CHALMERS
UNIVERSITY OF TECHNOLOGY

# Floatovoltaics

## *Possibilities with floating solar energy and how it is affected by salt*

Solar Energy: from Photons to Future (Societal) Impacts
TRA105 22/23


Måns Ljungström
Gerardo López Pinto
Ellinor Wagnsson

# Contents

# 1 Introduction

Looking at global trends, energy use is steadily increasing and is expected to increase even more [7]. To supply the future needs without increasing use of fossil fuels, preferably entirely without them, green energy has to start dominating the market. Green energy includes several technologies but the most common ones are wind, hydro and solar energy. Out of the mentioned, solar energy is the one with the greatest potential since it uses the steady flow of energy from our sun. However, it does not come without challenges...

One area of conflict is land usage where buildings, farming, infrastructure, and solar plants all compete for the same land. Solutions such as integrating solar cells in and on buildings, as well as merging agriculture and solar farms have been recently introduced. One solution that is less explored is completely moving photovoltaics (PV's) from land to water by placing them on floating structures, so called floatovoltaics.

## 1.1 Aim

The aim of this study is to analyze floating photovoltaics (FPV's) as an emerging solution for photovoltaic installations in order to increase the total photovoltaic capacity installed globally.

This study will describe the technology from different perspectives, such as technical, economical, environmental and social. It will also create a picture of the current status of FPV, including advantages, disadvantages, potential, limitations and other alternatives to traditional PV's.

## 1.2 Research Question

The research questions that this study will answer are the following:

- What are floatovoltaics and why are they a good alternative to photovoltaics installed on land?
- What are advantages and challenges for floatovoltaics?
- What is the current status of this technology?
- What are technical, economical, environmental and social implications of floatovoltaics?

# 2 Literature review

## 2.1 Photovoltaics

Our sun offers a free and abundant energy source available for everyone and everything on earth to take part of [10]. In one way or another, the sun is the source of almost all energy available on earth, but to directly turn this great source of energy into electricity has taken some time to accomplish. The first solar cell was manufactured in 1883 [19], but it is not until the last two decades that the solar energy market has begun to accelerate. Now we can see solar modules e.g., on rooftops, solar power plants along roads, and in several smart technologies used in our everyday society.

### 2.1.1 Solar cells, how do they work?

Solar cells, or photovoltaics, are based upon the principle of light being able to act as small particles, photons, and the photovoltaic effect where light is directly converted into electricity by using semiconducting materials [18]. How electricity is created within the solar cells is a quite simple process. First, light shines on the device through a protecting surface material, then the light hits the semiconducting material where electrons are excited when a photon with energy greater than its band gap is absorbed [10]. The free excited electron moves through an external created circuit, after which the electron returns back to the solar cell where the process repeat, which is illustrated in Figure 1 below. Solar cells are coupled in series into solar modules, and these modules are then coupled in series/strings and in turn are connected to inverters where the direct current (DC) is converted to alternating current (AC) sent to the electric grid.

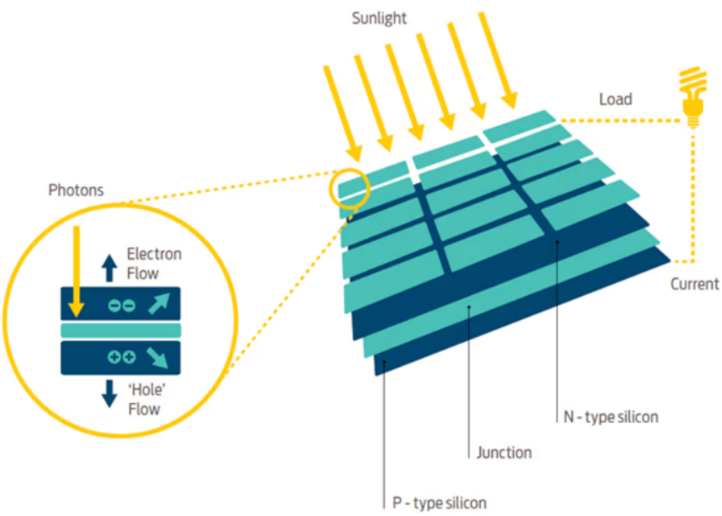



**Figure 1:** The photoelectric effect in a p-n junction silicone cell [8].

The theoretical maximum efficiency of a single junction solar cell is approximately 33%, but in reality the efficiency ranges between 15-21% for commercial modules (depending on materials)[10]. In addition to effectiveness varying between material compositions, shading has a large effect. In modules the solar cells are coupled in series and when a cell is shaded it causes all cells coupled in that string to drop down to the same level [10]. To prevent a power output of zero, bypass diodes are used. One bypass diode is used on a group of solar cells (to keep costs down) and if a cell in this group is entirely shaded the bypass diode let the current flow another way (thorugh the diode instead of the shaded cell) so that the module does not get affected and thus can keep creating current.

### 2.1.2 Materials

As mentioned, materials used for the photovoltaic energy conversion are semiconductors, where the important form of these includes a p-n junction [10]. P-n junctions create an "electron hole pair", meaning that the photon absorbed results in a free electron on the p-side traveling to the "hole" in the n-side through the external circuit. In conventional solar cells, crystalline silicone (c-Si) is the most exploited material due to its stability and abundance [16]. However there are some limitations using silicone where the major one is that the modules tend to be inflexible and "bulky". Therefore, new technologies are being developed, such as thin-film and perovskite PV, which both are thin-film options aiming to improve aestehics, color, flexibility and more light weight options. Materials used are e.g., Cadmium Telluride (CdTe) and Copper Indium Gallium di-Selenide (CIGS). They show great potential in high absorption coefficients, near ideal band gaps (≈1,5 eV), and low payback times while being around 40 times thinner. However, there are still some challenges regarding toxic material usage in thin-film manufacturing and reaching stability and efficiency as high or higher than c-Si PV to be a competitive option, thus silicone is still dominating the market.

### 2.1.3 Where are they used?

Solar power plants are most beneficially located where there is a large amount of yearly solar irradiation. The power plants can have different layouts where ground mounted with fixed or rotating axles are most common. However, due to the great potential of solar energy and new emerging, more efficient technologies, solar modules are used in more areas and places. To not take up valuable land, a combined agriculture and solar power plant "agrovoltaics" has been introduced. Similar thoughts are applied for building integrated photovoltaics, where solar cells are installed on buildings or used in building materials to not take up additional land areas. Furthermore, a technology which has taken the land usage problem even further is "floatovoltaics", where modules instead are floating on water. The mentioned alternative locations are dealt with in the following sections.

## 2.2 Floatovoltaics

Floating photovoltaics (FPV) or, floatovoltaics, is a rather new niche within the photovoltaics technology which consists of PV panels installed on floating structures that are placed at the surface of any type of water body, as for example lakes, ponds, reservoirs, hydroelectric dams, and perhaps even the sea (on- and offshore) [14]. This is an attractive photovoltaic alternative when land is scarce, expensive or highly disputed among industries. The first floatovoltaic system was installed in 2007 in Japan and following installations can be found, among others, in the United States, Italy, France, Spain, Norway, Korea and China, which has the largest installation to date with a capacity of 320 MW [4]. Given the relative young age of the technology, it must be mentioned that many of these installations have been rather small and serve as test projects to investigate the potential of the technology.

Floatovoltaics are a promising solution for solar energy generation, however it is a niche that is still growing and it is not as widespread as other alternatives. In the next sections their potential and limitations will be examined from different perspectives: technical, economical, environmental and social. Alternatives to this technology will also be briefly reviewed as a form of comparison between PV solutions.

### 2.2.1 Technical Aspects

Floatovoltaic installations function largely in the same manner as a land-installed photovoltaic installations, with the main difference being the platform on which the panels are installed. The floating platform and its anchoring system are key components of these installations. Another difference in the installation of FPV, which could be considered an advantage, is that the alignment of the panels does not have to be as strict as that of land installations due to the floating nature of the platform. Additionally, the site where FPV are installed does not have to be prepared beforehand [14]. Component-wise, the main parts that compose a floatovoltaic system are:

1. Floating platform
2. Anchoring and mooring system
3. Electrical components
4. Combiner box
5. Central inverter
6. Photovoltaic panels

The floating structure, as one of the main components for this type of PV installations, keeps the solar panels above the water level and are often made of plastic materials, such as HDPE (high-density polyethylene). The anchoring and mooring system are responsible to keep the PV installation in place so that drifting is avoided and so that the installation's position adapts to the changing water levels of the water body. The materials used for these systems usually are concrete ballasts or helical piles for the anchoring and steel wires or synthetic ropes for the mooring lines. Regardind the types of PV panels used for floatovoltais, the most common are the crystalline modules as well as glass modules; the latter are used due to the protection that the glass provides to the module against water [15].

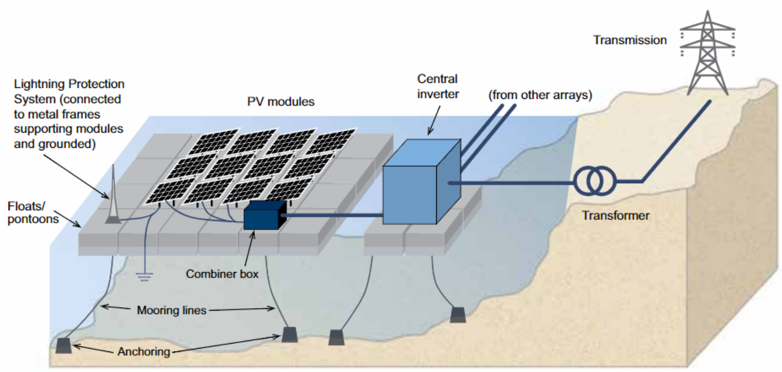



**Figure 2:** Components of a floatovoltaic installation, [14].

Regarding energy generation, a market report by the World Bank and the Solar Energy Research Institute of Singapore has stated that the global potential of the technology could, exceed 400 GW - this capacity was the total combined capacity of all PV installed globally in 2017 [20]. This potential is forecasted under very conservative assumptions as it only considers if FPV were installed on 1-10% of all man-made water reservoir area available in the world. This area corresponds to 4 000-40 000 $m^2$ out of a total 400 000 $m^2$.

Due to the type and potential places of installation, floatovoltaics present some advantages over other PV technology. Some of these, as proposed by Liu, Kumar, and Reindl [14] are:

- No or reduced land use.
- Easy installation and deployment.
- Increasing market potential.
- The panels could receive more direct sunlight due to less shading.
- Installation near existing electrical infrastructure and combination with other energy sources (e.g. hydropower).
- Installation near or in combination with already installed on- and offshore structures and/or industries (e.g. offshore wind installations or fish farming).

An important parameter for photovoltaic efficiency is the temperature of the modules; when the temperature is too high the efficiency of the modules starts to decrease. Because of this, an important advantage of FPV over conventional land-based PV is that due to their floating nature, it has been shown that the water acts as a natural cooling agent, keeping the floating modules at a lower temperature than land-based modules. An experiment performed by Gowami et al. in India compared the module temperature of one FPV installation and one land-mounted installation. This experiment showed, during a period of 30 days, that the surface temperature of the FPV modules was always lower than the surface temperature of the land-mounted modules. For a certain day with an outside temperature of 34°C, the temperature of the FPV module's surface was measured to be 47°C while the land-mounted module's temperature was 59°C [9]. This experiment also showed that the efficiency for the FPV was higher and this, the power output of the FPV outperformed the land-based installation; it is assumed that as temperature is an important parameter for solar cell efficiency, this played an important role in the increased efficiency of the FPV modules. In this specific experiment, the power output of the FPV module was calculated to be around 10.2% higher.

Regarding technical challenges, most of the current FPV installations are not found in off-shore locations but rather in in-land locations, as the water and wave movement in these freshwater locations is not as aggressive as in off-shore sites. With that in mind, one of the main challenges of the still-developing FPV solutions is the lack of appropiate floating structures that can withstand the stress from ocean waves. Currently, according to Oliveira-Pinto and Stokkermans "*the FPV sector lacks technology convergence with regards to floating systems*" [15]. Due to this lack of convergence/adaptability and current limited widespread use of PV on floating structures, there are limited possitiblites for off-shore floatovoltaics.

It is worth mentioning, as before, that floatovoltaics is a rather new and still small option for PV deployment and this could explain current lack of convergence between floating structures and floatovoltaics, hence the limited possibilities for off-shore FPV installations. However, there is ongoing research in floating structures specific for FPV and there are already few pilot installations in off-shore FPV: two in the North Sea and one in the

Maldives, to mention a couple [15]. If these installations are successful, the involved companies will look to expand and increase power generation capacity and improve their respective floating structures.

### 2.2.2 Economical Aspects

At the moment, the biggest market for floatovoltaics is Asia, as most of the current installations can be found in this continent. However, the European market is showing potential, especially in the Netherlands due to the amount of inland water bodies that the country possesses. Also, the potential for a FPV market has been studied in Germany and it has been stated that it could reach 3 GW-peak by using only coal mine lakes [15].

Regarding costs, capital costs for floatovoltaic systems are generally more expensive than a ground-mounted systems by approximately 18%; this is mainly due to the floating structure, the anchoring and mooring system and special electronic components. However, due to economies of scale, it is expected that the price will decrease as the technology becomes more developed and more widely adopted. Costs will also vary depending on the country and the size of the installation; as of 2018, Japan had installed the most expensive system with investment costs of 3.12 USD/Watt-peak and a capacity of 2 MW. On the other side of the spectrum, India had managed to install in 2018 the cheapest systems with the lowest cost at 0.83 and 0.92 USD/Watt-peak, and with capacities of 5 MW and 2 MW respectively [20]. It must be mentioned that despite installing the most expensive system in 2015, Japan also managed to install in 2018 a system at 0.97 USD/Watt-peak and capacity of 13.7 MW. The cost of ground mounted PV depends heavily on the country where it is installed, as the cost of land would change, but currently it would generally be cheaper than FPV by, as mentioned before, 18%; this would mean that while a flotavotolvaic installation would cost 0.83 USD/Watt-peak, its land-mounted counterpart would cost 0.68 USD/Watt-peak.

Despite capital costs being higher for FPV, these systems have shown to achieve a higher energy yield between 5% and up to 15% in warmer regions; this is because water serves as a cooling agent keeping the modules from getting too warm and thus increasing efficiency. Because of this higher energy yield, it has been estimated that for the current status of FPV the levelized cost of electricity (LCOE) does not differ considerably from PV installed on land [20]. Currently the LCOE for land-based installations ranges from 45-56 €/MWh and for FPV it is around 53 €/MWh, considering a 10% higher performance of the latter; this FPV LCOE cost is expected to decrease also due to economies of scale [15]. Additionally, due to a higher efficiency of FVP than the land-based solution, a higher return on investment of the system could be expected [9].

Cost of land, an important contributor to the overall cost of PV projects, depends on the country of installation; but it could be assumed that in most cases there will be competition for the land among different industries, and this could be an important factor that increases the cost of land. However, this cost is disregarded for floatovoltaic systems, since they are installed in water bodies. The costs related to location of floatovoltaic projects can vary depending on some parameters, such as depth of the water body and variations in that depth [20].

According to a report by the World Bank, financing for FPV project can be, divided into two groups [20]:

- Projects with an installed capacity greater than 5 MW-peak. The business model for this type of projects is self-generation and the ownership corresponds to independent power producers or public utilities. The financing for these installations comes from a mix of debt and equity (usually 80/20).

- Projects with an installed capacity of 5 MW-peak or lower. For these, the business model is usually self-generation of energy and the ownership corresponds to commercial and industrial companies. They are financed through pure equity or corporate financing. This means that the company decides by itself to install a FPV system for their own benefit.

### 2.2.3 Environmental Aspects

How a floatovoltaic installation will affect the environment varies greatly with the context of that environment. The first and main concern is the shade created by the installation, as this shade will impede the productivity of photosynthesis of aquatic plant life. This effect depends on the depth of the water column and if the bottom is within the euphotic zone (where enough sunlight is present for photosynthesis) sedentary lifeforms such as seagrass and corals will be highly affected [11]. In contrast, the rest of the water column in shallow water is only negligibly affected [13].

The second effect is the physical effect on the seabed. Tides and wind will affect how the cables for power and anchoring move. This may scrape the sea- or lakebed, again being particularly harmful to sedentary lifeforms. Additionally, this can disturb sediment and further reduce incoming sunlight and harming sedentary plants. The installation of the anchoring can potentially disturb sediment with a similar effect [11].

The third problem is the potential spread of invasive species [2]. The installations are usually constructed in harbours and towed to the deployment site. Invasive species are usually more common in harbours, and the towing risk spreading them to a new habitat. The installation further risk transform the area from an open water column with soft sediment, to and area more closely resembling a shore like area with hard structures close to the surface and hard concrete anchoring the installation to the seabed [11]. This creates a problem for the biodiversity in the local area. However, there are some positive aspects to this. The new habitat will disproportional favour smaller organisms at the base of the food web, with the possibility of creating a spill over effect and create more food for larger organisms in the surrounding area. Additionally, it can create a good spawning ground and nursery for open water species.

In lake and freshwater installations specifically, floatovoltaics have been shown to increase water quality by preventing algal blooms and through impeding evaporation [11].

These environmental issues and potentials have put a greater emphasis on the planning stage of a floatovoltaic installation, to choose the right location and minimise the harm done and maximize the potential benefits [11].

### 2.2.4 Social Aspects

If looking at the social benefits of floatovoltaics, they can be a great alternative energy source for the same reasons why it may be economically beneficial; they do not compete for the same land occupation as when installing conventional PV's. If floatovoltaics are further installed in combination with hydropower (e.g. on dams) it will not disturb ocean areas and decrease their values, while at the same time possibly reduce evaporation and increase PV efficiency due to cooling. Moreover, major part of existing floatovoltaic plants are installed upon industrial basins, drinking water reservoirs or irrigation ponds [20], where similar benefits can be distinguished.

A study from the Netherlands [3] examined the social aspects of implementing floatovoltaics on the lake *Oostvoornse*. By interviews with different stakeholders, results shows that the main concern amongst people was the negative effect on recreational values of the lake as well as the novelty of floatovoltaics and related uncertainties of how they might affect the environment. But worth mentioning was that recreationists had a positive view on installing floatovoltaics due to possible social gains in a broader perspective through green energy.

An example where installing floatovoltaics have had positive consequences is in China where collapsed coal mines are being converted into floatovoltaic power plants [20]. Besides replacing coal mines known to have poor working conditions and cause fossil fuel emissions, the floatovoltaic replacement has also contributed with education of former coal mine workers (in how to run and maintain the power plant) and an employment offer with higher salaries.

## 2.3 Alternative PV Technologies

Some benefits created by the floatovoltaics can be matched by other competing thechnologies using solar PV. These mainly save land area, similarly to flotovoltatics, either through building integration or dual-land use.

### 2.3.1 Agrovoltaics

Agrovoltaics is the integration and combination of photovoltaics with agriculture in a hybrid system. This is in opposition to the traditional land use, where distinct plots of land are sole used for one purpose: e.g., food production or fuel production. The theory is based on the idea form of agroforestry, meaning that combining production on the same plot of land will increase the overall productivity. In agroforestry, shading provided by trees increases the productivity of the crops enough to partially offset the productivity lost due to decreased area used for agriculture. Agrovoltaics utilises the same principle but uses PV modules instead of trees [5].

Simulations preformed by Drupraz et. al indicate that the overall productivity of the agrovoltaic system is 60-70% higher compared to separated land use. If these results are reprievable in a real world setting, agrovoltaic would prove a highly effective use on land area [6]. A potential application issue is that not all crops are suited for the mixed system. Wheat is a cereal that reacts poorly to decrease with decreased exposure to sun light. When grown in shade wheat productivity drops to 49%. This is opposition to lettuce, which simple grow larger leaves to adapt to reduced light levels [5].

When used properly the total increase of agrovoltaics seems like a great option. But the loss purely food-based productivity can be both a financial and political issue. The agricultural industry is engrained in the socio-economic and political system. As any establishment they are slow to change as can be exemplified in resent development in Scania, Sweden. Highly productive farmland was decided to be used for solar park, which was met by a large amount of pushback. While using agrovoltaics could reduce the pushback, other options might be easier to integrate into society.

### 2.3.2 Building Integrated Photovoltaic (BIPV)

Building Integrated Photovoltaics (BIPV) are materials with photovoltaic qualities replacing conventional materials in exterior parts of bulidings [12]. Advantages with BIPVs are mainly that new land does not have to be exploited since the building will occupy the land regardless. Main areas where BIPV can be found are roofs (sloped or flat), facades and shading systems, where the most beneficial is south-facing sloped roofs [1]. Thus, as implied, placement of solar panels are important. If used on a building the efficiency differs mainly depending on the angle, as can be seen in Figure 3 below, where a solar panel located on a tilted roof in southern direction is fully utilized.

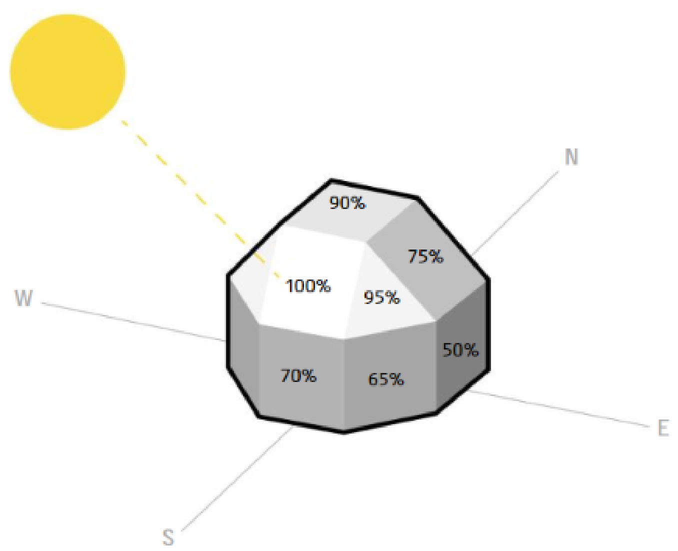



**Figure 3:** PV efficiency depending on angles of surfaces on buildings [1].

Angle and location of BIPVs are not only important in the aspect of reaching as high efficiency as possible but also if looking at shading effects. Homogeneous shadows (hard shadows created by e.g., chimneys) can cause the current to drop down to zero if not using bypass diodes, but heterogeneous shadows (soft shadows e.g., from trees) allows for some sun rays to pass through and the module can still create current [17].

There are different approaches to whether BIPVs should be visible or invisible, in some projects solar cells are "fronted" to show that solar energy is used, while in other projects the cells cannot be seen due to cultural heritage etc. With emerging thin-film technologies it enables a more integrated use of solar panels where for example modules can have the shape, color and surface structure as tiles which will not change the look of the building while still creating energy.

# 3 Experiment

One of the issues using PV's in a marine setting is the risk of salt getting stuck on the PV modules. Droplets from the sea will stick to the module and, when dried out by the sun, depositing a layer of salt. The deposited salt may block incoming photons and reduce the efficiency of individual cells and furthermore the entire power plant. Therefore, to appraise the effect salt has on module efficiency, a simple experiment trying to simulate this was conducted.

## 3.1 Method

The power output of a solar module is related to the created current (I) and Voltage (V) and can be displayed in an IV-curve, as in Figure 4 below. To create such IV-curve the important values are the short circuit current, $I_{SC}$, the open circuit voltage, $V_{OC}$, and the current and voltage at the maximum power point, MPP (where the power output is at its largest)[10]. $I_{SC}$ is measured when the voltage is at zero and vice versa ($V_{OC}$ is measured when current is zero).

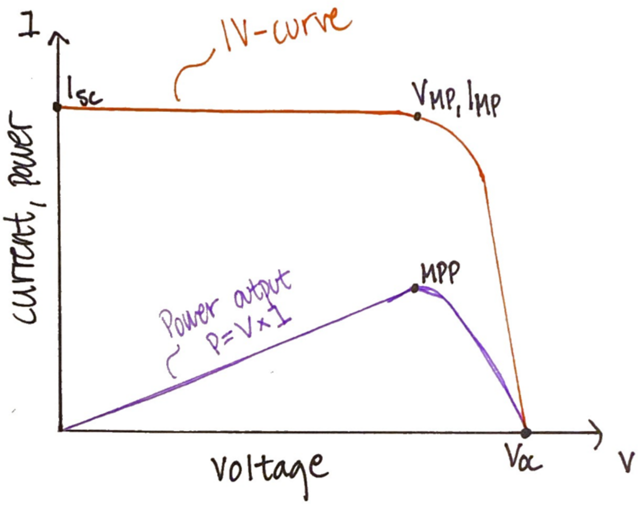
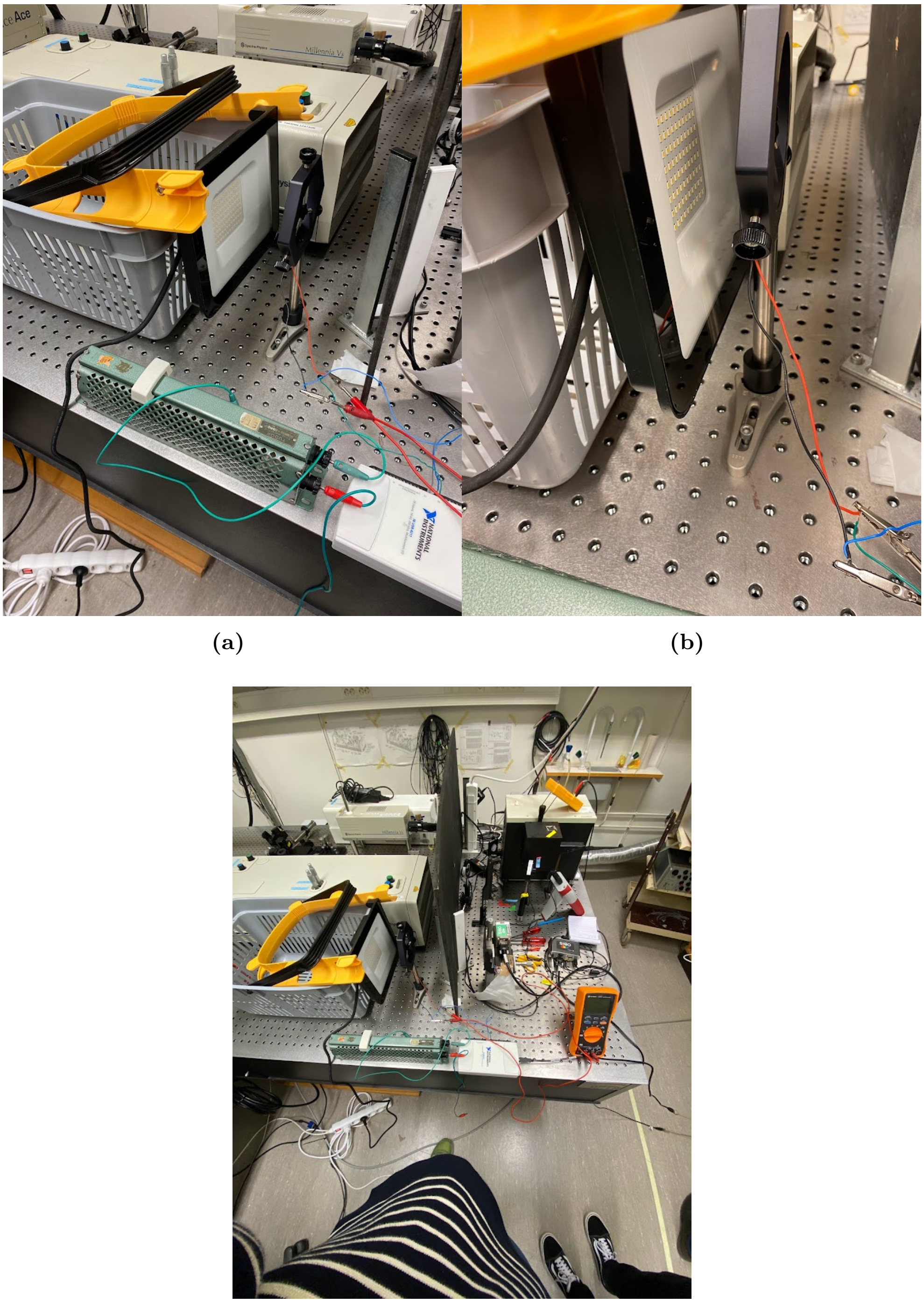



**Figure 4:** IV-curve displaying the relation between current and voltage in a solar cell. Furthermore, the maximum power point is also marked and correlates to at what current and voltage the power output is at largest.

The base conditions for the solar cell was measured by placing the solar cell close to a strong lamp (the lamp simulating the sun) see Figure 5 (a) & (b) below. The PV cell was then connected with a rheostat (variable resistor) and an amperemeter (measuring current) in series while also being connected parallel with a voltmeter, as visualised in Figure 5 (c) and also illustrated in Figure 6.



**(a)** **(b)**

**(c)**

**Figure 5:** (a) placing of module and lamp, (b) distance between lamp and module, (c) overview of whole testing setup.

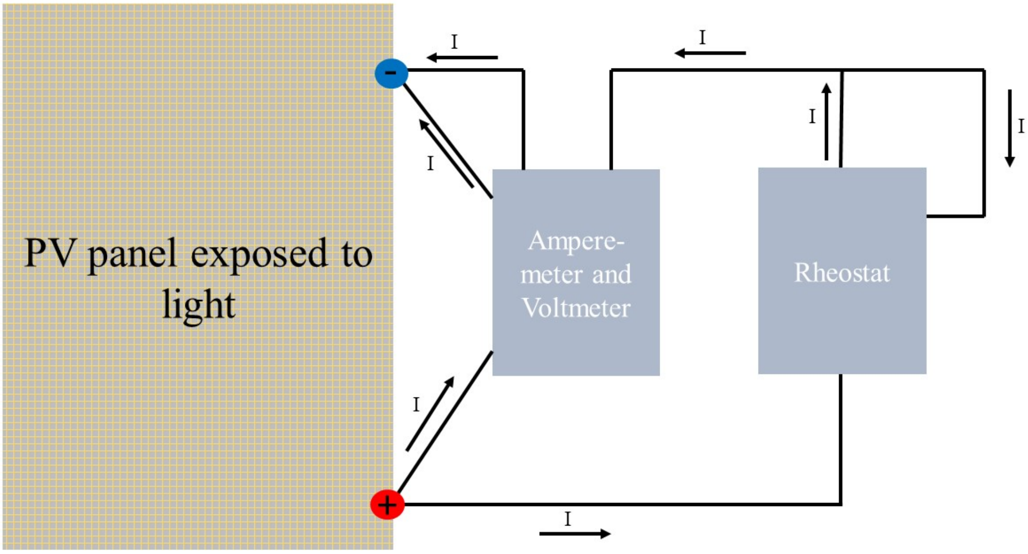



**Figure 6:** Illustration of the experiments set up, illustrating the connection between the PV panel, the rheostat, the ampere- and voltmeters and the direction of the current.

Following, to appraise how salt deposits affects the efficiency of solar modules, conditions trying to simulate what a floatovoltaic cell would experience on an off-shore installation was simulated in a lab. First, distilled water was sated with NaCl. Following, this water was applied to the solar cell and left to dry. Finally, when completely dried, the system was set up as before and left running until stable voltage and current could be measured.

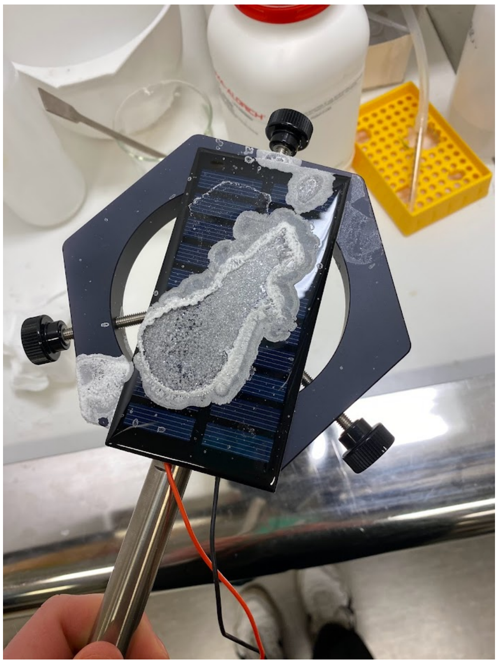


**Figure 7:** Setup for experiment with salt covering the module

Additionally, a high sensitivity thermal sensor was used to measure the output of the lamp. It was set up in the same way as the solar cell.

The solar cell used in the experiment was of the model "PG-120X62-001" manufactured by JPR Electronics Ltd. The lamp used was of the model "Work Lamp LED" form Anslut with 6000 lumen. The thermal sensor used was of the model "2A-BB-9" from Ophir Optronics.

### 3.1.1 Calculations

To relate the experiment to effect outside of the laboratory, the power output of the lamp has to be determined. To calculate this effect, of the lamp Equation 1 was used.

$$\frac{P_m}{A_s} * A_c = P_l \tag{1}$$

$P_m$ = *The power measured by the thermal sensor [mW]*

$A_s$ = *The area of the thermal sensor [$m^2$]*

$A_c$ = *The area of the solar cell [$m^2$]*

$P_l$ = *The power output of the lamp [mW]*

## 3.2 Result

Three runs were made with, respectively without salt cover. The MPP's from the runs are displayed in Table 1 and Table 2.

**Table 1:** MPP for solar cell with salt cover

| Data set | MPP [mW] |
|---|---|
| 1 | 414.11 |
| 2 | 410.46 |
| 3 | 407.98 |

**Table 2:** MPP for solar cell with no salt cover

| Data set | MPP [mW] |
|---|---|
| 1 | 428.90 |
| 2 | 428.01 |
| 3 | 423.71 |

The average loss of power due to the salt cover is approximately 4%. Two representative IV-curves are visible in Figure 8 and two representative curves are visible in Figure 9. The data in these curves are from the second run with and without salt respectively.

The thermal sensor measured an output from the lamp of $P_m = 45.7mW$ over an area $A_s = 70.8mm^2$. The area of the solar cell was $A_c = 7440mm^2$. Equation 1 gives the output of the lamp $P_l = 4802.3mW$.

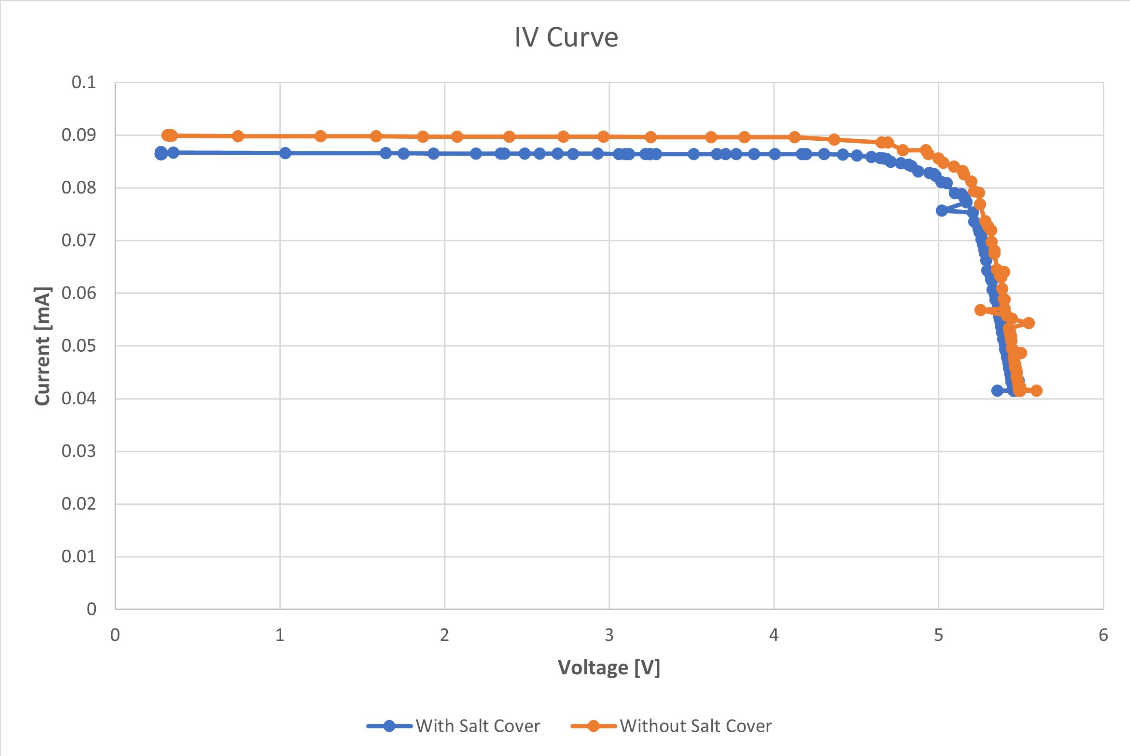



**Figure 8:** Current and voltage from the second run with and without salt plotted in a IV-curve

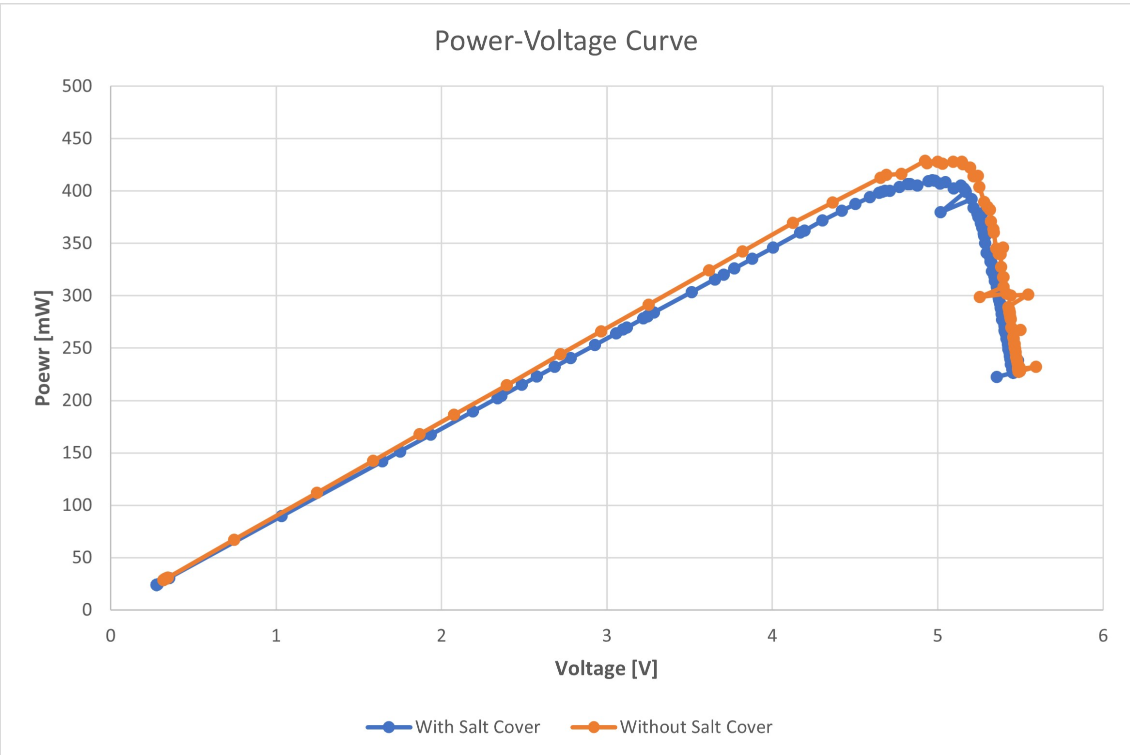



**Figure 9:** Power and voltage from the second run with and without salt plotted in a Power-Voltage curve

# 4 Discussion & Conclusion

A remarkable difference regarding efficiency could not be seen in the experiment, however a small difference in power output of 14 mW was noted (which corresponds to a 4 percentage loss). Based on this result the efficiency is not heavily dependant on salt covers. But worth mentioning is that a deposit such as used in the experiment would most likely not occur since the ocean climate probably rinses the module before resulting in a similar salt formation. Moreover, the experiment has to be repeated, both to have more results to compare and also using a better setup enabling a more true to ocean climate which would form a better-based conclusion. In addition, a more ocean-like experiment during a longer time period could also be needed to see what impact corrosion might have on the panels.

The overall efficiency of floatovoltaics has been observed to be higher than for land-based PV installations; an explanation for this is the cooling effect that water provides to the floating installations. Generally, high temperatures decrease the efficiency of PV panels, so the cooling effect from the water keeps the floating panels at a lower temperature than the temperature of PV panels installed on land. Experiments have shown that FPV can be up to 10.2% more efficient than land-mounted PV [9].

From an economic perspective, floatovoltaics might currently not be the first choice for investors looking to support photovoltaic systems; this is due to the fact that FPV systems are evidently more costly than ground-mounted systems. The promise of a higher efficiency might not be enough for more conservative and risk-averse investors to risk capital in a new technology that, at the moment, is more expensive and it is rather unknown when costs will competitive with other more mainstream and consolidated photovoltaic alternatives. Alternatively, the costs of of FPV could be mitigated if installed in combination with hydroelectric or wind power plants [14]. In this case, FPV could take the advantage of being installed in already existing power plants, resulting in cost saving due to the proximity of already installed grid connections [15]. Here, FPV systems could be viewed as a complement to these type of power plants, and as such complement, the overall energy output of these power plants could be increased by these floating systems. In the case of wind power, FPV could mitigate wind intermittency by producing energy whenever there is no wind. Regarding the addition of FPV to hydroelectric power, there are seasonal complementarities that could be exploited as seasons with a decreased flow of water are seasons in which the solar irradiation is higher; also, the intermittency of solar power generation is supported by *"fast-responding hydro turbines turbines"*, as proposed by Liu et al. [14]. A the moment, it could be said that floatovoltaics systems might be considered a niche market, so a proposition for current these systems would be to install them exclusively in locations where hydroelectric and wind power plants are already installed, this to mitigate some of the FPV costs: with more deployment of FPV under these circumstances knowledge will be gained through the development of technology, which could help decrease of overall costs for floatovoltaics overtime, which could eventually make them cost-competitive when installed on their own.

It is quite clear that floatovoltaics have a large adverse effect on the environment. From blocking sunlight from primary producers to hurting the local environment with an influx of anchorage points, most of the effects are primarily negative and the potential benefits do not compensate for the potential harm. The situation is slightly different in fresh water. The problems with shading the lakebed still remain, but the potential benefits of reduced alga blooms and reduced evaporation are both major benefits, especially in areas with freshwater issues. This also means that the potential for utilizing floatovoltaics in conjunction to damns and hydropower plants can create great value, and should be studied further. Over all, the potential harm is great if not planned for accordingly.

To conclude, it is most probably not arguable to install floatovoltaic power plants on lakes or off-shore if not combined with other renewable energy sources. If combined with off-shore wind, the resulting power output will increase since both of these energy sources are negatively correlated (i.e. usually when the weather is sunny there is no wind and when it is windy there is no sun) and since it is expensive to construct power plants off-shore, it is desirable to maximize power output of these installations. Moreover, combined floatovoltaics will not take up space in the ocean that will cause additional disturbance to sea-based industries or sea-life and it will spare land that could be exploited for other purposes, such as agriculture or built environment. Finally, it is worth keeping in mind that the technology of floatovoltaics is still rather new and it possesses big opportunities for development, improvement and consolidation, which could bring its costs down resulting in increased exploitation.

# References

[1] 3XN GXN. *PV Grid Teknologirapport*. Tech. rep. 3XN GXN Architects, 2014. URL: https://issuu.com/3xnarchitects/docs/pv_grid_teknologirapport/14.

[2] Thomas P. Adams et al. "Offshore marine renewable energy devices as stepping stones across biogeographical boundaries". In: *Journal of Applied Ecology* 51.2 (2014), pp. 330–338. ISSN: 13652664. DOI: 10.1111/1365-2664.12207.

[3] Vincent Bax et al. "Will it float? Exploring the social feasibility of floating solar energy infrastructure in the Netherlands". In: *Energy Research & Social Science* 89 (July 2022), p. 102569. ISSN: 2214-6296. DOI: 10.1016/J.ERSS.2022.102569.

[4] Emiliano Bellini. *World's largest floating PV plant goes online in China*. 2022. URL: https://www.pv-magazine.com/2022/01/03/worlds-largest-floating-pv-plant-goes-online-in-china/.

[5] Harshavardhan Dinesh and Joshua M. Pearce. *The potential of agrivoltaic systems*. Feb. 2016. DOI: 10.1016/j.rser.2015.10.024.

[6] C. Dupraz et al. "Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes". In: *Renewable Energy* 36.10 (Oct. 2011), pp. 2725–2732. ISSN: 09601481. DOI: 10.1016/j.renene.2011.03.005.

[7] Enerdata. *Total energy consumption*. 2022. URL: https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html.

[8] Goodenergy. *How do solar panels work?* URL: https://www.goodenergy.co.uk/how-do-solar-panels-work/.

[9] Anik Goswami et al. "Floating solar power plant for sustainable development: A techno-economic analysis". In: *Environmental Progress and Sustainable Energy* 38.6 (Nov. 2019). ISSN: 19447450. DOI: 10.1002/ep.13268.

[10] Christina Honsberg and Stuart Bowden. *PVEducation*. URL: https://www.pveducation.org/.

[11] Tara Hooper, Alona Armstrong, and Brigitte Vlaswinkel. "Environmental impacts and benefits of marine floating solar". In: *Solar Energy* 219 (May 2021), pp. 11–14. ISSN: 0038-092X. DOI: 10.1016/J.SOLENER.2020.10.010.

[12] Bjørn Petter Jelle, Christer Breivik, and Hilde Drolsum Røkenes. "Building integrated photovoltaic products: A state-of-the-art review and future research opportunities". In: *Solar Energy Materials and Solar Cells* 100 (May 2012), pp. 69–96. ISSN: 0927-0248. DOI: 10.1016/J.SOLMAT.2011.12.016.

[13] Thodoris Karpouzoglou, Brigitte Vlaswinkel, and Johan Van Der Molen. *Effects of large scale floating (solar photovoltaic) platforms on hydrodynamics and primary production in a coastal sea from a water column model*. Tech. rep. URL: https://www.pv-tech.org/news/worl.

[14] Haohui Liu, Abhishek Kumar, and Thomas Reindl. "The Dawn of Floating Solar—Technology, Benefits, and Challenges". In: *Lecture Notes in Civil Engineering*. Vol. 41. Springer, 2020, pp. 373–383. DOI: 10.1007/978-981-13-8743-2{_}21.

[15] Sara Oliveira-Pinto and Jasper Stokkermans. *Marine floating solar plants: An overview of potential, challenges and feasibility*. Dec. 2020. DOI: 10.1680/jmaen.2020.10.

[16] Senthilarasu Sundaram, Katie Shanks, and Hari Upadhyaya. “Thin Film Photovoltaics”. In: *A Comprehensive Guide to Solar Energy Systems* (Jan. 2018), pp. 361–370. DOI: 10.1016/B978-0-12-811479-7.00018-X. URL: https://linkinghub.elsevier.com/retrieve/pii/B978012811479700018X.

[17] Vattenfall. *Så väljer du rätt solceller om taket skuggas*. URL: https://www.vattenfall.se/fokus/solceller/sa-paverkas-solceller-av-skugga/.

[18] Wikipedia. *Solar energy*. URL: https://en.wikipedia.org/wiki/Solar_energy.

[19] Wikipedia. *Timeline of solar cells*. URL: https://en.wikipedia.org/wiki/Timeline_of_solar_cells.

[20] World Bank. *Where Sun Meets Water FLOATING SOLAR MARKET REPORT EXECUTIVE SUMMARY*. Tech. rep. 2018. URL: www.worldbank.org.