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Floating Solar: A Review on the Comparison of Efficiency, Issues, and Projections with Ground-Mounted Solar Photovoltaics

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ABSTRACT

Electricity generation is said to be a significant contributor to climate change. Now as the power demand is increasing daily, certain green innovations and technologies are emerging to cater to the energy demand. One such technology is Floating Solar Photovoltaic (PV) systems which helps to overcome conventional ground mounted solar systems. The purpose of the paper is to compare the Floating PV systems and ground mounted PV systems in terms of efficiency and energy projections. A secondary research was undertaken through global research databases such as Scopus and Web of Science to study the current body of literature. This literature review encompassed recent global cases, industry-related reports and policies/frameworks to analyze electricity generation, system efficiency and suggestions from secondary research on improving the prospects of Floating PV systems. The key finding emerging from the review was that Floating PV systems can resolve issues related to land availability and lower environmental impact. Based on the review it was also inferred that there is huge market potential which is untapped in comparison with ground-mounted PV. The study on Floating PV provides crucial insights for stakeholders, influencing decision-making, strategy development, shaping the future of renewable energy adoption and sustainable development.

1. INTRODUCTION

The world's population is steadily growing, and so is the energy demand, which also steadily increases, leading to a growth in fossil fuel use, directly impacting our environment as it releases greenhouse gases (GHG). As climate change worsens daily, the world is looking for alternate energy resources to reduce GHG emissions. Renewable energy sources provide sustainable, cost-effective, environment-friendly worldwide energy generation. Renewables provide 29% of the global electricity supply, including Hydro, Solar PV, Wind, Bioenergy, and Others, according to International Energy Agency (IEA) as of 2020 [1].

According to the International Energy Agency (IEA), solar energy generation must increase by 25% annually by 2050 to attain net zero emissions. An acre of solar panels in Virginia offsets more carbon dioxide emissions annually than an acre planted with trees can sequester. In Virginia, where natural gas is the primary source of electricity, utility-scale solar power produces between 394 and 447 MWh per acre per year. An acre of solar panels in Virginia saves between 267,526 to 303,513 pounds or 121 to 138 metric tons of carbon dioxide per year. In comparison, the average acre of forest in the United States sequesters 0.84 metric tons of carbon dioxide per year. The EPA estimates that the average acre of forest contains 81 metric tons of carbon, with approximately half of that amount sequestered in the soil. Even if all 81 metric tons of carbon were released upon conversion to a solar farm, those emissions would be offset within 2-3 years of operation [2].

Solar has risen drastically in the last 10 to 20 years as the promising renewable alternative to power or heat generation because of the abundant natural sunlight. Solar operations do not harm the environment by releasing any greenhouse gas. Some crucial advantages of using solar projects are increasing the energy mix at the national and regional levels, making it more independent of fossil fuel, and electrification of the rural part of the country that lives in remote areas. There are multiple reasons why people are interested in adopting more solar projects low cost, availability worldwide, ease of installation, and significantly less environmental impact. After looking at these benefits and advantages, solar PV lacks scalability for two reasons. First is essential land, we want to set up a big solar project, e.g., for a 1 MW plant, around 2.3 acres of land is required [3], and the second reason is the lack of R&D and manufacturing facilities across globe [4] because of which the PV market is suffering and due to which it is not able to compete with other RES. The purpose to write this paper is to address one of the two reasons i.e., availability of land which we can somehow overcome by adopting to floating solar PV systems and compare efficiency, issues, and projections with ground-mounted Solar PV systems for faster adoptability.

Floating solar PV is one alternative solution that can scale and harness the solar potential from a new angle. Floating solar PV has more potential and advantages in countries with high land rates or scarce lands like an island or something. To consider floating solar, we need sustainable water bodies in the region. Floating solar also helps reduce the environmental impact of land-based solar PV installations; as in floating, we do not perform deforestation, visual pollution, loss of habitat, etc. Additionally, Floating PV can generate more energy than traditional land-based PV systems because of the evaporation on the panels' backs; this reduces the PV cells' temperature and increases their effectiveness. This is beneficial in the case of reducing or preventing water loss from the lakes and reservoirs. Many examples of floating solar PV projects, including in India, have been successfully carried out [5]. Research is being done on Floating PV systems for use in other nations, such as Brazil, with its close vicinity towards the equator and abundant solar radiation, has tremendous promise higher than several European nations, now world leaders in solar energy generation. However, no technology is free from challenges and floating solar also brings itself with some sets of challenges like some occupational risks like lighting, hail, typhoons, strong winds, electrocution, unstable platform/wet-work exposure, seabed disturbance and damage to marine ecosystems, contamination of water, blockage of sunlight, etc.

This review paper highlights the benefits and drawbacks of installing Floating PV systems over land-based PV systems. In light of this, thorough comparisons between Floating PV and ground-mounted PV have been made regarding several performance factors, including power generation, environmental considerations, market potential, and challenges.

2. LITERATURE REVIEW

Floating solar has been an innovative technique for scaling solar PV project development. This research showcases the expected negative and positive ecological influences from photovoltaic frameworks with a specific interest in enormous scope ordinary and drifting photovoltaic. This research focuses on and thinks regarding the outcomes at all project execution stages; it includes arranging, development, activity, decommissioning, and zeroing in on encompassing situated in the jungles. The general effects related to project designation, like deforestation (for the undertaking execution and site getting to), bird deaths, disintegration, overflow, and climatic change, are expected to reach greater magnitudes during the execution of regular PV projects. The outcomes also feature the advantages of Floating PV over traditional PV during the functional and decommissioning stages [6].

The world is moving towards a net-zero emissions future, with solar energy being a key component. However, land use requirements for solar farms pose a challenge due to rising population density and land prices. Floating photovoltaics (FPV) addresses this by installing solar photovoltaics (PV) on water bodies. FPV is becoming a viable option for many countries, with a 1% coverage of global reservoirs generating 404GWp of benign power production. FPV offers numerous advantages over ground-mounted PV, but research on its impact on water quality and living organisms is still lacking. This review explores FPV's benefits, drawbacks, and future prospects, including its potential for integration with other technologies. A review of floating photovoltaic (FPV) systems found that while they offer numerous benefits, they also have known and unknown disadvantages. Advantages include cooling, no land use, reduced water evaporation, soiling, and algal blooms. Disadvantages include humidity effects on PV modules and unknown water quality effects. FPV is best suited for human-made water bodies like reservoirs, irrigation ponds, and industrial ponds. Hybrid systems with HPP reservoirs offer grid access and reduced water evaporation. Countries with high population densities are considering FPV as a renewable energy source [7].

Looking at the prospects of using new technology, the researchers study the performance compared to evaporation-based technology; in this study, they demonstrated that installing floating photovoltaics on US lakes would need a lot less space in terms of energy output than installing a potential evaporation-based solution. Floating PV systems may generate steady, round-the-clock electricity equal to 100% of US electrical demand if installed on the 128 greatest reservoirs in the US. If Floating PV were used on all lakes taken into consideration for the evaporation engine study, it would generate ten times as much energy. They also demonstrated and compared Floating PV systems connected to the hydroelectric power plants currently in service at the reservoirs beneath investigation; Floating PV is significantly more space-efficient. They can now generate an equivalent amount of electricity to hydropower by covering 1.2% of their surface with solar panels. This discovery may present significant opportunities for water managers. Managers might concentrate on achieving alternatives. Suppose hydroelectric production through turbines could be reduced or eliminated as a reservoir management aim by installing Floating PV on a very small percentage of the reservoir area. In that case, goals like flood control and adequate water supply may be achieved [8].

The energy-based parametric technique is employed in this research to comprehend the photovoltaic (PV) module's realistic performance and the energy conversion process in both water and land environments. Three amorphous silicon thin-film PV modules deployed using land PV, Floating PV, and submerged PV ways are being investigated to understand the energy performance further. The experimental findings demonstrate that each installation method has a different energy efficiency. The effectiveness of solar PV installation methods is shown should be accordingly 3.07 percent higher than that of Floating PV and 43.5 percent higher than that of land PV [9].

Floating solar arrays may be used in conjunction with other green technologies. and made a hybrid to expand the energy generation from a particular part of the area. Floating PV + hydrological systems, Floating PV + pumped hydrological, Floating PV + wave energy converter, Floating PV + tracking, Floating PV + conventional electricity, and Floating PV + hydrogen is some of the hybrid technologies considered. The review includes a list of the main advantages and disadvantages of hybrid floating solar PV operation. Hybrid Floating PV systems that combine hydropower and solar energy are among the most promising ones that have the potential to be employed for adequate power generation. The research highlights the potential of hybrid FPV systems to increase technological and economic competitiveness, offering an efficient alternative to traditional floating systems. The study also highlights the growth potential of hybrid FPV systems, particularly in hydro dams, and the potential for decarbonization. It emphasizes the need for more pilot studies and innovative approaches to achieve scale, cost reduction, energy yield, and high return on investment. The insights presented will support future research and pilot-scale deployment of hybrid FPV plants worldwide [10].

Looking at the Distributed Production of Flexible Floating Photovoltaic Modules for Aftermarket, a study suggests using extensive Flexible Floating PV systems are produced utilizing an open-source distributed manufacturing method. This study examines the three closed-cell foams that support the flexible thin-film solar PV's floating surface: neoprene, polyethylene, and minicell. The constructed Floating PV was tested indoors and outdoors for buoyancy, wave resistance, temperature, and resistance to algae build-up. While on comparison with land-based mounting, the average operating temperature for the Floating PV was reduced by 10 to 20 degrees Celsius, which indicates a significant increase in electricity output of about 2 to 4 percent for the amorphous Silicon used here and 5 to 10 percent for crystalline Silicon based PV when compared to the installation of any PV on the ground. It was also seen that foam-based Floating PV racking could drop prices to $0.37-0.61/W, which is much less expensive than raft-based Floating PV and traditional land-based racking [11].

3. GAP ANALYSIS

As Floating PV systems are new to adaption by many countries, particular challenges are faced to improve and scale the floating solar and consider them an alternative to ground-mounted PV. Some occupational risks like lighting, hail, typhoons, strong winds, electrocution, unstable platform/wet-work exposure, etc., are also faced [12]. Typhoon Faxai, a rare event, caused damage to Kyocera's 13.7-MW floating solar power plant at the Yamakura Dam in Japan [13]. The 120-mph winds caused overheating and fire, while 17-MW FPVs in Southern France experienced a fire accident due to strong winds [14]. Australia also faces challenges related to remote locations, harsh environmental conditions, and grid integration in some areas. In Brazil, water levels in many reservoirs can fluctuate seasonally, impacting the stability and efficiency of Floating PV systems. Research still needs to be done on how Floating PV affects the state of water bodies and the presence of life there as opposed to their natural habitat; land mitigation measures should be investigated in case they are needed when installing floating projects. Due to the microclimate, artificial lakes' impacts may differ from those in natural lakes. Thorough research must be done to determine whether floating solar systems have any social impact.

4. OBJECTIVE

There are many examples of floating solar PV projects successfully carried out. Still, as it is a new technology, many challenges and issues must be addressed to improve its efficiency and objectivity. The main aim related to review and study is to help and understand the:

(1) The benefits and drawbacks of installing Floating PV systems in aquatic bodies in comparison to land-based PV systems in terms of potential energy output and environmental issues.

(2) We are looking at the challenges the floating solar market faces regarding scalability.

5. METHODOLOGY

To achieve the goal established for this research paper, we have conducted secondary research related to floating solar PV and ground-mounted PV systems. Several industry-related reports and policies/frameworks were also reviewed. Scopus, Web of Science, Google Scholar, and Symbiosis International digital library were also used to locate pertinent data. To find relevant papers, specific keywords were used, like floating solar, Floating PV, Floating PV module, floating solar market, ground-mounted PV, ground-mounted solar, photovoltaics, etc. Research papers published after 2018 were subsequently considered because of only the most recent study.

6. TECHNOLOGY OVERVIEW

PV, short for photovoltaic energy, is a Solar energy uses a photovoltaic effect-based technique to directly turn sunlight into electricity. A solar panel is made up of several photoelectric cells, each of which has a face that is exposed to sunlight. When sunlight strikes one of these faces, it creates an electric voltage difference between the two faces that causes electrons to flow from one to the other, creating an electric current [15].

Installing solar photovoltaic energy has various benefits, including lowering your carbon footprint and yearly electricity expenditures, lessening the impact of rising energy prices, and earning a tax-free income for the next 20 years. Additionally, Solar PV systems and panels are simple to install, maintenance-free, and guaranteed to last [16].

Solar panel technology, invented by Bell Labs over 60 years ago, has been used for centuries to harness the sun's energy. However, it has only gained significant popularity in the last decade as a renewable energy source. In 1954, Bell Labs invented the first silicon solar panel, which was about 6% efficient. Since then, solar PV technology has rapidly evolved, with prototypes over 30% efficient, producing 25% more electricity than lower-tier economy panels. Researchers have achieved 47.1% efficiency using advanced cell structures, but these super high-efficiency panels are typically made of expensive materials, making them not currently cost-effective [17].

Solar energy is booming, and PV applications are expanding to different horizons. Therefore, we try to classify the most used applications related to PV i.e., Land-based, Rooftop and Floating based PV systems.

Land-Based PV systems is a facility that generates electricity from the sun's energy using photovoltaic (PV) panels or concentrating solar power (CSP) systems. These systems are typically located on large plots of land, either on the ground or on top of structures, such as buildings or poles. The land-based solar power plants provide a clean, renewable, and sustainable source of energy that can reduce dependence on fossil fuels. Ground-mounted solar panels are lightweight, easy to install, and efficient in producing solar electricity. They require a separate structure for accurate tilt angle and easy maintenance. However, they may require higher initial investment and a longer installation process [18].

Rooftop PV system is a system of solar panels installed on the roof of a building to generate electricity. The solar panels convert sunlight into direct current (DC) electricity, which is then converted into alternating current (AC) electricity using an inverter. This AC electricity can then be used to power lights, appliances, and other devices in the building. Rooftop solar power plants offer many benefits, including reduced dependence on traditional energy sources, lower energy bills, and a smaller carbon footprint. Additionally, they can be a cost-effective option for building owners as the long-term savings from reduced energy costs can offset the initial investment. With technological advances, rooftop solar power plants are becoming more efficient and easier to install, making them a popular choice for homeowners and businesses. This system is cheaper than Off-Grid or hybrid systems due to its lack of battery banks and standalone components. It also allows net metering, allowing extra electricity to be sold back to the utility. However, it lacks a battery bank, cannot store electricity during grid outages, and requires monthly utility fees [19].

Floating solar PV systems are a relatively new technology that involves installing solar panels on floating platforms on bodies of water, such as lakes and reservoirs. These systems offer several advantages over traditional ground-mounted solar PV systems, including the ability to save valuable land resources, reduce evaporation and water loss, and increase the cooling of the solar panels. The panels are also less susceptible to shading and dust build-up, which can improve energy efficiency. The water stabilizes, making floating solar PV systems more resilient in harsh weather conditions. These systems are an innovative solution for countries and regions with limited land resources but ample bodies of water, offering a sustainable way to generate renewable energy [20].

Some of the components used in floating solar projects are [21]:

(1) PV Panels: PV Panels are photovoltaic cells that are used to convert sunlight into electricity. They are made of Silicon, gallium arsenide, and cadmium telluride. PV panels are an essential component of renewable energy systems and are becoming increasingly popular for their cost-effectiveness and environmental benefits.

(2) Floaters: Floaters are the main components used in floating solar systems. Floaters provide buoyancy and stability to the PV modules above the water surface. These structures are made of many materials, including plastic, rubber, and even steel. Depending on the design of the floater, it can also provide mounting points for the PV modules and other components. Some floaters also come with an anode system for corrosion protection. The design and shape of the floater will depend on the size, weight, and type of PV module used in the system.

(3) Combiner boxes: Combiner boxes are essential components in floating solar systems. They combine and protect multiple strings of solar modules and protect the system from overcurrent and short-circuiting. A Combiner box typically consists of a NEMA-type enclosure with junction boxes, DC circuit breakers, surge protection devices, lightning arrestors, and a ground lug. The combiner box typically has two inputs for each string of photovoltaic modules, which are then connected to one combiner box output and then to the power inverter for energy conversion. It also helps to protect the system from overcurrent, undercurrent, and other electrical hazards. The combiner box is essential in a floating solar system, as it ensures the system's safety and protects it against harsh UV rays and other environmental hazards.

(4) Mooring System: Mooring systems are an essential component of floating solar systems. The mooring system consists of mooring lines, an anchor system, and a buoyancy system. The mooring lines are typically composed of steel chains, wire ropes, or synthetic ropes and are connected to the anchor and buoyancy systems. The anchor system consists of anchors, weights, and lines, which are used to keep the structure securely in place. The buoyancy system is typically made of floats and provides the necessary buoyancy to the structure. The mooring system is designed to resist external factors like wind and waves and to provide the required tension to maintain the stability of the structure.

(5) Inverter: An inverter is a critical floating solar PV system component. It is responsible for converting the DC power generated by the solar array into AC power that can be used for the distribution network or fed into the grid. Inverters for floating solar PV systems are designed to handle the unique environmental conditions associated with these systems, such as high levels of moisture and salt. Depending on the system design, the inverter can be either a string inverter, a central inverter, or a microinverter. Inverters for floating solar PV systems also have protective features such as surge arresters, over-voltage and over-current protection, and temperature monitoring to ensure the system operates safely and efficiently.

(6) Transformer: A transformer is a critical component in a floating solar system. It converts solar PV system's electricity into power for the grid. The transformer is responsible for transforming the high-voltage electricity output from the solar panels into a usable form. It also helps to protect the system from power outages caused by grid disturbances. The transformer is typically an oil-filled, three-phase unit with a rating of up to 100MVA. The transformer is also designed to minimize energy losses during transmission and reduce energy production costs.

(7) Cable Network: A cable network is an integral component of a floating solar system. It connects solar panels to the control system and the energy storage device. In a floating solar system, cables are typically used for connecting solar panels to the power converter, the power converter to the charge controller, the energy storage device, and the charge controller's connection to the power distribution system.

(8) Transmission System: The transmission system is a critical component of a floating solar system, as it converts the generated energy into usable power. Typically, the floating solar system's energy is transformed into alternating current (AC) via a photovoltaic inverter, which is then transmitted over an AC transmission line to a nearby substation. The AC transmission line comprises an insulated copper cable, a grounding conductor, and a surge arrester. In order to ensure efficient energy transmission, it is crucial to select transmission lines suitable for the site's specific conditions.

(9) Floating Walkaways: Floating walkways are essential to the floating solar system. They provide a support structure for the solar panels and a pathway for personnel to access the panels for maintenance and repair. Floating walkways are usually constructed from heavy-duty aluminum or galvanized steel, which is highly resistant to corrosion and designed to hold up to the weight of the solar panels.

Looking at the cost breakup in Figure 1 of components for floating solar systems in India includes high cost related to Modules or solar panels as it is the most important components for the system and the cost is high due to taxes and transportation cost involved to it. Floating platforms are another major cost intensive components as it is not manufactured by many but by some of the companies so these components are majorly imported from other countries [22].

According to the Figure 2 we can see China has the highest number of solar PV installations done so far and Japan is second in the race till 2020. In 2007, Japan built the first Floating PV system. However, the initial applications of Floating PV systems were seen in the USA using the water reservoir after they were thought to be constructed for commercial use [23]. The first Floating PV system in the USA reportedly had an installed capacity of 175 kW. Kerala in India has established the greatest floating solar power facility in India, marking a significant development. The 500 KWp (Kilo Watt peak) power plant was inaugurated on December 4th, 2017 [24]. According to estimates, the facility would produce 7.5 lakh power units annually. Many of the big floating solar projects are coming up in India.

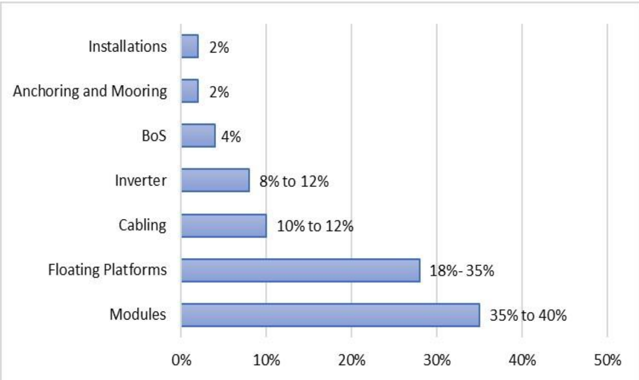

Figure 1. Cost breakup for installing floating solar [22]

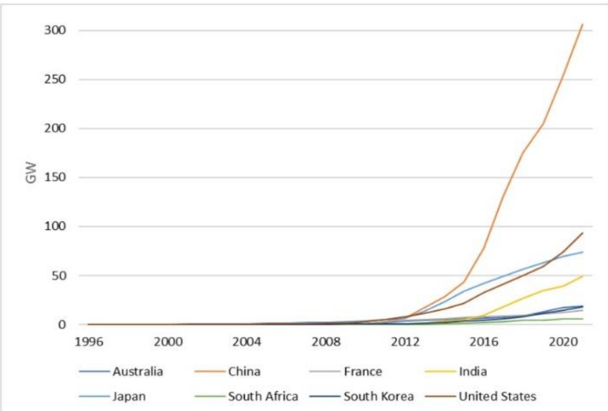

Figure 2. The installed capacity of Solar PV systems at a global scale [25]

7. RESULTS AND DISCUSSIONS

By adopting floating solar systems, there are multiple benefits which can be recorded that are:

(1) Land Use – One of the significant challenges why the land-based solar could not scale as expected, is because this system requires land, which, where available, is not cheap, and in some parts of the world, it is unavailable in great numbers as required [26]. However, floating solar is very much overcoming this challenge. On deploying Floating based solar we reduce land-use conflict where people are free to use the land as they require. Floating solar also preserves the area's natural habitat as deploying solar panels on land leads to habitat conversion [27]. As an illustration from a pilot plant in China, a 150 MW Floating PV system constructed on the sea surface of China's Anhui Province gives an approximate land save of 32,00,000-meter square, which is noteworthy [28].

(2) Enhanced Energy Generation– It has been discussed before also that solar efficiency is highly dependent on environmental conditions to which the PV modules are exposed [29]. Some of the other circumstances, like shadow effects, dirt, and dust, highly influence the electrical performance of PV and worsen it [30]. Due to the water's evaporative cooling impact, FPV PV modules often operate at lower operating temperatures, increasing panel efficiency. When aluminum frames are utilized to support floating solar PV modules, they transfer cooler water temperature, lowering the module's overall temperature [31]. FPVs receive more sunshine on average than comparable ground-mounted solar farms due of their positions, which also make them less subject to dust deposition.

(3) Water Security – One of the key benefits of adopting a Floating PV system is water conservation and saving because, in Floating PV, the water body is covered by PV panels which helps in less evaporation of water from the water basins. So, it is always suggested that areas with water scarcity go for Floating PV systems for electricity generation. Many nations, such as those in the Middle East and North Africa (MENA), for instance, have little trouble finding land for PV solar farms; yet, they are enthusiastic about FPVs and viewing this technology from a different angle, to reduce water evaporation [32]. In the MENA region, water shortage is a major issue that will only get worse as evaporation from open water reservoirs and longer heatwaves brought on by climate change increase [33].

(4) Tracking – By the help of tracking we can increase the efficiency of our solar system. In floating solar the tracking and actions like rotating vertically and moving horizontally is done very easily in comparison to land based solar systems. In land based solar system the equipment's can sometimes be complex and non-operational and costly depending on the project but in floating solar the tracking is easy and so do the actions which result in increasing the energy gain from 15 to 25% [34].

However, a brief comparison is done in Table 1 between floating solar PV and ground mounted PV systems to give a general outlook.

Table 1. Comprehensive comparison between Floating PV and Ground mounted PV systems [35]

Parameters	Different Solar PV Systems	
	Floating Solar PV	Ground Mounted Solar PV
Installations	Easy installation.	Little typical installations.
Investments	Due to multiple components, the cost is higher. Risk is high due to less maturity of technology.	As capacity increases, the investments also increase. Less risk due to matured technology.
Lifecycle	It depends on floats, but it takes 5 to 10 years normally.	More than 20 years.
Environment impact	Aquatic life is affected. It helps in reducing water evaporation.	Natural Land habitat loss. Impact during construction.
Regulations	Easy for artificial ponds than natural lakes.	Easy for rooftop than land.

Operations and Maintenance	Lack of defined regulations. Due to the presence of water, it is hard to repair and replace components. The risk of theft is lower. Access to water for cleaning.	Has clearly defined regulations. Ease to access. Easy for routine maintenance.
Safety	The absence of land leads to low insulation resistance. Risk of the system falling into the water.	No such safety issues.

7.1 Comparison related to energy generation potential

As we previously mentioned, the energy generation in Floating PV systems shows better energy performance when compared with ground-mounted PV systems. We have considered a certain number of case studies in our research, including a study done by Rai et al. [36] where he studied both the land and floating system and deduced that 1600 kWh and 1892 kWh was generated by both the systems respectively at a tilt angle of 28 degree and 10 degrees respectively. He resulted that around 18.25% more energy was generated by floating solar than the land-based solar systems. One research by Choi et al. [20] where he studies two solar plants first one is floating based in Hapcheon, which is of 100Kw, and the other is land-based in Haman of about 1 MW. Here they compared the electricity generation between both plants, which concluded that the efficiency associated with the Floating tends to be 10% more when compared with land-based systems. The floating system generated 421 kWh per day, and the land-based generated around 3486 kWh per day. Another study was done by Cazzaniga et al. [34] where the results come up related to setup of single axis tracking and water veil cooling system which was installed on two Italy in water farms where reflection angle played an important role in increasing the energy yield of about 30%. Azmi et al. [37] conducted a particular experiment in which the floating and land-based panels were scrutinized under different radiation levels of 417, 617, and 834 E/m^2. It results in an efficiency of around 4.38% for Floating PV systems and 4.22% for land-based PV systems for 417 W/m^2. If we look at the results for 617 W/m^2, the efficiency of the Floating PV is about 3.8 percent more than land-based PV. We also see that as the radiation increased, the efficiency increased to about 14.6 percent for 834 W/m^2. It also shows that at the 896W/m^2 level, the power generated was around 1190W for floating and 1030W for the land-based system. Another study by Rosa-Clot et al. [38] suggested that using submerged photovoltaics at different depths can increase the efficiency by about 20% as the thin films PV modules have more flexibility to resist typhoons and waves. They also found the difference in temperature of about 30 degrees and the reduction in thermal drift. Now take another case study by Yadav et al. [39] that reveals that land-based solar performs 7 percent less when compared to floating solar. According to a different study by Dörenkämper et al. [40] the cooling effect increased the energy yield of the FPV system by 6% in Singapore and by 3% in the Netherlands. An experiment done by Mittal et al. [41] showcased that energy generation is about 1715.57MWh/year for floating solar and 1673.98MWh/year for land-based solar systems. A study was done by Murthy et al. [42] demonstrates that if we submerge around 50% body of 10% of total solar panels in the water than around there is 14% decrease in temperature results in 18% more energy yield than land-based PV. Another simulation done by Golroodbari and van Sark [43] related to energy performance reveals that tilt angle is an essential component if we talk about the performance of PV systems because results say that Floating PV was 12.96 percent better annually in performance on an average when compared with the land-based PV by developing a mathematical model for both systems.

7.2 Comparison related to market potential

The primary determinants of the scalability of floating solar will be determined by certain factors like the distance between the floating plant and transmission lines, is the water source sustainable or how much convenient that source is, and the solar irradiance. Let's look into this in more detail:

7.2.1 Distance to transmission lines

(1) Proximity to Grid Infrastructure: One of the critical factors affecting the scalability of floating solar is how close the installation is to existing electrical transmission lines and grid infrastructure. The farther the floating solar plant is from the grid, the higher the costs and challenges associated with transmitting the generated electricity. Longer transmission lines result in energy losses and increased infrastructure costs.

(2) Transmission Capacity: The capacity and condition of the existing transmission lines also matter. If they have sufficient capacity to handle the additional load from the floating solar installation, it can reduce the cost and complexity of integration. In some cases, grid upgrades may be necessary.

7.2.2 Water source sustainability

(1) Water Availability: Floating solar installations require access to a stable and adequate water source, such as reservoirs, lakes, or ponds. Water scarcity or seasonal fluctuations in water levels can impact the feasibility of the project. Sustainable water management practices are crucial to ensure a consistent water source.

(2) Environmental Impact: Sustainability also involves assessing the environmental impact of the floating solar system on the aquatic ecosystem. Proper environmental studies and mitigation measures may be required to protect water quality, aquatic life, and local ecosystems.

7.2.3 Solar irradiance

(1) Solar Resource Assessment: The availability of sunlight, or solar irradiance, in the location where the floating solar panels are installed plays a vital role in determining the system's efficiency and energy output. Areas with higher solar irradiance receive more sunlight, resulting in greater electricity generation.

(2) Climate Variability: Climate conditions and weather patterns in the region can affect solar irradiance. Seasonal changes, cloud cover, and other climatic factors must be considered when designing and estimating the energy production of a floating solar system.

Based on the report by IEA PVPS Trends in photovoltaic applications 2022 [44] says that the installed capacity surpassed around 3GWp in 2021. Also, if we look at the project installation, we can see the Asia market is increasing, and more than 85% of projects are deployed in East and South-

East Asia. The densely populated area where a water source is available is often said to be the blessing of floating solar projects. In comparing it with land-based solar, we previously said that land is an important factor, and due to land cost, the project cost increases, which sometimes creates complications for moving on with the project. That is why Japan have to move to adopt floating solar, and also records have the highest number of floating projects, around 200 in its name. Singapore is another good example. In June 2021, a 60 MWp was inaugurated and proposed to install another 140 MWp plant. But now, if we talk about the highest capacity, then China leads in this case with around 1.3 GWp. China had a blessing in disguise when their coal mines were filled with water, so they utilized those spaces to install floating solar. Now, India is also said to install a big floating project of about 600 MWp with an investment of 3000 Crore Indian Rupees at a single location in Khandwa [45] which will address the electricity of the nearby regions. The Singareni thermal power station in Jaipur's Mancherial district houses the largest floating solar power plant in India with clear glass-to-glass modules. Phase 1 of the plant, which has been commissioned, has a capacity of 5 MW(AC)/6.5 MW and the facility as a whole has a capacity of 15 MW(AC)/19.5 MW(DC) (DC). The factory uses transparent glass-to-glass solar modules, which are more efficient than standard solar modules, and is the first of its kind to be made and used at this size in India [46]. According to the report published by the World Bank [35], 8,08,908 sq. km of the total surface area is available where there are many reservoirs where the floating solar can be installed. So, to utilize 1% of the area mentioned and install floating solar, a capacity of about 400 GW is required. It acts as a new market potential for renewables when we combine floating with hydro or wind, etc.

Another potential of floating solar is when we combine it with hydropower dams [47]. The capacity and efficiency of the particular reservoir can be increased if we conjointly operate both plants rather than only utilizing the full reservoir for the Floating PV. Not only utilizing the diurnal cycle where solar generates power in the day and water is utilized to generate power at night in hydro, but this can also help when the season changes from wet to dry and vice versa. Now, this purely depends on the turbines and their reaction time. We can reduce some seasonal shortcomings, and we can use the reservoirs to generate power when there are clouds in the sky. Many such examples are available today. In Laos, around 1.2 GWp is installed; in Korea, around 2.1 GWp capacity is installed; and Thailand also has 3.5 GWp installed [44].

New areas of interest can be the nearshore and offshore marine floating systems; though the challenges with these projects are high, the opportunities are so. Of course, the challenges like wind, waves, rich marine life, salt content in water, and tidal currents need to be considered for the project. But the opportunities in nearshore are big, where many unused spaces can be utilized and can be connected to coast load centers. If we look at offshore, it can replace Offshore wind farms, which power the oil and gas rigs and platforms easily at less cost and greater efficiency as the transmission network is already present offshore, so the Floating can take advantage of it. One such experiment was carried out in Netherlands and Belgium. If we talk about companies, then majorly, the HDPE float beds are used by Ciel and Terre and Sungrow [44], which have more than 50% of the market share. Many players also do not follow any pattern and design the structures according to the project, like combining the metal and the floats to the membrane, which are attached by big plastic rings. For offshore projects, many companies like Oceans of energy and SolarDuck are still testing their designs. Now, as many countries are focusing and shifting their target to installing floating solar, the agreements and investments have risen. Based on a study by Energy and Resources Institute, the potential of floating solar in India is said to be 280 GW on a water reservoir of 18000 sq. km [48].

The market potential for land-based and rooftop solar energy is significant, as both have the potential to generate large amounts of electricity. Land-based solar energy is generated by large solar panels installed on land, usually in open spaces like deserts or fields. This type of solar energy can generate a large amount of electricity and can be used to power entire communities or even small cities. Therefore, the market potential for land-based solar energy is significant, as it can provide a reliable source of electricity for many years and can be used to generate electricity even in remote areas [49]. Rooftop solar energy is generated by small solar panels installed on the rooftops of buildings. This type of solar energy is particularly useful for small businesses and residential homes, as it can provide significant electricity without taking up much space. In addition, the market potential for rooftop solar energy is about to increase 60% in FY2023 as per Institute for Energy Economics and Financial Analysis (IEEFA) JMK Research [50]. Land-based and rooftop solar energy can produce a substantial quantity of power, and they can be used to power a wide variety of applications. This includes powering homes, businesses, and even entire communities. Additionally, both land-based and rooftop solar energy are renewable sources, meaning they do not produce harmful emissions or pollutants. The market potential for land-based and rooftop solar energy is anticipated to increase during the next several years as the cost of solar technology continues to decrease and the demand for renewable energy increases [51]. Governments worldwide are also supporting the growth of solar energy through various incentives and subsidies. The increasing awareness about the environmental benefits of solar energy and the rising energy costs make it an attractive investment for individuals and businesses. However, some challenges must be addressed in order to fully realize the market potential for land-based and rooftop solar energy. The initial expense is one of the biggest obstacles. of installing solar panels. Additionally, the reliability of the electricity generated by solar panels can be affected by weather conditions, such as cloudy days and storms. Looking at the world's recent trends by energy sources done by IEA in Figure 3 we see how solar PV energy source is increasing year on year.

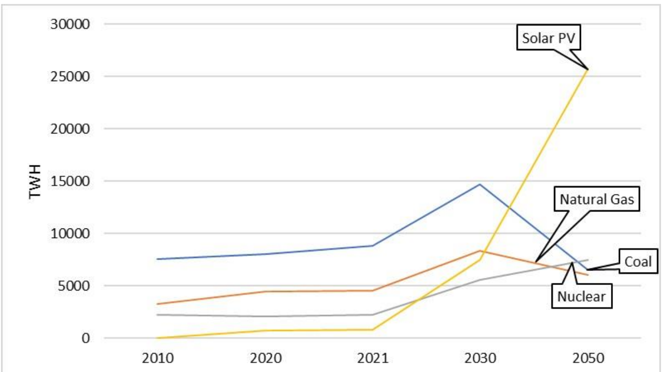

Figure 3. World energy consumption by energy source [52]

7.3 Comparison related to environmental impact

When we talk about energy generation then, two things are generally discussed: the energy generation potential and the impact on the nearby environment. Now, here we are talking about floating solar, so the impact, as we all know, on the environment is less, and it also helps us to save carbon and water [53] carried out a study to determine the quality of water and energy efficiency. Using a spectrophotometer, they performed the experiment twice in two times in 2 years, i.e., in 2020 and 2021. The study showed an increase in water quality, a decrease in algae biomass, and a decrease in ph. level, the water was much clearer, and organic carbon in the water was also increased.

We need to consider the environmental impact at every project phase, from planning and construction to operation and maintenance, to compare and understand the impact of land-based and floating solar systems. However, a brief comparison has been done in Table 2 for every project phases.

Table 2. Environmental aspect and impact at every project phase [6]

Phase	Environmental Analysis				
	Aspect	Impact	Floating solar	Land Based solar	Severity
During Planning Phase	Deforestation	The shift in the nearby environment	-	Prevailing	High for land-based
	Foundation structure	Soil erosion, impact on flora and fauna	In anchoring, soil trenches	Heavy machinery, foundation	High in Land-based
	Blockage of sunlight	The quality of water depletes	Occur in lakes	-	Low in floating solar
	Storm water infrastructure	Soil erosion	-	Required	High for land-based
During Construction	Bird collision with solar panels	Mortality of birds	Expected	Expected	High for land-based
	Noise	Disturbance to wildlife	Occurs	Occurs	Moderate for both systems
	Site Access	Traffic nearby	Expect increase	Expect increase	High for floating solar
	Waste generation	Pollution and contamination	Expected	Expected	Moderate for both systems
During O&M	Water Utilizations	Depletion of water resources	Occurs	Occurs	High for Land-based
	Use of Chemicals	Contamination and air pollution	-	Expected	Moderate for land-based
	Visual pollution	Discomfort	Expected	Expected	High for Land-based
	Waste	Pollution	Expected	Expected	High for Land-based

Solar projects require large land areas for construction, ranging from 2.2 to 12.2 acres/MW, and produce less energy compared to fossil fuels [54, 55]. However, these projects can lead to environmental impacts such as deforestation, habitat loss, and soil erosion. Deforestation also results in increased runoff and soil erosion, necessitating intense landscape infrastructure and heavy machinery, which negatively affects local geomorphology. The construction phase of a conventional utility-scale PV plant is considered the most impactful phase due to deforestation and loss of habitat [56, 57]. In forested areas, solar power plants emit 2–4 times more CO_2 than in desert areas, and changes in local microclimates and soil temperatures are reported as negative impacts [58].

The FPV system offers a solution to deforestation, land allocation, habitat loss, and runoff infrastructure requirements. However, it should be avoided in areas with legal restrictions for water protection, fishing, and marine leisure [59]. FPV systems may temporarily harm aquatic communities due to anchoring and mooring, making natural lakes more affected than artificial ones. Additionally, blocking sunlight penetration can prevent algae growth and ensure water quality by preventing excessive algae growth [31, 60].

Due to heavy and light vehicles, there are more excursions made to the nearby area during construction. These effects, though, might not be substantial. In both ground mounted and Floating PV plants (FPV), dust generation, heavy machinery, and increased local traffic are all possible sources of air pollution. Lakeside FPV may limit recreational and fishing opportunities, limiting public access to resources. Construction-related noise and trash management are regarded as short-term negative effects. During construction, a noise monitoring program should be implemented to determine how it may affect tourists and wildlife [61].

Waste management is crucial in construction to minimize impacts from incorrect waste disposal. FPV plants are considered more sustainable due to their lack of concrete structures and electrical machinery. However, the amount of waste may be higher due to the disposal of plastic used to wrap the buoyant structure [60].

Conventional PV facilities need a lot of water and dust suppressants to clean the panels and stop dust from accumulating [56]. Desert regions produce more dust due to the absence of vegetation, necessitating the use of chemicals to control it. These substances are poisonous and may have long-term detrimental effects on both animals and plants. Utilizing animals to suppress weed growth is an alternative. The use of water in PV facilities is a substantial social hurdle that hinders the growth of large-scale solar systems [62]. Additionally, suppressants used to clean panels raise concerns about water pollution as which includes salts, fibres, and other chemicals, can cause short-term animal mortality and water quality depletion due to algae growth and oxygen loss. Due to their location far from land and dust generated by the wind, Floating PV systems could only need a little amount of water for cleaning [34]. However, oil and lubricant spills, and natural component deterioration all have the potential to release toxins into the water body and atmosphere [6].

Some of the negative impacts which have been observed for floating solar projects are [63]:

(1) Any electrical equipment can harm the aquatic environment when coming in contact with water.

(2) Fire incidents where extinguishers are used can cause contact with water and harm the water ecosystem.

(3) If metal structures and equipment are used, corrosion might release chemicals into the water.

(4) Due to the coverage of the water surface, solar radiation penetration in water is reduced, which negatively affects the water ecosystem, decreases water temperature, changes in oxygen level, etc.

(5) Preventing wind from having an impact on the dynamic systems that are present on water surfaces.

8. CHALLENGES FACED BY FLOATING SOLAR

As we have seen in the above discussions, floating solar can have many positive effects and advantages, but to market and grow this technology, we need to mitigate certain challenges and improve the technology daily. Some of the major technological challenges are related to the mooring and anchoring layout, improved efficiency of solar panels, marine and logistics operations the material and components' durability [64]. The mooring systems usually ever hour experience clash with currents, waves and winds and help to keep the floating structure stationary. So, we need to innovate to come up with new and robust mooring components, which not only are less in price but maintenance is also less. We have encountered many applications of mooring systems in past when floating solar was not in the picture, like in offshore wind setups, oil and gas rigs/platforms, etc., but they all are costly affairs. Benassai et al. [65] discovered that by creating mooring patterns with a non-uniform angle distribution, mooring weight reduction can be accomplished for floating wind turbines in shallow water.

Benassai et al. [66] examined the motion control capabilities of tensioned line and catenary mooring systems for a Dutch tri-floater wind turbine at water depths between 50 m and 200 m, taking into account both operational and high load conditions. Benassai et al. [67] analysis was expanded to take into account line number, platform maximum acceptable offset, and mooring line pattern. Nine or twelve lines were suggested for mooring arrangements. The findings demonstrated that mooring line weight increases outside of this range, regardless of water depth, between 100 and 200 meters.

Brommundt et al. [68] created a numerical tool for catenary mooring system optimization, and a case study using a semi-submersible floating wind turbine with two different water depths was carried out [69].

The mooring system, which provides stability for vessels in deep water operations, is influenced by various types such as catenary, semi-taut, and taut. However, in harsh environments, these systems can experience instability due to extreme wave effects on the drillship and ship dynamics [70]. The mooring line dynamics become complicated in rough weather conditions, with large amplitude wave frequency motions and viscous flow-related hydrodynamic effects contributing to instability. The reliability of these systems is affected over time, as research shows that in large amplitude unstable sea states, the mooring system cannot keep the drillship on station [71, 72].

Now, taking up the issue of installing the structures in seas and rivers invites several complex activities like towing, positioning and maneuvering structures when and where required. The floating solar industry can take help and advantage of oil and gas companies working for many years related to the same. Another major challenge is the design of material/components used to sustain in a harsh oceanic environment where the material and components experience humidity, saltiness in water and stress; as we all know that saltiness in water compromises the materials and makes them corrosive, which can impact the increase of operation and maintenance costs and overall project costs and hamper the efficiency of the plant [22]. The tilt angle determination is another challenge faced in many projects, as the tilt is directly related to the site's latitude [73].

However, we see parameters like shading and soiling can influence it. If we increase the tilt angle, that would contribute to lower soiling but high self-shading. Certainly, a lower inclination will lower the wind effects and wind loads on the panels. Collecting data from surveys and studies such as geotechnical parameters, seasonal flow, bathymetry, water level variation, garbage quantity, and sediment movement is necessary. The industry does not have a standard approach to material life, testing, certification, and institutional process.

The supply chain is disjointed, and the suppliers' products differ. Floating solar panels require improved materials and coatings to withstand prolonged exposure to water, ensuring durability and corrosion resistance. Lighter panels and improved weight distribution mechanisms are crucial for stability and buoyancy. Improving solar panel efficiency is essential for both floating and ground-mounted installations.

Reducing heat sensitivity is also crucial for efficient solar panel use. Self-cleaning or low-maintenance solar panel coatings are beneficial for all solar installations, especially for floating solar. Minimizing the environmental impact of solar panel manufacturing and disposal is a global concern. Enhancing monitoring and control systems is essential for efficient power generation, distribution, and maintenance. Floating platform design needs continuous improvement to enhance stability, ease of installation, and resistance to extreme weather conditions. Water quality management is especially important for floating solar projects, as reduced circulation can lead to algae growth. Technologies for maintaining water quality and preventing ecological disruptions are specifically needed for floating solar projects.

Talking about commercial challenges faced by the floating solar business, especially in India, is because currently, in India, a handful of companies are present in the floating solar business. As we try to promote more floating solar businesses, more companies will come, and the knowledge pool will also increase, which can lead to lower costs by adapting certain innovative technologies and gradually decreasing the project cost [22]. However, the allocation and execution of projects are delayed by the lack of standard agreements for water rights and policies for using water bodies for floating solar. The lack of grids near solar power generating plants (FSPV) could be costly for developers and make the model inaccessible in hard-to-abate areas. Existing transmission lines near inland water bodies and the need for transmission infrastructure from water bodies to nearby sub-stations pose challenges.

The Maharashtra Bench of Authority for Advance Ruling and the Maharashtra Appellate Authority for Advance Ruling for Goods and Services Tax have determined that solar power generating plants are considered immovable property. However, with FSPV plants becoming mobile and floating over water bodies, legal determination or differentiation may be necessary [74].

Securing financing for floating solar projects can be challenging due to the relatively new and unique nature of the technology. However, promoting innovative financing mechanisms, such as green bonds, project financing, and risk-sharing models, can help attract investors. Collaboration with international funding agencies and banks can also provide access to low-cost capital. Encouraging private sector participation through public-private partnerships (PPPs) can also help attract investments. In addition, standard technical requirements for materials used in floats, mooring and anchoring, cables, solar panel technology, and balance of plant, among other things, are difficult to find but urgently needed.

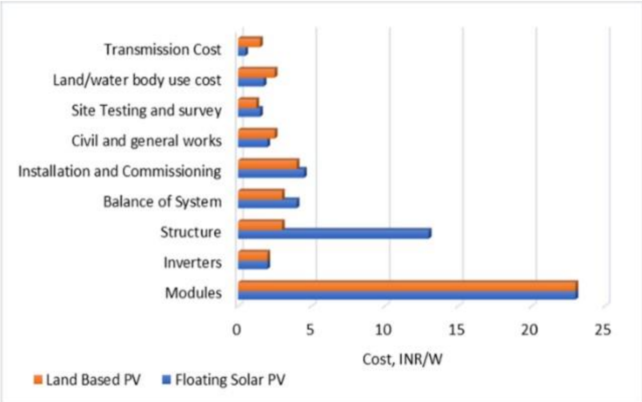

Figure 4. Comparison of Capital cost for floating solar PV & land-based PV systems [75]

Note: Costs are based on a 10 MW system(assume). GST, 20% DC:AC overloading, and 25% safeguard duty on modules are all included in the price. In floating solar, testing and surveying expenses are higher because to hydrographic and bathymetric studies [75]

Talking about financial challenges in India, in Figure 4 we see how price comparison is done by Bridge to India for land based and floating solar PV components. We can see the structure cost is major actor for costly implementation of Floating PV projects. According to Charles Rajesh Kumar and Majid [76], the investment for installing the floating system in India is about 800 to 1200 USD per kW and for the land-based is about 600-650 USD per kW. The difference between the price for both systems is about 25 to 45%. Another thing is the supply of materials like floats and others, for which India must depend on other countries in Europe and China. Logistics is another challenge because the floats require a large space to be transported. For example, we say that to transport 20kW of floats, the space required is as big as required to transport 100kW of panels. The materials required to manufacture floats is HDPE, but import and transport become very expensive. So, in September 2018, an agreement was established between NTPC India and the Central Institute of Plastics Engineering and Technology (CIPET) to establish specific quality strategies, increase the number of suppliers, as well as floating industrial capacity. It is anticipated that increased volumes and a large local production capacity will reduce the 10% to 15% higher cost of floating solar plant.

Occupational health challenges also need to be considered while installing, operating, and maintaining floating solar systems. Solar PV projects in high-solar irradiation areas pose a risk to workers, with heat stress potentially causing a 2.2% global working hour loss by 2030. Acclimatized workers have higher work capacity, but heat-related conditions can affect productivity [77]. Solar radiation exposure can lead to skin cancer [78], and early interventions in the FSPV sector can help protect workers from these long-term health effects by providing shade, rest areas, sun-safety training, using sunglasses, headgear, sunscreens, and medical check-ups [79]. Bakhiyi et al. [80] highlight ergonomic risks in solar PV panel installation and maintenance, including electrocution, arc flash, wind speeds, fire, solar heating, and fall from elevated positions. Maintenance personnel should be aware of the PV system's inability to turn off and potential electrical leakage in highly humid environments, especially in cleaning and replacing panels [81]. FSPV workers face risks from microclimate, toxic chemicals, noise, and vibration. Prolonged wet-work during maintenance and repair of solar panels can lead to occupational skin disorders like Irritant Contact Dermatitis [12, 82]. During the installation of floating solar, the engineers and divers can experience cold and become hypothermic while underwater for the anchoring and mooring process, resulting in drowning underwater [76]. Employees may experience serious cuts and bruises while working in confined spaces. And also, the operator may experience a glare effect, which can have serious vision problems from solar panels and nearby water surfaces. If the floating solar is installed in high altitudes in lakes/rivers, the engineers and operators may also experience cold pressure. Also, if working in rivers and oceans, operators and engineers can experience natural calamities like hurricanes and tides, which can challenge operations and so cause serious life threats.

Certain challenges for land-based PV compared with Floating PV systems:

(1) Zoning and land-use restrictions: Local zoning laws and regulations can make it difficult to find suitable land for solar projects. Land availability can be limited, and conflicts may arise with agricultural or other land uses whereas floating solar systems utilize water bodies, which can reduce land use conflicts and free up land for other purposes.

(2) Interconnection and permitting: Connecting a solar power system to the grid can be complex and time-consuming, requiring various permits and approvals. Intermittent power generation and grid integration challenges affect both land based and Floating PV systems, necessitating solutions such as energy storage and advanced grid management needs to be arranged.

(3) Environmental impact: Some land-based solar projects may negatively affect local ecosystems, wildlife, and habitats. Careful planning and mitigation measures can help to minimize these impacts whereas Floating PV systems, when well-planned, can have a lower environmental impact and may even improve water quality in certain cases.

(4) Access to transmission lines: Solar installations are often located in regions with ample sunlight, which may be far from urban centers where electricity demand is high. Transmitting electricity over long distances can result in transmission losses and higher costs. Encouraging localized distribution of solar power by establishing microgrids or distributed energy resources can reduce the need for extensive long-distance transmission.

(5) Land ownership and leasing: In the case of land-based solar systems, securing land rights and easements for transmission lines from the solar site to substations or distribution points can be complex and may face resistance from landowners. Engaging with local communities and landowners to address concerns and provide incentives for

allowing transmission lines to pass through their properties can help overcome land rights and easement challenges.

(6) Climate and weather: Land-based solar systems face climate and weather challenges like extreme temperatures, dust, and intermittent cloud cover. Solutions include robust panel materials, efficient dust control, weather forecasting technology, and solar tracking systems for improved performance. Floating solar systems can overcome climate and weather challenges by utilizing water's cooling effect, enhancing energy generation efficiency, reducing maintenance needs, and minimizing flood damage in flood-prone areas. This makes floating solar a resilient, climate-adaptive solution.

(7) High upfront costs: Both land-based PV and floating solar projects encounter the significant challenge of high upfront costs. In land-based PV installations, these costs include land acquisition, infrastructure development, and support structures. Similarly, floating solar systems require substantial investments for floating platforms, anchoring systems, and specialized components. The upfront cost challenge is common to both types of solar projects and underscores the importance of financial incentives, subsidies, and innovative financing models to reduce the economic burden on developers and promote the adoption of renewable energy solutions in India.

9. SUGGESTIONS

Floating solar, also known as floating photovoltaic systems, is a relatively new technology that involves installing solar panels on water bodies like lakes, reservoirs, and dams. There are a number of important techniques to increase the productivity and efficiency of floating solar systems.

9.1 Panel orientation and tracking

One of the most important factors in maximizing the efficiency of floating solar panels is to ensure that they are properly oriented and tracked to optimize their exposure to sunlight. This can be achieved by automatically tracking systems adjust the panels' angle to track the path of the sun throughout the day and through advanced control algorithms that optimize the panel orientation in real-time.

9.2 Water cooling

Another key strategy for improving floating solar panels' efficiency is using cooling water systems to dissipate heat. This can be achieved through specialized floating platforms that circulate water around the panels or through submerged water pipes that cool the panels directly. Water cooling for floating solar panels can offer several advantages however, it also comes with potential drawbacks, such as increased complexity and maintenance requirements. Some advantages of water cooling for floating solar panels are:

(1) Enhanced Efficiency: Water acts as a natural coolant, dissipating heat from the solar panels. Excess heat can reduce the efficiency of photovoltaic cells, leading to decreased energy production. Water cooling helps maintain the optimal operating temperature for solar panels, resulting in increased efficiency and energy generation.

(2) Extended Panel Lifespan: High temperatures can accelerate the degradation of solar panels over time. By cooling the panels with water, you can mitigate this heat-related wear and tear, potentially extending the lifespan of the solar panels and the overall system.

(3) Stabilized Electrical Performance: Elevated temperatures can cause electrical performance issues in solar panels. Water cooling helps stabilize the electrical characteristics of the panels, ensuring consistent and reliable energy output.

(4) Minimized Hot Spots: Water cooling can help distribute heat evenly across the panel's surface, minimizing the formation of hot spots. Hot spots can lead to localized overheating and long-term panel damage.

(5) Cooling Benefits for Floating Solar Farms: In the case of floating solar farms, water cooling provides an additional advantage by naturally cooling both the solar panels and the water body beneath them. This cooling effect can help maintain a more stable temperature in the water, potentially benefiting aquatic ecosystems.

Some of the potential drawbacks of water cooling for floating solar panels are:

(1) Increased Complexity: Implementing a water cooling system adds complexity to the overall floating solar installation. It requires the integration of water distribution and circulation systems, which can increase project costs and complexity.

(2) Maintenance Requirements: Water cooling systems need regular maintenance to ensure proper functioning. This includes cleaning and inspecting water channels, pumps, and cooling equipment. In the case of floating solar panels, access to these systems can be more challenging and may require specialized equipment or boats.

(3) Environmental Impact: Water cooling may have environmental implications, particularly in terms of temperature changes in the water body. Significant temperature variations can impact aquatic life, potentially leading to thermal pollution or algal blooms. Proper environmental assessments and mitigation measures are necessary.

(4) Risk of System Failures: Any malfunction or failure in the water cooling system can impact the overall performance of the floating solar installation. This risk underscores the importance of regular maintenance and monitoring.

9.3 Advanced materials

The use of advanced materials such as high-efficiency solar cells, transparent and low-emissivity coatings, and anti-reflective coatings can significantly increase the effectiveness of solar panels on the water. These materials can help maximize the amount of sunlight absorbed by the panels while minimizing losses due to reflection and heat dissipation.

9.4 Panel density and spacing

The density and spacing of floating solar panels can significantly impact their overall efficiency. Increasing the panel density can help to maximize the power produced per square inch while reducing the spacing between panels can help to minimize shading and optimize light transmission.

9.5 Advanced monitoring and control systems

Advanced monitoring and control systems can help optimize the performance of floating solar systems in real-time. These systems can monitor various parameters, such as panel temperature, voltage, current, and power output, and use this data to optimize the system's performance.

9.6 Durability and maintenance

Floating solar systems are subjected to challenging environmental elements as wind, waves, and UV radiation. Therefore, it's crucial to use materials that can withstand the elements and to regularly maintain the system to ensure it continues to operate at peak efficiency. Maintenance requirements for floating solar systems are similar in some aspects to land-based solar systems but also have some unique considerations due to their aquatic environment. So, breaking down further the frequency and types of maintenance required for floating solar systems are:

(1) Regular Cleaning: Floating solar panels, like their land-based counterparts, accumulate dust, dirt, and debris over time. Regular cleaning is necessary to ensure that the solar panels receive maximum sunlight. The frequency of cleaning can vary depending on the location and environmental conditions but may range from a few times a year to more frequently in dusty or polluted areas.

(2) Anchor and Buoy Inspection: Floating solar systems are anchored to the bottom of the water body, and they use buoys or other flotation devices. These components need periodic inspection to ensure they remain secure and functional. Inspections may be needed every few months or annually.

(3) Electrical and Mechanical Inspections: The electrical and mechanical components of a floating solar system, such as inverters, cables, and connectors, require regular inspections for signs of wear, corrosion, or damage. These inspections may occur annually or more frequently, depending on the system's size and design.

(4) Monitoring System Checks: Floating solar systems often include monitoring systems to track energy production and system performance. These systems should be regularly checked to ensure they are functioning correctly. Monitoring data can help detect issues early.

(5) Aquatic Plant Control: Aquatic plants and algae can grow on the water's surface and interfere with the operation of floating solar panels. Periodic control measures, such as manual removal or the use of biodegradable herbicides, may be required to prevent excessive growth.

(6) Weather Event Response: In the event of severe weather conditions, such as storms or heavy winds, floating solar systems may require immediate attention to assess and repair any damage. Emergency response plans should be in place.

Some of the maintenance types for floating solar systems compared to land-based solar systems are:

(1) Cleaning: Cleaning requirements for floating solar systems are typically more frequent compared to land-based systems due to the exposure to water, which can carry dirt and debris. Land-based systems also require cleaning but may be less prone to water-related issues.

(2) Corrosion and Water Resistance: Floating solar systems must be designed with corrosion-resistant materials and waterproof components to withstand the aquatic environment. Land-based systems may face different environmental challenges but generally do not require the same level of water resistance.

(3) Buoy and Anchor Maintenance: Floating solar systems have unique components like buoys and anchors that require maintenance and inspection, which are not applicable to land-based systems.

(4) Aquatic Plant Control: Controlling aquatic plant growth is specific to floating solar systems and is not a concern for land-based installations.

(5) Weather Vulnerability: Floating solar systems are more vulnerable to extreme weather events such as strong winds and waves. Land-based systems may be more resilient in this regard but can still require maintenance in case of damage.

(6) Access Challenges: Accessing floating solar systems for maintenance can be more challenging and may require specialized equipment or boats, while land-based systems are typically easier to access.

9.7 Grid integration and storage

Integrating floating solar systems with the grid, and using energy storage systems, such as batteries, can help to ensure that the electricity generated by the system is used effectively and efficiently. This can help to minimize losses due to transmission and distribution and can also help to ensure that the system can provide power even when the sun is not shining.

9.8 Cost reduction

The cost of floating solar systems remains higher than traditional land-based systems. However, economies of scale and technological advancements can help to bring down the costs, making it more accessible to a larger number of people.

9.9 Hybrid systems

Combining floating solar as compared to other renewable energy sources, such wind or hydropower, can help increase the system's overall efficiency and effectiveness. This can help to ensure that the system can provide power even when one of the sources is unavailable [10].

9.10 Environmental impact

The environmental impact of floating solar should be considered while installing the system. This can be done by conducting an Environmental Impact Assessment to minimize the impact on aquatic life and ensure the sustainability of the ecosystem.

As, floating solar technology has the potential to become a major source of renewable energy in the future. However, it's important to continue developing and improving the technology to maximize its efficiency and effectiveness by using advanced materials, optimizing panel orientation and spacing, and incorporating water cooling and advanced monitoring systems.

10. CONCLUSIONS

Floating solar panels, also known as floating photovoltaic systems, offer an alternative to traditional ground-mounted PV systems for harnessing solar energy. Both technologies have advantages and disadvantages, and their choice will depend on specific factors such as site location, environmental conditions, and project goals.

(1) Power generation: Floating PV systems can generate similar amounts of power as ground-mounted PV systems,

depending on the design and configuration of the system. However, floating solar panels can have an advantage in terms of power generation in areas with limited space for ground-mounted PV systems. Also, floating solar panels can provide shading benefits to the bodies of water they are installed on, reducing evaporation and promoting better water quality.

(2) Environmental aspects: Floating PV systems can have a lower environmental impact than ground-mounted PV systems in certain situations. For example, they can help preserve land and wildlife habitats and may also benefit the water bodies they are installed on. However, conducting an Environmental Impact Assessment before installing floating solar systems is important to ensure that the system does not harm aquatic life and a sustainable ecosystem. Some of the land use implications of ground-mounted solar panels are land occupation, loss of agricultural land, habitat disruption, aesthetic concerns, stormwater management which leads affect stormwater management and drainage patterns, potentially leading to runoff and erosion issues. By adopting to floating solar we can mitigate these issues as we need no land occupation, preservation of farmland and habitat protection can take place and major water management benefit will also occur in reservoirs and lakes where there will be reduction in water evaporation.

(3) Social Aspects: The installation of floating solar panels can impact local communities in terms of job creation and energy prices. Since they will be impacted by the reduced fishing area, they would receive preference when hiring workers for the floating solar farm, maintenance and operation jobs, training programs and partnerships with local educational institutions can help develop a skilled workforce [83]. Also, they can provide energy to the local communities in much cheaper energy price which can somehow not much but can help compensate the loss.

(4) Market potential: Floating solar systems are still a relatively new technology, and their market potential remains untapped. However, as the cost of floating solar systems continues to decrease and the market potential for Floating PV systems is anticipated to develop in the next years as the demand for renewable energy continues to rise.

(5) Challenges: Despite their potential advantages, Floating PV systems also have several challenges that must be overcome. One of the main challenges is the high cost of installation and maintenance. Traditional ground-mounted PV systems continue to be more expensive than floating solar systems. Additionally, floating solar systems are exposed to harsh environmental conditions such as wind, waves, and UV radiation, which can affect the durability and longevity of the system.

In conclusion, floating solar panels are an exciting and promising technology that has the potential to become a major source of renewable energy in the future. They offer an alternative to traditional ground-mounted PV systems, potentially generating similar amounts of power while minimizing environmental impacts and preserving land and wildlife habitats. However, it's important to consider the cost, environmental impact, and other challenges associated with Floating PV systems before deciding. It's crucial to comprehensively analyze all the factors before deciding between a ground-mounted PV system and a floating solar system. When deciding, factors such as site location, environmental conditions, and project goals should be considered. As the cost of floating solar systems continues to decrease and the demand for renewable energy continues to increase, the market potential for Floating PV systems is expected to grow in the coming years.

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