Department of Mechanical and Aerospace Engineering

Project

Techno-Economic Analysis of Floating Solar Power Plant: A Case Study in India

Author: Ajmal Moideen Akbar

Supervisor: Dr Stephanie Ordonez Sanchez

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Abstract

This study evaluates the feasibility of implementing floating solar photovoltaic (FSPV) systems on Vembanad Lake in Kerala, India to meet local energy demand in renewable way. Electrical demand analysis of Alappuzha and Kottayam cities estimated a requirement of 300-400 MWh/day. Three scenarios were simulated using PVsyst® to design optimized FSPV systems. The optimized system in Scenario 1 aligned with the energy demand, generating an estimated 399 MWh/day. Tilt angle optimization showed 15° as ideal for maximizing annual yield. Economic analysis indicated positive NPV and 8.7-10.6% ROI across \$0.079-0.118/kWh tariffs. The FSPV system demonstrated significant lifetime CO2 savings compared to conventional power, confirming the environmental benefits. The study demonstrates the techno-economic viability of FSPV systems to fulfil local energy needs. The scalability across scenarios highlights the replicability potential across suitable sites. The project provides a model for leveraging FSPV systems to advance India's renewable energy and sustainability goals.

Acknowledgements

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Abbreviations

Cop - Conference of the Parties

FRP - fiber-reinforced material

FSPV - Floating Solar Photovoltaic

FSPV - Floating Solar Photovoltaic

GW - gigawatt

GWAC - Gigawatt Alternating Current

HDPE - high-density polyethylene

IEA - International Energy Agency

IEC - International Electrotechnical Commission

IRR - Internal Rate of Return

kWh - kilowatt hour

LCOE - Levelized Cost of Energy

MDPE - medium density polyethylene

MPPT - , Maximum Power Point Tracking

MW - MEGAWATT

MWp - Megawatt Peak

NOCT - nominal operating cell temperature

PV - Photovoltaic

REN21 - Renewable Energy Policy Network for the 21st Century

TWh - terawatt-hours

WEO- World Energy Outlook

1.0 Introduction

Over recent decades, the world has witnessed a significant increase in greenhouse gas emissions which lead to climate changes. This resulted to a global realisation of the need for depending more on renewable energy sources. Solar energy is considered as the most suitable source due to its availability abundance and non-depleting nature [1]. India, with its substantial solar capacity, is actively engaged in exploring ways to optimise its renewable energy assets [2]. India holds fourth rank as the largest solar power market with a solar installed capacity of 70.09 GWAC as of June 2023 [3]. However, due to limited land resources, India is facing challenges in finding suitable areas for traditional solar energy installations that require vast land spaces [4].

India, struggling with an expanding population and limited land resources, can find a unique solution in floating solar power plants to overcome its land constraints. The vast array of water bodies in India, like reservoirs, lakes, and ponds, could be utilized effectively to harness substantial solar energy. This underutilized resource holds promising possibilities. Recently gaining global attention, this idea shows its potential to revolutionize the renewable energy sector.

This project aims to investigate the feasibility of floating solar PVs in Kerala (southern Part of India) water bodies. Section 1.1 provides a background on the current energy demand in India and highlights the potentials of renewable sources in energy production. Selection of FSPV is discussed under section 1.2, followed by a detailed literature review of the current research in this area. Aim, objectives, methodology undertaken for the study are presented in the final half of this report.

1.1 Energy Demand in India

A developing country like India is expected to show a remarkable increase in energy demand over the next 20 years. This surge will be driven by growing economy and population, leading to increased industrial activities, transportation needs, and domestic consumption. It is forecasted that India's renewable energy capacity will reach 405 Gigawatts by 2030 due to the ever-expanding industrialisation and urbanisation [5].

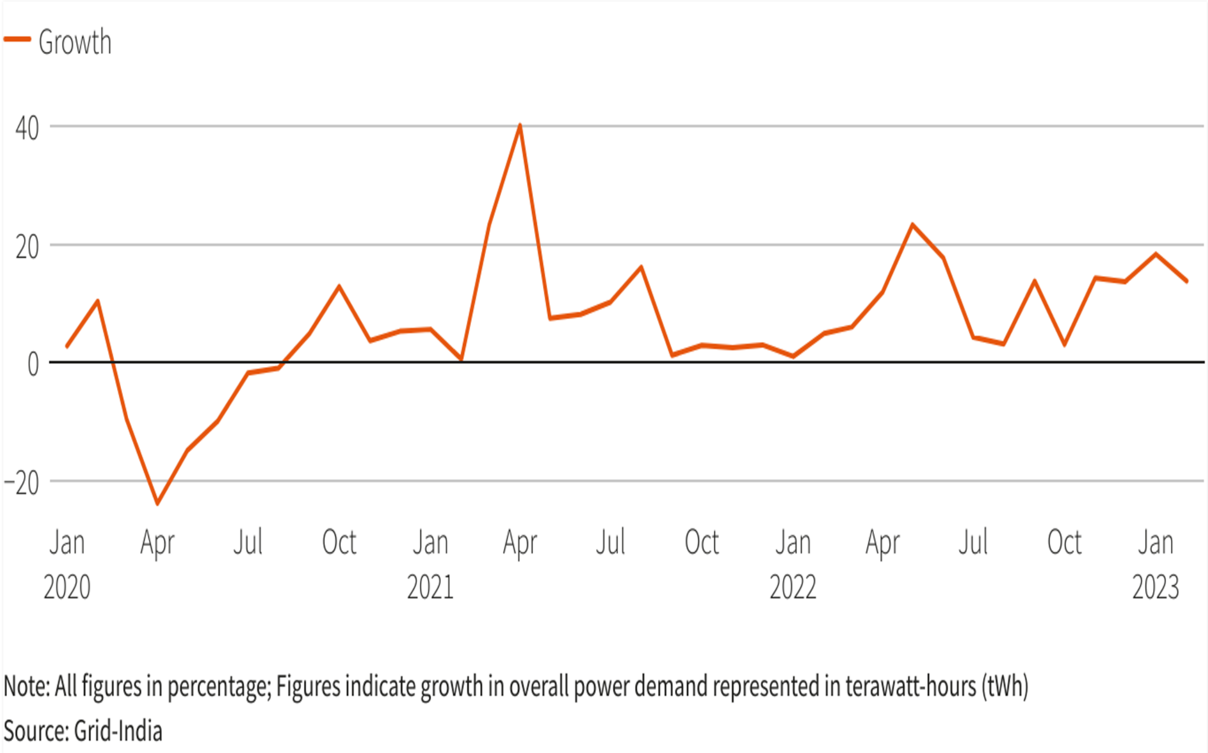

Figure 1: Energy Demand Growth, 2022-2023 (Source: Grid India)[6]

Figure 1 shows that, India witnessed an approximately 8% surge in its power demand during 2022, which was almost twice as much as the growth rate observed in the Asia Pacific region. This amounted to an increase of over 149.7 TWh compared to the preceding year. Furthermore, in the initial months of 2023, there was a notable 10% rise in demand relative to the same period the previous year. The intense heatwaves combined with the relaxation of COVID-19 restrictions fueled the surge in power consumption during the early part of 2022. Alongside, abnormal weather conditions and increased agricultural needs amplified electricity consumption in the latter half of the year [6].

Since 2000, India's energy usage has significantly increased. Coal, oil, and solid biomass cater to over 80% of the nation's energy requirements. While natural gas and modern renewables are emerging, solar PV stands out for its rapid growth. Due to abundant potential, favourable policies, and decreasing technology costs, it's becoming the most cost-effective choice for new power generation [7] This can be seen in figures 2 and 3 below.

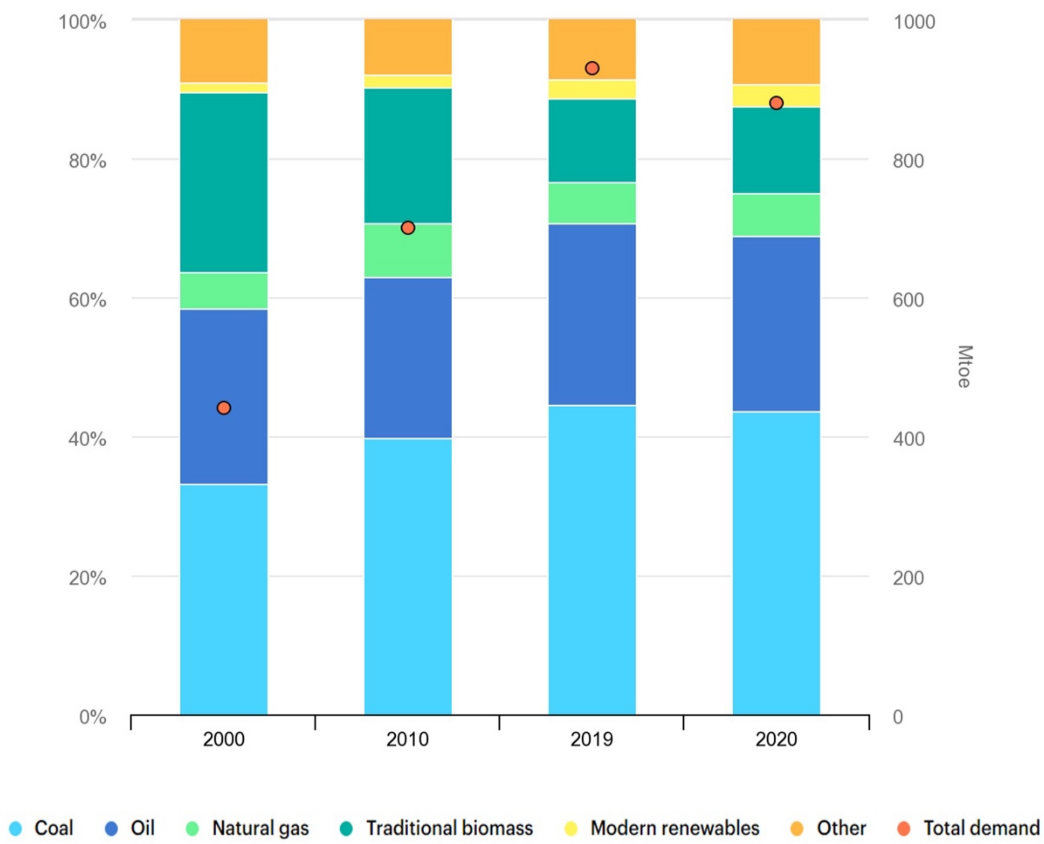

Figure 2 : Primary Energy Demand in India, 2000-2020 (Source: IEA)[7]

1.1.1 Renewable Energy Solutions and India

Recent studies show that India is making fast progress in the field of renewable energy. A study conducted by the WEO in collaboration with the International Energy Agency found that there was a significant increase in installed capacity of solar PV in India. Solar PV capacity increased at an average rate of 60% during 2015 to 2019. Simultaneously, wind capacity has seen a steady growth of around 10%. These figures significantly outpace the 7% growth observed in the overall installed capacity [7]. As depicted in the figure 3 showcasing annual power sector capacity additions from 2010 to 2019, the momentum towards renewable energy in India has been steadily increasing.

India's commitment to renewable energy is evident in its global rankings. According to the REN21 Renewables 2022 Global Status Report, India holds the 4th position worldwide in terms of Renewable Energy Installed Capacity. It also stands 4th in both Wind Power and Solar Power capacities [8][9].

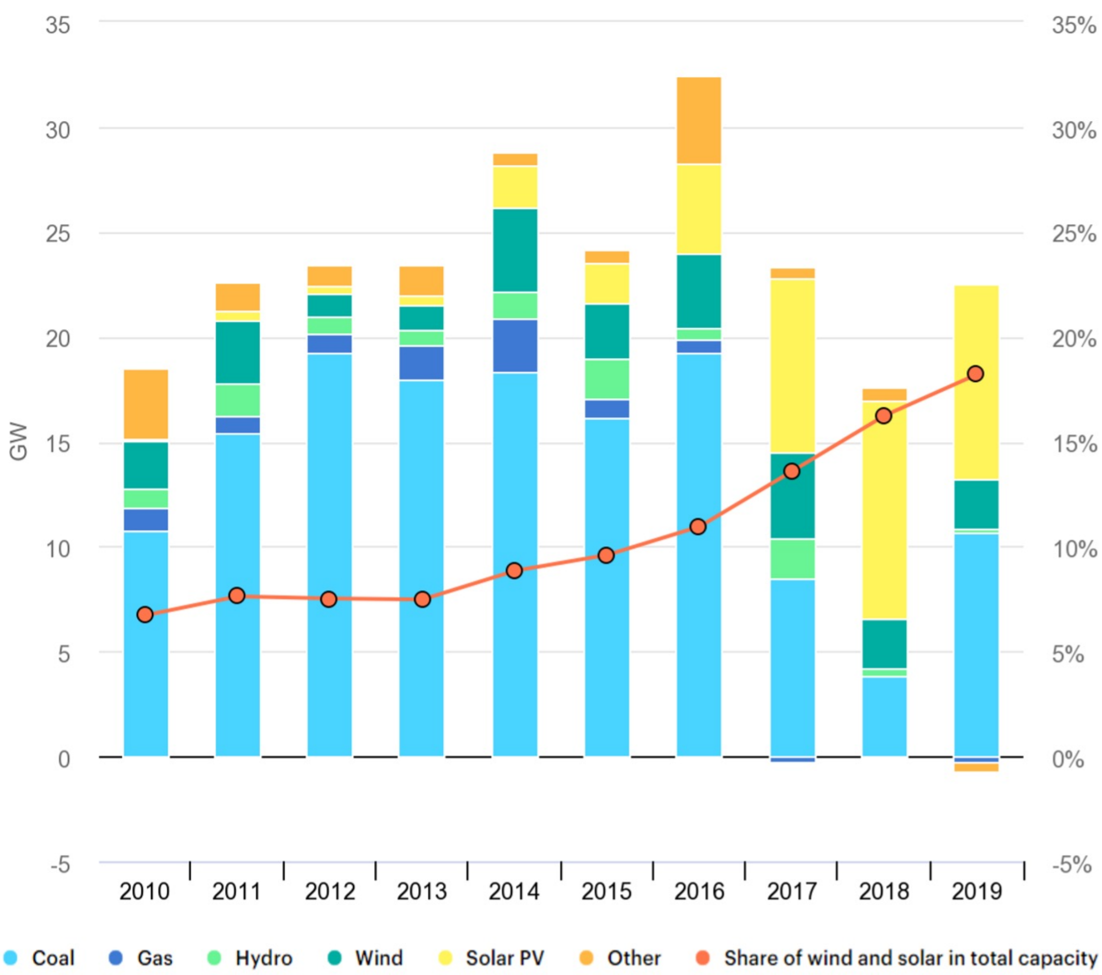

Figure 3 : Annual Power Sector Capacity Additions In India, 2010-2019 (Source: IEA) [7]

India has announced target of 500 GW of non-fossil fuel based energy by 2030 at COP26 summit. India's installed non-fossil fuel capacity has gone up in last 8 years to about 396%. As of May 2023, 43% of India's total capacity is from non-fossil fuel energy. The consistent growth in renewable energy capacity is a testament to India's efforts in transitioning to sustainable energy solutions. With government initiatives and supportive policies in place, the future looks promising for further advancements in this sector. In 2022, India experienced a notable year-on-year growth rate of 9.83% in the addition of renewable energy sources. The solar energy capacity has experienced a significant growth rate of 24.4 times over the course of the past nine years, resulting in a current installed capacity of 66.7 GW as of May 2023 [8].

1.1.1.1 Solar Energy

India annually receives roughly 5000 trillion Kilowatt-hours (kWh) of energy. The majority of regions within the country experience a daily average of 4-7 kWh per square metre. India has the potential to achieve significant scalability in the utilisation of solar photovoltaic power [9].

Currently, solar energy accounts for less than 4% of India's electricity generation. However, according to the forecast by the International Energy Agency, it is expected that solar power will match coal's share in the Indian power generation within the next two decades [7]. This is depicted in figure 4.

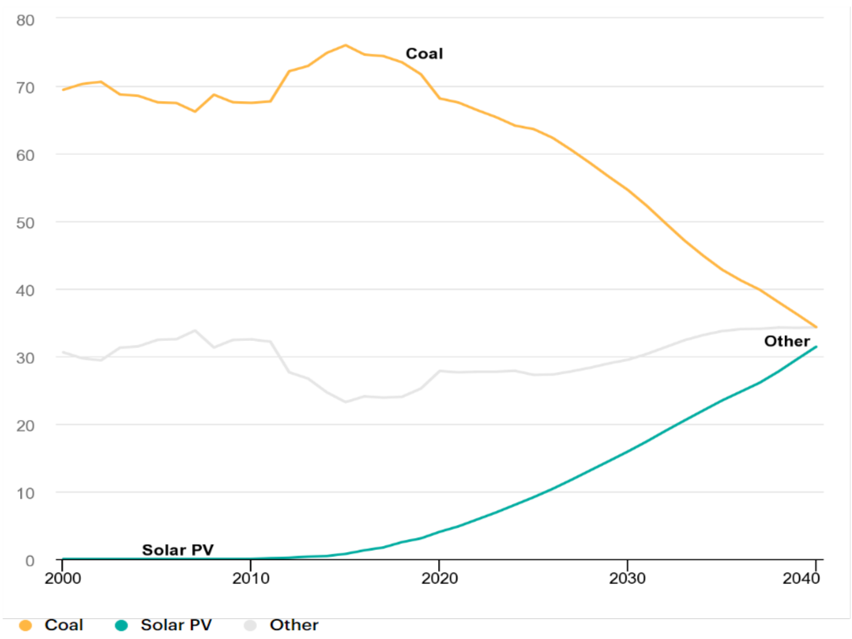

Figure 4 : Forecasted Share Of Power Generation In India (Source: IEA) [7]

Even though, India has the advantage of vast solar energy potential, land intense nature of solar PV brings challenges in many situations. To align with the national targets for solar capacity expansion, it is crucial to explore and establish alternative approaches. Floating solar PV (FSPV), also known as Floatovoltaics as one such solution that is gaining global attention and expected to experience robust growth in the forthcoming years [10].

1.2 Floating Solar Power Plants

Floating solar PV systems refer to the installation of solar photovoltaic panels on floats or floating structures on water bodies such as lakes, reservoirs, ponds or calm seas. This allows for utilization of the large surface area of water bodies for deploying solar arrays to generate clean and renewable electricity from sunlight. The key concept is to enable large-scale solar power generation by overcoming land constraints for building ground-mounted solar farms. By floating the PV arrays on water, unused and unutilized water surface areas can be leveraged to produce solar energy. It transforms the water body into a solar energy harvesting system. Moreover, the shading provided by FSPV panels prevents excessive water evaporation, reduces algae growth and contributes to improved water quality [11]

In comparison to land-mounted solar PV plants, installing a typical FSPV plant is generally easier and simpler. This is because (a) no civil work is necessary to prepare the site; (b) modular individual floats that are prefabricated and connected to form a large section are used to create floating platforms used to float solar PV arrays on a water surface; and (c) floating platforms are assembled on land by arranging rows of these modular interconnecting floats. Every individual row is submerged into the water when the subsequent row is added, resulting in the construction of a substantial platform. After the construction process is finished, the entire platform is transported to the precise position on the waterbody by the assistance of boats. Floating solar power plants are an emerging technology for the solution of challenges faced in land based solar energy generation. India is capable of producing 227 GW by using just 10% of water sources [1].

Kerala, with its extensive aquatic ecosystems, is an ideal candidate for leveraging this technology. Kerala, often referred to as "God's Own Country", is replete with water bodies, including lakes, rivers, and reservoirs. These aquatic resources offer vast surfaces ideal for FSPV installations, reducing the need to allocate terrestrial spaces for solar energy harnessing. Given Kerala's tropical climate, water conservation is paramount. FSPV installations not only generate power but also reduce Usage of land.

Kerala's proactive approach towards FSPV aligns with India's ambitious renewable energy targets. Kerala had originally set targets to install 500 MW of solar capacity by 2017, with plans to reach 2500 MW by 2030 [12]. As of March 2023, Kerala's installed solar capacity stands at 761 MW [13].

In 2017, Kerala State Electricity Board (KSEB) commissioned a 500 kW FSPV plant in Banasura Sagar Dam at Wayanad. This was one of the first major FSPV projects in India [14]. Tata Power Solar Systems commissioned India’s largest floating solar power project of 101.6 Megawatt Peak (MWp) in Kerala backwaters. The project is installed on a 350-acre water body in Kayamkulam, Kerala [15], [16].

2.0 Literature Review

2.1 Components of the FSPV

Floating solar power plants differentiate from the ground-mounted solar power plants, primarily in their module mounting structures. Central to the FSPV system is the floating platform or pontoon, predominantly fabricated from high-density polyethylene (HDPE). The PV module support infrastructure consists of several integral components: floats, which act as buoyant supports and solar panel bases; upright stands for providing the requisite panel inclination; and bridges that ensure stability and connectivity between floats during both construction and maintenance phases. Furthermore, binding bands, available in two variations, are instrumental in connecting floats, especially in counteracting varied wind pressures. Secure attachment of the panels to the floats is achieved through anchor bolts and specialized brackets. Given the inherent challenges posed by their aquatic setting, such as fluctuating water levels and wind pressures, FSPVs consists of a robust anchoring and mooring system [17].

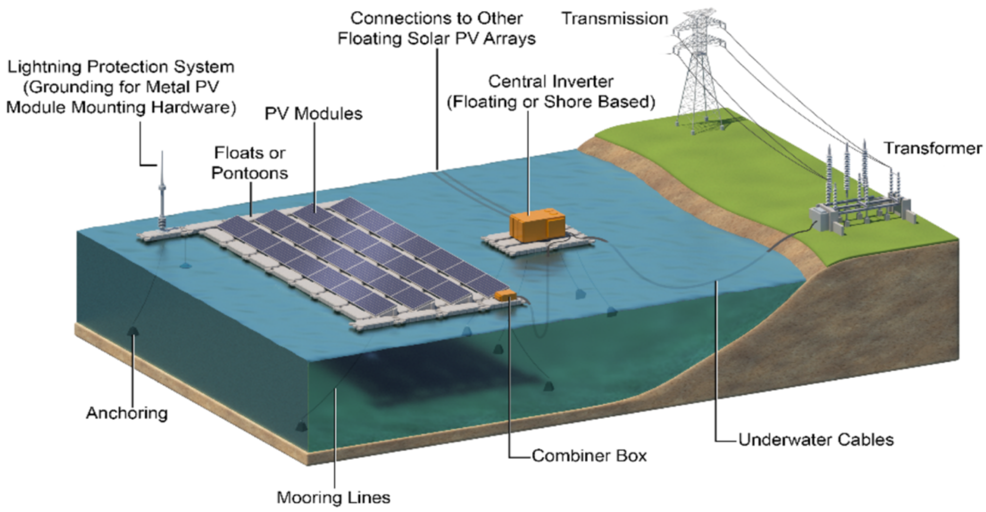

Figure 5 : Schematic description of FSPV with its main elements[18]

The design involves a complex array of interconnected pontoons or floats. This arrangement helps distribute the weight of the solar panels evenly, enhancing the system's stability and preventing undesired movement or submergence. HDPE is the most popular material being used in a majority of the FSPV power plants across the globe. Other materials like FRP, medium density polyethylene (MDPE), and ferro-cement are also been utilized as materials for the floating platform [19].

Anchoring and Mooring System: The anchoring and mooring system plays a vital role in maintaining the FSPV system's position in the water body. It primarily consists of an anchor, lines (chains, ropes, or wires), and a buoy. The anchor type depends heavily on the water body's conditions, such as depth and seabed composition. A well-designed mooring system accounts for environmental factors like wind, waves, and water current, preventing the FSPV system from unwanted drift or rotation [20]. The intricacy of designing an effective anchoring and mooring system is an area of ongoing research in the field of FSPV systems. For FSPV power plants near the slope of the reservoir or located in waterways, anchor–pull mooring is usually adopted and [21] Mooring can be done in the following three ways – bank anchoring, bottom anchoring, and piles.

PV Module: Photovoltaic (PV) modules, or solar panels, are the core of the FSPV system, converting sunlight into electricity. These modules are layered with anti-reflective coatings to maximize light absorption[19]. Each panel comprises numerous solar cells, typically constructed from silicon, a semiconductor material. Furthermore, there are two primary types of floating solar modules: Monocrystalline, which is more efficient but costly, and Polycrystalline, which is more affordable and common. The energy efficiency of FSPV systems can be enhanced with advancements like PERC (Passivated Emitter and Rear Cell) and bifacial solar cells [22].

Cables and Connectors: In the aquatic setting of an FSPV system, cables and connectors, which facilitate electricity transmission, must be resistant to water and corrosion. Specialized submersible or marine-grade cables are preferred due to their resilience against environmental factors. Crucial considerations for cable sizing and routing in FSPV plants include plot size, distance to shore, and water level variations [19].

Inverter: The inverter in an FSPV system is responsible for converting the direct current (DC) generated by the solar panels into an alternating current (AC), suitable for home use or grid feed-in. Based on the plant's scale and distance from shore, inverters may be located on a separate floating platform or on land. The inverter's efficiency in minimizing power loss during the conversion process is critical. Inverters are equipped with protective features to handle potential overvoltage, undervoltage, or overheating issues. Notably, there are various types of PV system inverters, such as String inverters, Central inverters, and Microinverters, each having unique advantages and applications. Central inverter architecture is the standard choice for high-power PV systems because it is the simplest and cheapest option as just a few inverters are used with many PV modules [23].

Transformer: Transformers in an FSPV system step up the voltage to minimize power loss during transmission. They need to be resilient against environmental challenges. Notably, Anurag et al. developed a grid-connected transformer less PV system including a DC-DC converter for grid integration with the purpose of keeping the efficiency in the grid voltage peaks [24].

Substation: Substations aggregate the power generated by FSPV systems and convert it to higher transmission voltages. The substation is typically located on land adjacent to where the network of underwater cables from the floating solar array connects to the shore. They house essential equipment like transformers, switchgear, monitoring systems and and protective relays inside an enclosure designed to be water-resistant and corrosion-proof due to the proximity to water. Lightning protection is essential for the substation and underwater cables given the floating solar farm's location on water [25][26].

Overhead Transmission Lines for Grid Connection: Once the electricity is stepped up at the onshore substation, overhead power lines transmit this power to the grid. These lines, typically ranging from 11kV to 765kV, facilitate efficient power transfer over vast distances. Monitoring systems and breakers embedded within the transmission infrastructure provide control, protection and fault management capability[25][26].

Each of these components plays an essential role in the overall functioning of an FSPV system. Design considerations, material selection, and installation techniques must account for the unique challenges posed by the aquatic environment and local climate conditions. As such, research in these areas is vital for the advancement and optimization of FSPV technology.

2.2 Comparison between Traditional and Floating Solar PV

Conventional grid-connected photovoltaic (PV) systems installed on land have been widely adopted for renewable energy generation. However, land constraints have led to increasing interest in floating PV systems installed on water reservoirs as an alternative. A significant advantage of FSPV systems is their ability to harness vast stretches of otherwise unutilized water expanses. For instance, the 2013 research by Ferrer-Redon team highlighted a project where these systems were set up on farming water reservoirs, maximizing the water's expansive surface. The research suggests that such solar PV systems, when angled at 10°, might outperform traditional 30° angled land systems by an estimated 15% in energy output [27].

Another study on FSPV test systems found negligible albedo effects from the water surface on performance compared to ground-mounted arrays. While water can reflect solar radiation, the effect on the rear side of PV panels is marginal. However, FSPV enables higher energy yield through cooling and tracking [28]. In other research, spray cooling technique was proposed and experimentally tested on a monocrystalline PV module for different cooling options: cooling of front surface, cooling of rear surface and cooling on both surfaces of the PV module. It was found that active water spray or thin water veil cooling can further improve performance, with experimental FSPV systems demonstrating substantially higher outputs [29]. In a study by Liu et al. (2017) [30], it was highlighted that Floating Solar Photovoltaic (FSPV) modules, which leverage the water-cooling effect, demonstrated a temperature difference of 3.5°C compared to conventional land-based PV modules.

Research, including a study by Young-Kwan Choi, has consistently shown that FSPV systems can surpass the power generation efficiency of ground-mounted PV (GMPV) systems. For example, data from a 100kW FSPV system revealed a 13.5% higher capacity factor than its GMPV counterpart over a year. Similarly, a 500kW FSPV system demonstrated a 10.3% higher capacity factor than the GMPV system over a 6-month period. This enhanced efficiency is mainly due to the cooler operating temperatures of FSPV modules, especially during peak daylight hours. Measurements showed the FSPV modules had lower temperatures than the GMPV modules during peak daylight hours when generation occurs. The study also investigated the environmental impacts on FSPV systems, such as waves, wind and movement of the floating platforms. It was found that wind speeds below 10 m/s produced minimal platform displacement and wave action. However, higher winds did rotate the platforms and reduced energy generation demonstrating the importance of the mooring system design [31].

The installation costs of FSPV systems can be higher than those of land-based systems due to the need for floating platforms and mooring systems [32]. However, these costs have been decreasing with technological advancements and economies of scale. On the other hand, land-based systems have lower installation costs but may incur additional costs for land acquisition or leasing [33].

FSPV systems also offer environmental advantages. They can reduce water evaporation from reservoirs, beneficial in arid regions with limited water resources. A study [17] estimated that a 1 MW FSPV system can save approximately 1395 cubic meter per MWp of water per year through evaporation reduction. FSPV systems can contribute to environmental protection by controlling algal blooms. By blocking sunlight, these systems can inhibit the photosynthesis process of algae, thereby reducing their growth. This can improve water quality and prevent the negative impacts of excessive algal blooms, such as oxygen depletion and harm to aquatic life [20].

Both FSPV and land-based solar panels offer viable solutions for sustainable power generation, and their suitability depends on various site-specific factors, including available land or water resources, local climate, and existing infrastructure. With the continuous advancements in technology and supportive policies, both types of systems are expected to play a critical role in the transition towards renewable energy. Overall, while floating PV shows promise for utility-scale renewable energy generation, further innovations to reduce costs and ensure environmental sustainability are needed.

2.3 Optimising Floating Solar PV Systems

In the ongoing development of Floating Solar Photovoltaic (FSPV) technology, numerous advancements and optimization methods have emerged to bolster system performance, reliability, and economic viability. Different strategies can be applied to optimize both the efficiency and affordability of FSPV installations. These include optimizing the layout of the solar panels to minimize shading effects, optimizing the tilt angle of the solar panels to maximize solar irradiance capture, and using advanced power electronics to optimize the power output.

2.3.1 Orientation and Tilt Angle

The efficiency of solar collectors in capturing solar radiation is predominantly determined by the PV panel's orientation and tilt angles. These parameters directly impact the angle of incidence of sunlight on the panel, thereby influencing the solar radiation received on the earth's surface. Achieving an optimal orientation ensures maximized solar irradiance on the panels throughout daily and annual cycles. Given that India is situated in the northern hemisphere, a south-facing orientation is considered optimal [34].

While maximising incident solar radiation, we require ideal tilt inclination of PV module [35]. Existing literature has extensively discussed the optimum tilt angle for solar systems. For instance, a study by Kaveri Markam and K. Sudhakar [34] investigated the optimal tilt angles for PV modules in six different locations across India. They adjusted the tilt angle by $\pm 5^{o}$ from each location's latitude for their estimations. Their simulations revealed that most locations had an average solar radiation exceeding 5 $KWh/m^2/d$, primarily falling within the 5-6.5 $KWh/m^2/d$ range. The results from their research showed that the annual optimal tilt angles varied by $+2^{o}$ to $+3^{o}$ from the latitudinal values of the respective locations.

A study conducted by Milan Despotovic and Vladimir Nedic [35] examined the optimal angles for solar collectors in Belgrade, Serbia. Four seasonal and two biannual scenarios are studied, and energy collected in ten different scenarios is compared. The research found that changing the tilt angles daily, fortnightly, or monthly didn't make a big difference in energy collection. The best angles for spring and summer, and autumn and winter, were similar, so it's enough to adjust them only twice a year. There is a significant difference in energy collected in the biannual scenarios, especially between adjustments on January 1 and July 1 versus the beginning of spring and autumn. A case study showed that by adjusting the panels to optimum angles at least seasonally, energy gains increased up to 15.42%, proving it as an effective but cheaper alternative to Sun-tracking systems.

While the optimum tilt angle often correlates with the geographical latitude of a location, achieving the precise angle for maximum energy collection can be complex. Various optimization techniques are employed to find this angle, including experimental analysis, solar tracking methods, and simulation or modelling techniques. Within the context of India, where the solar radiation intensity measures at 1000kW/m², the optimal tilt angle varies minimally from the latitude. This research particularly focuses on the determination of optimal tilt angles in a lake in Kerala using PV simulation software PVsyst®.

2.3.2 Azimuth Angle

The azimuth angle, a critical parameter in the design of solar photovoltaic (PV) systems, refers to the angle between the North direction and the projection of the solar panel onto the horizontal plane. Essentially, it indicates the orientation of the solar panel with respect to the North. The optimal azimuth angle ensures maximum solar radiation capture throughout the day.

A study in Iran using generic algorithm was conducted to determine the ideal slope and azimuth angles of solar collectors for maximum solar radiation capture. Optimum angles and the corresponding solar energies are assessed hourly, daily, monthly, seasonally, and yearly. The study investigated the impact of various solar radiation components on these optimum angles and energy gains. Preliminary findings denoted that daily, monthly, and yearly optimum azimuth angles are found to be zero [36], with hourly angles varying.

2.3.3 Irradiation

Irradiation is a key factor in the design of floating solar systems. Irradiation refers to the amount of solar energy that reaches a surface per unit area and time. It depends on several factors, such as the location, the season, the weather, the orientation and tilt of the surface, and the shading effects of nearby objects. Irradiation affects the performance and efficiency of floating solar systems, as well as the optimal sizing and layout of the modules. Therefore, it is important to measure and model the irradiation levels at the site of interest, and to consider the possible variations and uncertainties in the design process. Irradiation is measured in kWh/m^2 and is often classified into two major forms: Global Horizontal Irradiation (GHI) and Direct Normal Irradiance (DNI) [37] . The Global Horizontal Irradiance (GHI) represents the combined sum of direct and diffuse solar radiation that is received by a horizontal surface. It is the parameter that is deemed significant when evaluating the energy generation potential of photovoltaic (PV) technology[38].

2.3.4 Albedo effect

The albedo, or solar reflectance, of water bodies can have a significant impact on the performance of floating solar photovoltaic (PV) systems installed on them. The albedo value is the proportion of solar energy that is reflected by the Earth's surface and subsequently captured by photovoltaic (PV) modules[39] [40]. As an example, it can be observed that fresh grass exhibits an albedo factor of 0.26, but fresh snow demonstrates an albedo value of roughly 0.8. The default albedo value of water is 0.2[41]. This higher reflectance results in increased irradiation on the underside of floating solar panels, providing extra diffuse irradiation.

Research on floating PV systems found over 10% higher energy yield compared to ground-mounted systems due to this albedo effect [42]. Periodic cleaning of lake surfaces may help maintain higher albedo. Overall, the installation of floating solar PV on lakes and reservoirs can provide improved performance versus land-based systems, but site-specific albedo effects should be evaluated. The albedo effect can influence the efficiency of solar panels. Higher albedo can potentially increase the amount of sunlight reaching the solar panels, especially if they are bifacial panels that can capture reflected light[41]. Proper site selection and water management can help maximize the albedo benefits for floating solar in India.

Research done by Shahina S. Patel and Arnold J. Rix [43] evaluates the albedo of a flat water surface, analysing its dependence on time, temperature, and wavelength. The results indicate that the albedo of a smooth water surface is not constant, and that it is principally influenced by the position of the Sun rather than temperature or wavelength. Particularly, higher albedo values are observed during early morning and late afternoon, while midday observations show a value lower than the typically used default value of 0.2. Consequently, the findings imply that lower water surface albedo can lead to a decrease in bifacial module performance on open water surfaces.

2.3.5 Thermal Parameter

The operating temperature of solar photovoltaic (PV) panels is a critical thermal parameter that influences performance and efficiency. Solar irradiation, ambient temperature, wind speed, and PV technology affect panel temperature. Studies in India show that PV module temperatures can reach 45-70°C on hot sunny days, reducing electrical efficiency by 8-20% compared to 25°C standard test conditions [44]. Higher temperatures degrade performance due to increased resistance and voltage loss. Panel technology also impacts temperature; monocrystalline silicon PV was found to have better thermal performance than polycrystalline and amorphous silicon panels in Indian conditions. High ambient temperatures, intense irradiance, and inadequate panel ventilation contribute to high operational temperatures. PV system design in India must provide proper elevation, spacing, and cooling to minimize temperature rise. The nominal operating cell temperature (NOCT), a key thermal metric, ranges from 42-52°C for typical panels in India [44].

2.4 Floating Solar PV Losses

The performance of solar plants, both terrestrial and floating, in India has been systematically investigated by the Central Electricity Regulatory Commission. The efficiency of a power plant is influenced by multiple factors like site location, solar insolation, climatic variables such as temperature, and technical inefficiencies. These inefficiencies comprise soiling losses, cabling losses, module mismatch, Maximum Power Point Tracking (MPPT) losses, transformer and inverter losses [45] .

Soiling losses result from substances like bird droppings and dust that obstruct sunlight on the panels are higher in floating PV systems than in ground-mounted systems. The loss from soiling can be more than 15% in deserts and under 4% in other locations, except in snowy areas. A study in Morocco reported energy production losses due to soiling reaching up to 2 Wh/Wp [46][47].

Uneven sunlight exposure on modules in the same string can lead to voltage and current differences, termed as "mismatch". Mismatch losses arise when interconnected photovoltaic (PV) cells on a string exhibit varied electrical attributes at a given moment, predominantly due to partial shading [48]. As per study Numerical modelling indicates that when PV systems comprise parallel strings of varied lengths mismatch losses are typically kept under 1% for most system configurations. If configurations with a string shorter by just one module than its counterparts mismatch losses were less than 0.5% [49]. While many studies have investigated mismatch losses in general photovoltaic systems, this a literature gap concerning mismatch losses specific to floating photovoltaic (FSPV) systems.

Shading losses within photovoltaic (PV) systems are instigated by various environmental factors such as water reflections, waves, and ripples that lead to intermittent shading. To counteract this phenomenon, strategic planning of the floats' spacing and orientation is pivotal. On the other hand, wiring losses are a result of the flexing and subsequent movement of electrical cables, giving rise to resistance losses. Consequently, an optimal cabling design is essential to mitigate these effects. Moreover, an important aspect of the configuration lies in the tilt of the PV modules; an increase in the tilt angle necessitates a corresponding increase in the spacing between neighbouring modules in order to curtail the shading losses [46].

Connection losses stemming from improper connections and connectors can cause contact resistance and voltage drops, emphasizing the need for regular inspections. Light-induced degradation and voltage drop across series diode concern the reduction in output capacity due to solar radiation's slow degradation and loss due to bypass diodes, respectively [46] Age losses, indicating the gradual decline in performance over time, are typically marked at 0.5-1% annual degradation. Availability losses, resulting from time spent on operations, maintenance, cleaning, and repairs, can lead to periods of no output. Effective scheduling is vital to minimize these periods.

Proper design considerations and maintenance practices are fundamental to minimize the additional loss factors exclusive to floating PV systems in India. Regular monitoring and data analysis remain key elements in bridging the performance gaps [45][46][47].

2.5 Conclusion and Gap Statement

In conclusion, the literature presents persuasive evidence regarding the vast potential of floating solar photovoltaic (FSPV) systems in effectively harnessing India's abundant water resources to meet its ambitious renewable energy goals. Experimental studies consistently demonstrate FSPV's superiority over conventional ground-mounted PV, with 10-15% higher energy yields attributed to enhanced cooling and reduced shading effects. Ongoing research aims to further optimize system performance through ideal tilt angle configuration, advanced PV technologies like bifacial modules, and customized component selection suited for aquatic environments.

However, ensuring long-term reliability and minimizing power losses linked to soiling, cabling, and shading remain key focus areas, especially with limited India-specific research currently. The higher capital costs associated with floating platforms and anchoring systems persist as a roadblock, though projected to decline with economies of scale. Detailed techno-economic feasibility studies focused on suitable Indian sites can illuminate the path forward. Policy incentives encouraging large-scale adoption and local manufacturing can accelerate cost reductions.

In essence, the literature strongly advocates the immense scalability potential of FSPV in India given its expansive waterbodies. With bespoke optimizations in system design, operation and costs, India can replicate global success stories. FSPV's dual benefits in clean power generation and land conservation make it uniquely poised to fast-track India's renewable energy transition. Targeted research unlocking its fullest potential can enable FSPV's emergence as the third pillar alongside rooftop and ground-mounted solar PV in India's sustainable energy future.

The techno-economic feasibility of floating solar photovoltaics (FSPV) in India remains under-researched, with most existing studies centered on developed nations. Critical analyses, such as cost-benefit evaluations for utility-scale FSPV in regions like Kerala, are scarce. Essential elements like levelized costs, profitability metrics based on local parameters, and demand-aligned system sizing for Indian locales are pivotal for bolstering investor confidence. Additionally, comprehensive assessments of FSPV's environmental advantages, including carbon reduction and water conservation, as well as its integration with hydropower reservoirs in India, are sparse. To expedite FSPV adoption, rigorous data-centric studies aimed at substantiating the commercialization investment case across India's vast water bodies are vital, positioning Kerala as an ideal location for pioneering research in this sector.

3.0 Project Aim and Objectives

This project aims to design and assess the feasibility of floating solar PV systems in Kerala, India, to meet energy demand and promote sustainable renewable energy solutions. In order to achieve the aim , specific project objectives were defined as follows:

O1: Assess the feasibility of floating solar photovoltaic (PV) systems, considering the electrical demand of the targeted location

O2: Design an optimized floating solar PV system for maximum energy generation using simulation software

O3. Evaluate the scalability of the project

O4: Evaluate the economic feasibility of implementing a floating solar plant in the chosen location

O5: Evaluate the reduction in carbon footprint resulting from the implementation of the floating solar PV system.

4.0 Methodology

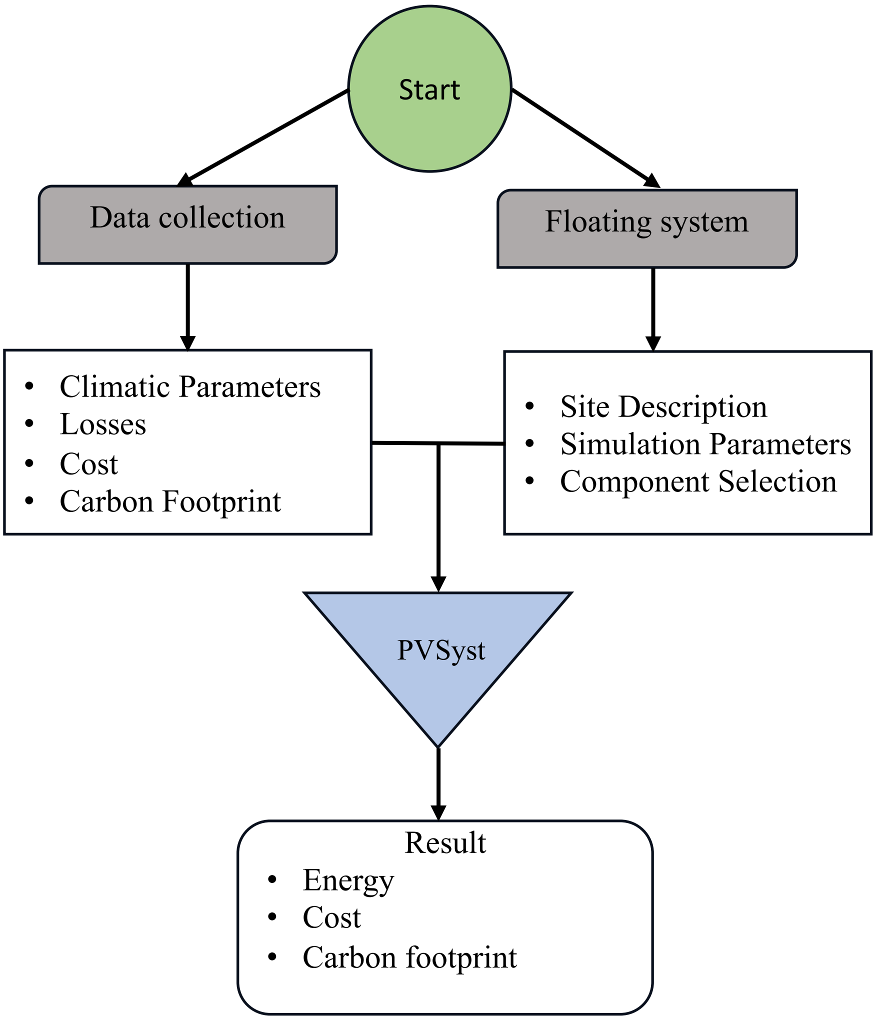

Figure 6 : Overview of Methodology

The workflow primarily focuses on two control parameters. This section delves into data collection and parameters of the floating PV system to meet the objectives outlined in Section 3.0. Figure 6 provides a concise overview of our adopted methodology. The collected data is then input into PVsyst® for further analysis. For a detailed understanding of the specific modelling techniques employed is explained subsections 4.1 to 4.7

4.1 Site Description

4.1.1 Location

This research presents a thorough case study examining the viability of deploying photovoltaic (PV) systems on lakes. The selected site for this Floating Solar Power Plant is Vembanad Lake, situated in Kerala. As the longest lake in India and the largest in Kerala, Vembanad Lake's geographical coordinates are 9.58° N latitude and 76.38° E longitude. The lake covers an depth

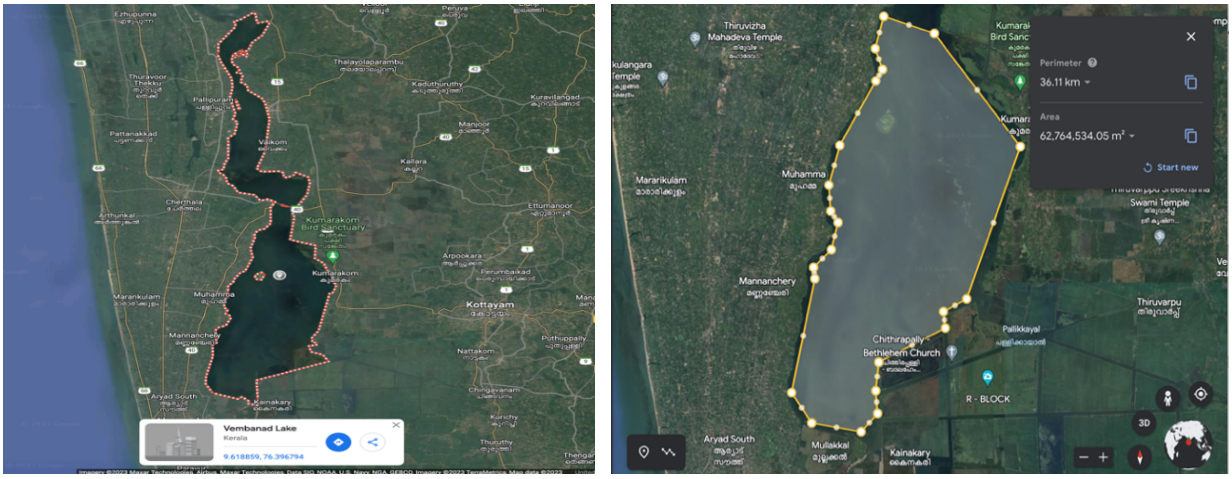

Figure 7 : Satellite view of Vembanad lake and chosen site area

of 12 meters and a surface area of 2033 square kilometres[50]. Its proximity to the cities of expansive area of 230 square kilometres, extending to a maximum length of 96.5 km, with a Alappuzha and Kottayam presents a significant opportunity for harnessing solar power. The location, size, and geographical features of Vembanad Lake make it an attractive and promising site for the proposed Floating Solar Power Plant with site area 62,764,534 m². Figure 6 presents the total area covered by the lake (left) and the proposed site area (right).

The reasons for selecting location, it is surrounded by major cities in Kerala, this lake interconnected with other lake and cities, so future expansion is possible and also in approximately two substations, Pathirappally, Alappuzha 66kV substation 5KM away & 66kV Substation, Muttambalam, Kottayam 12KM away was nearby, was a significant factor influencing the site selection. This strategic location has gird connections that are already available. No need to invest too much in grid expansion. Hence deploying FSPV plants in such cases may save investment cost by utilizing the already existing infrastructure. and offers the potential to cater to the energy demands of both cities.

4.1.2 Electrical demand

Understanding the electrical demand in a region is vital for energy planning and the design of renewable energy projects. In the recent analysis of energy consumption in Kerala, the daily electricity utilization has been observed to surpass 100 million units. This corresponds to an approximate daily power demand of 4,800 MW [51][52]. Hypothetically, if the cities of Alappuzha and Kottayam together represent 10% of Kerala's total demand, the maximum power demand would be 334.9 MW, with evening and morning peaks of 389.1 MW and 313.2 MW, respectively. This analysis not only highlights the energy consumption trends within the region but also emphasizes the necessity for meticulous planning to accommodate fluctuating demand across different times of the day.

In light of this context, the daily energy demand in the region is estimated to vary between 300 MW and 400 MW. Therefore, the design of the proposed Floating Solar Power Plant should align with this energy requirement.

4.1.3 Climatic Parameters

The weather data for the selected location was obtained from Meteonorm database 8.1, table 1 presents the values of the average horizontal insolation and land surface temperature for an average day of the month at Vembanad lake. The calculation of average monthly values over a span of 10 years involves the utilisation of interpolation techniques to estimate values based on the data obtained from the nearest weather stations[38]. While this study focuses on the lake's specific coordinates and their implications, a comprehensive understanding of other environmental conditions would require data on Avg. global horizontal solar irradiance, daily normal solar irradiance, daily diffuse horizontal solar irradiance, and average temperature. Each of these parameters can have a significant impact on the efficiency of solar panels, as well

Table. 1 : Weather Data (Vembanad Lake)

Monthly Meteo Values

Source Meteonorm 8.1 (1991-2010), Sat=85%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	162.8	158.5	172.6	168.6	156.0	132.3	131.3	135.4	144.9	144.4	138.8	146.7	1792.3	kWh/m²
Horizontal diffuse	62.0	72.0	85.6	92.5	87.2	82.7	90.3	91.8	80.3	78.4	71.4	66.2	960.4	kWh/m²
Extraterrestrial	277.8	271.1	318.4	315.6	322.4	307.0	318.2	322.4	309.6	305.3	274.1	269.8	3611.6	kWh/m²
Clearness Index	0.586	0.585	0.542	0.534	0.484	0.431	0.413	0.420	0.468	0.473	0.506	0.544	0.496	ratio
Ambient Temper.	27.5	28.2	29.2	29.0	29.0	26.7	26.6	26.7	26.8	27.4	27.3	27.8	27.7	°C
Wind Velocity	1.0	1.2	1.4	1.4	1.5	1.3	1.4	1.5	1.4	1.1	0.8	0.9	1.2	m/s

as the power output.

An essential tool used in solar design is the Solar Path diagram see Figure 7. This diagram graphically represents the sun's path across the sky throughout the year at the specific location of the PV system [53]. By analysing the solar path, designers can ascertain the amount of sunlight available at the site and identify potential shading obstacles. This information aids in optimizing the placement and orientation of the PV system, ensuring maximum energy efficiency and production [54].

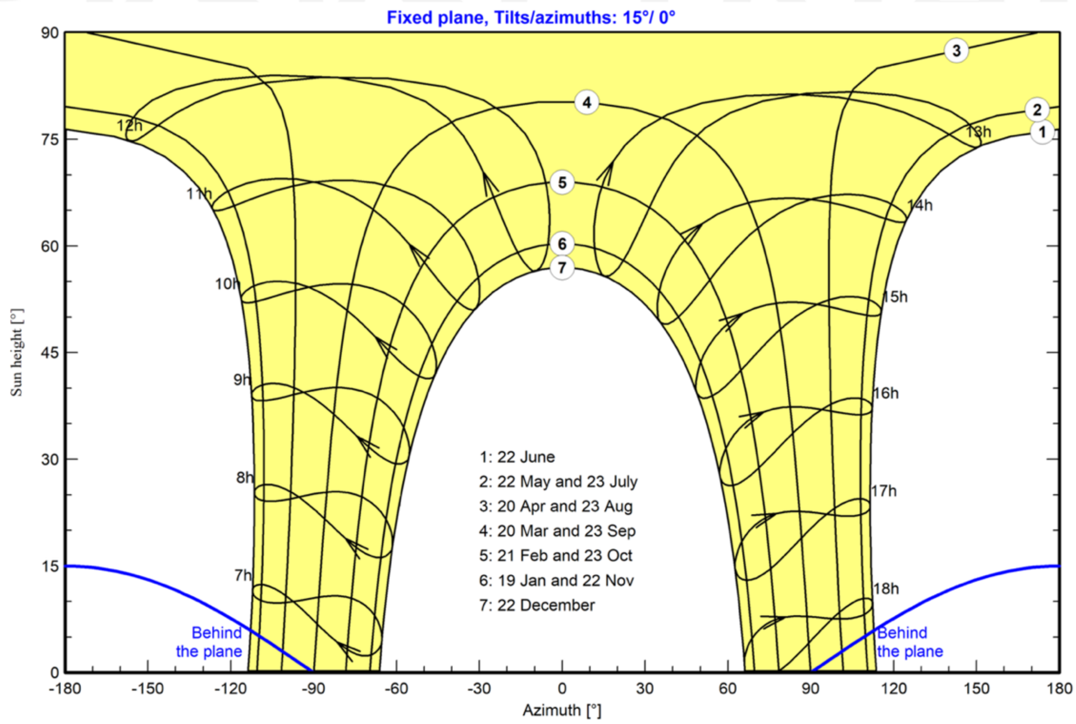

Figure 8 : Sun Path Graph

The climatic conditions around the lake contribute significantly to its suitability for a Floating Solar Power Plant.

4.2 System Simulation

The simulation of solar photovoltaic (PV) systems is an essential aspect of designing and evaluating their performance. Among the tools available for simulation, PVsyst® stands out as a robust and comprehensive software package widely utilized for studying solar PV plants. PVsyst® (version 7.4.0) enables detailed estimation of solar power generation, considering a multitude of variables including site location, weather data, albedo, component selection, sizing, module orientation, and potential losses. Although it does not yet have native support for Floating Photovoltaic systems, the software's flexibility allows it to be adjusted to simulate these particular systems, focusing only on relevant computation simulation parameters.

In the realm of photovoltaic system simulations, PVsyst® is recognized as a premier software, offering an in-depth perspective on anticipated system performance. It provides essential data on expected yields, potential challenges, and guides future implementation and adjustments by analysing specific geographical and climatic conditions, as well as the technical specifications of the selected equipment.

The simulation process itself in PVsyst® is systematic and analytical. It begins by calculating the effective irradiance in the array plane, using the Perez transposition model based on meteorological data for the selected location. Subsequently, the software calculates PV module parameters by applying the one-diode model, evaluating losses and determining inverter and AC side losses. Finally, the simulation yields the main output variables, including energy injected into the grid, system yield, performance ratio, Levelized Cost of Energy (LCOE), Internal Rate of Return (IRR), and module temperature among others. The entire modeling process in PVsyst® incorporates distinct stages, as depicted in Figure 8.

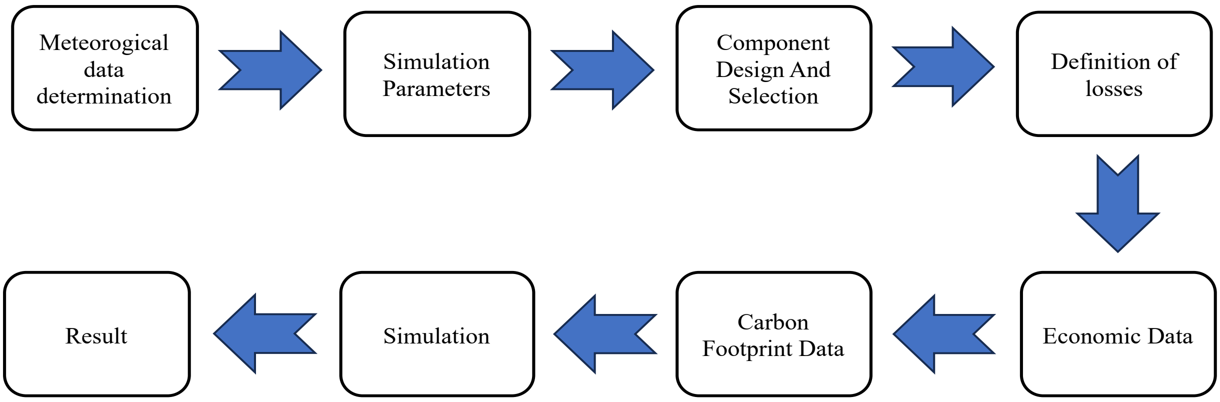

Figure 9 : Simulation Process Flow Diagram

4.3 Scenario Selection

Vembanad Lake has been evaluated under three different scenarios to assess its potential for solar power generation. The total project area measured was 62,764,534.05 m², but the allocated space for PV panel installation was limited to 45,000,000 m² to ensure efficient O&M, prevent shading effects, and allow for water transportation.

The first scenario focuses on electrical energy demand, where the efficiency of solar panels is optimized to meet the specific energy needs of the location. This scenario ensures that the power output is sufficient to fulfil the electrical requirements. The second scenario takes into account the total project area and divides it into 10 phases. This allows for a phased implementation of the project, which can be scaled up or down as needed. The third scenario also takes into account the total project area, but divides it into 5 phases. This results in a larger initial investment, but it also allows for a faster return on investment.

The results of the study show that Vembanad Lake has the potential to generate significant amounts of solar power. The optimal scenario for the project will depend on the specific needs of the location and the available budget.

4.4 Simulation Parameters

4.4.1 Azimuth Angle and Orientation

In regions such as India, which lies in the Northern Hemisphere, the sun's trajectory appears to move from East to West, peaking towards the South for optimal energy capture. Consequently, for maximized energy capture in Indian terrains, solar panels are predominantly oriented to the South. The ideal azimuth angle for such fixed solar setups is noted to be either 0° or 180° [55][56].

4.4.2 Tilt Angle

In the context of India's extensive geographical and climatic variations, the optimal tilt angle for solar panels varies across different regions. Previous studies have identified a tilt angle between 10° and 30°, facing due south, as the most favourable for most areas within the country [57][58]. In this study, a detailed analysis was undertaken to determine the optimal tilt angle. This analysis involved varying the tilt angle at 5° intervals, ranging from 0°, where the panels were aligned parallel to the water surface, to 40°. The primary objective of this examination was to evaluate the power output at each tilt angle and identify the particular angle that would maximize the power output of the FSPV model.

4.4.3 Albedo Coefficient

In India, the albedo coefficient for water reservoirs ranges from 0.16 to 0.2 [59]. For the specific site under consideration, an albedo value of 0.2 has been assumed. This coefficient provides essential insights for photovoltaic (PV) systems, which are highly dependent on solar irradiance. Understanding the albedo can contribute to the optimal design and operation of PV installations in the region.

4.5 Component Parameter

In the development of solar projects utilizing PVsyst®, it is imperative to consider several pivotal parameters to enhance the overall performance of the system. One of the principal considerations in this process is the configuration of the power plant strings, as highlighted in

Table 2. The maximum permissible modules in a string are significantly influenced by the location's lowest temperature. This is because the temperature coefficient affects each module's voltage, and at lower temperatures, the module voltage can increase. Thus, knowing the minimum temperature at the project location within a five-year period is essential. For instance, in a location with the lowest recorded temperature of 15°C, the inverter's absolute voltage limit needs careful attention in string design. And the absolute voltage limit for the inverter is set at 1000V.

The usual operating temperature is around 50°C this value is considered from metero data of PVsyst®, representing the average temperature during plant operation. In India, temperatures typically range from 50°C to 60°C, in summer the temperature reaches up to 60°C.

Table. 2 : Component Design Parameters

Lower temp for absolute voltage limit	15 °C
Winter operating for Vmpp Max	36 °C
Usual operation temp under 1000 W/m	50 °C
Summer temp Vmpp Min	60 °C
DC/AC ratio or overloading loss for design	1%
Transposition model of the project	Hay model

In this study Array maximum Voltage is set based on the International Electrotechnical Commission (IEC). Due to constraints such as the unavailability of diffuse irradiance and the precise albedo value, the Hay model was chosen as the transposition model for this project. Additionally, a DC/AC ratio limit, which envisions a 1% loss, was incorporated during the design phase to address potential overloading challenges. As for other design constraints, default values were retained. It is noteworthy to mention that in the preferences section, the project site meteorological default maximum search radius was set to 10 km. This parameter is crucial for the PVsyst® software, which utilizes it to pinpoint specific latitude and longitude data. In scenarios where PVsyst® lacks weather data for the designated location, it compensates by sourcing data from within the stipulated radius.

4.5.1 PV module and Inverter design

Trina Solar, the chosen manufacturer provided PV modules with a power rating of 595 Wp at 29v. The design process further involved adjusting the number of modules in series, which directly correlated to the set temperature values for absolute voltage limits and PV module stringing. SMA company supplied the inverters, each have a power rating of 4600 KW. This brand was not only well in the industry but also in PVsyst® for its high voltage values compared to other locally available brands. Throughout the three scenarios the same panels and inverters were utilized as depicted in the table 3.

Table. 3 :Simulation Design Parameter

Parameters	**Scenario: 01**	**Scenario: 02**	**Scenario: 03**
Area Coverage	As per demand	Total area/10	Total area/5
Total Area (m^2)	62,764,534		
Name of location	Vembanad Lake		
State, country	Kerala, India		
Geographical coordinates	9.58° N : 76.38° E		
Average temperature	15°C - 60°C		
PV module power	595 Wp		
PV module manufacturer	Trina solar		
Inverter power	4600 kw		
Inverter manufacturer	SMA		
Orientation	fixed orientation		
Azimuth Angle	0° or 180°		
Albedo Co-efficient	0.2		

4.6 Floating Solar Losses

The table 4 presents parameters associated with losses in a Photovoltaic (PV) field, including the field thermal loss factor represented by its U-Value. This U-value is calculated as: $U = UC + UV. Vw$, where U signifies the constant loss factor in W/m K, UV is the wind loss factor, and Vw is the wind velocity. Due to inconsistencies in wind velocity data, PVsyst® software developers advise against incorporating the wind loss factor, UV. Instead, the suggested approach is to integrate the expected wind effect into the thermal constant loss factor directly. In a research conducted by Liu et al. [60] average U-values were established for varying floating structures, such as well-ventilated structures at 29 W/m^2 K, semi-integrated modules at 20 W/m^2 K, and insulated back modules at 15 W/m^2 K. For the simulation, a U-value of 29 W/m^2K was used, assuming the structures were well-ventilated. The spectral correction loss for the monocrystalline module was established using the manufacturer's specifications.

In the research, a comprehensive analysis was conducted on the parameter values pertinent to a photovoltaic (PV) system, considering both empirical evidence from prior studies[61][62] and the manufacturer's specifications as detailed in the PVsyst® datasheet (Table 4). The study specifically accounted for the transformer being disconnected from the grid at night to mitigate iron loss, and the integration of the PV system to the grid through a 33 kV HV line. The placement of the HV transformer was noted to be 20 meters from the injection point, which helped in the analysis of Ohmic losses across both DC and AC circuits. Various losses were quantified including DC circuit loss (1.50%), voltage drop across series diodes (0.7V), AC loss at STC (0.36%), transformer iron loss (0.10%), and copper loss (0.98%). Module quality assessment was performed, accounting for factors like LID-mismatch such as module efficiency loss (-0.40%), LID loss factor (2%), module mismatch loss (1%), strings voltage mismatch (0.15%), an annual soiling loss factor of 1%, and IAM loss of 2.5%. Aging was also a significant consideration with the global degradation factor for individual modules calculated at 9.80%, mismatch degradation factor at 5.77% and average degradation factor including Imp and Vmp dispersion at 0.40% per year. The system's unavailability was carefully described, characterized by a time fraction of 2%, equivalent to 7.3 days per year, occurring over four distinct periods. The research thereby provided an in-depth understanding of various parameters and losses that may affect the efficiency and reliability of a PV system.

Table. 4 : Losses in PV systems

field thermal loss factor	U-Value	29 W/m2 K
Ohmic loss	DC Circuit	1.50%
	Voltage drop accoss series diode	0.7V
	AC loss at STC	0.36%
	transformer iron loss	0.10%
	copper loss	0.98%
module quality - LID-Mismatch	Module efficieny loss	-0.40%
	LID loss Factor	2%
	Module mismatch loss	1%
	Strings voltage mismatch	0.15%
soiling loss	yearly soiling loss factor	1%
IAM losses		2.50%
aging	individual module : Glob Degrad. Factor	9.80%
	mismatch degrad. Factor	5.77%
	Avg. Degradation factor	.40%/yr
	Imp RMS dispersion	.40%/yr
	Vmp RMS dispersiom	.40%/yr
unavailability	unavailability time fraction	2%
	unavailability duration	7.3 days/yr
	number of perods	4

4.7 Economic Analysis

The cost of FSPV shows in table 5 depends on manpower requirements, capital spending, and operating and maintenance costs, affecting domestic and commercial energy supply. These costs can vary depending on factors such as the size of the solar installation, the location, and the technology used. However, overall, FSPV systems have become more cost-effective in recent years, making them an attractive option for both residential and commercial applications. By analysing the cost breakdown, it is clear that the PV panel and mounting structure contribute significantly to the total cost, while the inverter, balance of system components, and installation costs make up a smaller portion. Ultimately, the economics of FSPV systems depend on various factors and can be optimized through efficient design, installation, and maintenance practices.

In a detailed cost analysis [63] [64] for a solar power project, the PV panel emerged as the most expensive component, priced at $0.22/Wp [65]. The inverter costs $0.03/Wp, while the mounting structure, design, and civil construction come to $0.14/Wp. Further costs like electrical systems and balance of system expenses amounted to $0.13/Wp, and other miscellaneous costs, including installation and land, were $0.08/Wp. The cumulative cost for the entire project, CapEx was $0.60/Wp [63][66], marking an 88% reduction from the country's per kW installation cost in 2010 [19]. Notably, the EPC cost for India's pioneering large-scale FSPV in Kayamkulam, Kerala, was $0.50/Wp in 2018 [63]. Another study [67] indicates a capex of $0.59/Wp for larger plants [20]. The costs achieved for EPC are site-specific and may include certain hidden costs; therefore, these figures should not be universally applied for estimation purposes.

Table. 5 : Components Cost per Watt (Wp): CapEx

Parameter	**Cost ($/Wp)**
PV Panel	0.22
Inverter	0.03
Mounting Structure, Design, civil construction	0.14
Electrical/Balance of system	0.13
Installation cost, land cost and other expenses	0.08
total	0.6

In the financial assessment of the solar initiative, a comprehensive examination of costs and prospective revenue was conducted. As shown in the table 6, the Operations & Maintenance (O&M) costs, critical for ensuring operational efficacy, are approximated at $0.072 Wp [63][68]. Guiding this evaluation, several base assumptions were made: a 10% discount rate to represent the current value of future financial flows [69][70], an expected operational lifespan of 25 years for the solar setup, and an inevitable 1% annual efficiency degradation [69][71], indicating a consistent decrease in energy output due to natural wear. As of December 2022, India's electricity prices stood at 0.079 U.S. Dollar per kWh for residential consumers [72][73] and 0.118 U.S. Dollar for commercial entities[72][74], encompassing all electricity bill components. The analyses were based on the premise of no land loss.

Table. 6 : OpEx, Assumption & Ele. price

Parameter		**Cost ($/Wp)**
O&M - OpEx		0.072/Wp
Assumptions considered	Discount rate	10%
	LIFE TIME	25 Years
	Degradation rate	1%
Electricity sale price		0.079 - 0.118 USD/kWh

4.8 Carbon footprint

Carbon footprint quantifies the greenhouse gas emissions linked with every phase of a product's life span, determined using a Life Cycle Assessment (LCA) methodology. The software PVsyst® employs default LCE values from literature references[75] and estimates emissions based on India's electricity production data in the IEA list. Analysing the lifecycle emissions of a photovoltaic solar power system, it was found that solar modules emitted 1,415 kg CO_2 per kilowatt peak (kWp). Additionally, the supporting structures for these panels emitted 6.24 kg CO_2 per kilogram, while inverters which change electricity from direct to alternating current accounted for 619 kg CO_2 each. The solar system displayed a yearly degradation of 1%, implying a 1% yearly decrease in energy output. Compared to the solar system, the grid's lifecycle emissions stood at 936 grams of CO_2 per kWh. By incorporating the system size, support weight, and inverter count, the system's total emissions were computed. The yearly degradation was crucial for predicting the system's energy output over its life, and the grid's LCE value provided insights into its environmental impact. However, this analysis might have inherent constraints due to certain assumptions and other influencing factors such as raw material procurement, production methods, transportation, and disposal processes.

Table. 7 : Components Carbon Emissions

System Lifecycle Emissions Details	**Item**	**LCE**
	Modules	1415 $kgCO_2/kWp$
	Supports	6.24 $kgCO_2/kg$
	inverters	619 $kgCO_2$/units
Annual degradation		1%
Grid Lifecycle Emissions:		936 gCO_2/kWh

5.0 Results and Discussion

5.1 FSPV Methodology Verification and Analysis

5.1.1 Tilt Angle Estimation:

The study aimed to determine the optimal tilt angle for peak performance by analysing a range of angles (0° to 40° in 5° increments) to maximize power output in the FSPV model. The impact of the tilt angle on sunlight reception over a year was examined, revealing distinct trends for both summer and winter. The greatest annual sunlight collection occurred at a 15° tilt angle. Beyond this, sunlight collection gradually decreased as the angle approached 40°. In the summer the maximum sunlight capture is at an angle of 0°, but this value decreased as the angle increased. On the other hand, in winter, sunlight collection increased with the angle, peaking at 30°. Nevertheless, a minor reduction was noted beyond this peak.

These findings indicate that the optimal tilt angle is situational. For enhanced sunlight collection during winter, a tilt angle near 30° was found more beneficial. On the other hand for summer, an angle of 0° was found ideal. However, if consistent year-round sunlight collection is desired, a tilt angle of 15° is recommended. Table 8 shows the detailed effect of tilt angle on yearly and seasonal irradiation yields.

Table. 8 : Tilt Angle And Irradiation Yields Across Months

Tilt Angle	Irradiation Yield		
	Summar (Apr -Sep)	Winter (Oct -Mar)	Year
0°	869	924	1793
5°	860	958	1818
10°	847	987	1834
15°	830	1009	1839
20°	807	1026	1833
25°	781	1036	1817
30°	750	1040	1790
35°	716	1038	1754
40°	679	1029	1708

5.1.2 Irradiation Effect

Figure 10 illustrates the monthly variations in two types of solar radiation measurements: Horizontal Global Irradiation (GHI) and Horizontal Diffuse Irradiation (DHI). GHI encompasses both direct and scattered sunlight, reaching a peak of 172.6 kWh/m^2 in March and a minimum of 131.3 kWh/ m^2 in July. This results in a yearly total of 1792.3 kWh/ m^2. In contrast, DHI, which only accounts for scattered sunlight, achieves a high of 91.8 kWh/m^2 in August and a low of 61.98 kWh/ m^2 in January, summing up to 960.35 kWh/ m^2 over the year.

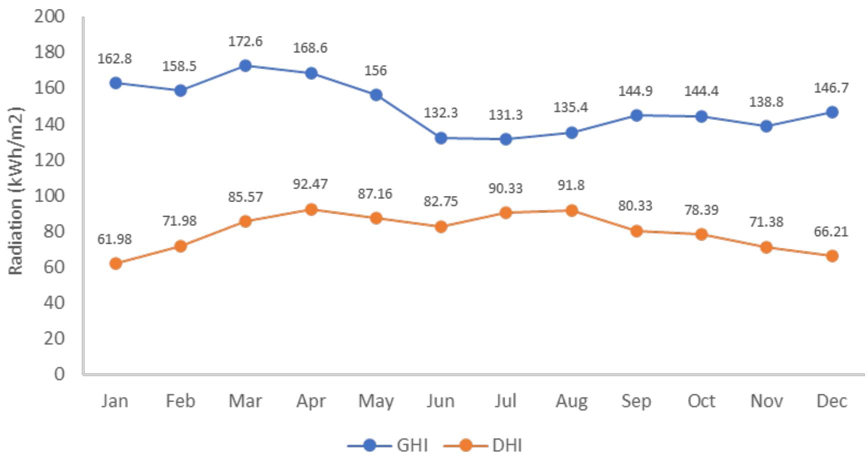

Figure 10 Yearly Irradiation

These values fluctuate throughout the seasons, reflecting changes in daylight and the sun's position in the sky. During the summer, when the days are extended and the sun is more elevated, both GHI and DHI attain their maximum values. Conversely, in the winter, shorter days and a lower sun position lead to the lowest GHI and DHI values.

Additionally, the data indicates a higher ratio of DHI to GHI during winter compared to summer. This trend can be attributed to an increase in cloud cover during the winter months, which results in more scattering of solar radiation. In order to achieve economic feasibility, photovoltaic systems usually need an annual sun irradiation level of 1100 kWh/m2 per year [76] So This area is suitable for FSPV installation.

5.1.3 Global Incident Energy vs Temperature

The study focused on understanding the correlation between sunlight, measured as global Incident Energy, and ambient temperature. Table 9 provided a clear depiction of how sunlight and temperature variations influenced energy output. The global Incident Energy is the reflected amount of sunlight reaching each square meter. For instance, January experienced a sunlight intensity of 181.3 kWh/m^2, which correlated to heightened energy production due to its richness in sunlight. Contrarily, while ambient temperatures witnessed minor fluctuations throughout the year—between 26.64°C to 29.21°C—it was observed that March, being the warmest month at 29.21°C, recorded higher energy output than February. This anomaly was attributed to March receiving more sunlight, 174 kWh/m^2, in contrast to February's 167.9 kWh/m^2. Moreover, June, characterized by the least sunlight at 123.7 kWh/m^2, saw a decline in energy output despite a relatively cooler environment. These results clearly demonstrated that energy production was significantly influenced by sunlight and temperature, with sunlight emerging as the primary determinant. Months like January, abundant in sunlight, were notably more beneficial for the solar power plant than sunlight-scarce months such as June.

Table. 9 : Global Incident Energy vs Temperature and Energy Output

Scenario 1			
Date	**GlobInc (kWh/m²)**	**T_Amb (°C)**	**E-Grid (kWh)**
January	181.3	27.45	13,832,987
February	167.9	28.2	13,618,043
March	174	29.21	14,021,535
April	163.5	28.98	13,250,372
May	146.3	28.96	11,937,665
June	123.7	26.66	9,758,864
July	124.2	26.64	10,353,224
August	130.7	26.65	10,844,810
September	144	26.78	11,379,180
October	148.7	27.36	11,175,154
November	149.2	27.34	12,286,660
December	162.8	27.75	13,308,409
Year Total	1816.2	27.66	145,766,902

5.2 Scenarios Analysis

5.2.1 Scenario 01: Demand-Based Coverage

The first scenario considered in the analysis of the floating solar power plant (FSPV) was designed specifically with coverage determined by demand. This unique approach required an intricate understanding of the energy demands to ensure that the solar setup was neither overproducing nor underdelivering. The solar panels' occupation was measured at 573,393 m², a size that was meticulously chosen to align with the demand-driven approach.

When it comes to the configuration of the photovoltaic (PV) panels, there was a clear emphasis on optimizing the setup to suit the requirements. The configuration comprised 38 modules connected in series. This combination was formulated with precision, merging to form 5,775 strings. The culmination of this setup was a total of 219,450 modules. These modules were powered by 26 inverters, ensuring efficient energy conversion and delivery.

The results from this scenario were quite enlightening. The FSPV site was rated at 119.6 MWp. This rating, when translated to power metrics, amounted to a nominal PV power of 119,600 kWp. Impressively, the nominal AC power was also gauged at 119,600 kWAC, reflecting a near-perfect conversion from PV power. Over the course of a year, this scenario was capable of producing 145,766 MWh. To put this into perspective, when this annual energy production was broken down on a daily basis, it was found to produce approximately 399 MWh/day.

As daily energy demand of the cities Alappuzha and Kottayam was estimated to be between 300 MWh and 400 MWh, Scenario 01 emerges as an ideal solution. However, it's crucial to compare this data with real-world instances. For instance, the energy produced by the solar PV in Scenario 01 deviated by 13% from real-time data of an installed 100 MW Tata Power capacity located in Kayamkulam, Kerala[16], [77]. Such discrepancies underline the importance of considering local weather variations, component differences, and unique parameters when extrapolating results from one scenario to a real-world application. Detailed values selected for parameters and energy produced in scenario 1 are provided in table 10

Table. 10 : System Components & Energy Produced - Scenario 01

Parameters	Scenario: 01
Coverage area	As per demand
Area (m²)	573393
Orientation type	fixed orientation
Tilt angle	15°
Azimuth	0°
Modules in series	38
No: of string	5775
Total No. of modules	219450
No: Inverter	26

Parameters	Scenario: 01
FSPV site rating (MWp)	119.6
Nominal PV power -(kWp)	119600
Nominal AC Powe -(kWAC)	119600
DC/AC ratio	1
Energy produced (mwh/yr)	145766
Specific Production (kWh/m²)	1219
Normalized Production (kWh/kWp/day)	3.34
Performance Ratio	67%

5.2.2 Scenario 02: 1/10th Area Coverage

The second scenario escalated the scale, focusing on a coverage that spanned 1/10th of the total area. The vastness of this approach was evident as the occupied space measured approximately 4,500,000 m². This size was a significant leap from Scenario 01, being 7.8 times larger.

In terms of PV panel configuration, this scenario underwent a recalibration. The panels were organized with 33 modules connected in series, which translated into 48,183 strings. The cumulative outcome was a staggering 1,590,039 modules. To manage this vast array, 203 inverters were judiciously used, ensuring the system ran seamlessly.

The metrics from Scenario 02 revealed some intriguing insights. The FSPV site was rated at an impressive 946.1 MWp, almost eight times that of Scenario 01. The nominal PV power was logged at 946,073 kWp. Interestingly, the nominal AC power for this setup was slightly lower, recorded at 933,800 kWAC. Over a year, the energy production from this scenario amounted to 1,212,968 MWh. One of the standout results was the performance ratio for Scenario 02, which was determined to be 70.60%, the highest among the three scenarios. Detailed values selected for parameters and energy produced in scenario 2 are provided in table 11

Table. 11 : System Components & Energy Produced Scenario 02

Parameters	Scenario: 02
Coverage area	Total area /10
Area (m²)	4500000
Orientation type	fixed orientation
Tilt angle	15°
Azimuth	0°
Modules in series	33
No: of string	48183
Total No. of modules	1590039
No: Inverter	203

Parameters	Scenario: 02
FSPV site rating (MWp)	946.1
Nominal PV power -(kWp)	946073
Nominal AC Powe -(kWAC)	933800
DC/AC ratio	1.013
Energy produced (mwh/yr)	1212968
Specific Production (kWh/m²)	1282
Normalized Production (kWh/kWp/day)	3.51
Performance Ratio	70.60%

5.2.3 Scenario 03: 1/5th Area Coverage

The third scenario was the most ambitious of the lot. Here, the FSPV was designed to cover 1/5th of the total area. This expansive approach saw the solar panels sprawl across a remarkable 90,000,000 m², a size that was 157 times larger than Scenario 01.

The PV panel configuration for this behemoth setup involved 34 modules in series, which contributed to 93,532 strings. The culmination of this arrangement was a whopping 3,180,088 modules. To ensure that this vast system was operational and efficient, 407 inverters were incorporated into the setup.

The data from Scenario 03 was nothing short of astounding. The FSPV site was rated at 1,892 MWp, which essentially doubled the capacity of Scenario 02. The nominal PV power was ascertained to be 1,892,152 kWp, while the nominal AC power was slightly less, at 1,872,200 kWAC. In terms of annual energy production, Scenario 03 was capable of generating 2,422,533 MWh. When this figure was broken down daily, it equated to an energy production of 6,637 MWh/day. Given that Kerala's daily energy demand is 4,903 MWh, this scenario not only has the potential to cater to the entire state but also holds the promise of exporting excess energy to other regions.

The three scenarios presented a comprehensive spectrum, ranging from a demand-specific setup in Scenario 01 to expansive configurations in Scenarios 02 and 03. Each scenario offers unique insights into the scalability, efficiency, and adaptability of solar power systems. The optimal choice among these would be influenced by a matrix of factors including energy requirements, logistical feasibility, and economic considerations. Detailed values selected for parameters and energy produced in scenario 3 are provided in table 12.

Table. 12 : System Components & Energy Produced Scenario 03

Parameters	Scenario: 03
Coverage area	Total area /5
Area (m^2)	90000000
Orientation type	fixed orientation
Tilt angle	15°
Azimuth	0°
Modules in series	34
No: of string	93532
Total No. of modules	3180088
No: Inverter	407

Parameters	Scenario: 03
FSPV site rating (MWp)	1892
Nominal PV power -(kWp)	1892152
Nominal AC Powe -(kWAC)	1872200
DC/AC ratio	1.011
Energy produced (mwh/yr)	2422533
Specific Production (kWh/m^2)	1280
Normalized Production (kWh/kWp/day)	3.51
Performance Ratio	70.50%

5.3 Economic Projections

In the comprehensive analysis undertaken to understand the different scenarios shown in the table 12, the tariff emerged as a crucial factor influencing the project's profitability and economic feasibility. This investigation encompassed three scenarios—S1, S2, and S3—each reflecting tariff ranges between $0.079 and $0.118. The consistency of this range across the scenarios allowed for a meaningful comparison of different aspects, such as Net Present Values (NPVs), Capital Expenditure (CAPEX), Operational Expenditure (OPEX), and other financial metrics.

Within Scenario S1, the tariffs were observed to fluctuate between $0.079 and $0.118, with corresponding NPVs ranging from -$4,53,65,263 to $62,52,598. Similar tariff ranges were noted for Scenarios S2 and S3, and they corresponded to variations in NPV as well.

In terms of CAPEX, consistency was noted across all scenarios, with values recorded at 7,17,60,150 for S1, 568,152,291 for S2, and 1,136,450,292 for S3. This uniformity was also mirrored in the OPEX, recorded at 86,11,218 for S1, 73,895,384 for S2, and 147,819,231 for S3. The Levelized Cost of Electricity (LCOE) further strengthened the evidence of uniformity, presenting nearly identical values of 0.1133, 0.1125, and 0.1127 for S1, S2, and S3 respectively. This indicates that the efficiency in electricity production remained unaltered, regardless of the project size.

The study also delved into the analysis of NPV in relation to the tariffs for each scenario. Particularly in Scenario S1, the NPV exhibited a severe decline at the $0.079 tariff, only to improve to $62,52,598 as the tariff escalated to $0.118. Analogous patterns were discerned in Scenarios S2 and S3, with their NPVs ranging from -$36,91,01,635 to $60,29,4295 and -$74,10,47,304 to $116,540,017 respectively.

The Internal Rate of Return (IRR) further exhibited fluctuations, with none of the scenarios yielding a profitable return at the lowest tariff of $0.079. The IRRs were 0.00% for S1, -28.00% for S2, and -33.00% for S3 at this point. However, as the tariff increased to $0.118, the IRR augmented to 11.12% for S1, 11.36% for S2, and 11.32% for S3.

In alignment with the observed trends, the payback period was initially deemed "unprofitable" at lower tariffs. However, a rise in tariffs saw a reduction in the payback period to 18.9 years for S1, 18 years for S2, and 18.2 years for S3, underscoring the correlation between tariffs and financial feasibility.

Lastly, the Return on Investment (ROI) followed a trajectory analogous to the above patterns. Negative ROIs at the lowest tariffs transitioned to positive as tariffs grew, culminating in 8.70% for S1, 10.60% for S2, and 10.3% for S3 at the tariff pinnacle of $0.118. This trend further illuminates the complex interplay between tariffs and the various dimensions of economic viability within the project.

Table. 13 : Cost Projections

Scenario	S1				S2			
Tariff	0.079 USD	0.113 USD	0.114 USD	0.118 USD	0.079 USD	0.112 USD	0.114 USD	0.118 USD
CAPEX	7,17,60,150				568152291			
Depreciable asset	2,99,00,063				237026669			
OPEX USD/Yr	86,11,218				73895384			
LCOE USD/kWh	0.1133				0.1125			
NPV USD	-4,53,65,263	-3,65,076	9,58,458.00	62,52,598	-36,91,01,635.00	-5766618	5243534	60294295
IRR	0.00%	0.00%	10.18%	11.12%	-28.00%	0.00%	10.12%	11.36
Payback period in year	unprofitable	unprofitable	23.7	18.9	unprofitable	unprofitable	24.10	18
ROI	-63.20%	-0.50%	1.3%	8.70%	-65.0%	-1.0%	0.90%	10.60%

Scenario	S3			
Tariff	0.079 USD	0.112 USD	0.114 USD	0.118 USD
CAPEX	1136450292			
Depreciable asset	474196966			
OPEX USD/Yr	147819231			
LCOE USD/kWh	0.1127			
NPV USD	-74,10,47,304.00	-15396494	6592925	116540017
IRR	-33.00%	0%	10.08	11.32
Payback period in year	unprofitable	unprofitable	24.4	18.2
ROI	-65.2%	-1%	0.60%	10.3

5.4 Carbon Emission

In the course of the research, the carbon dioxide (CO2) emissions saved over a span of 25 years for three distinct scenarios: S1, S2, and S3 were examined. For S1, It was found that 2,844,098.8 tonnes of CO2 (tCO2) were saved over a span of year 25 years. To comprehend the significance of this finding, this was compared it to a conventional power plant. The chosen model for this comparison was a 101.6 MWp TATA power plant in Kerala. It is known to save 142,077 tonnes of CO2 annually[16], [77].

When normalized to a yearly scale, S1 translates to approximately 113,763 tCO2 saved per annum. The difference between this and the CO2 from the TATA power plant can be attributed to the different materials, components used, and the specific values selected during the calculations for the S1 setup.

The other two scenarios, S2 and S3, were evaluated under similar premises, yielding even more substantial savings. In |S2, the saved CO2 emissions amounted to 25,037,520.9 tCO2 over the same 25-year period. Meanwhile, S3 exhibited a savings of 50,192,142.7 tCO2.

These findings are representative of the potential for significant CO2 emission reductions through the application of alternative strategies and technologies. It demonstrates that tailored choices in materials and components, as well as careful consideration of values in calculations, can lead to a substantial positive impact on the environment. The findings from this project both validate the efficacy of the strategies employed in scenarios S1, S2, and S3 and offer insightful perspectives that could shape subsequent efforts in sustainable energy and environmental preservation.

6.0 Conclusion

This project demonstrates that floating solar PV systems can provide a viable large-scale renewable energy solution to meet local demands in Kerala, India. The extensive data analysis and tailored system modelling enabled the design of an optimized 119 MW FSPV system on Vembanad Lake to fulfil the 300-400 MWh/day electricity requirements of Alappuzha and Kottayam.

The project's rigorous methodology and simulation using PVsyst® were instrumental in identifying the ideal tilt angle of 15° for maximum annual yield in the region. This optimization alone can lead to a 15% boost in energy generation compared to suboptimal tilt angles.

The economic analysis revealed strong financial viability across varying tariffs of $0.079-0.118/kWh. The system demonstrated positive NPV up to $62 million, 8.7-10.6% ROI, and attractive 18-19 year payback period. The levelized cost of electricity stood at $0.11/kWh comparable to conventional energy costs. These metrics substantiate the commercial attractiveness of investing in FSPV.

Most crucially, the FSPV system's staggering 2.8 million tonnes of lifetime CO2 savings quantify the immense sustainability benefits. By avoiding dependency on fossil fuels, this solar alternative can prevent over 113,000 tonnes of emissions annually.

The project's success demonstrates the merits of site-specific modelling and optimization in efficiently harnessing the vast solar potential of Kerala's water bodies. The results validate the scalability and commercial viability of large, utility-scale FSPV systems to promote energy access while enabling sustainability. With further innovation and policy support, India could replicate such solutions across suitable inland and coastal sites, propelling the nation closer to its renewable energy goals.

7.0 Future Work

The potential for enhancing the reliability and flexibility of Floating Solar Photovoltaic (FSPV) installations through the integration of energy storage systems, such as batteries or pumped hydro storage, represents a promising avenue for further research. This approach could be complemented by the application of artificial intelligence (AI) and data analytics, which may offer optimization of system performance through predictive maintenance and real-time adjustments.

An investigation into hybrid FSPV systems, in conjunction with other renewable energy sources like wind or hydro power, could provide insights into ways to improve energy yields. It is recommended that future studies also focus on the techno-economic feasibility of these hybrid systems to evaluate their practicality and efficiency.

The development of solutions to address specific challenges in FSPV installations is essential for their large-scale adoption. These challenges include PV module maintenance, the potential impacts on aquatic life, and the resilience of the systems against adverse weather conditions. Progress in mooring and anchoring techniques may contribute to enhancing stability during extreme weather events.

Moreover, the utilization of advanced software for operational simulations of hybrid FSPV systems can provide valuable understanding of the performance capabilities and limitations of these systems. In the context of ongoing innovations in areas such as hybrid systems, energy storage integration, water conservation, and advanced analytics, FSPV stands poised to become an efficient, reliable, and sustainable solution for large-scale renewable energy generation. The continued exploration and development of these areas will be instrumental in realizing the full potential of FSPV technologies.

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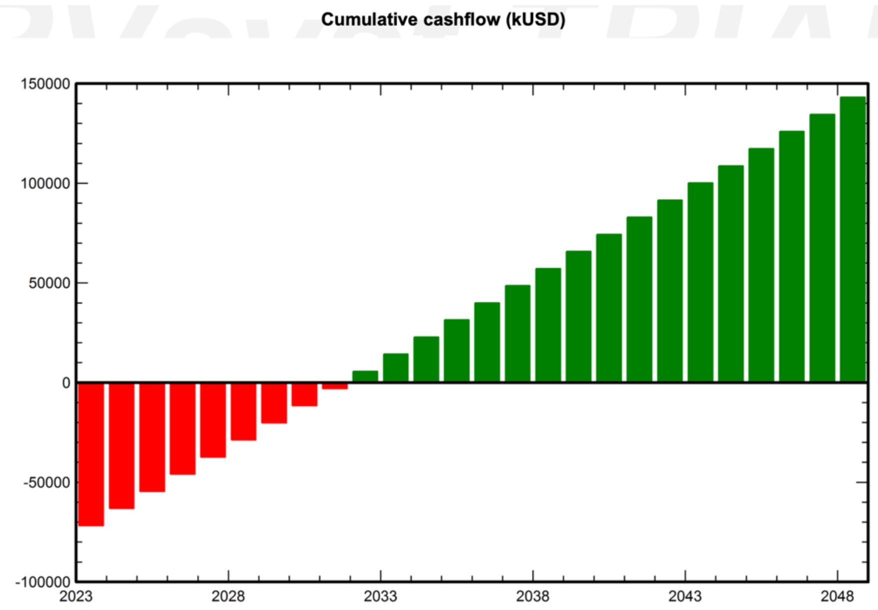
Appendices

PVsyst® Data of scenario 1

Financial analysis

Detailed economic results (kUSD)

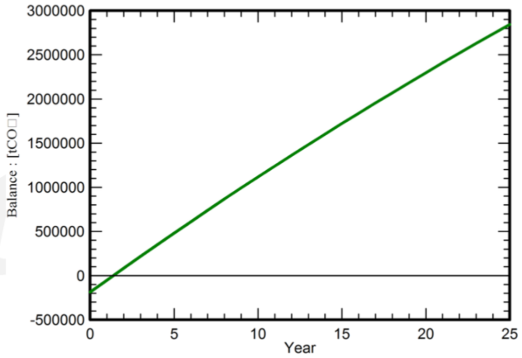
Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	71,760,150	0	0	0	0	0	-71,760,150	0.0%
1	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-63,946,955	10.9%
2	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-56,844,051	20.8%
3	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-50,386,866	29.8%
4	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-44,516,697	38.0%
5	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-39,180,180	45.4%
6	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-34,328,801	52.2%
7	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-29,918,456	58.3%
8	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-25,909,052	63.9%
9	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-22,264,139	69.0%
10	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-18,950,582	73.6%
11	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-15,938,257	77.8%
12	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-13,199,780	81.6%
13	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-10,710,256	85.1%
14	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-8,447,051	88.2%
15	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-6,389,593	91.1%
16	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-4,519,176	93.7%
17	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-2,818,798	96.1%
18	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	-1,272,999	98.2%
19	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	132,273	100.2%
20	17,205,732	0	8,611,218	1,495,003	7,099,511	0	8,594,514	1,409,793	102.0%
21	17,205,732	0	8,611,218	0	8,594,514	0	8,594,514	2,571,174	103.6%
22	17,205,732	0	8,611,218	0	8,594,514	0	8,594,514	3,626,976	105.1%
23	17,205,732	0	8,611,218	0	8,594,514	0	8,594,514	4,586,795	106.4%
24	17,205,732	0	8,611,218	0	8,594,514	0	8,594,514	5,459,358	107.6%
25	17,205,732	0	8,611,218	0	8,594,514	0	8,594,514	6,252,598	108.7%
Total	**430,143,301**	**71,760,150**	**215,280,450**	**29,900,063**	**184,962,788**	**0**	**214,862,851**	**6,252,598**	**108.7%**


Cumulative cashflow (kUSD)
150000
100000
50000
0
-50000
-100000
2023
2028
2033
2038
2043
2048

CO_2 Emission Balance

Total:	2844098.8 tCO_2
Generated emissions	
Total:	187258.18 tCO_2
Source: Detailed calculation from table below	
Replaced Emissions	
Total:	3410945.5 tCO_2
System production:	145766.90 MWh/yr
Grid Lifecycle Emissions:	936 gCO_2/kWh
Source:	IEA List
Country:	India
Lifetime:	25 years
Annual degradation:	1.0 %

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

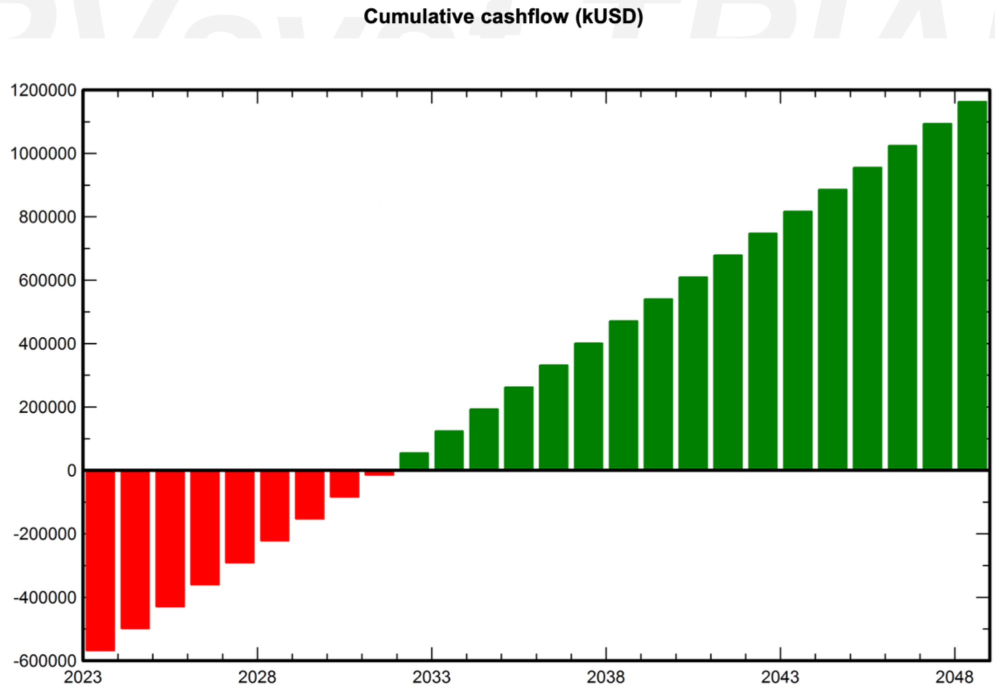
Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1545 kgCO2/kWp	112815 kWp	174322549
Supports	6.24 kgCO2/kg	2070000 kg	12923258
Inverters	619 kgCO2/units	20.0 units	12370

PVsyst® Data of scenario 2

Financial analysis

Detailed economic results (kUSD)

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	568,152,291	0	0	0	0	0	-568,152,291	0.0%
1	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-505,211,610	11.1%
2	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-447,992,810	21.1%
3	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-395,975,718	30.3%
4	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-348,687,453	38.6%
5	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-305,698,121	46.2%
6	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-266,616,910	53.1%
7	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-231,088,537	59.3%
8	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-198,790,016	65.0%
9	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-169,427,724	70.2%
10	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-142,734,731	74.9%
11	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-118,468,374	79.1%
12	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-96,408,049	83.0%
13	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-76,353,209	86.6%
14	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-58,121,535	89.8%
15	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-41,547,287	92.7%
16	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-26,479,788	95.3%
17	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-12,782,062	97.8%
18	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	-329,584	99.9%
19	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	10,990,850	101.9%
20	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	21,282,155	103.7%
21	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	30,637,886	105.4%
22	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	39,143,096	106.9%
23	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	46,875,105	108.3%
24	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	53,904,204	109.5%
25	143,130,132	0	73,895,384	9,481,067	59,753,682	0	69,234,749	60,294,295	110.6%
Total	**3,578,253,310**	**568,152,291**	**1,847,384,590**	**237,026,669**	**1,493,842,051**	**0**	**1,730,868,720**	**60,294,295**	**110.6%**



CO_2 Emission Balance

Total: 25037520.9 tCO_2

Generated emissions

Total: 187258.18 tCO_2

Source: Detailed calculation from table below

Replaced Emissions

Total: 28383443.0 tCO_2

System production: 1212967.65 MWh/yr

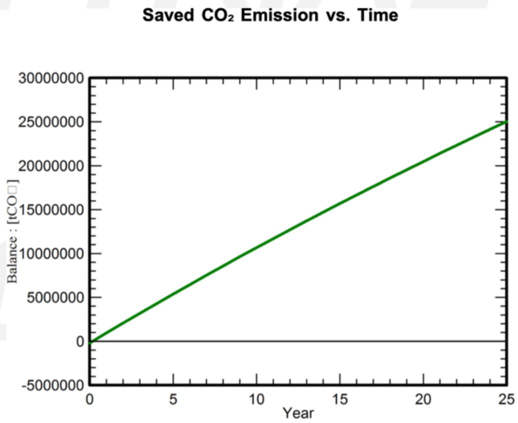
Grid Lifecycle Emissions: 936 gCO_2/kWh

Source: IEA List

Country: India

Lifetime: 25 years

Annual degradation: 1.0 %



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1415 kgCO2/kWp	123165 kWp	174322549
Supports	6.24 kgCO2/kg	2070000 kg	12923258
Inverters	619 kgCO2/units	20.0 units	12370

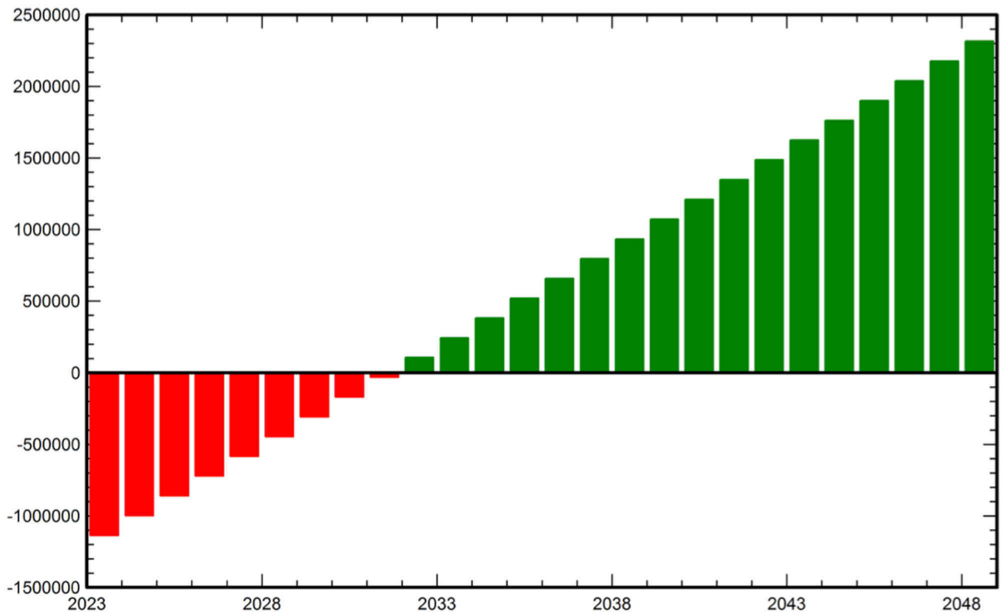
PVsyst® Data of scenario 3

Financial analysis

Detailed economic results (kUSD)

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	1,136,450,292	0	0	0	0	0	-1,136,450,292	0.0%
1	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-1,010,956,931	11.0%
2	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-896,872,058	21.1%
3	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-793,158,537	30.2%
4	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-698,873,518	38.5%
5	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-613,159,865	46.0%
6	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-535,238,361	52.9%
7	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-464,400,631	59.1%
8	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-400,002,694	64.8%
9	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-341,459,116	70.0%
10	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-288,237,680	74.6%
11	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-239,854,557	78.9%
12	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-195,869,900	82.8%
13	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-155,883,848	86.3%
14	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-119,532,892	89.5%
15	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-86,486,568	92.4%
16	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-56,444,455	95.0%
17	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-29,133,444	97.4%
18	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	-4,305,251	99.6%
19	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	18,265,833	101.6%
20	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	38,785,000	103.4%
21	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	57,438,788	105.1%
22	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	74,396,778	106.5%
23	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	89,813,132	107.9%
24	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	103,827,999	109.1%
25	285,861,927	0	147,819,231	18,967,879	119,074,818	0	138,042,696	116,568,787	110.3%
Total	**7,146,548,178**	**1,136,450,292**	**3,695,480,770**	**474,196,966**	**2,976,870,443**	**0**	**3,451,067,409**	**116,568,787**	**110.3%**

Cumulative cashflow (kUSD)



Student No. 202267339

CO_2 Emission Balance

Total: 50192142.7 tCO_2

Generated emissions

Total: 187258.18 tCO_2

Source: Detailed calculation from table below

Replaced Emissions

Total: 56687943.4 tCO_2

System production: 2422561.69 MWh/yr

Grid Lifecycle Emissions: 936 gCO_2/kWh

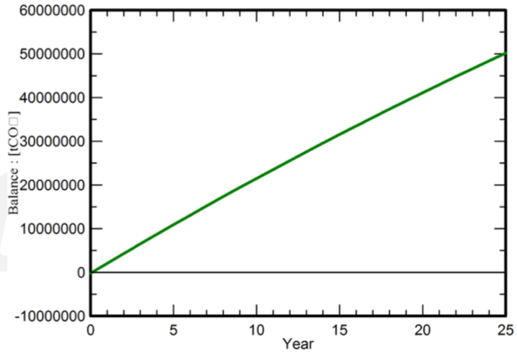
Source: IEA List

Country: India

Lifetime: 25 years

Annual degradation: 1.0 %

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1415 kgCO2/kWp	123165 kWp	174322549
Supports	6.24 kgCO2/kg	2070000 kg	12923258
Inverters	619 kgCO2/units	20.0 units	12370