept
Norway	Fed Olsen 1848	Pontoon concept
France	HelioRec	Flat mat system based on floating pontoons
Norway	Moss Maritime	Elevated system based on steel, rectangular platforms
Netherlands	Oceans of Energy	Flat mat system based on floating pontoons
Norway	OceanSun	Floating "fish farm" foil concept
Austria	Swimsol	Elevated system
Belgium	SeaVolt	Elevated system based on 4 big steel floaters
Germany	SINN Power	Elevated system
Netherlands	SolarDuck	Elevated system based on aluminium, triangular platforms
France	SolarInBlue	Elevated system based on steel

6.2. Overview of differences between onshore floating PV, near-shore floating PV and offshore floating PV (technical aspects, economic aspects, business case)

In spite of apparent similarities in the technology, essential differences in the technologies exist due to the varied conditions on freshwater/sheltered waterbodies and the open sea.

While the basic concept is similar, a key difference is the substructure of offshore floating PV systems in comparison to onshore floating PV.

The flat pontoon concept is specifically designed for heavy ocean conditions and harsh wave heights and interactions. It has been operational for several years in high-wave offshore conditions in the North Sea. The concept addresses the wave action offshore by using the sea surface for the carrying capacity and by following the waves with flexibility. Specific components are used to interconnect pontoons and allow curvature over the length of multiple pontoons. By building up the modular array towards very large scales of 1+km²/200 MW, wave dampening effects may allow for further reductions of the sea forces. The systems are close to the surface and thereby protected from the heavy wind patterns at sea.

The elevated truss concept is specifically designed to withstand harsh ocean conditions and heavy wave action offshore. Consequently, the truss structure is dimensioned to allow the waves to move under the structure and the PV panels to remain at a sufficient distance away from the water surface. This results in larger structures than required on sheltered or freshwater bodies. The saltwater conditions also drive the use of materials that are not necessarily required for onshore floating PV applications (e.g. aluminium).

In the case of membrane-based concepts, the designs used for onshore floating PV are more similar to the ones aimed to be deployed for offshore floating PV application. However, the greater exposure of those concepts to wave conditions likely will impose limits for deployable areas in terms of metocean conditions. Whilst the principle design for these concepts is similar for freshwater/sheltered waterbodies as well as the open sea, sea conditions still need to be taken into account for design and certification.

The special requirements for anchoring and mooring in the open sea pose a further difference. For onshore floating PV, first of all, mooring can often be arranged from the berth of the water body, and in any case simpler methods of anchoring and mooring can be used, as the forces imposed by waves and wind are not as significant, and water depths are often much smaller. On the other hand, the anchoring and mooring design for offshore floating PV is inspired by floating wind or oil and gas platform solutions. Nevertheless, it is worth emphasising that a need and opportunity exist to develop anchoring and mooring systems optimised specifically for offshore floating PV.

For the electrical equipment, the requirements for the cables are particularly distinct. In onshore floating PV systems, electrical cables are laid over water, whereas for offshore floating PV subsea cables are often required. Due to the additional loads experienced in the open sea, dynamic cables need to be considered. These cables are developed especially for export connection of floating platforms. On the other hand, the majority of inland or freshwater floating PV system technologies today are based on HDPE (High Density Polyethylene) floats, with a small number of PV panels per float which results in a larger number of connections being exposed to constant movement and fatigue, whilst in the case of elevated/truss structures, only the connections between platforms will be dynamic, module to module cables will be static.

Among the main differences between onshore and offshore floating PV are the more demanding installation, and operations and maintenance conditions for offshore PV. The majority of these activities will have to be carried out offshore with vessels, trained personnel and higher safety requirements (more or less demanding depending on the architecture of the technology). Additionally, the distance to the shore varies for onshore floating PV and offshore PV systems, with an offshore system potentially being tens of kilometres out at sea. O&M frequency and inspection requirements could be different for both technologies. Having said that, even though offshore floating PV will put much less stringent demands on people and equipment than other offshore technologies, it is useful that for specific O&M and safety requirements, offshore PV can leverage existing solutions and the expertise of the offshore energy sector.

In summary, offshore floating PV presents at the same time a unique set of challenges, as well as unique opportunity to establish a new asset class that likely will become an essential tool in the energy revolution.

It is more important now than ever to think outside the box to deal with the clear and present danger of climate change resulting from CO_2 emissions. Offshore floating PV has the potential to scale to GW's whilst overcoming the hurdles of land scarcity, grid bottlenecks and societal resistance.

6.3. Stand-alone and hybrid applications

Offshore floating PV may be deployed either as a stand-alone solution or hybridised with other technologies.

Stand-alone

The first series of standalone offshore floating PV projects are expected to be deployed in regions where offshore wind resource is limited and solar resource is high. This will include countries which have close proximity to the equator and lie between the Tropics of Cancer and the Tropic of Capricorn. This region features a number of areas with a combination of high solar irradiance, a dense population and land scarcity issues.

Hybrid "PV + X" projects

Another market opportunity exists where offshore floating PV technology could be combined with other offshore renewable technologies, chiefly but not exclusively offshore wind.

Those hybrid offshore floating PV projects will most likely be developed in markets that are land space or grid constrained, and have both good (enough) wind and solar resource. The most promising offshore solar locations will have high solar resource, benign metocean conditions, and are located near load centres.

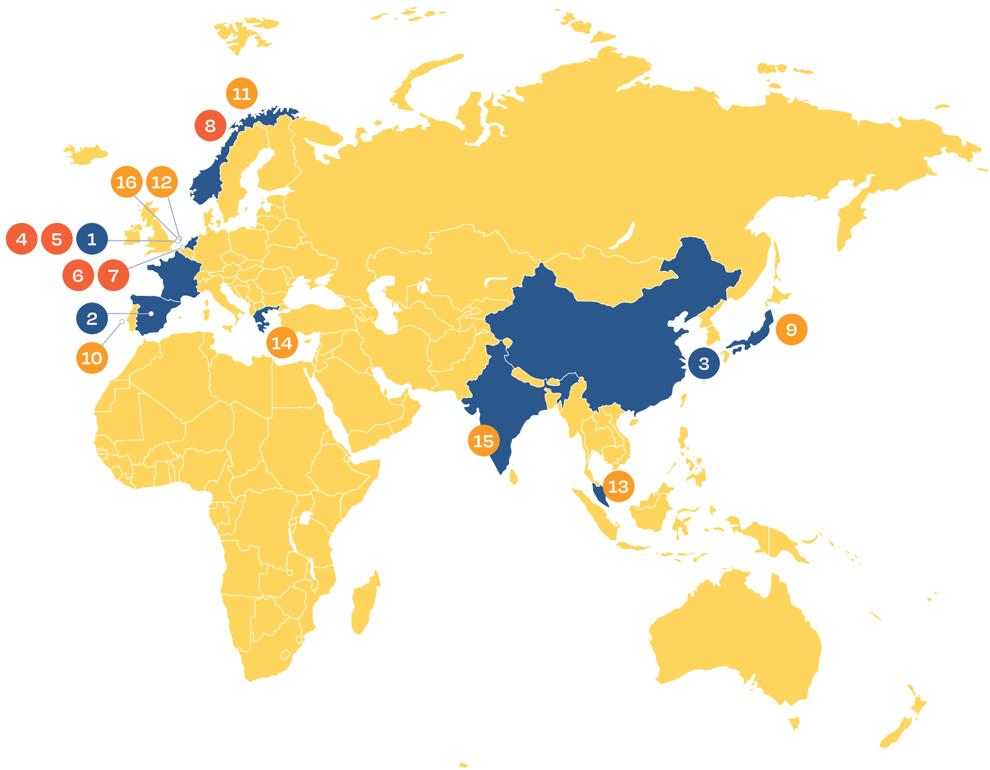
6.4. Highlighted pilot projects

Currently, there are eight offshore solar pilot projects operational or under construction, with a further eight projects under development (see Figure 7). The projects are predominately located in Europe with several projects also emerging in Asia Pacific.

The most significant pilot projects currently under development include EU-SCORES, Merganser, and HKN1, two European technologies piloting at megawatt scale.

- EU-SCORES is a European commission funded 2.6 MW offshore floating PV system by Oceans of Energy, which will be installed off the Belgian coast, co-located with an offshore monopile. The project, led by the Dutch Marine Energy Centre, will de-risk the combination of offshore solar and wind from a financial, regulatory and technological perspective. EU-SCORES has 17 partners which, next to Oceans of Energy and DMEC, also include large commercial partners like RWE, EGP, and SBM offshore, in additionto research partners like Uppsala University, LUT and TU Delft. The project has a commercial operation date of 2024.
- Merganser – an offshore floating PV demonstration project, jointly developed by SolarDuck and RWE, situated off the coast of Scheveningen in the Dutch North Sea. The project has a commercial operation date of 2024. Merganser will be an operational laboratory for SolarDuck, which together with consortium partners TU Delft, TNO, MARIN and Deltares will gather relevant data, such as platform motions, energy output, and life below the water surface. This will also allow TNO to make a validated digital twin of the concept, and Deltares to gain insight on the ecological effects of offshore floating PV technology. The project will comprise 6 linked floating units and have a total capacity of 0.5 MW.
- HKN1 - The 0.5 MW HKN1 Offshore Floating PV project integrated within an offshore wind farm in the North Sea - the 700 MW Hollandse Kust Noord windfarm of Crosswind (developed by Shell & Eneco). The Oceans of Energy technology is planned to be implemented for this purpose and will be grid connected to the baseload power hub. The pilot is part of the innovation programme of the Crosswind wind farm and will become operational in 2025.

FIGURE 9 OVERVIEW OF MOST PROMINENT OFFSHORE FLOATING PV PROJECTS ON GLOBAL SCALE



	Project Title	Developers	Capacity
OPERATIONAL			
1	**NS1 & NS2**	Oceans of Energy	50 KWp & 1 MWp
2	**Sun Sete**	SolarinBlue, Equity, ADEME	0.3 MWp
3	**Haiyang**	OceanSun & SPIC	0.5 MWp
CONSTRUCTION			
4	**BlueWater & Genap Pilot**	BlueWater & Genap	0.2 MWp
5	**Merganser**	SolarDuck & RWE	0.5 MWp
6	**NS3/EU-SCORES**	Oceans of Energy	2.6 MWp
7	**Seavolt Pilot**	Tractebel, Deme, Jan De Nul	
8	**BOLETTE Pilot**	Fred. Olsen 1848	0.15 MWp
DEVELOPMENT			
9	**Tokyo Bay ESG**	SolarDuck, Tokyo Land Corporation & Everblue Technologies	0.2 MWp
10	**BOOST/OceanSun Pilot Gran Canaria**	OceanSun, Fed Olsen Renewables & Partners	0.25 MWp
11	**Moss Maritime Pilot**	Moss Maritime	<1 MWp
12	**HKN I**	CrossWind & Oceans of Energy	0.5 MWp
13	**Malaysia Pilot**	SolarDuck, TNB Renewables, TNB Research and Norsk Hydro	0.78 MWp
14	**Greece Pilot Projects**	(Developers to be announced)	1 MWp
15	**Arabian Sea SolarinBlue Pilot**	SolarinBlue	1 MWp
16	**HKW II**	RWE & SolarDuck	5 MWp

SOURCE: RWE.

CASE EXAMPLE:

North Sea One (NS1), followed by North Sea Two (NS2) projects, are the first offshore solar projects at the North Sea, as well as the first solar farms in high-wave offshore conditions in the world. Under development by Oceans of Energy, the NS2 Offshore Solar farm is currently being expanded to MW-scale and grid connection. It is situated 12km offshore the Hague, and has been operational since the end of 2019. The pilot has withstood all storms incl. Ciara, Dennis, Bella (2020), Evert (2021), Corrie, Dudley, Eunice, Franklin (2022), Poly, and Ciaran (2023) with 10+m high waves. The project placed offshore solar on the map, and is supported by partners including: TKF; Primo-Marine; TNO; Deltares; WMR; NIOZ; Utrecht University; the Dutch Ministry of Economic Affairs and Climate. The project collaborates with several innovation programs incl. Horizon-2020 "UNITED," Interreg 2SEAS "ENCORE," and MOOI "SENSE-HUB."

Images of the North Sea Two (NS2) offshore solar pilot (0.5 MW) during summer day (top) and during storm (Poly 2023) (bottom) at 2 km offshore in conditions similar to Holandse Kust Zuid wind. The Oceans of Energy offshore solar system has been operational since 2019-Q4 and technology received certifcation from DNV & Bureau Veritas.

6.5. Policy frameworks starting to emerge in the EU

There currently are no existing frameworks in Europe or worldwide that specifically accommodate offshore solar standalone or hybrid projects. However, there are several European markets, including the Netherlands, Malta, Italy, and Greece which are developing emerging policy frameworks to accommodate this nascent technology.

RECOMMENDATIONS FOR POLICYMAKERS:

- Consider practices applied by other EU member states (e.g. Netherlands) and the role those specific national targets for installation of offshore floating PV may have in supporting the technology development and LCOE improvements.
- Identify barriers (e.g. complex planning permission process) and measures to overcome these barriers (e.g. streamlined permitting process with thorough EIA, socio-economic assessments and public consultation levels), including concerted action and involvement of regional and local planning authorities in defining these measures.
- Increase public support to offshore solar projects by encouraging consultation with local authorities and communities during the development phase.
- Support innovation in offshore solar technologies by means of additional public-sector funding (e.g. NextGenEU) to national R&D and demonstration programmes and projects.
- Provide adequate level of financial support to offshore solar projects, especially in their early stages of operation and/or where market conditions may be challenging (e.g. costly grid connection due to land and other environmental constraints, inadequate supply chain and/or port infrastructures).
- Ensure the transmission grid is effectively developed and reinforced to allow connection of offshore solar projects, especially those located off islands or other remote areas.

Birds resting on floating solar panels in artificial lake Sekdoornse Plas,Zwolle, The Netherlands.

6.6. Benefits of offshore solar

To meet global targets and reach net-zero by 2050, the world needs to significantly increase the use of renewable energy sources. Offshore solar opens a new frontier for solar energy, having the potential to provide a crucial answer to increasing land scarcity by allowing gigawatt-scale solar deployment. The technology offers a number of additional benefits as compared to other renewable technologies.

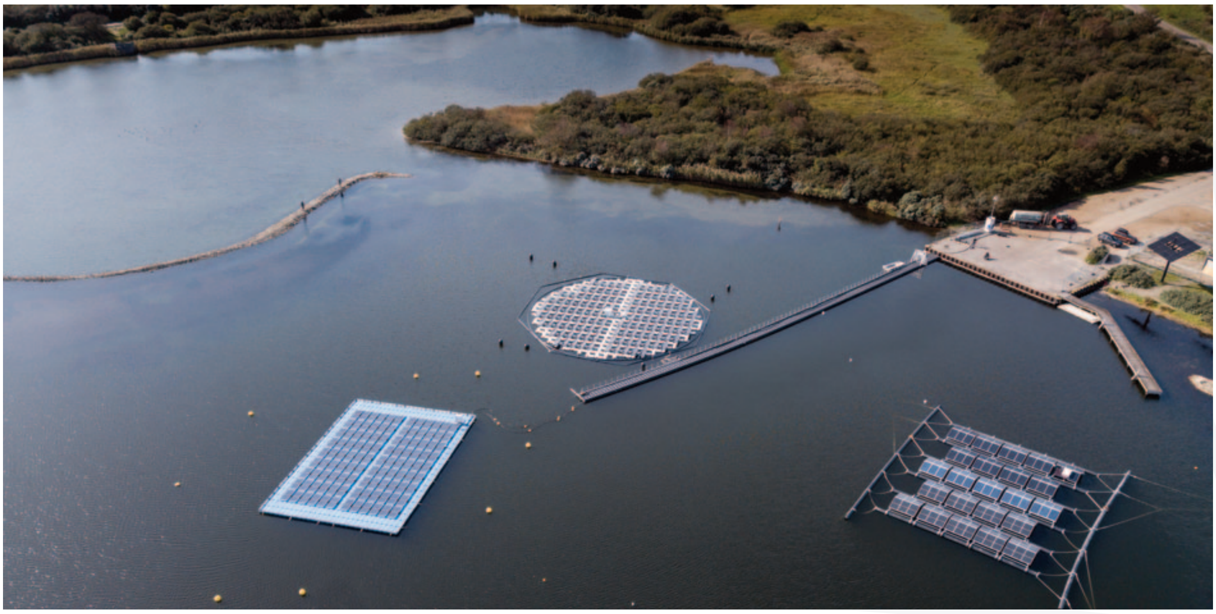
BENEFITS OF OFFSHORE SOLAR

- Offshore floating PV could **open up new markets** in locations where other renewable energy solutions are simply not feasible or economical.
- The solar resource at sea **is superior to land**, with less cloud over and no shading issues, resulting in an extremely abundant resource.
- Offshore floating PV has a very high "energy density", in other words **much more capacity** in MW terms can be deployed per unit of area (km^2). Even taking into account the lower capacity factors, a given area of ocean should be able to **generate significantly more energy** from PV technology, even though as mentioned above wherever possible a combination of both is likely to yield the optimum outcomes.
- Offshore solar can **utilise the existing supply chain** of oil and gas and floating wind, for example the mooring equipment, which is particularly advantageous for markets which host the assets because they may benefit from the manufacturing, construction and maintenance of the projects by **creating jobs** and local manufacturing development.
- The technology also lends itself to some components being manufactured centrally, and shipped around the world in standard containers, which will **enable economies of scale** and **low assembly costs.**
- Onshore solar PV has demonstrated its potential to be the renewable energy with the **most explosive growth potential,** time and time again exceeding mainstream deployments forecasts. Offshore floating solar presents the same scalable potential, with arguably **less of some of the barriers** that land-based PV has had to deal with in the past.
- It has a very **low visual impact** which means that in addition to being offshore, and less exposed to the "NIMBY" challenge, it is also less visually challenging than offshore wind turbine generators might be, which in some markets has triggered community resistance. Offshore solar can help **mitigate tensions or conflicts** regarding the use of land for renewable energy generation.
- Once regulatory frameworks are in place, it is likely that **development timelines will be significantly shorter** than other technologies. Offshore floating PV does not require the highly-specialised assets that offshore wind does, and the individual structures involved in terms of mass and dimensions are an order of magnitude smaller, **reducing the effort and time required.**

ADDITIONAL BENEFITS FOR OFFSHORE SOLAR HYBRID PROJECTS

- In offshore wind and solar hybrid projects, it can leverage significant synergies in project development, grid connection infrastructure and possibly other construction, operation and support resources.

- In addition, offshore wind and offshore solar energy availability profiles are largely inversely correlated, meaning that in general when one is high, the other is low both on an intra-day basis as well as over a yearly period (seasonal variations). A TNO study commissioned by RVO and TKI Wind op Zee, released in 2022 (Analysis of wind and solar generation profiles for multi-use offshore wind farms), suggested that adding 1 GW of offshore floating PV to 1 GW of offshore wind would result in 20% more energy output with only 6% of the total energy having to be "curtailed", in other words limiting the renewable output in the infrequent times when both wind and solar PV outputs would exceed the export cable capacity. The benefits are a higher utilisation of the available grid connection, more renewables for the specific market and a "smoother" injection of renewable energy into the grid with fluctuations dampened by the complementary technologies.



Different types of floatings solar Pv. © TNO

6.7. Challenges of offshore solar

To accelerate the commercialisation of offshore solar there are challenges that the industry must overcome.

CHALLENGES OF OFFSHORE SOLAR

- Durability: **additional experience** for performance at sea in real conditions over time needed to **prove survivability** in harsh conditions and over plant life (extreme loads, fatigue and corrosion).
- Substructure: design of the substructure **needs to be optimised** for cost-efficiency and simple manufacturing without comprising durability.
- Integration: concepts for cost-effective electrical interconnection of stand-alone and hybrid farms need **to be developed.**
- Yield: **certainty** on offshore solar resources, the cooling effect and soiling and effects of movement is needed to predict production.
- O&M: requirements for cleaning and maintenance **need to be understood** and robotic solutions established.
- HSE: **Safe by design** methodology to be implemented from the start preferably by leaning on the extensive experience and expertise within the offshore industry for safe installation, access and maintenance.
- Environmental:
  - i. The impact of marine life on offshore floating PV systems, for instance marine growth is a **much larger challenge** than in freshwater habitats and is a function of the amount of submerged area.
  - ii. Evidence on the potential impacts of large-scale offshore floating PV on ecosystems still **requires more research**, especially regarding **potential impacts** on ecosystems from blocked or reduced sunlight.
- Policy frameworks: Adequate policy frameworks **need to be developed** and promoted while respective tenders are launched to firstly support the deployment of stepping stone projects followed by commercial-scale capacities. To drive the technology advancement forward, the characteristic costs of innovative technologies must be taken into account and **financial incentives** as specific feed-in-tariffs need to follow.

Summary

Offshore solar opens a new frontier for solar energy, having the potential to provide a crucial answer to increasing land scarcity by allowing gigawatt-scale solar deployment. The emergence of offshore solar presents the introduction of new technologies, which are distinct from its inland predecessors, to withstand the harsh offshore conditions.

There is a large market opportunity for offshore solar, either as a stand-alone or a hybrid business case in combination with other forms of renewable energy. Currently, pilot projects are predominantly located in Europe, where there is emerging supportive policy framework, but there is also emerging activity in Asia Pacific. Offshore solar technology has several benefits, including high scalability and supporting decarbonisation but there are several challenges that the technology must overcome to accelerate commercialisation. In spite of these, the establishment of a new assets is an essential tool in the growth of renewable energy.

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