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Performance Analysis of Floating Solar Photovoltaic System for Humid and Saline Conditions

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WHAT IS ALREADY KNOWN ON THIS TOPIC?

- *Floating solar photovoltaic (FSPV) systems can improve energy performance compared to land-based photovoltaic (LSPV) systems because the surrounding water provides natural cooling and reduces dust accumulation, which helps maintain lower module temperatures and higher electrical efficiency.*
- *Knowledge gap: Most existing studies focus on the cooling benefits and energy yield improvement of FSPV systems, while the effects of humidity, salinity, and long-term exposure to coastal environments on system performance and reliability remain insufficiently explored.*

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ABSTRACT

Floating solar photovoltaic (FSPV) systems have emerged as a promising alternative to conventional land-based photovoltaic (LSPV) systems by reducing land-use constraints and improving electrical performance through the natural cooling effect of water bodies. However, long-term deployment in humid and saline coastal environments may accelerate moisture ingress, salt deposition, and corrosion, reducing system reliability and energy generation. This study presents a comparative performance assessment of a conventional LSPV system, a freshwater FSPV system, and an FSPV system operating under humid and saline conditions using the System Advisor Model. All three systems were modeled with identical installed capacities, module technologies, inverter configurations, and meteorological inputs to isolate the influence of environmental conditions on system performance. The freshwater FSPV system generated 14 900 kWh of annual alternating current energy in the first year compared with 14 248 kWh for the LSPV system, corresponding to an improvement of approximately 4%–5%. The direct current capacity factor increased from 16.30% to 18.90%, the energy yield improved from 1424 to 1656 kWh/kW, and the performance ratio increased from 0.71 to 0.82 because of lower module operating temperatures. When humidity- and salinity-induced degradation was considered, the annual energy generation decreased to 14 400 kWh, the performance ratio declined to 0.72, and the lifetime energy output reduced to approximately 6347 kWh after 25 years owing to accelerated corrosion. The results demonstrate that freshwater FSPV systems provide superior energy performance compared with LSPV systems. However, their long-term advantages in coastal environments can be substantially reduced by humidity- and salinity-induced degradation, highlighting the need for corrosion-resistant materials, improved encapsulation, and effective maintenance strategies for reliable long-term operation.

***Index Terms*—**Coastal climate, floating solar photovoltaic, humidity, land scarcity, performance ratio, salinity

I. INTRODUCTION

The global energy sector is experiencing an unprecedented transformation driven by the urgent need to reduce greenhouse gas emissions, mitigate climate change, and ensure long-term energy security. Fossil-fuel-based electricity generation remains one of the largest contributors to anthropogenic carbon emissions, making the decarbonization of the power sector a central objective of international climate policies and sustainable development strategies. Consequently, countries across the world are accelerating the deployment of renewable energy technologies through supportive policy frameworks, carbon pricing mechanisms, and electricity market reforms. Shuyue and Yue [1] demonstrated that increasing renewable energy penetration is fundamental to achieving deep decarbonization of the electricity sector, while Bajpai and Koul [2] reported that replacing fossil-fuel-based electricity with renewable energy substantially reduces environmental pollution and improves public health. Thompson [3] further emphasized that a complete transition towards renewable electricity is indispensable for achieving global carbon neutrality without compromising future energy demand. Despite these developments, the pace of renewable energy deployment continues to be influenced by technological advancement, policy implementation, economic incentives, and infrastructure readiness. Yu et al. [4] showed that carbon emission trading mechanisms and renewable energy support policies significantly accelerate renewable energy integration into electricity markets, whereas Bogdanov et al. [5]

WHAT THIS STUDY ADDS ON THIS TOPIC?

- *This study evaluates and compares the performance of LSPV, FSPV, and FSPV under humid and saline coastal conditions using the System Advisor Model, providing insights into how coastal environmental stresses influence energy generation, performance ratio, capacity factor, and system losses.*

highlighted that future energy systems will increasingly rely on renewable electricity as the primary energy carrier linking the power, transport, heating, industrial, and desalination sectors.

Among the available renewable energy technologies, solar photovoltaic (PV) systems have emerged as one of the fastest-growing sources of electricity because of their modularity, technological maturity, declining installation costs, and widespread resource availability. Recent reviews have highlighted the importance of PV technology in achieving sustainable energy development and long-term decarbonization objectives [6]. However, the practical performance of PV systems cannot be evaluated solely on the basis of installed capacity because the actual electricity generated depends strongly on environmental conditions, operational characteristics, and long-term degradation behavior. Consequently, performance assessment has become an essential aspect of PV system evaluation, with parameters such as annual energy generation, specific energy yield, performance ratio, capacity utilization factor, and system efficiency being widely adopted to quantify real operating performance [6]. Several long-term field investigations have demonstrated that PV system performance is governed by the interaction of solar irradiance, module operating temperature, environmental exposure, and system losses. Boddapati et al. [7] investigated the techno-economic performance of a 50 MW grid-connected PV plant and demonstrated that electricity generation is significantly influenced by module temperature, inverter losses, and grid evacuation constraints. Saleheen et al. [8] monitored a commercial grid-connected PV installation under Malaysian climatic conditions and observed a strong correlation between solar irradiance and electrical output, while increasing module temperatures reduced conversion efficiency. Mishra et al. [9] performed a long-term degradation assessment of a five MW PV power plant and demonstrated that seasonal variations in humidity, ambient temperature, and environmental exposure substantially influence performance ratio and long-term energy generation. These studies collectively demonstrate that actual PV performance is governed by continuously changing environmental conditions that cannot be fully represented using laboratory testing or short-term simulations.

Beyond short-term environmental variations, PV systems experience gradual degradation throughout their operational lifetime due to prolonged exposure to outdoor conditions. Environmental stressors including elevated temperatures, dust accumulation, ultraviolet radiation, atmospheric pollutants, moisture, and mechanical aging progressively reduce module performance and electrical reliability. Edalati et al. [10] demonstrated that variations in irradiance, dust deposition, and operating temperature significantly influence PV energy production under real outdoor conditions. Navothna and Thotakura [11] reported continuous reductions in performance ratio during long-term monitoring of grid-integrated PV installations operating under tropical climatic conditions. Sepulveda-Oviedo [12] concluded that PV degradation rates vary considerably with climatic conditions, module technology, manufacturing quality, and environmental exposure, emphasizing that long-term field monitoring is indispensable for accurately evaluating PV reliability. Among the numerous environmental parameters affecting PV performance, module operating temperature is recognized as one of the most influential factors governing electrical efficiency. Manufacturer ratings are determined under Standard Test Conditions (STC), whereas actual operating environments frequently differ because only a small fraction of incident solar radiation is converted into electricity while the remaining energy is dissipated as heat. Tahir et al. [13] experimentally evaluated five PV technologies under different climatic conditions and demonstrated that increasing module temperature consistently reduces electrical efficiency. Villarruel-Jaramillo et al. [14] emphasized the importance of effective thermal management, demonstrating that natural convective cooling produced by higher wind velocities reduces module temperature and improves electrical performance. Recent investigations have further demonstrated that effective thermal management significantly improves the operational performance of floating PV systems. Elminshawy et al. [15] showed that combining passive cooling with intelligent maximum power point tracking enhances electrical efficiency, increases power generation, and improves the overall energetic, environmental, and economic performance of floating PV installations, thereby highlighting the importance of thermal regulation in maximizing long-term system productivity.

Despite the rapid expansion of PV technology, its large-scale deployment is increasingly constrained by land availability. Utility-scale PV power plants require extensive land resources, often resulting in competition with agriculture, urban development, forestry, biodiversity conservation, and other socioeconomic activities. Lazo et al. [16] demonstrated that high-productivity agricultural land is economically unsuitable for utility-scale PV deployment because of its high

opportunity cost, whereas marginal and low-productivity land offers greater potential for future solar development. Diffendorfer et al. [17] estimated that achieving deep decarbonization scenarios in the United States could require between 14 000 km^2 and 35 000 km^2 of land for PV deployment, potentially affecting agricultural and natural landscapes. Regulatory restrictions further reduce the availability of suitable installation sites. Ranjgar et al. [18] reported that after considering environmental regulations, protected ecosystems, cultural heritage sites, and hazard-prone regions, only about 26% of Italy's total land area remains suitable for ground-mounted PV installations. Biswas et al. [19] observed that module manufacturing contributes nearly 76% of the total environmental footprint of rooftop PV systems, highlighting that large-scale terrestrial deployment continues to involve land-use and material-resource challenges. These limitations have motivated researchers to investigate alternative deployment strategies capable of expanding solar electricity generation without increasing pressure on valuable terrestrial resources.

Floating solar photovoltaic (FSPV) technology has emerged as one of the most promising alternatives for overcoming the land constraints associated with conventional PV installations. Instead of occupying agricultural or urban land, FSPV systems utilize underexploited water bodies such as reservoirs, lakes, quarry pits, irrigation canals, wastewater treatment ponds, and hydropower reservoirs. This approach not only preserves valuable land resources but also enables renewable electricity generation using existing water infrastructure. Global deployment has increased rapidly during the past decade, with several countries investing extensively in FSPV projects to diversify renewable electricity generation while minimizing conflicts with agriculture and urban development. The technical potential of FSPV systems has attracted considerable international attention. Jamalludin et al. [20] evaluated six potential FSPV locations in Malaysia and estimated that these installations could collectively generate approximately 14 530 MWh of electricity annually. Silalahi and Blakers [21] identified extensive marine FSPV potential around the Indonesian archipelago, the Gulf of Guinea, and several protected coastal regions of Europe. These investigations demonstrate that FSPV technology has evolved from a niche concept into a practical solution capable of supporting future large-scale renewable energy deployment in regions where land availability has become a critical limitation.

In addition to overcoming land scarcity, FSPV systems provide several operational and environmental advantages over conventional land-based installations. Reservoir-based FSPV systems can utilize existing electrical infrastructure associated with hydropower plants while reducing transmission expansion requirements. Raimundo et al. [22] demonstrated that integrating FSPV systems with hydropower reservoirs significantly increases electricity generation while improving overall system reliability. Singh et al. [23] reported that hybrid hydropower–FSPV systems improve energy economics, reduce greenhouse gas emissions, and decrease reservoir water evaporation. Another major advantage of FSPV technology is the improvement in module operating conditions resulting from the cooling effect of the surrounding water body. Water continuously removes heat from PV modules through evaporative and convective cooling, producing lower operating temperatures than comparable land-based systems. Recent research has shown that the benefits of FSPV systems extend beyond improved thermal regulation. Adak [24] demonstrated that the cooling effect of water can significantly enhance module efficiency and electrical output, while also highlighting the importance of effective inverter control and harmonic mitigation for maintaining power quality and reliable grid integration under practical operating conditions. Anusuya and Vijayakumar [25] compared floating and ground-mounted PV systems under Indian climatic conditions and reported superior electrical performance for floating installations. Boduch et al. [26] experimentally observed module temperature reductions ranging from 4.10 °C to 6.50 °C, leading to measurable improvements in annual energy production. Ravichandran et al. [27] demonstrated that offshore FSPV systems operating in island environments maintained module temperatures approximately 3.50 °C lower than equivalent land-based systems. Essak and Ghosh [28] concluded in their comprehensive review that reduced operating temperature represents one of the principal reasons for the superior performance of FSPV systems. Recent experimental investigations have further confirmed the technical advantages of FSPV technology under practical operating conditions. Elminshawy et al. [29] demonstrated that the natural cooling effect of the water surface significantly reduced PV module temperature, resulting in improved electrical performance compared with conventional land-based systems. The study also emphasized that FSPV installations simultaneously reduce water evaporation, improve resource utilization, reduce cost of electricity and strengthen the water-energy nexus, highlighting their potential as a sustainable solution for future renewable energy deployment. Collectively, these studies establish that the aquatic operating environment provides significant thermal advantages capable of improving both electrical efficiency and long-term energy generation.

However, FSPV systems should not be regarded simply as conventional PV installations mounted on floating structures. The aquatic environment fundamentally alters the operating conditions experienced by PV modules, introducing new environmental interactions that influence electrical performance, maintenance requirements, and long-term reliability. Unlike ground-mounted PV plants, floating installations operate under persistently high humidity, elevated moisture levels, frequent condensation, and, in coastal or estuarine locations, continuous exposure to saline aerosols. These environmental factors influence both the electrical and mechanical integrity of PV modules and may progressively reduce their long-term performance. Humidity has long been recognized as one of the primary environmental factors influencing PV module reliability. Continuous exposure to high relative humidity promotes moisture diffusion through encapsulation materials, edge seals, backsheets, and junction boxes, eventually reaching electrically active components. Kumar et al. [30] experimentally demonstrated that localized moisture accumulation significantly influences module durability by accelerating material degradation and producing non-uniform aging. Wisniewski et al. [31] quantified moisture ingress in double-glass PV modules and showed that water diffusion depends strongly on module architecture, encapsulation materials, and exposure duration. Marwaha and Ghosh [32] confirmed that prolonged damp-heat exposure accelerates moisture transport through encapsulation layers, increasing the probability of electrical degradation. Hendarti et al. [33] investigated FSPV systems installed over tropical ponds and demonstrated that high ambient humidity significantly influences module operating conditions. Ramanan et al. [34] identified environmental durability as one of the major technological challenges limiting the long-term deployment of FSPV systems. Deilami et al. [35] concluded that maintaining long-term reliability under humid operating conditions remains an important research challenge. Garrod et al. [36] emphasized that understanding environmental

degradation mechanisms is essential for ensuring the sustainable expansion of FSPV technology.

Saline environments introduce an additional level of complexity to FSPV operation. Coastal reservoirs, estuaries, lagoons, ports, and offshore installations are continuously exposed to airborne sea-salt aerosols transported by wind. Salt particles gradually accumulate on module surfaces and dissolve in condensed moisture, forming conductive electrolyte layers that accelerate electrochemical corrosion of metallic contacts, busbars, interconnect ribbons, connectors, and junction-box terminals [37]. As FSPV deployment expands towards coastal regions, understanding the influence of salt deposition has become increasingly important for ensuring long-term system reliability. Gao et al. [38] proposed an analytical framework for evaluating offshore PV performance by relating electrical degradation to salt deposition characteristics, demonstrating that salt accumulation has a measurable influence on PV power generation. Rizvi et al. [39] experimentally investigated the influence of seawater salt deposition on FSPV systems and demonstrated that salt accumulation significantly reduces electrical performance while increasing maintenance requirements. Suzuki et al. [40] demonstrated that exposure to salt-mist environments substantially accelerates potential-induced degradation (PID) in crystalline silicon PV modules by increasing surface conductivity and facilitating leakage current formation. An et al. [41] reported that corrosion and aging significantly influence maximum power point tracking performance in coastal PV systems. These investigations collectively demonstrate that humidity, salt deposition, and electrical degradation mechanisms are strongly interconnected and should therefore be evaluated simultaneously when assessing FSPV performance.

Beyond improvements in floating platform design and thermal regulation, recent investigations have explored intelligent control strategies to further enhance FSPV performance. Elbaksawi et al. [42] demonstrated that an advanced hybrid maximum power point tracking algorithm significantly improved annual energy generation, electrical efficiency, and overall system performance under varying environmental conditions, emphasizing the role of intelligent energy management in maximizing the operational effectiveness of FSPV systems. Recent studies have further highlighted that the performance of FSPV systems is governed not only by module cooling but also by dynamic environmental conditions and intelligent operational control. Elminshawy et al. [43] demonstrated that fluctuations in solar irradiance and weather conditions substantially influence FSPV performance, while advanced hybrid maximum power point tracking strategies enhance energy extraction, operational stability, and overall system efficiency under practical operating conditions.

Despite substantial progress in understanding individual degradation mechanisms and performance enhancement strategies, few studies have evaluated their combined influence under actual FSPV operating conditions. Most existing investigations have concentrated either on laboratory-based damp-heat testing, moisture diffusion modeling, or accelerated salt-mist exposure experiments, whereas comparatively few have examined utility-scale FSPV systems operating under natural environmental conditions. Although several studies have compared FSPV systems with conventional land-based installations, differences in system capacity, module technology, inverter specifications, geographical location, and meteorological conditions often hinder direct comparison. In addition, most simulation-based investigations primarily emphasize annual energy generation and techno-economic feasibility, with limited attention devoted to detailed electrical performance indicators under aggressive environmental conditions. Long-term degradation assessments have predominantly focused on conventional land-based PV plants, while comparable investigations for floating systems in humid subtropical or saline coastal environments remain scarce. Recent field-based studies have emphasized the limited availability of long-term datasets for FSPV installations. Consequently, the absence of standardized comparative investigations limits the understanding of how environmental stressors, combined with intelligent control strategies, influence the long-term performance and reliability of FSPV systems.

This study addresses these critical research gaps by performing a systematic comparative performance assessment of three PV deployment configurations using System Advisor Model (SAM): (i) a conventional land-based photovoltaic (LSPV) system, (ii) a FSPV system operating under freshwater conditions, and (iii) an FSPV system operating under humid and saline coastal conditions. All three systems are developed using identical installed capacities, module technologies, and inverter configurations to ensure that observed differences arise primarily from variations in environmental operating conditions rather than system design parameters. The comparative assessment evaluates key performance indicators including annual energy generation, specific energy yield, performance ratio, capacity factor, array efficiency, inverter efficiency, and overall system losses. Unlike previous investigations that have primarily focused on thermal advantages, techno-economic feasibility, or individual degradation mechanisms in isolation, the present work systematically examines the combined effects of humid and saline environmental conditions through a direct, design-controlled comparison. The findings are expected to provide valuable insights into the suitability of FSPV technology for deployment in humid tropical and coastal regions while contributing to improved system design, environmental adaptation, operational reliability, and long-term performance prediction. Ultimately, the outcomes of this study will support researchers, project developers, utility operators, and policymakers in designing more resilient and sustainable FSPV systems capable of delivering reliable low-carbon electricity under challenging environmental conditions.

II. MATHEMATICAL MODELLING

A. Photovoltaic Cell Current

The electrical behavior of the PV cell can be described using the single-diode equivalent circuit model. This model represents the PV cell as a current source in parallel with a diode and a shunt resistance, together with a series resistance that accounts for internal losses. The output current of the PV cell is determined by the balance between the generated photocurrent, the diode current, and resistive losses. The resulting current–voltage relationship is expressed as given in Eq. 1 [44]:

$$I = I_{PV} - I_d - \frac{V + R_s I}{R_P} \quad (1)$$

Where I_{PV} represents the current generated from the photoelectric effect. I_d is the diode current, which depends on the thermal characteristics and material properties of the PV cell, given by Eq. 2 [44]. It describes the nonlinear current–voltage behavior of the semiconductor junction.

$$I_d = I_0\left(e^{\frac{V+R_sI}{aV_t}} - 1\right) \quad (2)$$

Where I_0 is the saturation current, R_s is the series resistance, V is the cell voltage, and a is the diode ideality factor.

The thermal voltage of the PV cell, which depends on the cell temperature (T), is given by Eq. 3 [44]. This relation highlights the influence of temperature on the electrical characteristics of the PV cell. As temperature increases, the thermal voltage increases, which affects the diode current and consequently the overall operating point of the cell.

$$V_t = \frac{kT}{q} \quad (3)$$

Where k is the Boltzmann constant and q is the charge of an electron.

This equation highlights how temperature affects the operating voltage of the cell, which influences overall efficiency.

The photocurrent, which is directly proportional to the incident irradiance and depends on temperature, is expressed as follows[45]:

$$I_{PV} = I_{PV,ref} + k_I \Delta T \cdot \frac{L}{L_{ref}} \quad (4)$$

$$\Delta T = T_c - T_{ref} \quad (5)$$

Where $I_{PV,ref}$ is the photocurrent under STC. k_I is the temperature coefficient of current. T_c is the cell temperature and T_{ref} is the reference temperature. This equation shows how changes in irradiance and temperature affect the current output of a PV cell.

Eq. 6 models the variation of the saturation current with temperature [44]. This relation captures the thermally activated recombination mechanisms within the diode. As temperature increases, the saturation current increases rapidly, which reduces the open-circuit voltage and negatively affects PV performance.

$$I_0(T) = I_{0,ref}\left(\frac{T_c}{T_{ref}}\right)^3 e^{\frac{qE_g}{k}\left(\frac{1}{T_{ref}} - \frac{1}{T_c}\right)} \quad (6)$$

Where $I_{0,ref}$ is the saturation current at reference temperature. E_g is the energy bandgap of the material in electron volts (eV). This equation models the thermally induced recombination effects within the diode, which can degrade performance at higher temperatures.

For a PV module with multiple cells, the overall current (I_m) is derived as given in Eq. 7 [44]:

$$I_m = N_S I_{PV} - N_S I_0\left(e^{\frac{V_m + R_{s,eq} I_m}{aV_{tm}}} - 1\right) - \frac{V_m + R_{s,eq} I_m}{R_{p,eq}} \quad (7)$$

Where N_S is the number of strings in the module. V_m is the module voltage. $R_{s,eq}$ and $R_{p,eq}$ are the equivalent series and shunt resistances of the module, respectively. V_{tm} is the thermal voltage of the module. This equation represents how the configuration of cells in a module influences its current output.

The energy conversion efficiency (η) of a PV system is sensitive to the cell temperature (T_m) and is given as follows [46]:

$$\eta = \eta_{ref}\left[1 - \beta\left(T_m - T_{ref}\right)\right] \quad (8)$$

Where η_{ref} is the efficiency at the reference temperature. β is the temperature coefficient of efficiency. This equation emphasizes the importance of temperature regulation to maintain efficiency, as higher temperatures generally reduce efficiency.

The temperature of a PV module (T_m) is influenced by ambient conditions, irradiance, and wind speed (U_w), which is given as

$$T_m = L \cdot e^{(a+bU_w)} + T_a \quad (9)$$

Where T_a is the ambient temperature. a and b are empirical constants adjusted for module material and mounting conditions. This equation captures how environmental factors affect module temperature, a critical parameter for performance.

The power output of a PV system considering temperature and irradiance is modeled as given in Eq. 10 [47]

$$P_{PV} = \eta_{PV}\eta_{inv}A_m L\left(1 - \alpha_p\left[T_m - T_{ref}\right]\right) \quad (10)$$

Where η_{PV} and η_{inv} are the efficiencies of the PV module and inverter, respectively. A_m is the area of one module. α_p is the temperature coefficient of power. This equation shows how both environmental and system-specific factors influence the system's power output.

The energy yield (Y_E) is defined as the ratio of the annual energy output to the installed capacity

$$Y_E = \frac{E_G}{P_{in}} \quad (11)$$

Where E_G is the annual energy generated in kWh. P_{in} is the installed capacity in kW.

Energy yield is a critical metric for assessing the performance of PV systems.

The Capacity Utilization Factor (CUF) measures the efficiency of a PV plant over an extended period and is defined as [48]

$$CUF = \frac{E_S}{365 \cdot 24 \cdot P_C} \cdot 100 \quad (12)$$

Where E_S is the annual energy output in MWh. P_C is the installed capacity of the plant in MW. Capacity Utilization Factor provides insights into how effectively the plant is utilizing its capacity year-round.

III. METHODOLOGY

A. Site Selection

The site selection is significant to measure the performance of the PV systems in the actual environmental conditions. The yield of the energy, the temperature, and the humidity of the surrounding atmosphere, winds, and the salinity of the atmosphere are local climate factors that can affect the yield of energy, the temperature of the

module, and the reliability of the system in the long term. Selection of an appropriate site will thus ensure that the performance of the system is in line with realistic operating conditions.

Mambakkam Lake (12.8359N, 80.1641ºE), which is close to Chennai, Tamil Nadu, India, is the site of the study. The area is in the coastal climate zone, which is affected by the humidity and salinity of the Bay of Bengal. This leads to high levels of humidity in the region and salt air that is carried by the coastal winds, which expose the region on a periodic basis. These are conducive factors that help to test the behavior of FSPV systems in humid and salty conditions, and the location receives good solar radiation all through the year, promoting stable PV power. The lake also provides a water surface on which the floating installations can be placed, and the system is also exposed to the natural environmental conditions. Such properties qualify Mambakkam Lake as a good place for testing FSPV behavior in a coastal environment.

B. Photovoltaic Design

The PV system was designed using the SAM software to evaluate the performance of the FSPV installation under the climatic conditions of the selected site. Meteorological inputs used in the simulations were obtained from the National Solar Radiation Database (NSRDB) through the SAM. The simulations were performed using a Typical Meteorological Year (TMY) weather file, which represents long-term average climatic conditions derived from multiple years of historical observations and satellite-based data. Consequently, the annual performance results presented in this study correspond to a representative meteorological year rather than measurements collected during a single calendar year. The array capacity was estimated using the relation between available installation area, module efficiency, and the standard test condition irradiance of 1000 W/m^2. Based on the available area, the system was designed with a nominal direct current (DC) capacity of 10 kW.

The DC to alternating current (AC) ratio of 1.25 was selected to ensure efficient inverter utilization under varying irradiance levels. Accordingly, the inverter capacity was estimated at approximately 8.00 kW AC. The system uses PV modules rated at 250 W under standard test conditions. To achieve the required 10 kW capacity, a total of 40 PV modules were selected.

Each PV module has an open-circuit voltage of 37.60 V. String sizing was determined based on inverter voltage constraints. Using the maximum allowable DC voltage of 480 V, the maximum number of modules per string was calculated to be approximately 12 modules. The minimum string size was determined using the lower voltage limit of 350 V, which corresponds to approximately nine modules per string. Based on these limits, the array configuration was finalized as four strings with ten PV modules connected in series in each string. The schematic diagram of the FSPV system in given in Fig. 1.

This configuration ensures that the operating voltage remains within the inverter limits while maintaining stable power generation. The site location details and environmental parameters used for the FSPV system design are summarized in Table I.

IV. RESULTS

This part involves a comparative study of three PV systems. The aim is to test the impact that installation environments have on the performance and energy generation of a system. To begin with, the standard LSPV system is examined. The outcome of this case can serve as a standard on which the work of floating installations is assessed. The second setup takes into account an FSPV system mounted on a water surface. The study is dedicated to how the water affects the temperature of the modules and efficiency of the system. The third setup is used to measure the FSPV system under further environmental factors regarding the saline coastal environment. In this case,

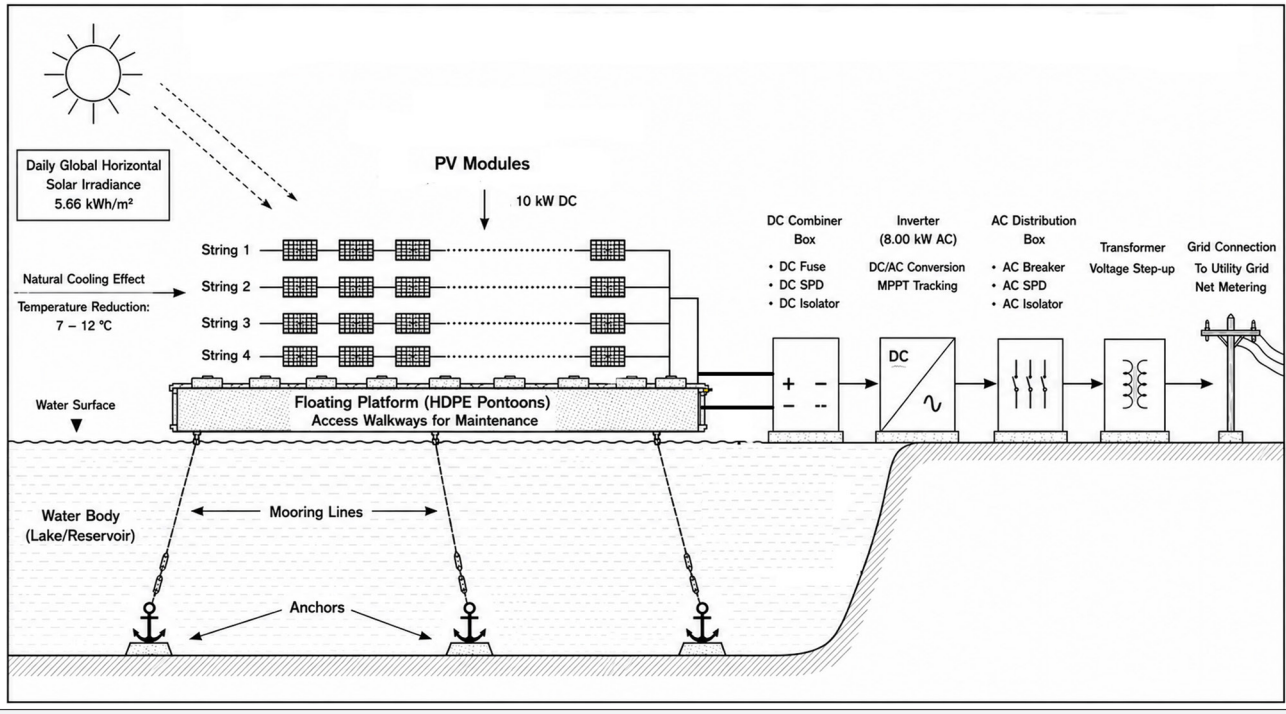

Fig. 1. Schematic diagram of the FSPV system. Note: FSPV = floating solar photovoltaic.

TABLE I. LOCATION DATA

Parameter	LSPV	FSPV
District	Chennai	Chennai
State	Tamil Nadu	Tamil Nadu
Latitude	12.84 °N	12.84 °N
Longitude	80.17 °E	80.17 °E
Daily global horizontal solar irradiance	5.66 kWh/m^2	5.66 kWh/m^2
Average temperature	28.20 °C	17.19 °C
Average wind speed	3.20 m/s	3.20 m/s
Annual albedo	0.16	0.16
Data source	NSRDB	NSRDB

Note: LSPV = land-based photovoltaic; NSRDB = National Solar Radiation Database.

the role of humidity and effects of salt degradation are included to determine their possible effect on the electrical performance and energy production in the long term.

Each of the three configurations is simulated with the same system sizing, inverter parameters, and meteorological data. This ensures that variations in performance emerge as a result of environmental circumstances as opposed to variation in system design. To compare the benefits and shortcomings of FSPV installations with the standard LSPV systems, the comparison is made based on key performance indicators, such as annual energy production, performance ratio, capacity factor, and system losses.

A. Output for Land-Based Photovoltaic Model

In order to present the performance of the PV system, loss analysis is first done in detail. Despite the nominal capacity at which a PV plant is rated, the total amount of energy supplied to the grid is lower since, during the process of operation, several optical, thermal, electrical, and conversion losses do take place and reduce the overall energy supplied to the grid. Determining and enumerating these losses is useful to comprehend the actual system and give an essential background to compare the LSPV system with the FSPV systems. The nominal plane-of-array irradiance that the system receives is about 130 008 kWh. The major sources of initial optical losses are soiling (8.00%) and reflection losses (1.79%), whereas the shading losses are insignificant due to the appropriate orientation of the system as well as installation conditions.

The LSPV system generates 18 156 kWh of nominal DC power. The loss in modules in the form of temperature (7.84%) is a significant portion of the reduction in power. Other electrical losses include inverter Maximum Power Point Tracking (MPPT) clipping (8.84%), DC wiring (2.00%), diodes and connections (0.50%), and power optimizer losses (1.00%). When these effects are taken into consideration, there is a net DC electricity of 14 602 kWh. In converting DC to AC, the conversion work of inverters only decreases the output as well. They are inverter operation consumption (0.56%) and inverter efficiency losses (2.10%). Subsequently, the gross AC electricity produced is 14205 kWh. Lastly, there are other small AC-side losses, including AC wiring (1.00%) and battery losses (0.84%), on the way to the grid. The system exports 14 248 kWh of net AC electricity in a year after all losses are taken into account. These results indicate that temperature effects and environmental factors such as module heating and surface soiling are the dominant contributors to performance reduction in the LSPV installation.

TABLE II. PERFORMANCE ANALYSIS OF LSPV SYSTEM

Metric	Value
Annual AC energy in year 1	14 248 kWh
DC capacity factor in year 1	16.30%
Energy yield in year 1	1424 kWh/kW
Performance ratio in year 1	0.71

Note: AC = alternating current; DC = direct current; LSPV = land-based photovoltaic.

In Table II, the performance of the LSPV system is outlined. The AC-generated energy in the first year is 14 248 kWh, and this is the actual flow of electricity to the grid after taking into account all optical, thermal, and electrical losses. This value is the practical operating output of the system, and not the installed nominal capacity of the system. The DC capacity factor of 16.30% implies that the PV array can work at its rated output during 16.30% of the total annual hours. This is characteristic of LSPV solar installations whereby energy generation is dependent on the daily and seasonal availability of the sun. The energy yield of 1424 kWh/kW represents the annual electricity produced per kilowatt of installed capacity. This standardized parameter enables one to compare various PV installations and ensure that the system will be running in the expected range of performance under the conditions present in the environment. Lastly, the performance ratio (PR) is 0.71, which indicates that about 71% of the total solar energy incident on the array is converted to usable AC power, and the rest is wasted by the influence of temperature, wiring losses, inefficiencies in inverters, and environmental conditions like soiling.

Fig. 2 shows the monthly change in the energy production of the LSPV system. The production is in line with the anticipated seasonal solar irradiance cycle, with the production being high in the months that have the highest sunshine and relatively low in the monsoon season and winter seasons. The peak energy generation of 1.40 MWh is achieved during March–May, which is characterized by high irradiance, and the lowest generation of about 0.9–1.0 MWh is experienced during December–February. This would be mainly due to the variations in solar insolation, cloud cover, and ambient temperature; these factors directly affect the module operating conditions and efficiency.

On the long-term scale, the trend of electricity production is illustrated in Fig. 3 that depicts the net electricity production every year throughout the project life period. A progressive drop in energy production is seen as the years of operation increase. The initial production is approximately 14.30 MWh and thereafter the generation gradually reduces because of module degradation and aging effects in electrical parts. Fig. 2 and Fig. 3, combined, affirm the notion that, although the LSPV system has a consistent long-term performance, its output is highly seasonal based on the availability of sunlight and long-term processes of degradation.

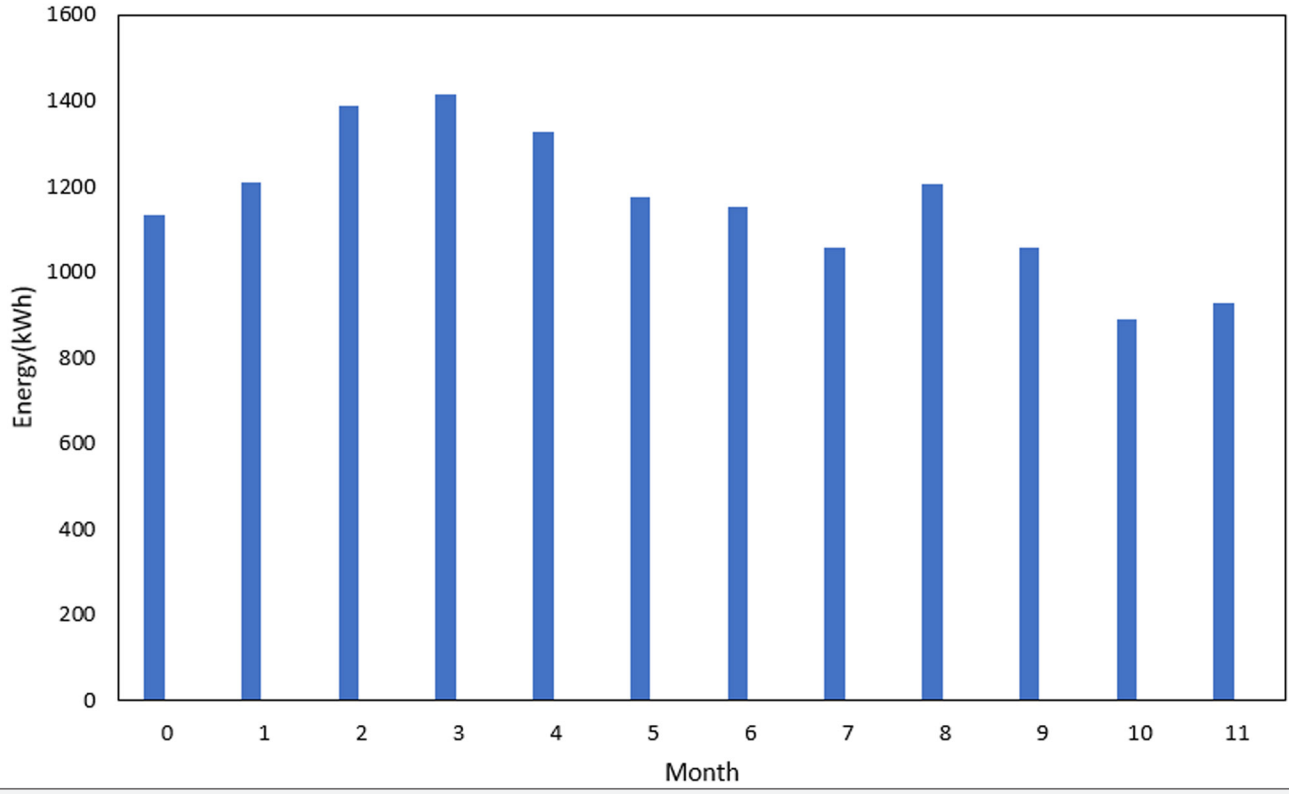

Fig. 2. Monthly energy generation of the LSPV system. Note: LSPV = land-based photovoltaic.

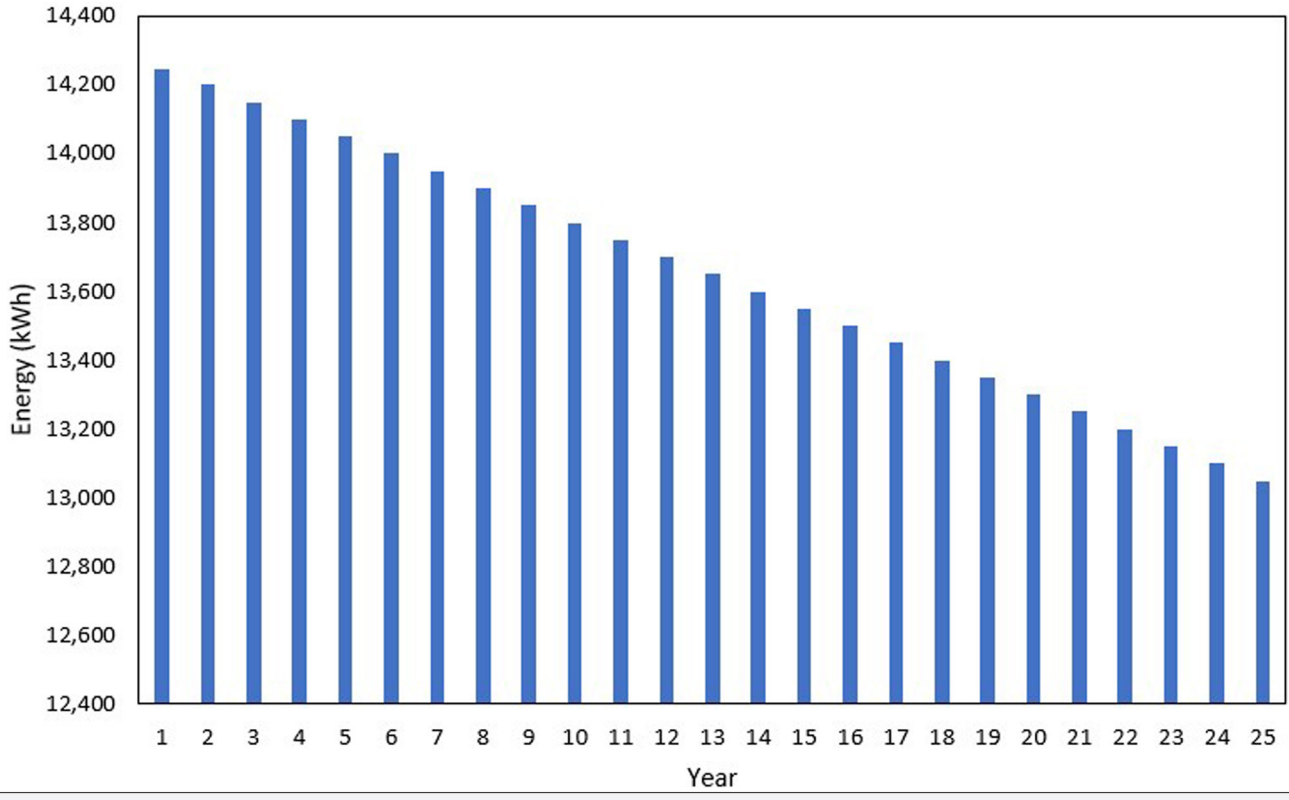

Fig. 3. Annual electricity generation of the LSPV system. Note: LSPV = land-based photovoltaic.

TABLE III. PERFORMANCE ANALYSIS OF FSPV SYSTEM

Metric	Value
Annual AC energy in year 1	14 900 kWh
DC capacity factor in year 1	18.90%
Energy yield in year 1	1656 kWh/kW
Performance ratio in year 1	0.82

Note: FSPV = floating solar photovoltaic.

B. Output for Land-Based Photovoltaic Model

After assessing the LSPV, the identical system arrangement was modeled on the FSPV to investigate the impact of a water-based mounting environment on performance. The loss analysis shows that there is very little difference between the available plane-of-array irradiance of about 130 009 kWh, with optical losses to soiling (5.00%) and reflection (1.79%) being similar to the case of the LSPV system. There is, however, some observable improvement at the DC generation stage. The loss incurred through the module temperature reduces considerably to 3.35%, which is lower compared with the LSPV system. This decrease is due to the fact that the presence of a water body under the panels increases the convective cooling, hence reducing the operating temperature of the modules. The efficiency of the photovoltaic system is directly proportional to the temperature of the cell, which means that the better the cell is cooled, the higher the electrical conversion efficiency is. This causes the increase of the net DC electricity to 15 063 kWh. Whereas inverter MPPT clipping rises to 13.41%, this means that the array is generating higher instantaneous power as a result of a higher module efficiency, which sometimes surpasses the processing capability of the inverter. Electrical losses including DC wiring (2.00%), diode and connection losses (0.50%), and optimizer losses (1.00%) do not change as the electrical setup and system size are the same. Inverter-related losses (efficiency, operating consumption, and night-time consumption) are almost similar in DC-to-AC conversion compared to the system on land. The gross AC electricity produced is 14 654 kWh, and after small losses due to AC wiring (1.00%) and battery losses (0.81%), the net AC electricity to the grid is 14 900 kWh. Table III provides the performance of the FSPV system.

From Table III, it is seen that the FSPV system demonstrates a noticeable improvement in performance compared with the conventional LSPV installation. The first-year annual AC energy generation of the FSPV system is 14 900 kWh, exceeding the 14 248 kWh produced by the LSPV system. The increase in delivered electricity is primarily attributed to the thermal regulation provided by the underlying water body, which lowers module operating temperature and enhances conversion efficiency. The DC capacity factor increases from 16.30% for the LSPV system to 18.90% for the FSPV system, indicating that the PV array operates closer to its rated output for a greater portion of the year. Because both systems were simulated using identical meteorological conditions, this improvement can be directly associated with reduced temperature-induced efficiency losses in the floating configuration. A similar trend is observed in the energy yield, which rises from 1424 kWh/kW (LSPV) to 1656 kWh/kW (FSPV). Since energy yield normalizes production with respect to installed capacity, the higher value confirms that the floating system extracts more electrical energy from the same solar resource and system size. Furthermore, the PR improves significantly from 0.71 to 0.82, indicating a substantial reduction in overall system losses and

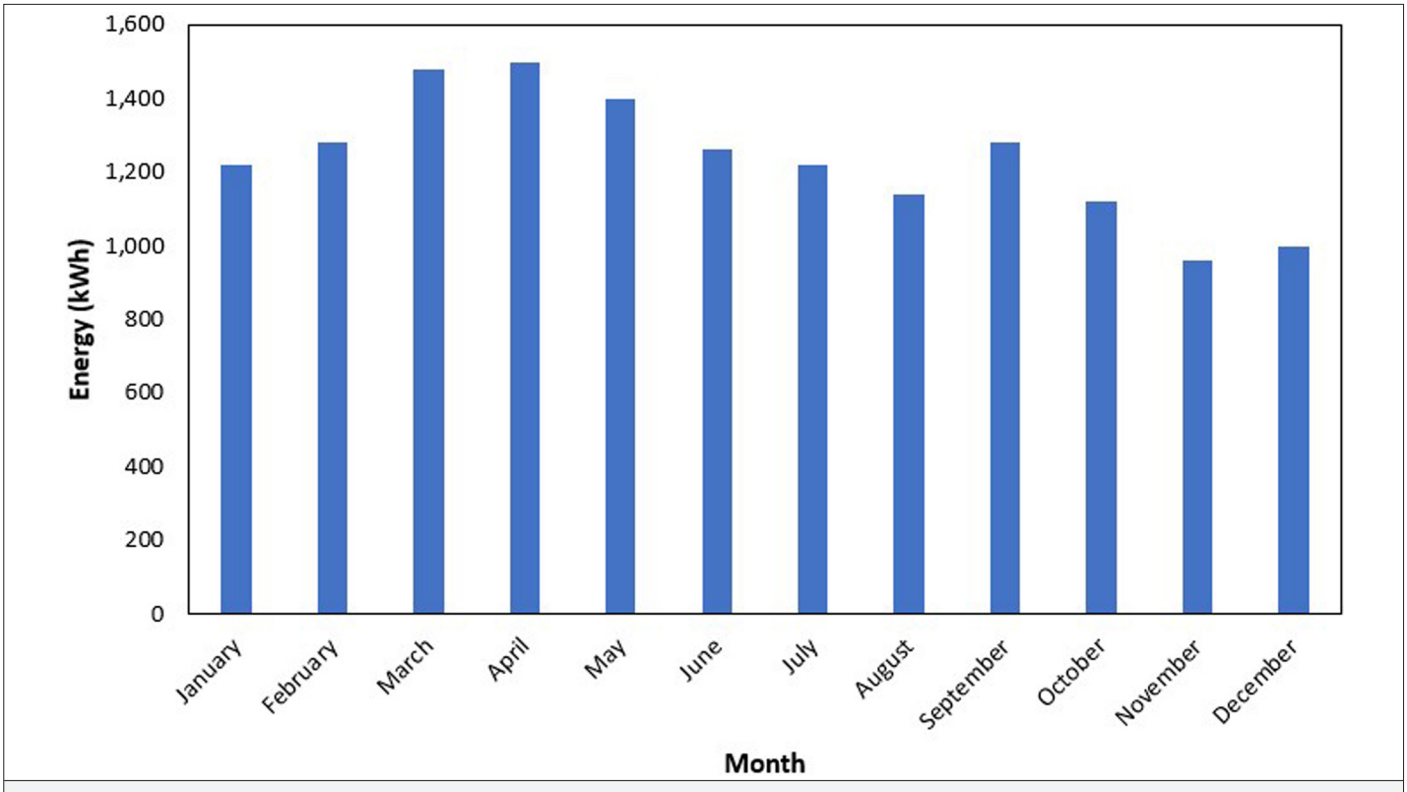

Fig. 4. Monthly energy generation of the FSPV system. Note: FSPV = floating solar photovoltaic.

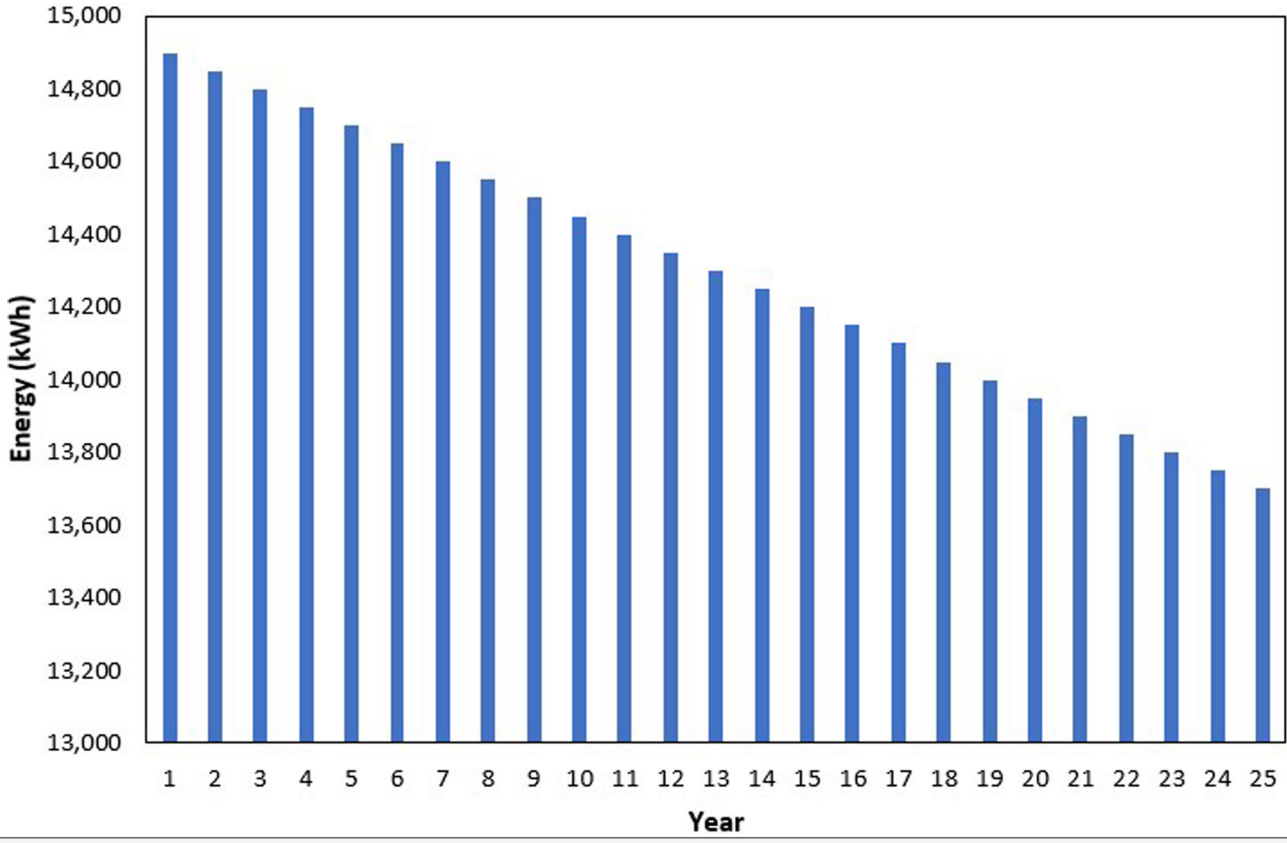

Fig. 5. Annual energy generation of the FSPV system. Note: FSPV = floating solar photovoltaic.

more effective conversion of available solar irradiance into usable AC power.

Fig. 4 presents the monthly energy generation profile of the FSPV system. The FSPV system follows a similar trend; when the irradiance is high, energy production is high in the summer months and low in monsoon and winter months. However, the energy generated by the FSPV system is higher than that of the LSPV system. March–April is the most productive period, as the energy reaches around 1.48–1.50 MWh. Similarly, in low-irradiance months (October–November), both systems indicate lower output, but still the FSPV system continues to generate relatively higher energy. This is due to the fact that the water surface under the modules cools it down. The reduced operating temperature of the module improves the efficiency of conversion, and the FSPV system generates more power under the same conditions of solar irradiance. Consequently, not only does the floating system boost energy production every year, but it also improves monthly energy stability by lowering the performance deterioration caused by the temperature.

Fig. 5 shows the long-term electricity production of the FSPV system over a year. The FSPV installation generates about 14 900 kWh in the first year, which is significantly higher compared to the 14 248 kWh that the LSPV system generates. The two systems display a similar decrease in the yearly output as a result of the degradation of the modules and the aging of the electrical components, but the output of the FSPV is always higher across the 25 years of the project. This long-term benefit is based on the fact that a module mounted above water operates at a lower temperature and hence minimizes heat loss and maximizes performance. As a result, although both installations are subjected to degradation, the FSPV system has a better lifetime energy yield than the traditional land-mounted PV system, which means that it is more reliable and efficient over time and yields more energy.productivity.

C. Floating Solar Photovoltaic Model with Salinity and Humidity-Based Degradation

Besides the normal FSPV, the FSPV system was tested further in the saline waters with the addition of the saline water effects and the high ambient humidity. Salt deposition, humidity, and corrosion of metallic contacts are other environmental conditions that may occur in the coastal and brackish water environment and may impact the module effectiveness as well as electrical stability. In order to model these effects, the simulation incorporates degradation-related losses due to exposure to high humidity and salinity [49]. This analysis will aim to measure the effect of these environmental factors on the generation of energy and system performance and determine whether the benefits of floating PV systems remain under more hostile operating conditions.

TABLE IV. PERFORMANCE ANALYSIS OF FSPV SYSTEM WITH DEGRADATION

Metric	Value
Annual AC energy in year 1	14 400 kWh
DC capacity factor in year 1	16.40%
Energy yield in year 1	1439 kWh/kW
Performance ratio in year 1	0.72

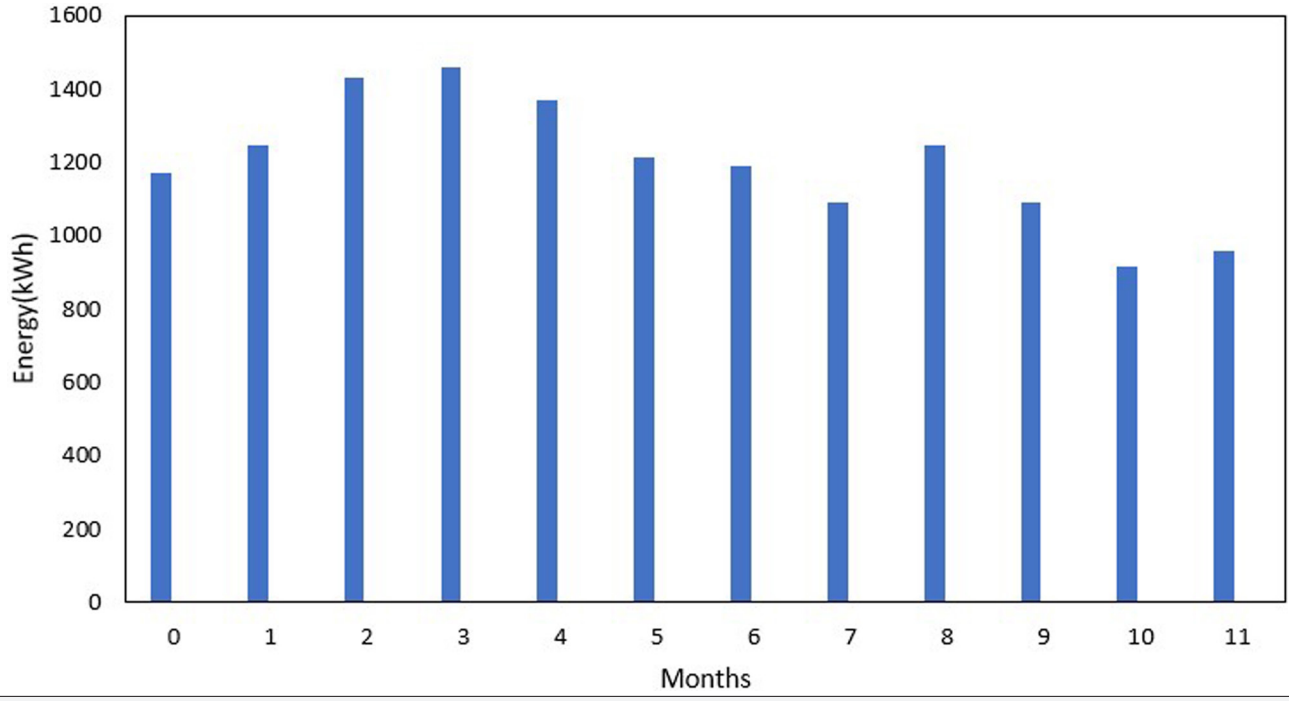

Fig. 6. Monthly energy generation of the FSPV system with degradation. Note: FSPV = floating solar photovoltaic.

The effects of humidity and salinity were also taken into consideration by adding the degradation of modules and electrical losses. Moisture intrusion, salt accumulation, and corrosion of metallic contacts are more prevalent in coastal conditions and augment series resistance and hasten the degradation of PV modules. Under normal conditions, literature reviews show that the typical crystalline silicon degradation rate is about 0.50%, and at the coast or in a high-humidity environment, the degradation rate is 1.50 to 3% per year [50]. Therefore, the FSPV system exposed to saline water was modeled using an elevated degradation rate along with additional soiling and ohmic losses to represent corrosion and salt-induced deterioration. Table IV provides the performance of the FSPV system under the conditions of corrosion and humidity.

From Table IV, it is seen that the key performance indicators experience a significant shift in the behavior of the systems in contrast to the normal FSPV system. The AC energy produced in the first year is 14 400 kWh, which means that the energy system continues to provide the grid with reliable power but with lower efficiency than that in the standard FSPV case. The DC capacity factor is 16.40%. On the same note, the power output is 1439 kWh/kW, indicating a decline in the power output per unit of installed capacity. Similarly, the PR is 72%, which is also lower than the FSPV system without degradation.

The decline in performance is due to environmental stress factors related to high humidity and salinity. The ingress of moisture and the deposition of salts along the module surfaces and metallic contacts may cause more surface contamination, corrosion of connectors, and series resistance in the electrical pathways. All these effects decrease the efficiency of modules and elevate electrical losses, thus reducing the overall performance of the system. Fig. 6 presents the monthly amount of energy produced by the system.

The monthly energy generation profile of the FSPV system under degradation conditions shows a clear seasonal trend similar to the other configurations, with higher output during the summer months and reduced production during monsoon and winter periods. Peak generation occurs around March–April, reaching approximately 1.4–1.45 MWh, while the minimum output is observed during October–November, where the generation falls below about 1.0 MWh.

However, compared to the freshwater FSPV case, the monthly energy levels are consistently lower across almost all months. This reduction indicates the impact of humidity and corrosion-related degradation, which increases electrical losses and reduces module efficiency. Although the system still benefits from partial cooling due to the water surface, the presence of moisture and salt deposition offsets a portion of this advantage. Consequently, the degraded FSPV system maintains the same seasonal behavior but with reduced monthly energy production and overall annual output.

The lifetime electricity generation of the FSPV system under humidity and corrosion conditions is illustrated in Fig. 7. The system produces approximately 14.4 MWh in the first year, after which a continuous year-to-year decline in annual energy output is observed. The reduction follows a nearly linear degradation trend, with generation gradually decreasing throughout the project lifetime and reaching nearly 6–6.5 MWh by the end of the operating period. This behavior reflects the long-term impact of environmental stressors such as moisture ingress, salt deposition, and corrosion of electrical contacts, which increase internal resistance and reduce module conversion efficiency over time. Consequently, the system experiences a higher effective degradation rate than a standard floating installation.

D. Comparison with Freshwater Floating Solar Photovoltaic and Land-Based Photovoltaic Systems

Table V presents a comparative performance evaluation of the LSPV, freshwater FSPV, and FSPV system operating under humid and saline conditions. When the FSPV system with degradation is compared

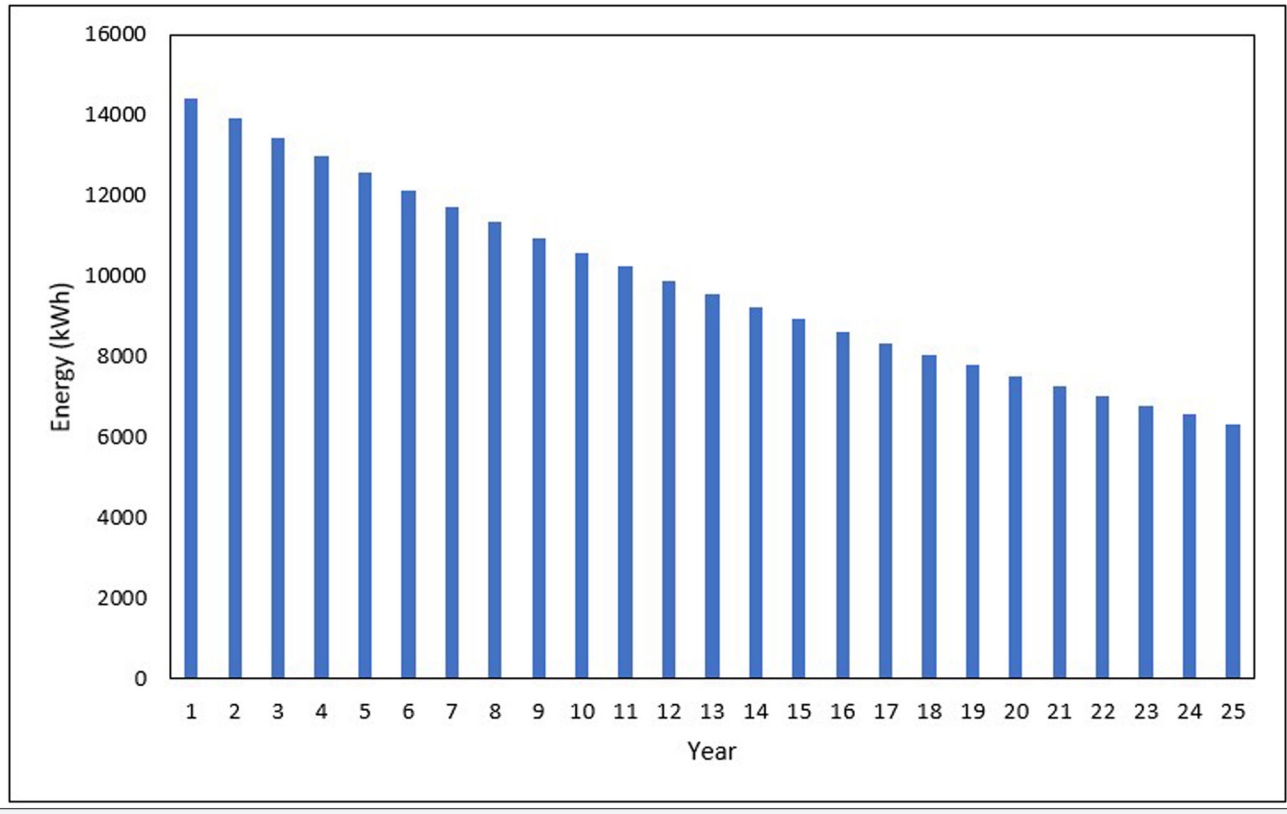

Fig. 7 . Annual energy generation of the FSPV system with degradation. Note: FSPV = floating solar photovoltaic.

with the freshwater FSPV installation, a clear degradation in performance is observed. The annual energy generation decreases from 14 900 kWh to 14 400 kWh, corresponding to a reduction of approximately 3.40%. The DC capacity factor drops from 18.90% to 16.40% (≈13% decrease), and the energy yield reduces from 1656 kWh/kW to 1439 kWh/kW (≈13% decrease). Likewise, the performance ratio declines from 0.82 to 0.72 (≈12% decrease). These reductions indicate that the efficiency gains achieved in freshwater floating conditions are significantly offset by corrosion and moisture-related losses in saline environments.

However, when compared with the LSPV system, the saline FSPV system still performs slightly better. The annual AC energy increases from 14 248 kWh (LSPV) to 14 400 kWh, representing an improvement of about 1.1%. The DC capacity factor also shows a marginal increase from 16.30% to 16.4%, while the energy yield improves from 1424 kWh/kW to 1439 kWh/kW. The performance ratio rises from 0.71 to 0.72, indicating a small but positive efficiency gain. The land-mounted PV system shows a slightly lower initial output and a similar but marginally higher degradation trend. Its generation decreases from 14 248 kWh to about 13 050 kWh over 25 years. Although the reduction is steady, the overall drop is greater than the freshwater floating system because land-mounted modules experience higher operating temperatures and consequently higher thermal losses throughout their lifetime.

TABLE V. COMPARATIVE PERFORMANCE OF LSPV, FSPV, AND DEGRADED FSPV SYSTEMS

Parameter	LSPV (Land PV)	Freshwater FSPV	Saline/Humidity FSPV
Year-1 energy (kWh)	14 248	14 900	14 400
DC capacity factor (%)	16.30	18.90	16.40
Energy yield (kWh/kW)	1424	1656	1439
Performance ratio (PR)	0.71	0.82	0.72
Year-25 Energy (kWh)	13 050	13 700	6347

In contrast, the FSPV system operating under humid and saline conditions exhibits a substantially faster decline in energy generation. While the first-year production (14 400 kWh) is slightly higher than the land-mounted system, the output drops sharply to nearly 6350 kWh by year 25. The significantly steeper reduction indicates accelerated degradation caused by corrosion, moisture ingress, and salt deposition on module surfaces and electrical connections. These factors increase series resistance, deteriorate electrical contacts, and reduce module efficiency over time.

The freshwater floating PV system consistently outperforms the land-mounted installation by approximately 5% over its lifetime, confirming the beneficial cooling effect of the water surface. However, when humidity and salinity are introduced, the performance advantage is drastically reduced. Although the degraded FSPV initially produces about 1% more energy than land PV, accelerated corrosion leads to severe long-term deterioration, resulting in nearly 56% loss of output over 25 years and over 50% lower generation than both conventional floating and land-mounted systems at the end of life. This demonstrates that environmental corrosion, rather than thermal

behavior, becomes the dominant factor governing long-term floating PV performance in saline water bodies.

V. CONCLUSION

This study presented a comparative performance analysis of three 10 kW PV system configurations, including a conventional LSPV system, a FSPV system operating under freshwater conditions, and a FSPV system operating under humid and saline coastal conditions. All configurations were modeled using the SAM for Chennai, India. The first-year results demonstrate that the freshwater FSPV system consistently outperformed the conventional LSPV system owing to the natural cooling effect provided by the underlying water body, which reduced module temperature losses from 7.84% to 3.35%. Specifically, the freshwater FSPV system generated 14 900 kWh of annual AC energy during the first year compared with 14 248 kWh for the LSPV system, representing an improvement of 4.58%. Similarly, the DC capacity factor increased from 16.30% to 18.90%, the energy yield improved from 1424.00 kWh/kW to 1656.00 kWh/kW, and the performance ratio increased from 0.71 to 0.82 (a 15.49% improvement), confirming the highly beneficial effect of lower module operating temperatures on photovoltaic conversion efficiency. Over the 25-year project lifetime, the freshwater FSPV system maintained a sustained energy advantage of approximately 5.00%, generating 13 700 kWh annually compared to 13 050 kWh for the LSPV counterpart.

However, when humidity- and salinity-induced degradation effects were incorporated through accelerated degradation rates of 1.50% to 3.00% per year compared to 0.50% for standard conditions, the performance advantages of the floating system were severely diminished. The saline FSPV system generated 14 400 kWh in its first year, which is only 1.07% higher than the LSPV system and 3.36% lower than the freshwater FSPV system. It also exhibited significant long-term performance deterioration due to moisture ingress, salt deposition, and corrosion of electrical components. By the end of the 25-year operating period, the annual energy generation of the saline FSPV declined drastically to approximately 6347 kWh. This represents a 56.00% reduction from its first-year output and a 53.70% reduction compared to the freshwater FSPV system at the same operational stage. These findings indicate that while floating PV systems offer clear performance advantages in freshwater environments, environmental degradation becomes the dominant factor governing long-term performance in humid and saline coastal regions, shifting the primary design constraint from thermal management to structural and material longevity.

Despite these insights, this study has certain limitations. The analysis was entirely simulation-based using SAM with TMY weather data for a single geographic location, and the effects of humidity and salinity were represented via literature-derived degradation rates and electrical losses rather than long-term field measurements. Furthermore, mechanical and environmental stressors such as wave-induced motion, biofouling, structural loading, and floating platform aging were not explicitly modeled. The system design configuration remained fixed, and vital economic parameters, such as the levelized cost of electricity (LCOE) and complex maintenance strategy trade-offs, were omitted. Therefore, the reported results serve as a rigorous quantitative baseline under controlled modeling assumptions rather than an empirical confirmation.

To address these limitations, future research should prioritize long-term experimental validation through field monitoring of actual coastal FSPV installations to capture real-world synergistic degradation effects. This includes developing advanced degradation prediction frameworks utilizing machine learning approaches and exploring novel corrosion-resistant materials, encapsulation techniques, and protective coatings. Additionally, subsequent works should execute multi-environment comparative studies across diverse climatic zones, coupled with comprehensive techno-economic, LCOE, and life-cycle assessments. Integrating intelligent condition monitoring with predictive maintenance and conducting thorough environmental impact assessments on aquatic ecosystems will also be essential. Ultimately, these steps will guide researchers, developers, and policymakers in designing resilient, sustainable, and commercially viable FSPV systems capable of contributing significantly to global renewable energy targets under diverse environmental conditions.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Artificial Intelligence Usage Statement: This study used ChatGPT (OpenAI) and Claude (Anthropic) to improve language and edit grammar during the preparation of the manuscript.

Peer-review: Externally peer-reviewed.

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REFERENCES

1. W. Shuyue, and W. Yue, "The long-term impact of carbon emission trading and renewable energy support policy on China's power sector under the context of electricity marketed reform: an analysis based on system dynamics," *Environ. Dev. Sustain.*, pp.1–39, 2025. [CrossRef]
2. A. Bajpai, A. Bajpai, and M. Koul, "Impact of the energy transition in the electricity sector on the environment and climate change in an industrial State of Andhra Pradesh, India: a life cycle assessment approach and policy directions for developing economies," *Renew. Energy*, vol. 246, p.122909, 2025. [CrossRef]
3. S. Thompson, "Strategic analysis of the renewable electricity transition: power to the world without carbon emissions?," *Energies*, vol. 16, no. 17, p.6183, 2023. [CrossRef]
4. B. Yu, D. Fang, K. Xiao, and Y. Pan, "Drivers of renewable energy penetration and its role in power sector's deep decarbonization towards carbon peak," *Renew. Sustain. Energy Rev.*, vol. 178, p. 113247, 2023. [CrossRef]
5. D. Bogdanov, A. Gulagi, M. Fasihi, and C. Breyer, "Full energy sector transition towards 100% renewable energy supply: Integrating power, heat, transport and industry sectors including desalination," *Appl. Energy*, vol. 283, p.116273, 2021. [CrossRef]
6. N. S. M. N. Izam, Z. Itam, W. L. Sing, and A. Syamsir, "Sustainable development perspectives of solar energy technologies with focus on solar Photovoltaic—A review," *Energies*, vol. 15, no. 8, p.2790, 2022. [CrossRef]
7. V. Boddapati, A. S. R. Nandikatti, and S. A. Daniel, "Techno-economic performance assessment and the effect of power evacuation curtailment of a 50 MWp grid-interactive solar power park," *Energy Sustain. Dev.*, vol. 62, pp.16–28, 2021. [CrossRef]
8. M. Z. Saleheen, A. A. Salema, S. M. M. Islam, C. R. Sarimuthu, and M. Z. Hasan, "A target-oriented performance assessment and model development of a grid-connected solar PV (GCPV) system for a commercial

building in Malaysia," *Renew. Energy*, vol. 171, pp.371–382, 2021. [CrossRef]
9. P. R. Mishra, S. Rathore, K. S. V. Varma, and S. K. Yadav, "Long-term performance and degradation analysis of a 5 MW solar PV plant in the Andaman & Nicobar Islands," *Energy Sustain. Dev.*, vol. 79, 101413, 2024. [CrossRef]
10. S. Edalati, M. Ameri, and M. Iranmanesh, "Comparative performance investigation of mono-and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates," *Appl. Energy*, vol. 160, pp.255–265, 2015. [CrossRef]
11. B. Navothna, and S. Thotakura, "Long-term performance of grid-integrated solar photovoltaic system on institutional buildings in tropical wet and dry climates of India — A practical study," *Environ. Sci. Pollut. Res. Int.*, vol. 30, no. 37, pp. 88036–88048, 2023. [CrossRef]
12. E. H. Sepulveda-Oviedo, "Impact of environmental factors on photovoltaic system performance degradation," *Energy Strategy Rev.*, vol. 59, p.101682, 2025. [CrossRef]
13. Z. R. Tahir *et al.*, "Effect of temperature and wind speed on efficiency of five photovoltaic module technologies for different climatic zones," *Sustainability*, vol. 14, no. 23, p.15810, 2022. [CrossRef]
14. A. Villarruel-Jaramillo, J. F. Rosales-Pérez, M. Pérez-García, J. M. Cardemil, and R. Escobar, "Modeling and performance evaluation of hybrid solar cooling systems driven by photovoltaic and solar thermal collectors—Case study: greenhouses of Andalusia," *Energies*, vol. 16, no. 13, p. 4888, 2023. [CrossRef]
15. N. A. S. Elminshawy, A. Ahmed, A. Osama, A. E. Kabeel, and O. Elbaksawi, "The potential of optimized floating photovoltaic system for energy production in the Northern Lakes of Egypt," *Eng. Anal. Boundary Elem.*, vol. 161, pp.226–246, 2024. [CrossRef]
16. J. Lazo, E. T. Baute, and D. Watts, "Real option approach to solar PV investment amid uncertainties and land opportunity costs," *Sustain. Futures*, vol. 10, p.101031, 2025. [CrossRef]
17. J. E. Diffendorfer *et al.*, "The interplay of future solar energy, land cover change, and their projected impacts on natural lands and croplands in the US," *Sci. Total Environ.*, vol. 947, p.173872, 2024. [CrossRef]
18. B. Ranjgar, A. Niccolai, and S. Leva, "Where can solar go? Assessing land availability for PV in Italy under regulatory constraints," In *Solar*. MDPI. DOI, vol. 5, No. 3, p. 40), 2025, September [CrossRef]
19. A. Biswas, D. Husain, and R. Prakash, "Life-cycle ecological footprint assessment of grid-connected rooftop solar PV system," *Int. J. Sustain. Eng.*, vol. 14, no. 3, pp.529–538, 2021. [CrossRef]
20. M. A. S. Jamalludin *et al.*, "Potential of floating solar technology in Malaysia," *IJPEDS*, vol. 10, no. 3, pp.1638–1644, 2019. [CrossRef]
21. D. F. Silalahi, and A. Blakers, "Global atlas of marine floating solar PV potential," In *Solar*. Multidisciplinary Digital Publishing Institute. DOI, vol. 3, No. 3, pp. 416–433), 2023, September [CrossRef]
22. D. R. Raimundo, C. K. Nakao Cavaliero, and M. Pereira da Cunha, "Contribution of floating photovoltaic systems in hydropower plants for the expansion of Brazilian electricity sector," *Renew. Energy*, vol. 254, p.123754, 2025. [CrossRef]
23. N. K. Singh, A. Goswami, and P. K. Sadhu, "Energy economics and environmental assessment of hybrid hydel-floating solar photovoltaic systems for cost-effective low-carbon clean energy generation," *Clean Technol. Environ. Policy*, vol. 25, no. 4, pp.1339–1360, 2023. [CrossRef]
24. S. Adak, "Analysis of harmonic distortion and efficiency enhancements in floating solar photovoltaic systems," *Iran. J. Sci. Technol. Trans. Electr. Eng.*, vol. 50, No. 2, pp.727–758, 2026. [CrossRef]
25. A. K, and V. K, "A comparative study of floating and ground-mounted photovoltaic power generation in Indian contexts," *Cleaner Energy Syst.*, vol. 9, p.100140, 2024. [CrossRef]
26. A. Boduch, K. Mik, R. Castro, and P. Zawadzki, "Technical and economic assessment of a 1 MWp floating photovoltaic system in Polish conditions," *Renew. Energy*, vol. 196, pp.983–994, 2022. [CrossRef]
27. N. Ravichandran, N. Ravichandran, and B. Panneerselvam, "Comparative assessment of offshore floating photovoltaic systems using thin film modules for Maldives islands," *Sustain. Energy Technol. Assess.*, vol. 53, p.102490, 2022. [CrossRef]
28. L. Essak, and A. Ghosh, "Floating photovoltaics: a review," *Clean Technol.*, vol. 4, no. 3, pp.752–769, 2022. [CrossRef]
29. N. A. S. Elminshawy, A. Osama, A. Gagliano, E. Oterkus, and G. M. Tina, "A technical and economic evaluation of floating photovoltaic systems in the context of the water-energy nexus," *Energy*, vol. 303, p.131904, 2024. [CrossRef]
30. R. Kumar, G. Von Gastrow, N. Theut, A. M. Jeffries, M. I. Bertoni, and D. P. Fenning, "Quantitative moisture mapping to determine local impacts on module durability," In 47th IEEE Photovoltaic Specialists Conference (PVSC), 2020, June pp. 1846–1849. [CrossRef]
31. D. Wisniewski, R. Lv, S. V. Nair, J. N. Jaubert, T. Xu, and H. E. Ruda, "Measurement and modelling of water ingress into double-glass photovoltaic modules," *Prog. Photovolt.: Res. Appl.*, vol. 27, no. 2, pp.144–151, 2019. [CrossRef]
32. S. Marwaha, and K. Ghosh, "Analytical modeling of diffusion of moisture in silicon photovoltaic module under damp heat testing condition," *Silicon*, vol. 14, no. 9, pp.4757–4766, 2022. [CrossRef]
33. R. Hendarti, J. Linggarjati, J. C. Kurnia, H. Arkan Hanan, and R., "Influence of humidity on the performance of floating photovoltaic systems over ponds in a tropical urban environment," In *IOP Conf. S.: Earth Environ. Sci.*, vol. 1375, No. 1, 012015, 2024, July [CrossRef]
34. C. J. Ramanan, K. H. Lim, J. C. Kurnia, S. Roy, B. J. Bora, and B. J. Medhi, "Towards sustainable power generation: recent advancements in floating photovoltaic technologies," *Renew. Sustain. Energy Rev.*, vol. 194, p.114322, 2024. [CrossRef]
35. S. Deilami, H. A. Ozgoli, L. Callegaro, F. Taghizadeh, and K. H. Kim, "Floating photovoltaic solar in Australia-A feasibility study," *J. Electron. Electric. Eng.*, 2024. [CrossRef]
36. A. Garrod, S. N. Hussain, A. Ghosh, S. Nahata, C. Wynne, and S. Paver, "An assessment of floating photovoltaic systems and energy storage methods: a comprehensive review," *Results Eng.*, vol. 21, p.101940, 2024. [CrossRef]
37. A. Goswami, A. Kumar, U. Goswami, and P. Sadhu, "Degradation of floating photovoltaic systems," in *Floating Photovoltaics*. Amsterdam: Elsevier, 2026, p.109–147. [CrossRef]
38. X. Gao *et al.*, "An exploratory framework for analyzing the impact of salt deposition on offshore photovoltaic system," *Renew. Energy*, vol. 242, p.122439, 2025. [CrossRef]
39. S. A. A. Rizvi, A. K. Janjua, A. A. Ansari, M. U. B. Ahmed, H. A. Raza, and G. Abbas, "Assessment of salt-induced performance decline in floating photovoltaics in marine environments: experimental analysis of electrical degradation, design and economic implications," *Renew. Energy*, vol. 260, p.125189, 2026. [CrossRef]
40. S. Suzuki *et al.*, "Acceleration of potential-induced degradation by salt-mist preconditioning in crystalline silicon photovoltaic modules," *Jpn. J. Appl. Phys.*, vol. 54, no. 8S1, 08KG08, 2015. [CrossRef]
41. Q. An, C. Gao, and Q. Deng, "Intelligent maximum power point tracking for coastal photovoltaic system concerning the corrosion and aging of modules," *J. Intell. Fuzzy Syst.*, vol. 45, no. 3, pp.4051–4070, 2023. [CrossRef]
42. O. Elbaksawi, N. A. S. Elminshawy, S. Diab, A. M. Eltamaly, A. Mahmoud, and H. Elhadidy, "Innovative metaheuristic algorithm with comparative analysis of MPPT for 5.5 kW floating photovoltaic system," *Process Saf. Environ. Prot.*, vol. 185, pp.1072–1088, 2024. [CrossRef]
43. N. A. S. Elminshawy, A. Osama, O. Elbaksawi, M. Arıcı, and N. Naeim, "Energetic, environmental and economic (3E) analysis of a CSA algorithm optimized floatovoltaic system integrated with heat sink: modeling with experimental validation," *Eng. Anal. Boundary Elem.*, vol. 159, pp.384–401, 2024. [CrossRef]
44. C. Yang, and B. Ai, "Accurate calculation of seven DDM parameters of solar cells or photovoltaic modules using the 7-dimensional Newton-Raphson method," *Renew. Energy*, vol. 256, p.124420, 2026. [CrossRef]
45. B. S. S. Ganesh Pardhu, and V. R. Kota, "Radial movement optimization based parameter extraction of double diode model of solar photovoltaic cell," *Sol. Energy*, vol. 213, pp.312–327, 2021. [CrossRef]
46. M. Alshawaf, R. Poudineh, and N. S. Alhajeri, "Solar PV in Kuwait: the effect of ambient temperature and sandstorms on output variability and uncertainty," *Renew. Sustain. Energy Rev.*, vol. 134, p.110346, 2020. [CrossRef]
47. J. Liu, X. Li, Y. Yang, and Y. Wu, "Advancing PV temperature modeling: comparative evaluation and a novel empirical model," *Appl. Therm. Eng.*, vol. 291, p.130228, 2026. [CrossRef]
48. R. Prusty, N. Sivakumar, A. Telukdarie, M. G. Nkadimeng, L. Malebo, and T. H. Katsumbe, "Optimizing solar energy generation through machine learning: a framework for CUF analysis," *Renew. Energy*, vol. 256, p.124251, 2026. [CrossRef]
49. A. Goswami, "Effect of humidity on the generation capacity of floating solar photovoltaic system," *Jordan J. Electr. Eng.*, vol. 9, no. 1, pp.31–41, 2023. [CrossRef]
50. N. K. Singh, and P. K. Sadhu, "The investigation of energy and economy for floating solar PV system on saline water," *Microsyst. Technol.*, vol. 30, no. 9, pp.1079–1086, 2024. [CrossRef]

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