



## Feasibility of Floating Photovoltaic Systems in Nong Han Lake, Sakon Nakhon Province, Thailand

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### Abstract

This study aims to assess the potential and feasibility of developing and installing a floating solar photovoltaic (FPV) power generation system on Nong Han Lake in Sakon Nakhon Province, Thailand. This novel assessment of a large-scale, natural water body fills a research gap, as most previous FPV initiatives in Thailand have focused on artificial reservoirs. The feasibility analysis focuses on both technical and economic aspects. The methodological approach integrates field data, a comprehensive site suitability analysis, and simulations using PVsyst software. The results indicate that an FVP system in the 80-hectare pilot area can support a capacity of 96.34 MWp, generating approximately 132.25 GWh/year, with a performance ratio of 80.64% and a levelized cost of energy of 1.40 THB/kWh, which is significantly lower than the current feed-in tariff. The project demonstrates strong economic viability, featuring a 14-year payback period and an internal rate of return of 7.5–8.5%. This study highlights FPV as a promising renewable energy solution and offers a strategic framework for FPV deployment in unique natural aquatic environments across the region.

**Keywords:** Solar Energy, Floating Solar Photovoltaics (FPV), Nong Han Lake

### 1. Introduction

In response to pressing global energy and environmental challenges, Thailand introduced the Alternative Energy Development Plan (AEDP 2015–2036) to strengthen energy security and reduce dependence on fossil fuels. Despite this plan, data from the Ministry of Energy [1] indicate that Thailand remained heavily reliant on imported energy and experienced rising greenhouse gas emissions between January and July 2024, highlighting the need for accelerated adoption of renewable energy sources. Among the various renewable alternatives, solar energy stands out due to its abundance, cleanliness, and compatibility with Thailand's tropical climate. The country enjoys approximately 4–5 hours of peak sunlight daily and has an average solar irradiance of 4–5 kWh/m<sup>2</sup>/day. Sakon Nakhon, a province in northeastern Thailand, situated on the Khorat Plateau [2], receives approximately 4.93 kWh/m<sup>2</sup>/day. One of the most prominent natural features in the province is Nong Han Lake, the largest freshwater lake in the region, spanning over 123 square kilometers. Natural water sources like this are very important in the countryside for living, consumption, agriculture, and livestock [3]. With its year-round sunlight and expansive water surface, Nong Han Lake is an ideal candidate for a floating photovoltaic (FPV) system, where solar panels are installed on floating platforms on water bodies. FPV technology not only conserves land but also reduces water evaporation and improves panel efficiency due to the naturally cooler environment above water surfaces. At present, however, the lake's solar potential remains untapped, and systematic feasibility assessments are lacking [4].

Globally, solar energy is increasingly harnessed via FPV systems due to land constraints and the added efficiency benefits of deploying panels over water surfaces [6]. The Electricity Generating Authority of Thailand (EGAT) has initiated 16 hybrid FPV–hydropower projects under the Power Development Plan (PDP 2018 Revision 1), with a combined capacity of 2,725 MW. The flagship Sirindhorn Dam project in Ubon Ratchathani,

inaugurated in 2021, is currently the world's largest hybrid FPV system, featuring 144,420 panels over approximately 72 hectares and generating 45 MWp [7].

While FPV systems generally require 10–25% higher capital expenditure (CAPEX) than ground-mounted systems, they offer competitive long-term benefits. The resulting land-use savings and improved energy yield due to lower operating temperatures contribute to a lower levelized cost of electricity (LCOE) [8]. Investment viability, however, is influenced by a wide variety of factors, such as carbon pricing, electricity tariffs, and interest rates [9]. Comprehensive feasibility assessments for FPV projects must consider hidden environmental and social costs, including permitting, conflict mitigation, ecological monitoring, and maintenance, all of which affect key financial metrics [10].

FPV systems can be deployed on reservoirs, ponds, and lakes without competing with agricultural or urban land use [11]. When integrated with hydropower, they also enhance energy system stability. In addition, FPV systems help mitigate water loss from evaporation and contribute to the reduction of greenhouse gas emissions [12, 13]. Studies by Alhassan [14], Farfan and Breyer [15], and Lee et al. [16] have shown that FPV systems can improve panel performance by alleviating heat stress, thus maintaining higher efficiency over time. Notably, a study in Bangalore, India, found that FPV systems could generate up to 459 MW—covering approximately 26% of the city's electricity demand—while reducing annual water evaporation by 22.87 million cubic meters and decreasing CO<sub>2</sub> emissions by up to 70%. A 145 MWp FPV project at Indonesia's Cirata Dam—comparing monocrystalline, polycrystalline, and thin-film panels—recommended polycrystalline panels for their space efficiency, though environmental and maintenance considerations were found to require further investigation [17, 18]. Evidence from Bangladesh, Indonesia, India, and China highlights the feasibility and benefits of FPV systems in promoting clean energy expansion without land-use conflict. These benefits include energy diversification, environmental protection, and long-term sustainability, provided the systems are properly designed and managed.

In Thailand, the development of FPV projects, mainly led by EGAT, has largely focused on installations in hydropower dams and artificial reservoirs. Large, natural water bodies such as Nong Han Lake have received relatively little research attention, despite their high development potential. Because natural water bodies differ from managed reservoirs due to their more complex ecosystems and seasonal water-level fluctuations, assessing their suitability for FPV systems requires a more comprehensive approach that has not yet been attempted in the literature. To bridge this gap, this study aims to assess the feasibility of designing and installing an FPV system on Nong Han Lake in Thailand, using interdisciplinary frameworks from energy engineering, energy economics, and environmental science. By evaluating the lake's solar energy potential, projected generation capacity, and investment viability, this research ultimately contributes to local renewable energy development and environmental sustainability.

## **2. Materials and Methods**

This study conducted a systematic assessment of the feasibility of installing an FPV system on Nong Han Lake in Sakon Nakhon Province, Thailand, focusing on site suitability and the economic viability of the investment.

### *2.1 Equipment and Tools*

PVsyst software, version 8.0.14, was used as the primary tool for analyzing and simulating electricity production from the solar photovoltaic system. PVsyst can evaluate solar energy potential, analyze system losses (loss diagram), and design systems at a technical level that supports engineering planning and decision-making. It was employed to assess the suitability of the installation site and to design the FPV power generation system. The objective was to ensure that the system could generate sufficient energy to meet the actual demand within the study area.

### *2.2 Data Collection and Site Assessment*

Secondary data related to the environmental conditions of the study area were collected from the Global Solar Atlas (GSA), a project of the World Bank Group operated by Solargis, focusing on key variables such as solar irradiance intensity and water surface characteristics. The GSA provides long-term average solar irradiance values derived from satellite data analysis combined with high-resolution climate modeling for the period from 1994 to 2020. These factors are essential for assessing the solar energy potential and the technical suitability of installing an FPV system.

**Table 1** Summary of Solar Resource Data for Nong Han Lake from Global Solar Atlas (1994–2020)

| Radiation Type                       | Average | Maximum | 90th Percentile |
|--------------------------------------|---------|---------|-----------------|
| Global Horizontal Irradiation (GHI)  | 4.98    | 5.02    | 5.01            |
| Direct Normal Irradiation (DNI)      | 3.70    | 3.77    | 3.76            |
| Diffuse Horizontal Irradiation (DIF) | 2.38    | 2.39    | 2.38            |
| Global Tilted Irradiation (GTI)      | 5.24    | 5.28    | 5.28            |

Table 1 presents the key parameters of solar irradiance in the study area of Nong Han Lake. Global tilted irradiance (GTI), which represents the solar radiation received by solar panels tilted at an optimal angle, has an average value of 5.24 kWh/m<sup>2</sup>/day. Global horizontal irradiance (GHI), or the total radiation on a horizontal plane, averages 4.98 kWh/m<sup>2</sup>/day, which is a suitable level for developing fixed solar power systems. Direct normal irradiance (DNI) and diffuse horizontal irradiance (DIF) have average values of 3.70 kWh/m<sup>2</sup>/day and 2.38 kWh/m<sup>2</sup>/day, respectively. These values reflect moderate levels of direct and diffuse radiation in the atmosphere, which is characteristic of tropical climates.

Field data collection and site surveys were conducted at nine locations around Nong Han Lake in Sakon Nakhon Province, within five subdistricts: Chiang Khruea, Tha Rae, Na Tong Watthana, Lao Po Daeng, and That Choeng Chum. Survey locations were selected based on representative land-use and land-cover types around the lake to ensure diverse environmental and socio-economic settings. Field coordinates were collected using a handheld GPS device; the recorded data were imported into QGIS as point features and visualized on a satellite basemap to support spatial analysis and mapping of the study sites. Data were analyzed to identify suitable areas for the installation of an FPV system.

**Figure 1** Surveyed areas along the shoreline of Nong Han Lake within five subdistricts.

### 2.3 Site Suitability Analysis

The field data collected from the site surveys were analyzed to identify connection points for the design and installation of the FPV system, as detailed in Table 2. Based on these connection points, strengths and weaknesses for the design and installation of an FPV system on Nong Han Lake were identified, as summarized in Table 3.

**Table 2** Connection Points for Floating Photovoltaic (FPV) Design and Installation

| Main Issue                   | Details                                                                                                                                                                                           |
|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Topography                   | Nong Han Lake is located in a shallow floodplain with abundant aquatic vegetation and multiple floating islands scattered throughout the area.                                                    |
| Traditional Land Use         | The surrounding land is primarily used for agriculture, livestock farming, local fisheries, and sourcing aquatic plants for weaving mats.                                                         |
| Conservation Areas           | Several aquatic species conservation zones exist in the region, including Tha Rae, Don Koen, Pratu Nam Suratsawadi, and Nong Non Thong.                                                           |
| Community Acceptance         | The FPV system is considered a promising approach, provided that safety measures are ensured. It has the potential to increase income and create development opportunities for local communities. |
| Precautions / Considerations | Community concerns include risks of electrical leakage, impacts on aquatic life, disruptions to fishing livelihoods, and effects on the visual landscape.                                         |

**Table 3** Strengths and Weaknesses in the Design and Installation of a Floating Photovoltaic (FPV) System on Nong Han Lake

|            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Strengths  | <ol style="list-style-type: none"> <li>1. The topography of Nong Han Lake is characterized by a shallow floodplain with abundant aquatic vegetation, making it suitable for the installation of floating platforms for the FPV system. This environment supports structural stability and reduces the complexity of floating structure design. Additionally, the existing aquatic plants can help reduce light reflection and moderate the temperature around the solar panels.</li> <li>2. Multiple floating islands serve as natural barriers that mitigate wind and wave forces, enhancing the stability and durability of the FPV system under environmental stresses.</li> <li>3. Traditional land uses include agriculture, raising livestock, fisheries, and sourcing aquatic plants for weaving mats. Installing FPV systems on the water surface reduces land use requirements for the project, particularly in agricultural and community areas, minimizing disruption to local livelihoods and traditional ways of life.</li> <li>4. Several aquatic species conservation zones exist within the region. Installing FPV systems outside these conservation zones will help preserve the ecosystem and reduce impacts on aquatic life compared to land-based energy production.</li> <li>5. Overall community acceptance is positive, increasing the likelihood of project success. The community views the FPV system as a viable and safe alternative that, if properly managed, can increase income and promote development opportunities in the area.</li> </ol> |
| Weaknesses | <ol style="list-style-type: none"> <li>1. Installing solar panels on the water surface may reduce the amount of sunlight penetrating the water, affecting the photosynthesis of aquatic plants and the overall aquatic ecosystem. This can alter algae and aquatic organism growth, potentially disrupting the food chain within the ecosystem.</li> <li>2. The floating system may restrict the movement of boats or fishing equipment, potentially limiting traditional fishing activities.</li> <li>3. Concerns exist regarding electrical leakage or accidents associated with underwater or surface electrical systems. Floating systems require continuous monitoring and maintenance to prevent damage caused by weather conditions such as strong winds or high waves.</li> <li>4. Compared to land-based systems, FPV systems tend to have higher initial investment and maintenance costs due to the need for specialized materials and technologies adapted to aquatic environments. Accessibility and repair operations may also be more complex.</li> <li>5. Improper planning and installation could disturb habitats of aquatic species within conservation zones, affecting their movement and behavior, potentially harming biodiversity.</li> </ol>                                                                                                                                                                                                                                                                                                          |

According to general FPV design standards, no more than 5–10% of the water surface area should be utilized to minimize impacts on the ecosystem and traditional uses. Nong Han Lake has a total water surface area of approximately 12,320 hectares, so a suitable coverage area for FPV installation ranges from 616 hectares to 1,232 hectares) of the water surface. For the feasibility study of the FPV system on Nong Han Lake, system design and simulation were conducted within this range. Areas located outside of aquatic conservation zones and those that do not interfere with traditional fishing activities are suitable sites for FPV development. Specifically, shallow basin areas with abundant aquatic vegetation, floating islands, or natural wave-reducing plant belts near the electrical grid (such as transmission lines or substations) are ideal.

A pilot project area of approximately 80 hectares was established at Khu Sud, located within the Sakon Nakhon Municipality. This site features a long, narrow peninsula extending about 1.5 kilometers into Nong Han Lake, and a shallow floodplain with seasonal water level variations. The area hosts a rich ecosystem with diverse aquatic plants and animals and serves as a new recreational and exercise destination in Sakon Nakhon Province.

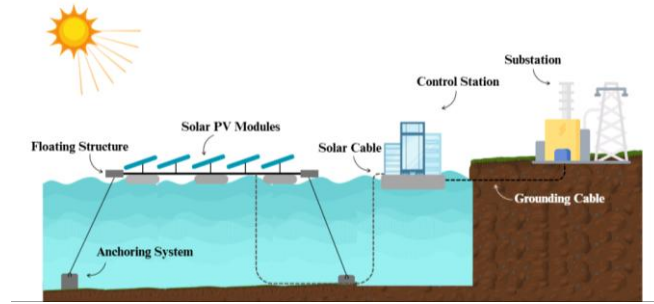


**Figure 2** Khu Sud, the pilot site for the FPV system design simulation.

## 2.4 Design of the FPV Power Generation System

The primary objectives of the simulated FPV system design were to maximize the use of the water surface area, reduce the use of land space, and enhance the efficiency of electricity production through natural cooling from the water surface. The system design incorporated monocrystalline PERC solar panel modules (Generic Model: LR7-72HYD-650M), featuring a unit nominal power of 650 Wp and a photovoltaic conversion efficiency of 24.11% at STC. A total of 148,212 modules are arranged in 6,444 strings (23 modules in series per string). For power conversion, the system utilized 31 central inverters (Generic Model: SG2500HV), each with a nominal power of 2,500 kWac, or 77,500 kWac total. Additionally, the system included key components such as the AC combiner/transformer station, a real-time monitoring control system via dedicated software, grounding and lightning protection systems, and floating platform structures and anchoring systems designed to accommodate seasonal water level fluctuations and wind forces over the large water surface area.

To improve simulation transparency, specific loss parameters were defined in PVsyst. Thermal loss factors were set with a constant  $U_c$  of 18.0 W/m<sup>2</sup>K and a wind-dependent  $U_v$  of 1.2 W/m<sup>2</sup>K/m/s, reflecting the cooling effect of the water surface. Other technical assumptions included soiling losses (3.0%), module mismatch (2.0%), DC wiring losses (1.5%), and AC wiring losses (3.81%). The incidence angle modifier utilized the Fresnel smooth glass model ( $n = 1.526$ ), and system unavailability was accounted for at 2.0% (approximately 7.3 days per year).



**Figure 3** Floating solar photovoltaic (FPV) system structure

## 2.5 Economic Analysis

The simulated energy production data from PVsyst were used to conduct an economic feasibility analysis of the FPV system, based on a project lifetime of 25 years. To ensure transparency and reproducibility, key economic parameters were defined, including a discount rate of 7%, an annual electricity price escalation rate of 2%, and a system degradation rate of 0.5% per year. These assumptions formed the basis for calculating key financial indicators, including the payback period, the internal rate of return (IRR), and the LCOE.

The payback period is used to assess the rate at which the initial investment in the project will be recovered, and can be calculated using Equation (1) [19]:

$$\text{Payback period} = \frac{\text{Cost of Investment}}{\text{Average Annual Cash Flow}} \quad (1)$$

Where:

$\text{Cost of Investment}$  = Initial investment cost

$\text{Average Annual Cash Flow}$  = Average annual net cash inflow from the project

The IRR is used to evaluate the financial viability of an investment project. If the IRR is higher than the required rate of return or the cost of capital, the project is considered financially attractive. It can be calculated using Equation (2) [20]:

$$NPV = \sum_{t=0}^n \frac{C_t}{(1+IRR)^t} = 0 \quad (2)$$

Where:

$C_t$  = Net cash flow in year  $t$

$IRR$  = Required internal rate of return to be determined

$T$  = Year of cash flow  $t$

$n$  = Project lifetime in years

The LCOE is used to assess the economic viability of solar photovoltaic power generation systems. It is calculated by dividing the total cost of the project, including initial investment and maintenance expenses, by the total electricity generated over the project's lifetime, as shown in Equation (3) [21]:

$$LCOE = \frac{CAPEX + \sum_{t=1}^n O\&M_t}{\sum_{t=1}^n E_t} \quad (3)$$

Where:

$CAPEX$  = Initial project cost (THB)

$O\&M$  = Annual operation and maintenance cost (THB/year)

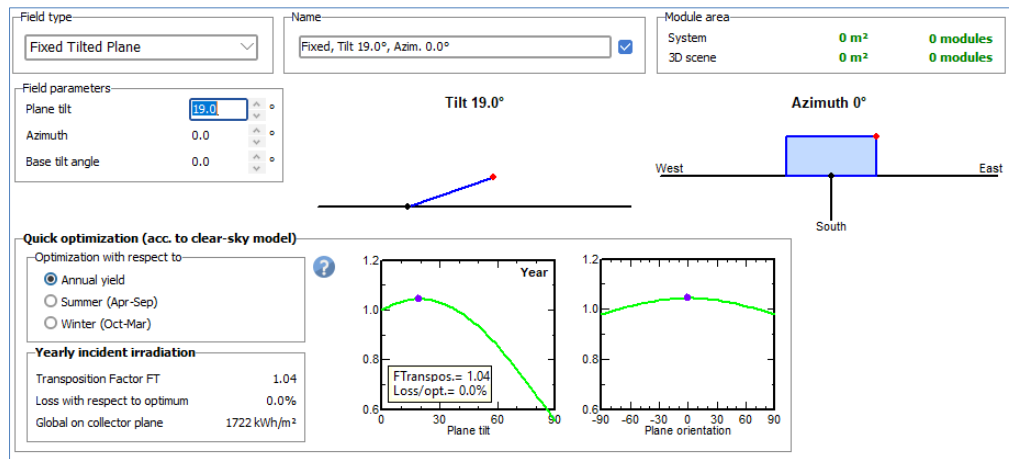
$E_t$  = Electricity generated in year  $t$  (kWh)

$n$  = Project lifetime (years)

### 3. Results and Discussion

#### 3.1 Energy Production Analysis

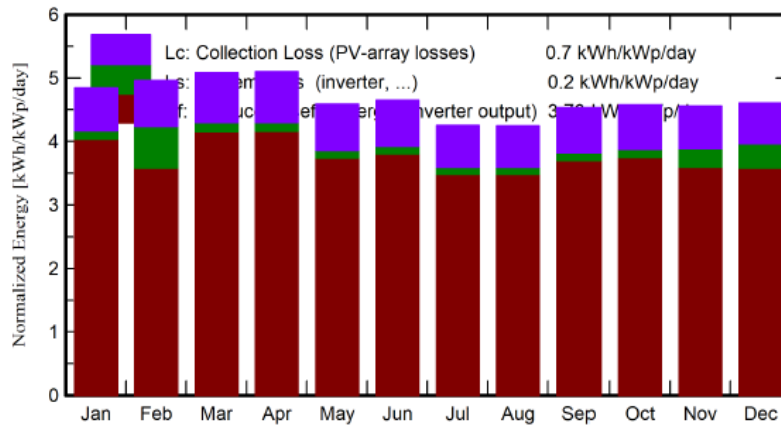
In the FPV system simulation for Nong Han Lake, the solar panels were set to face south, with a tilt angle of 19 degrees, which is optimal for maximizing solar irradiance in this region. The distance between the solar panels and the inverter was set to approximately 150 meters, and the connection distance to the grid system did not exceed 500 meters. The constant loss factor ( $U_c$ ) was set at approximately  $18 \text{ W/m}^2\cdot\text{K}$ , and the loss factor ( $U_v$ ) was  $1.2 \text{ W/m}^2\cdot\text{K}/(\text{m/s})$ . Under the conditions outlined in Section 2.4, the simulated system can achieve a maximum annual energy yield of  $1,722 \text{ kWh/m}^2$ , as shown in Figure 4.



**Figure 4** Suitability analysis for installing a floating solar photovoltaic (FPV) system, using PVsyst software.

According to a study by Sukarso and Kim [21] comparing the performance and economic feasibility of FPV systems with ground-mounted photovoltaic systems in West Java Province, Indonesia, since the FPV panels are installed above the water surface, wind passing through enhances cooling. The water surface temperature was  $8^\circ\text{C}$  lower than that of the ground, resulting in a 0.61% increase in efficiency and an LCOE that was 3.37 cents per kilowatt-hour lower than ground-mounted systems. Anusuya and Vijayakumar [22] concluded that the decrease in temperature plays a significant role in enhancing the electricity production efficiency of photovoltaic panels. For every  $1^\circ\text{C}$  drop in panel temperature, the system's efficiency increases by approximately 0.4–0.5%. As a result, FPV systems are able to generate about 6–7% more electricity compared to ground-mounted systems.

Other energy loss factors for the simulation were set according to the program's standard values. Simulation results showed that the system can produce up to 132.25 GWh/year, with a performance ratio of 80.64%. The months with the highest electricity production are March and April, generating more than 12 GWh, while November and December generate approximately 10.4 GWh. The performance ratio of 80.64% and LCOE of 1.40 THB/kWh align with successful FPV benchmarks in Southeast Asia. The 145 MWp Cirata Dam project in Indonesia, for instance, demonstrated the viability of large-scale FPV in natural and managed water bodies, and suggests that the results from Nong Han Lake are consistent with regional performance standards for tropical climates [18,21]



**Figure 5** Normalized productions per installed kWp

### 3.2 Analysis of Losses in Solar Power Generation Systems

Analysis of the simulation results reveals that the system experiences energy losses from several key factors. The most significant loss is thermal loss, accounting for approximately 6.7% of the total energy. Elevated temperatures directly affect the efficiency of photovoltaic panels, as the performance of solar modules decreases with increasing surface temperature. Additionally, soiling loss caused by dust accumulation on the panel surface accounts for about 3.0%, and incidence angle modifier loss due to the angle of sunlight incidence is approximately 2.9%. These external factors can be managed through proper system design and maintenance.

The theoretical maximum energy production of the system is 154.58 GWh/year. However, after accounting for losses, the actual energy delivered to the grid is estimated at 132.25 GWh/year, which corresponds to approximately 85.5% of the ideal energy production under standard conditions. Energy attenuation is a critical issue that requires careful attention in system design, planning, and ongoing maintenance. To mitigate the identified losses, particularly the 3.0% soiling loss, a rigorous bi-monthly or quarterly schedule for panel cleaning is recommended, especially during the dry season when dust accumulation is highest. Furthermore, to optimize the thermal cooling effect, which currently accounts for a 6.7% loss, optimized panel spacing should be implemented to enhance air circulation between the water surface and the modules.

**Table 4** Energy Losses in the Solar Power Generation System

| No. | Loss Type                     | Loss Percentage (% of Total Energy) |
|-----|-------------------------------|-------------------------------------|
| 1   | Thermal Loss                  | 6.7%                                |
| 2   | Soiling Loss                  | 3.0%                                |
| 3   | Incidence Angle Modifier Loss | 2.9%                                |
| 4   | Mismatch Loss                 | 2.2%                                |
| 5   | Ohmic Loss                    | 2.9%                                |
| 6   | System Downtime               | 2.0%                                |
| 7   | Inverter Efficiency Loss      | 1.3%                                |

### 3.3 Economic Feasibility and Cost Analysis

The simulation results from the PVsyst program were paired with cost data and assumed electricity selling prices to determine the LCOE, payback period, and IRR of the FPV system. The simulation FPV system is installed on a water surface area of approximately 80 hectares, with an actual installation area of about 400,000 square meters, supporting a total solar panel capacity of 96.34 MWp. According to the simulation results, the system can generate approximately 132.25 GWh/year, with a performance ratio of 80.64%. Over the 25-year project lifetime, the system is expected to produce more than 3,306 GWh of electricity.

The initial investment cost (CAPEX) was estimated at 3,371.9 million baht, or 35 THB/Wp, with an average annual operation and maintenance cost of about 50.58 million THB/year, equivalent to 1.5% of the initial investment. Considering the electricity selling price under the feed-in tariff (FiT) scheme of approximately 2.20 THB/kWh, the project is expected to generate annual revenue of about 290.95 million baht. After deducting annual operation and maintenance costs, the net annual income is approximately 240.37 million baht.

The calculated LCOE over the project lifetime is approximately 1.40 THB/kWh, which is significantly lower than the FiT selling price, indicating strong economic feasibility. The payback period is about 14 years, which is

within the typical lifespan of solar panels. The IRR calculated from the net cash flow over 25 years ranges from 7.5% to 8.5%, which is considered suitable for investment in large-scale renewable energy projects.

### 3.4 Sensitivity Analysis

To demonstrate the robustness of the economic results, a sensitivity analysis was conducted on two critical factors: CAPEX and the FiT. If CAPEX increases by 10% from the estimated 35 THB/Wp, the payback period extends to approximately 15.5 years, while the IRR remains above the minimum attractive rate. A 10% reduction in the FiT rate significantly impacts the IRR, suggesting that the project's financial viability is highly sensitive to government energy policies and electricity purchase rates. This sensitivity analysis ensures that the proposed FPV system remains a resilient investment under varying economic conditions.

## 4. Conclusion

This simulation conducted in this study confirms that Nong Han Lake represents a high-potential frontier for FPV development in Thailand, distinguished by its status as a large-scale natural freshwater ecosystem. The research demonstrates that FPV systems can be integrated into rural landscapes without disrupting traditional livelihoods, such as agriculture or local fisheries, provided that installation is restricted to shallow floodplain areas away from designated aquatic conservation zones.

To ensure long-term operational efficiency and maximize the technical benefits of the water's cooling effect, a systematic cleaning schedule is essential to mitigate soiling losses, alongside optimized module spacing to enhance air circulation and further reduce thermal losses. Local authorities should consider this FPV model as a strategic policy guideline for decentralized renewable energy development that preserves land resources.

Future studies should focus on long-term ecological monitoring to assess the specific impacts of reduced sunlight on aquatic biodiversity and photosynthesis within natural lake environments. Additionally, exploring community-led management models and conducting more extensive sensitivity analyses for fluctuating energy policies would further strengthen the project's socio-economic relevance

## 5. Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, the authors used ChatGPT (developed by OpenAI) to assist with preliminary content structuring and refinement of language in selected sections. After using the tool, the authors thoroughly reviewed and edited the content as necessary and bear full responsibility for the final content of the publication.

## 6. Acknowledgements

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## 7. Author Contributions

Conceptualization: R.P., N.P.; Methodology: R.P.; Software: R.P.; Validation: N.P.; Formal Analysis: R.P.; Investigation: R.P.; Data Curation: R.P.; Writing – Original Draft: R.P.; Writing – Review & Editing: N.P.; Visualization: R.P.; Supervision: N.P.; Project Administration: N.P.; Funding Acquisition: N.P.

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