

Modeling of a Grid-Connected Solar Photovoltaic Power Generation System for Thailand

Sujinna Karnasuta¹ and Chriss Allen Uptegrove²

Received: June 12, 2026; Revised: June 18, 2026;

Accepted: June 27, 2026; Published: June 30, 2026

Abstract

The creation of a 3D Solar System Simulation Model for the buildings and surrounding areas of Mission Hospital Phuket was conducted using PVSyst Photovoltaic Software Version 7.3.1 to design and simulate the performance and energy losses of the solar photovoltaic system. The research methodology involved data collection and analysis to simulate system performance through four main steps: (1) collection of meteorological and site-specific data; (2) configuration of system parameters; (3) simulation and energy production analysis under the Grid-Connected System mode; and (4) technical evaluation aimed at maximizing installation and operational efficiency. The study reveals that the annual electricity production simulation results are as follows: (1) Produced Energy: 329,664 kWh/year (kilowatt-hours per year) (2) Specific Production: 1,475 kWh/kWp/year (annual energy yield per kilowatt-peak of installed capacity) (3) Performance Ratio (PR): 78.56% (4) PV Field Orientation: Fixed planes configured across 4 distinct directions (5) Horizon: Free Horizon, indicating no landscape obstacles to obstruct horizontal sunlight (6) Sheds Configuration: Comprises 352 rows of identical solar PV modules with identical electrical specifications (7) Models Used: Transposition (Radiation Calculation): Perez Model; Diffuse Sky Radiation: Perez, Meteornorm separate model; Circumsolar Radiation: Meteornorm separate model (8) Near Shadings: Evaluated using the Linear Shadings calculation method (9) User's Needs: Configured as an "Unlimited load (grid)," denoting a grid-connected system with continuous grid backup. Ultimately, the findings of this research serve as a practical guideline for assessing the actual feasibility of solar power system installations within the Thai context.

Keywords: Modeling, Solar Photovoltaic, Power Generation System, Grid-Connected System

¹*Faculty of Environment, Kasetsart University*

²*Agricultural Training and Development Centre*

(Wat Yansangvararam Woramahaviharn) Under His Majesty the King Initiative

*Corresponding Author: sujinna.k@ku.th

Introduction

The demand for electricity in Thailand has been continuously increasing, prompting both the public and private sectors to turn their attention toward renewable energy to enhance energy security and mitigate environmental impacts. Solar Photovoltaic (PV) energy, in particular, stands out as a clean and sustainable resource. Consequently, assessing the efficiency and cost-effectiveness of a PV system is a crucial prerequisite before actual installation to ensure that the project will be financially viable and highly productive under Thailand's specific climatic and geographical conditions (Uptegrove Chriss Allen, 2025). Currently, the analysis of solar energy installations incorporates spatial and environmental factors, aligned with the organization's electrical consumption, through the use of the PVsyst modeling and simulation program for various installation configurations.

A study on a 3-kW rooftop PV system installed in Phatthalung Province, which utilized the PVsyst program to simulate electricity yield, revealed that the average daily "array yield" exceeded 5.0 kWh/kWp/day (during March–June) and was estimated at 4.855 MWh/year. The system achieved an average annual Performance Ratio (PR) of 81.1%, while the efficiency of the polycrystalline silicon panels stood at 15.46% when utilizing only a 3.0-kW inverter. This demonstrates that climatic conditions and module design significantly influence electricity yield (Pholnak et al., 2017).

Another study involved designing a grid-connected rooftop PV system for the Mae Moh Subdistrict Municipality in Lampang Province, utilizing a roof area of 704 square meters. The system's performance was simulated using PVsyst

7.1 based on the municipality's actual historical load data from the previous year. The simulation results showed an annual electricity yield of 152.12 megawatt-hours (MWh) and an average "system performance" (Performance Ratio) of 0.711. In terms of economic viability, the analysis yielded a Return on Investment (ROI) as high as 164.30% and a payback period of approximately 8.3 years, along with a greenhouse gas emission reduction of about 91.06 tons of CO₂-eq per year. This indicates that implementing rooftop PV systems for local government organizations is practically feasible and highly cost-effective (Thipsupawong et al., 2022).

Utilizing an open area of over 420,000 square meters to install a solar photovoltaic system was analyzed through PV system simulation using the PVsyst 7.1 program. This expanded the research scope to a broader spatial level, based on a case study on the spatial feasibility of solar PV system installation in Mae Moh District, Lampang Province. The results indicated that the area could generate an average annual electricity yield of 815.2 megawatt-hours per year (MWh/yr), with a rapid payback period of only 3.63 years and an ROI as high as 311.97%. This case study demonstrates high potential for large-scale renewable energy projects (Wongpanyo et al., 2024).

The installation of floating solar (floating PV) systems was also investigated in a study titled "Simulations of floating solar cell system in Bang Pra basin Chonburi province." By simulating a 1 MW (1,000 kW) capacity system using PVsyst, the study found that lake areas and water resources in eastern Thailand possess high potential for this type of PV installation. This is particularly evident when considering the cooling effect on module temperature and the productive utilization of

vacant spaces, installed without causing negative impacts on the natural aquatic ecosystem (Jakpattanajit, 2020).

In the context of public transportation infrastructure, the study Assessment of the Technical Performance and Investment Economics of the Photovoltaic Rooftop of the BTS Sky Train Station assessed rooftop PV systems installed at BTS stations. Results indicated a specific energy of 1,380 kWh/kWp and a performance ratio of 77.2% (Praphitthar & Sirisamphanwong, 2020),

The process of a solar cell involves generating electricity from light. The secret behind this process lies in the use of semiconductors that can be adapted to release electrical charges, which are negatively charged particles that form the basis of electricity. The most commonly used semiconductor in solar cells is silicon; an element abundantly found in sand. Every solar cell consists of two layers of this semiconductor: one is positively charged, and the other is negatively charged. When light strikes the semiconductor, the electric field passing through the junction where these two layers meet causes the electricity to flow, thereby generating electricity. The stronger the light intensity, the greater the flow of electricity. Consequently, solar cell systems do not solely require bright sunlight to operate; they can also generate electricity on cloudy days in proportion to cloud density. Furthermore, partly cloudy days can yield even higher energy outputs than clear, cloudless days due to the reflection of sunlight off the clouds (Phra Jamlong Philaphan and Pakdee Pusing, 2019)

A study on farm characteristics, rearing costs, and on-farm energy management in Pacific white shrimp (*Litopenaeus vannamei*) farms, along with an incremental financial investment analysis of solar cell implementation categorized by farm

size, collected in-depth data through interviews with a total of 5 respondents. This group included shrimp farmers who had installed solar cells, Department of Fisheries officials, and solar cell suppliers/installers for shrimp farms. Additionally, questionnaires were administered to 150 white shrimp farmers, and the data were analyzed using descriptive statistics, cost-benefit analysis, and financial investment metrics. The findings revealed that the characteristics of the white shrimp farms were as follows: small-scale farmers had an average pond size of 3.14 rai, medium-scale farms averaged 4.07 rai, and large-scale farms averaged 5.48 rai, with a rearing frequency of 2–3 cycles per year. The majority utilized intensive farming practices certified under the Department of Fisheries' GAP standard. Energy consumption for farming management was primarily driven by operating paddlewheel aerators, air injectors, and farm lighting systems, relying chiefly on electricity followed by fuel oil. Furthermore, the incremental financial investment analysis of solar cell adoption categorized by farm size showed that small, medium, and large farms—with electricity generation capacities of 1,100.00, 2,200.00, and 4,400.00 watts, respectively—yielded a Net Present Value (NPV) of 34,878.34, 114,837.41, and 260,315.20 Baht. The Benefit-Cost Ratio (BCR) stood at 1.63, 2.58, and 2.96; the Internal Rate of Return (IRR) was 9%, 17%, and 19%; and the discounted payback period was achieved in years 7.95, 5.2, and 4.95, respectively (Chonticha Thongbuntho et al., 2024).

The break-even analysis for installing solar panels on a multi-family residential building located on Ngamwongwan Road, Nonthaburi District, was conducted by gathering electricity billing data from the Metropolitan Electricity Authority (Nonthaburi district office). The target

building comprised a total of 61 guest rooms, with each room equipped with a 15(45) Ampere electricity meter. Six primary types of electrical appliances were identified: televisions, refrigerators, air conditioners, 36-watt light bulbs, 12-watt light bulbs, and water heaters. Consequently, the break-even calculation for the solar panel installation investment evaluated the feasibility and selected 250-watt solar panels, totaling 156 panels for installation. With a total cost of 1,755,500 Baht, the investment yielded a payback period of 4.80 years, or 4 years, 9 months, and 18 days (Ouaychai Wongrat et al., 2020).

Solar photovoltaic (PV) power generation systems, including both rooftop PV and floating PV, possess high potential for efficient power generation and economic viability under Thailand's climatic conditions, catering to households, corporate sectors, large open areas, and public infrastructure.

The evaluation of solar power installations utilizes PVsyst (PVsyst Photovoltaic Software) to generate a system simulation report. This software serves as an international standard for designing and simulating electricity production from solar PV systems. PVsyst is globally recognized by engineers and solar system designers for its accuracy and reliability in calculating and simulating various system parameters. The software is available in multiple versions to accommodate ongoing database updates for components—such as solar panels and inverters—as well as advancements in calculation algorithms.

Present research thus focuses on studying the technical efficiency and electricity yield of rooftop PV systems under the specific environmental conditions and constraints of Thailand. By relying on PVsyst simulations to obtain precise quantitative data and comparing them with

findings from previous studies, this research serves as a guideline for assessing the actual feasibility of solar power system installations within the Thai context.

Methodology

1. Study Area: The study area is Mission Hospital Phuket in Phuket Province. The solar photovoltaic system evaluated in this research is a Grid-Connected System, which operates in parallel with the main electrical grid. When electricity is generated, it is prioritized for internal consumption within the building. Any surplus electricity can be sold back to the grid, depending on prevailing policies and agreements. Conversely, during periods of insufficient generation or at night, power is drawn normally from the utility grid.

2. Research Tools: The research utilizes PVsyst Photovoltaic Software Version 7.3.1 to generate a system simulation report for the design and simulation of electricity production from the solar PV system.

3. Data Collection for Performance Simulation: Data collection was conducted to simulate the performance of the grid-connected solar PV system using the PVsyst program. This simulation aims to evaluate the generated electrical energy, system efficiency, and energy losses across various system components. The operational procedure is divided into four main steps:

3.1 Collection of Meteorological and Site Data: Meteorological parameters, including Global Horizontal Irradiance (GHI), ambient temperature, wind speed, and geographical data, were obtained from standard meteorological databases embedded within the PVsyst software and cross-verified with local weather station record Geographical

coordinates, roof slope/tilt, and shading distances were acquired through field surveys and satellite imagery.

3.2 Solar Photovoltaic System Configuration: Within the PVsyst software, the system configuration was defined based on key components. This includes the solar PV module type (e.g., monocrystalline), the system's installed capacity (e.g., 3–5 kWp), the number of modules along with their series-parallel string configuration, the tilt angle, and the azimuth orientation. It also incorporates the inverter model, equipment efficiency, loss factors (such as soiling loss, mismatch loss, and wiring loss), and 3D shading scene creation via the Near Shading function. These parameters were set in accordance with PV system design standards and the specific climatic conditions of the study area.

3.3 Simulation and Energy Production Analysis: The simulation process was executed in the Grid-Connected System mode. PVsyst calculates hourly energy production throughout a full-year data cycle. The performance indicators obtained from the simulation include Annual Energy Production, Specific Yield (kWh/kWp/year), Performance Ratio (PR), categorized energy loss (such as thermal loss and ohmic loss), and the net Energy Injected to the Grid.

3.4 Technical Evaluation: The simulation results were analyzed to achieve several key objectives: assessing the system's power generation potential, identifying factors contributing to energy losses, evaluating the suitability of the tilt angle, installation orientation, and system sizing, and benchmarking the yield values against PV system standards in tropical climates. These outcomes facilitate optimal system design and installation planning for maximum efficiency

Results

The 3D Simulation Solar System Model for Mission Hospital Phuket involves creating a 3D digital twin of the buildings and their surrounding areas to achieve high simulation accuracy. This is particularly crucial for calculating shading impacts caused by building structures, trees, or adjacent objects that might obstruct the solar PV panels at different times of the day and across various seasons.

The solar PV panels are mounted on racking structures (tables/racking) placed on the building roofs, typically on the rooftops. Installed Capacity: The system has a capacity of 224 kilowatts (kWp). This figure represents the total maximum theoretical power output of all installed solar panels under Standard Test Conditions (STC).

Geographical Location: Mission Hospital Phuket, Thailand. This data is critical for the simulation because the PVsyst software utilizes weather and solar radiation data specific to this coordinate—such as solar intensity, temperature, and sunshine hours—to compute annual energy generation. The site's geographical coordinates are Latitude: 7.91° N, Longitude: 98.39° E, Altitude (above sea level): 22 meters, and Time Zone: UTC+7. The meteorological data is sourced from Meeonorm 8.1 (1991–2009), a synthetic climate database used for weather simulation.

System Design and Installation: PV Field Orientation: Utilizes fixed planes configured in 4 distinct orientations, each with varying tilt and azimuth angles.

System Components: Comprises 352 PV modules with a total power capacity of 224 kWp, paired with 4 inverters delivering a combined output of 200 kWac. This results in a DC/AC power ratio (Inverter Sizing Ratio) of 1.118.

User's Needs: Defined as an "Unlimited load (grid)," denoting a system where generated electricity is consumed on-site or fed into the grid, with continuous grid backup.

Annual System Simulation Results:

1. Produced Energy: 329,664 kWh/year (kilowatt-hours per year).

2. Specific Production: 1,475 kWh/kWp/year (annual energy yield per kilowatt-peak of installed capacity), which serves as a metric to benchmark project performance.

3. Performance Ratio (PR): 78.56%. This value reflects the overall system efficiency by comparing the actual energy produced against the theoretical ideal output.

4. PV Field Orientation: Reconfirmed as fixed planes across 4 orientations with distinct tilts and azimuths.

5. Horizon: Defined as a "Free Horizon," indicating no landscape obstacles on the horizon line to obstruct sunlight.

6. Sheds Configuration: Number of sheds: 352 rows, categorized as identical arrays, meaning each row possesses identical specifications.

7. Models Used:

7.1 Transposition (Radiation Calculation): Perez Model, a sophisticated and highly accurate model for computing solar radiation incidents on tilted planes.

7.2 Diffuse: Perez, Meteonorm separate model for calculating diffuse sky radiation.

7.3 Circumsolar: Meteonorm separate model.

8. Near Shadings: Evaluated using the Linear Shadings calculation method.

9. User's Needs: Described as Unlimited load (grid).

Near Shadings Parameters:

The 3D model presents the solar PV modules (colored blue) installed on the roofs of two buildings, referencing the different arrays. The buildings are depicted in grey, showing both the installation structures and adjacent facilities. The coordinate axes define the spatial orientation: Zenith (vertical axis pointing skyward), North-South (vertical alignment axis), and East-West (horizontal alignment axis).

This model simulates shading impacts from nearby structures such as adjacent buildings, chimneys, or architectural features of the host building itself. The software uses this 3D layout to calculate specific energy losses caused by shadows falling onto the solar panels at any given hour of the day and throughout every season of the year. (Figure1)

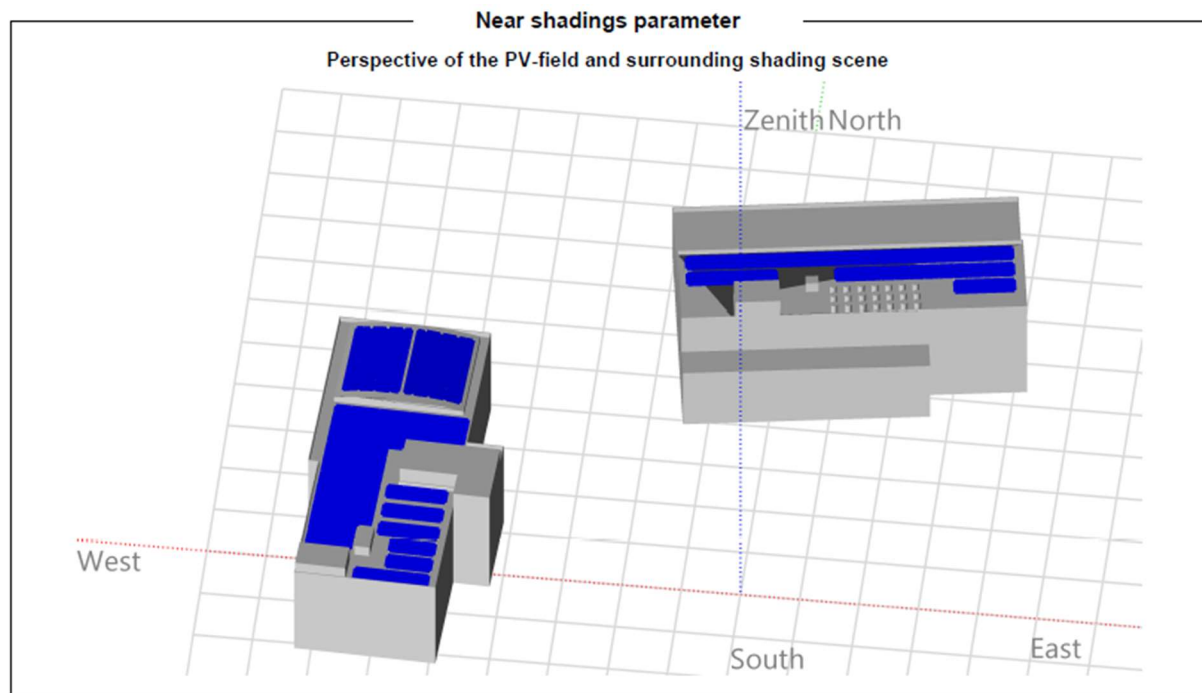


Figure 1: Near Shadings Parameters

Iso-shadings Diagram: This diagram illustrates the shading simulation and its impact on solar panel efficiency, focusing specifically on energy losses caused by shadows from nearby objects, such as buildings. The diagram presents results for two distinct parts based on the system's installation orientation. The core components of the diagram include: **Vertical Axis (Sun height [°]):** Represents the elevation angle of the sun above the horizon (in degrees). **Horizontal Axis (Azimuth [°]):** Represents the sun's azimuth angle relative to True South (0° indicates South, 90° indicates West, and -90° indicates East). **Solid Black Curves (Sun paths):** Represent the sun's trajectory across the sky throughout the day for key dates of the year, as

specified in the legend (e.g., 22 June, 22 May, etc.). **Dashed Black Curves (Shading loss lines):** These lines define the levels of energy loss caused by shadows, ranging from 1%, 3%, 5%, 10%, up to 40%. **Yellow Area (Shaded area):** The region bounded within the dashed lines indicating various loss levels, which represents the portion of the sun's path affected by shading. **Blue Line (Horizon line):** Represents the horizon line from the perspective of the solar PV array. **Attenuation values include:** **Attenuation for diffuse:** Indicates the reduction factor of diffuse sky radiation resulting from nearby shadings. **Albedo:** Indicates the ground reflectance value from surrounding surfaces. (Figure 2)

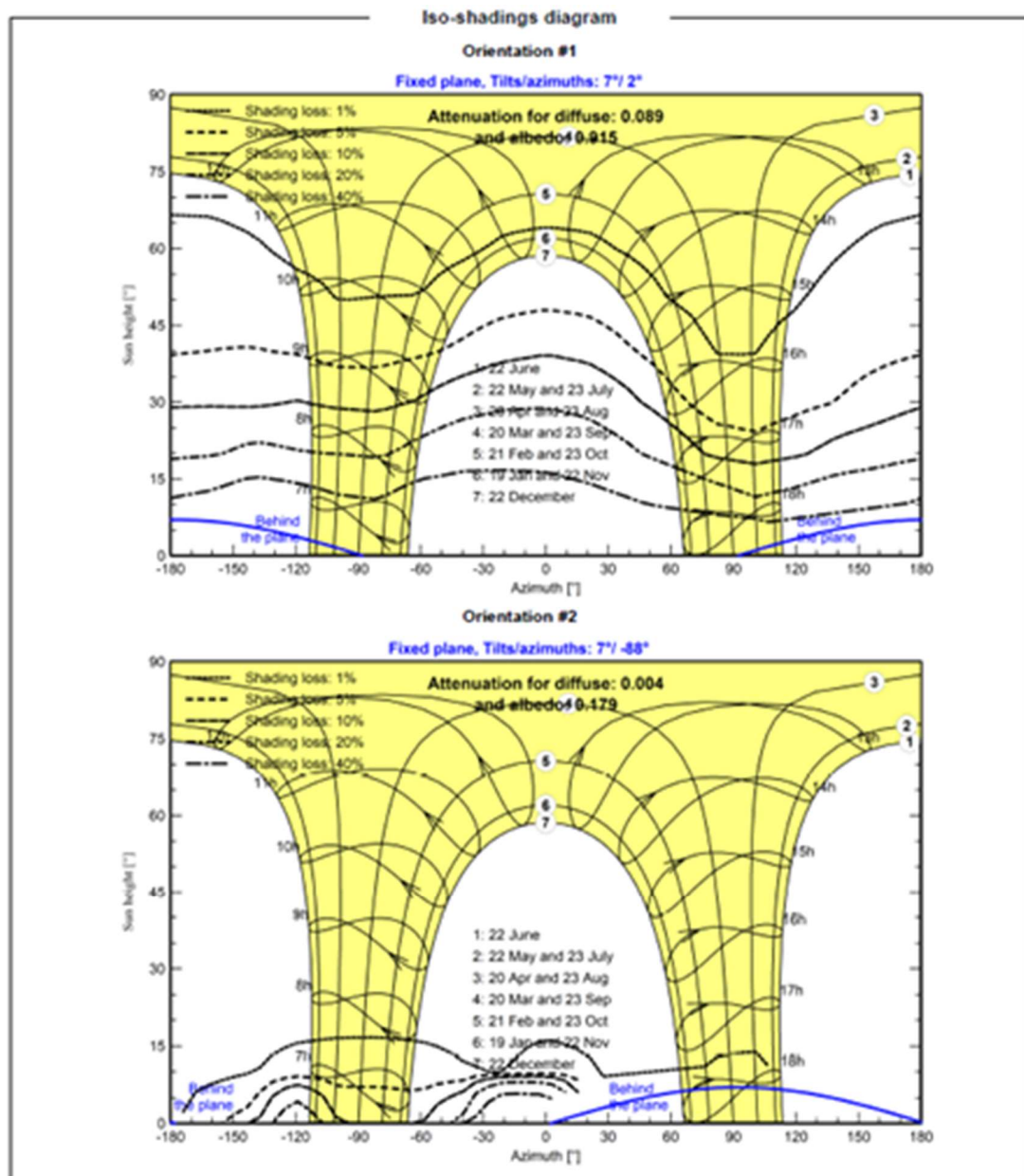


Figure 2: Iso-shadings diagram

Normalized Energy Production is the energy production and losses for each month, normalized to energy generated per day per 1 kWp of installed capacity (kWh/kWp/day). This provides a clear visualization of how the system performs on a daily basis throughout each month. The vertical axis (Y-axis) represents the Normalized Energy in kWh/kWp/day, while the horizontal axis (X-axis) denotes the months of the year (Jan–Dec). The color-coded segments within each bar (from top to

bottom) details the following components:

Purple (Lc: Collection Loss): Represents losses occurring within the PV array field itself (PV array losses). These include temperature-induced losses, soiling or dust accumulation losses on the module surface, and DC wiring losses. The annual average for collection loss stands at 0.9 kWh/kWp/day. Green (Ls: System Loss): Represents losses in other parts of the system outside the PV array, such as the DC-to-AC conversion losses

within the inverter (Inverter Loss). The annual average for system loss stands at 0.2 kWh/kWp/day. Red (Yf: Produced Useful Energy): Represents the actual Alternating Current (AC) electricity generated and ready for consumption after passing through the inverter. This is the "net useful yield" of the system, with an annual average of 4.04 kWh/kWp/day. Graph

Performance Ratio (PR): This graph illustrates the PR values for each month, demonstrating how the system's efficiency fluctuates throughout the year. The vertical axis (Y-axis) represents the Performance Ratio, while the horizontal axis (X-axis) denotes the months of the year (Jan–Dec). The dashed horizontal line represents the annual average useful yield ($\bar{Y}_f$ or reference PR line), which indicates an average annual PR of 0.786 or 78.6% (corresponding

Analysis: The chart indicates that energy production peaks during March and April, which aligns with Thailand's summer season characterized by high solar irradiance. Conversely, power generation drops slightly during the middle of the year (June–September), which can be attributed to the rainy season and increased cloud cover, before rising again toward the end of the year. (Figure 3) directly with the value provided in the Main Results section). Graph Analysis: The chart indicates that the PR is relatively high during cooler months (such as the end and beginning of the year) and drops to its lowest levels during the hottest months (such as March–May). This trend occurs because as ambient and cell temperatures rise, the efficiency of the solar PV panels decreases, which is a standard thermal behavior characteristic of silicon-based modules. (Figure 4)

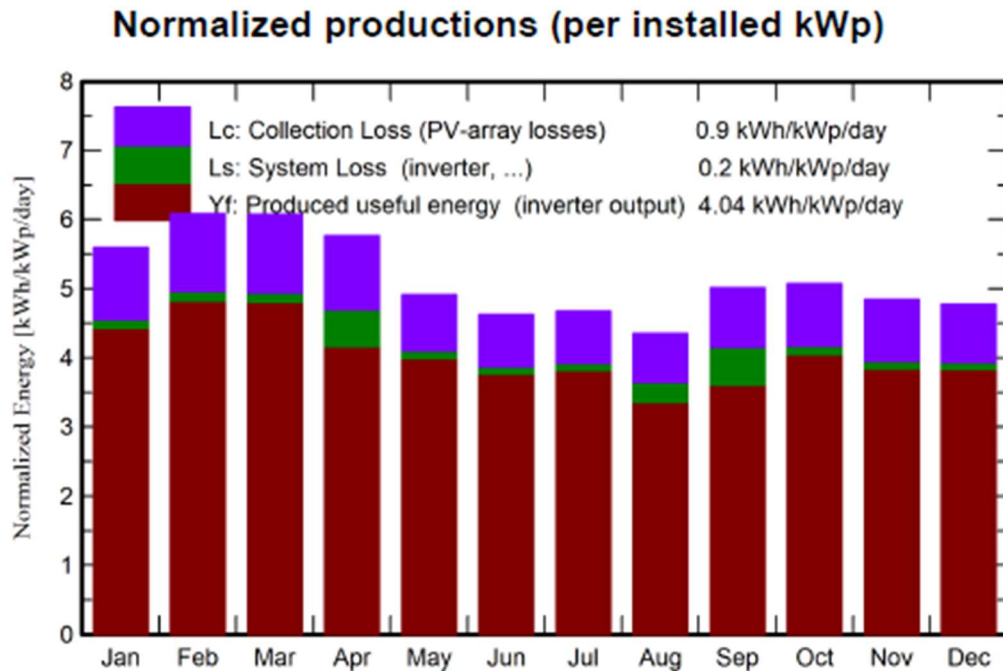


Figure 3: Normalized energy productions

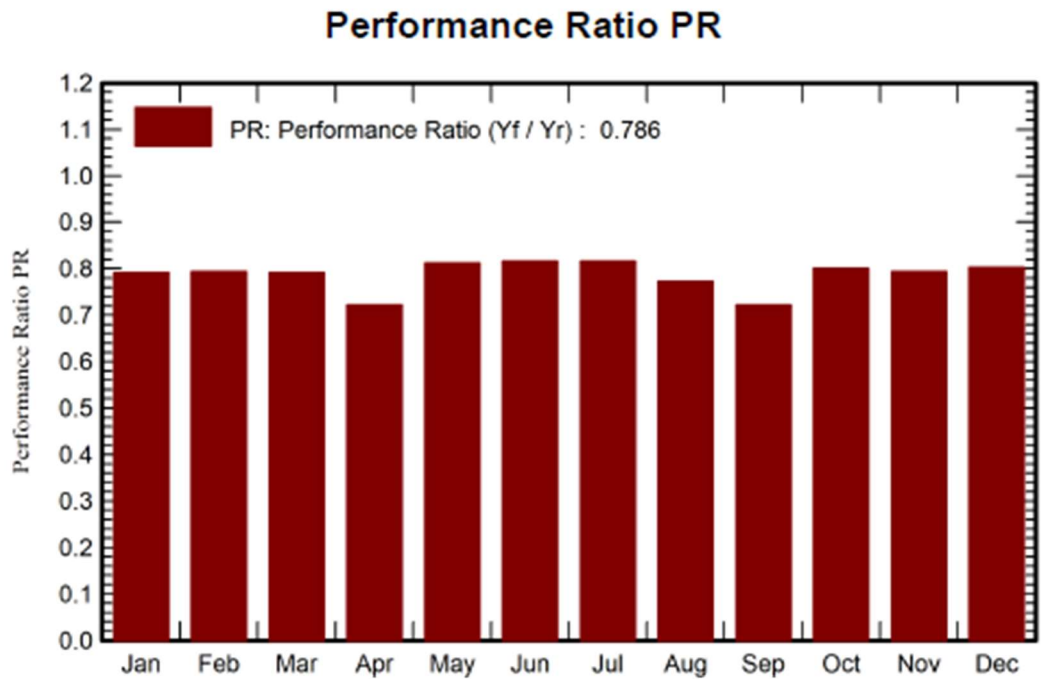


Figure 4: Performance Ratio PR

Balances and Main Results (Solar Radiation Data and Core Parameters) provide detailed raw data and monthly results, which form the foundation of all charts and summaries. The key parameters include: GlobHor (Global Horizontal Irradiance): The total solar radiation incident on a horizontal surface (Unit: kWh/m^2). DiffHor (Horizontal Diffuse Irradiance): The amount of "diffuse" solar radiation (scattered daylight in the sky, excluding direct sunlight) incident on a horizontal surface (Unit: kWh/m^2). T_Amb (Ambient Temperature): The average monthly ambient temperature (Unit: $^{\circ}\text{C}$). The data shows that April experiences the highest average temperature at 29.01°C . GlobInc (Global Incident in Collector Plane): The total solar radiation incident specifically on the tilted plane of the installed solar PV panels (Unit: kWh/m^2). This is the most critical radiation metric since it represents the actual solar energy received by the array. GlobEff (Effective Global Irradiance): The net usable solar

radiation remaining after subtracting optical losses caused by the Incidence Angle Modifier (IAM) and shading effects. E_Array (Effective energy at the output of the array): The total Direct Current (DC) electrical energy generated by the PV array before entering the inverters (Unit: kWh). E_Grid (Energy injected into grid): The net Alternating Current (AC) electricity produced and supplied for consumption (or fed into the utility grid) after inverter conversion and associated system losses (Unit: kWh). The cumulative annual value of 329,664 kWh represents the P50 estimate. PR (Performance Ratio): The monthly performance ratio, calculated by comparing the actual energy generated against the theoretical maximum yield expected from the received solar radiation and system size. Overall Summary from the Table: The tabular data corroborates the trends visualized in the graphs. During March and April, both the solar irradiance and ambient temperature peak, resulting in the highest electricity production. However, the PR

values dropped slightly during this period due to thermal degradation. Conversely, December records the lowest ambient temperature (27.70°C), yielding the highest monthly PR of the year (0.802), despite producing less total energy than the summer months. (Figure 5)

Daily Input/Output Diagram: the daily relationship throughout the year (from 01/01 to 12/31) between the incident solar radiation on the PV array plane (X-axis: Global incident in coll. Plane and the electrical energy injected into the utility grid (Y-axis: Energy injected into grid. The key interpretations of the graph include: **Linear Relationship:** The majority of the data points align in a straight line, demonstrating that as the incident solar energy increases, the electrical energy generated and injected into the grid increases proportionally. **Operational Performance:** The high

density of points along the linear trajectory indicates that the system maintains a high and consistent efficiency in converting solar energy into electricity. **Outliers and Deviations:** Certain data points deviate from the main linear trend, which can be attributed to various factors: Points with low Y-values (near 0): Represent days with very low or no sunlight (where X-axis values are near 0), or days with high solar irradiance but low power output (where X-axis values are high but Y-axis values remain low). The latter scenario typically points to technical issues, such as system shutdowns, grid outages, or scheduled maintenance. **Scattered Y-values:** Represent days with highly volatile weather conditions, such as intermittent cloud cover alternating with bright sunlight, which leads to unstable and fluctuating electricity production throughout the day. (Figure 6)

Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray kWh	E_Grid kWh	PR ratio
January	165.6	64.98	28.04	173.5	163.5	31598	30713	0.792
February	165.1	69.55	29.00	170.4	162.2	31098	30225	0.794
March	186.4	80.12	29.43	188.4	180.2	34298	33333	0.792
April	174.7	73.56	29.18	173.0	165.7	31547	27931	0.722
May	155.7	89.97	29.01	152.4	144.9	28456	27676	0.813
June	142.6	80.79	28.13	138.7	131.6	26030	25314	0.817
July	148.7	88.40	28.50	145.1	137.7	27241	26492	0.817
August	136.9	89.44	28.33	135.0	127.9	25295	23294	0.772
September	150.4	83.62	27.55	150.3	142.9	27870	24239	0.721
October	154.0	74.47	27.64	157.1	149.3	28898	28088	0.800
November	140.0	60.44	27.70	145.3	137.1	26547	25792	0.794
December	141.8	71.95	28.02	148.1	138.8	27320	26567	0.802
Year	1861.8	927.30	28.37	1877.3	1781.7	346198	329664	0.786

Legends

GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings

EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Figure 5: Solar Radiation Data and Core Parameters: raw data and monthly results

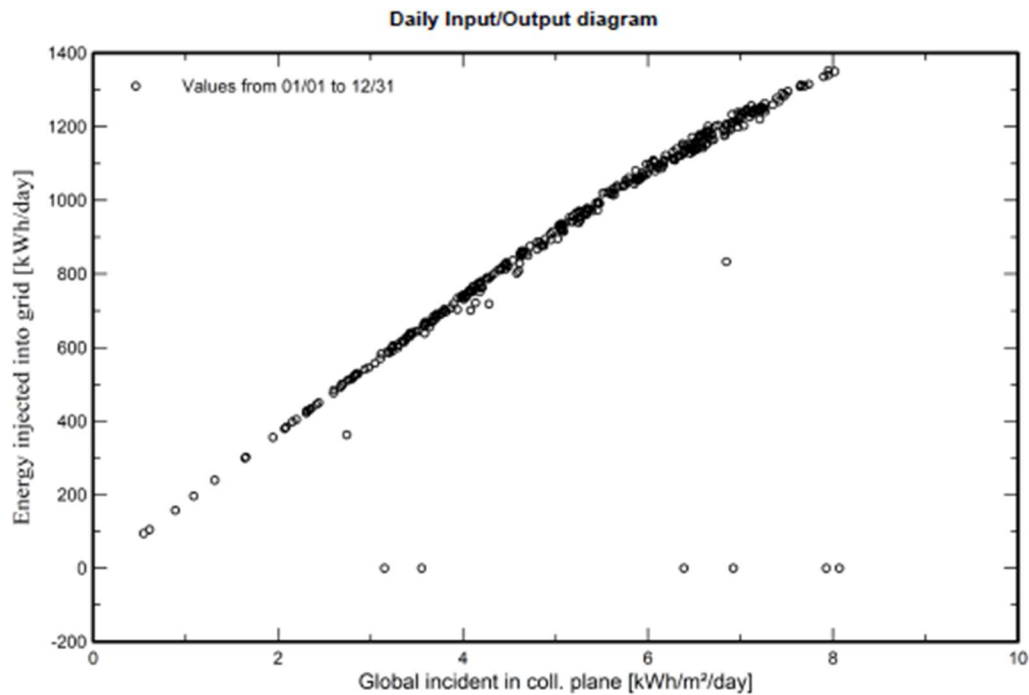


Figure 6: Relationship of the incident solar radiation on the PV array plane

System Output Power Distribution: The chart below is a histogram illustrating the distribution of electrical power injected into the grid (X-axis: Power injected into grid [kW]). The height of each bar (Y-axis: Energy injected into grid [kWh / class of 2 kW]) represents the total amount of energy delivered to the grid at different power output levels. The interpretation of the graph is as follows: (Figure 7)

Peak Power Range: The histogram reaches its peak within the power range of approximately 140–160 kW. This indicates that the system most frequently generates and feeds electrical power into the grid at this specific power level.

Power Distribution: The chart demonstrates that the system is capable of producing power across a wide range of levels, from low power outputs (20 kW) up to the maximum capacity (160 kW). The most prominent production period corresponds to times of high solar irradiance when the system operates at full capacity.

Low Power Range: Energy generation at lower power levels is visible at the lower end of the spectrum on the chart. This represents periods such as sunrise and sunset, or times when sunlight is intermittently obstructed by cloud cover.

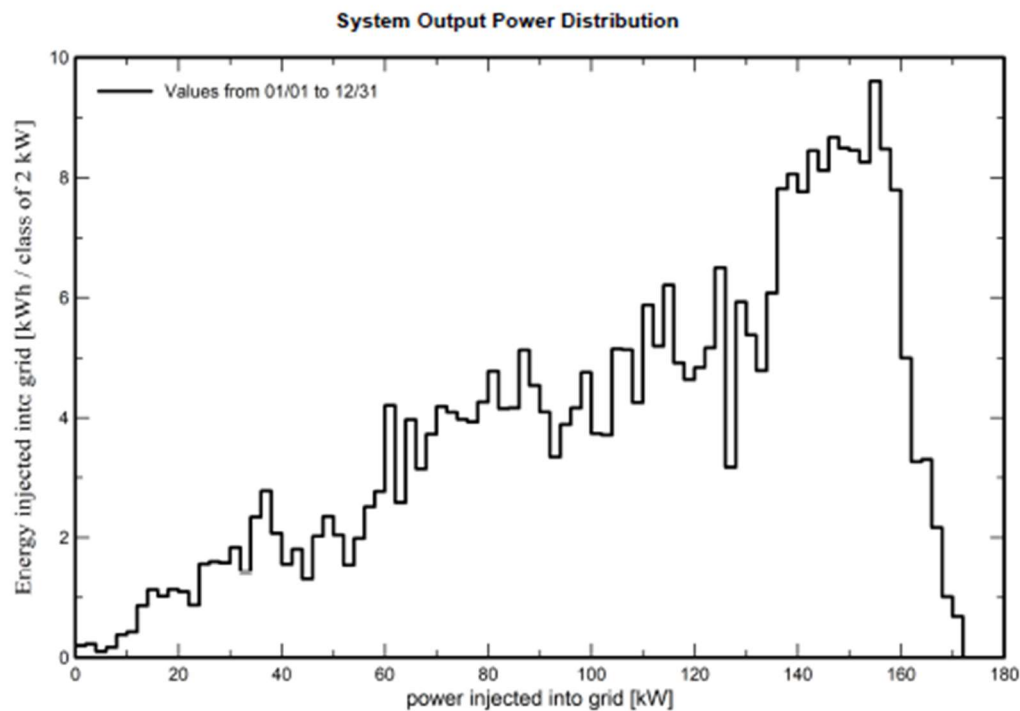


Figure 7: istribution of electrical power injected into the grid

Aging Parameters: This section displays the simulation results for the solar power system's degradation over a 25-year period using the "Aging Tool." The operational parameters utilized in this calculation include. Time span of simulation: 25 years Module average degradation: 0.4% per year
Loss factor: 0% Meteo used in the simulation: "Ban Ku Ku MN81 SYN - 1990" (Synthetic

meteorological data from the year 1990) Years simulated: Years 1, 6, 11, 16, 21, and 25
Mismatch due to degradation: The data on the right indicates the electrical mismatch resulting from degradation for both Current at maximum power and Voltage at maximum power, both of which are specified at 0%. (Figure 8)

Aging Tool			
Aging Parameters			
Time span of simulation	25 years		
Module average degradation	Mismatch due to degradation		
Loss factor	0.4 %/year	Imp RMS dispersion	0 %/year
		Vmp RMS dispersion	0 %/year
Meteo used in the simulation			
#1 Ban Ku Ku MN81 SYN			
Years	1990 (reference year)		
Years simulated	1,6,11,16,21,25		

Figure 8: Solar power system's degradation over a 25-year period

System Output Energy: This parameter represents the annual electrical energy generated by the system throughout its 25-year operational lifespan. The analysis of the graph is detailed below: X-Axis: "Year of operation" indicates the system's operational timeline, ranging from Year 1 to Year 25. Y-Axis: "kWh" represents the volume of electrical energy produced, measured in kilowatt-hours per year. **Main Trend:** The graph exhibits a continuously declining bar chart, demonstrating a year-over-year reduction in energy output. **Degradation:** This decline in energy production is driven by the natural degradation of solar panels (solar panel degradation), a standard phenomenon inherent to all types of photovoltaic modules. As

the panels age, their efficiency in converting sunlight into electricity gradually diminishes. **Actual vs. Estimated Data:** Dark-shaded bars: Represent the actual calculated data obtained directly from the simulation, specifically for Years 1, 6, 11, 16, 21, and 25. Light-shaded bars: Represent the interpolated data utilized to fill in the annual gaps for the years that were not directly simulated. **Energy Yield Values:** Year 1: The initial energy production starts at approximately 329,000 kWh. Year 25: The energy production drops to approximately 301,000 kWh, illustrating a significant reduction in energy output over the 25-year period. (Figure 9)

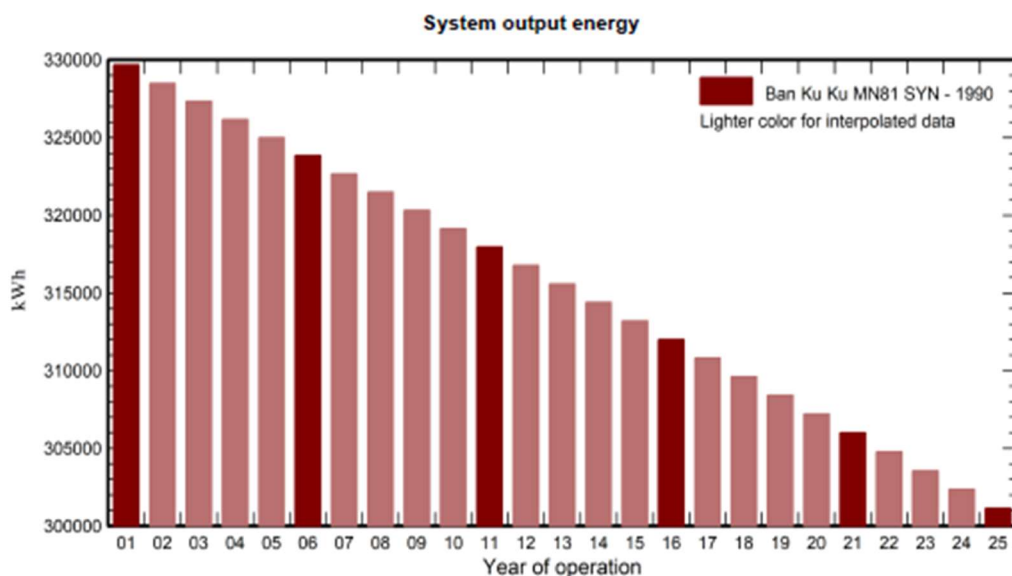


Figure 9: Annual electrical energy generated by the system, 25-year operational lifespan

Performance Ratio (PR) over a 25-Year Operational Lifespan: This section illustrates the long-term degradation of the solar power system relative to its operational timeline. **Graph Analysis:**

X-Axis: "Year of operation" indicates the system's operational timeline, from Year 1 to Year 25. Y-Axis: "PR" (Performance Ratio) represents the

system's overall efficiency index. **Continuous Decline:** The graph shows a uniformly descending bar chart, indicating that the PR values decrease annually, which reflects a degradation of the system's overall efficiency over time. **Degradation:** This reduction is caused by solar module degradation, a normal wear-and-tear process

affecting all electrical equipment. Consequently, the panels generate less energy compared to their baseline capacity as time progresses. Bar Chart Color Coding: Dark-shaded bars: Represent the actual data calculated directly from the simulation (e.g., at Years 1, 6, 11, 16, 21, and 25). Light-shaded bars: Represent the interpolated data used to

complete the timeline for the years that were not directly computed. Initial and Final Values: The PR in the first year (Year 01) begins at approximately 0.78 (or 78%), representing a strong initial performance standard for a solar PV system. The PR by the 25th year declines to approximately 0.715 (or 71.5%). (Figure 10)

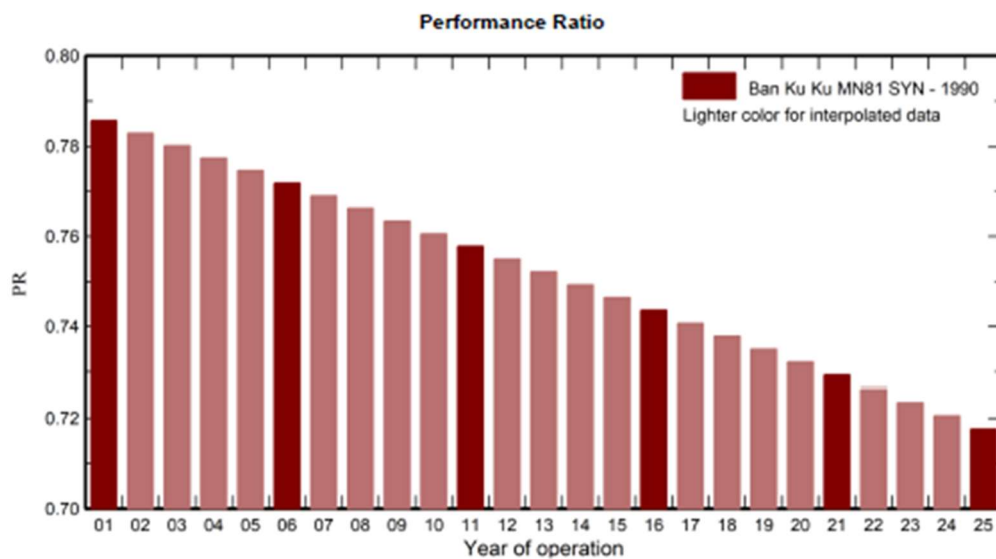


Figure 10: Performance Ratio (PR) over a 25-Year Operational Lifespan

Aging Tool (Solar PV System Degradation Simulation) This report is structured into three main sections: Aging Parameters, Meteorological Data Used in the Simulation, and the Annual Simulation Results Table (Ban Ku Ku MN81 SYN). (Figure11)

Aging Parameters, this section defines the configuration for the system's performance degradation over the project's entire lifespan. Time span of simulation: 25 years – Indicates that this simulation forecasts the operational performance of the solar PV system over a 25-year period, which represents the standard industry lifespan for conventional solar panels. Module average degradation: 0.4 %/year – This is one of the most critical parameters, specifying that the efficiency of

the solar panels will decline at an annual average rate of 0.4% relative to the previous year. This degradation is a natural physical process inherent to photovoltaic materials. Loss factor: No specific value is defined; however, this parameter is typically adjusted to account for site-specific degradation conditions. Mismatch due to degradation: 0 %/year – Within a solar PV system, individual modules do not degrade at an identical rate, which usually leads to a specific power loss known as "Mismatch Loss." In this simulation, this value is set to 0% per year, assuming that all modules degrade at an identical rate for computational simplicity.

Aging Tool

Aging Parameters

Time span of simulation 25 years

Module average degradation

Loss factor 0.4 %/year

Mismatch due to degradation

Imp RMS dispersion 0 %/year

Vmp RMS dispersion 0 %/year

Meteo used in the simulation

#1 Ban Ku Ku MN81 SYN

Years 1990 (reference year)

Years simulated 1,6,11,16,21,25

Ban Ku Ku MN81 SYN

Year	System output	PR	PR loss
	kWh		%
1	329664	0.786	0%
2	328501	0.783	-0.4%
3	327338	0.78	-0.7%
4	326175	0.777	-1.1%
5	325012	0.775	-1.4%
6	323850	0.772	-1.8%
7	322672	0.769	-2.1%
8	321495	0.766	-2.5%
9	320318	0.763	-2.8%
10	319141	0.761	-3.2%
11	317963	0.758	-3.5%
12	316773	0.755	-3.9%
13	315583	0.752	-4.3%
14	314392	0.749	-4.6%
15	313202	0.746	-5%
16	312012	0.744	-5.4%
17	310809	0.741	-5.7%
18	309605	0.738	-6.1%
19	308402	0.735	-6.4%
20	307198	0.732	-6.8%
21	305995	0.729	-7.2%
22	304780	0.726	-7.5%
23	303564	0.723	-7.9%
24	302349	0.721	-8.3%
25	301134	0.718	-8.7%

Figure 11: Aging Tool of Solar system

Meteo used in the simulation (Meteorological Data Used in the Simulation), This section outlines the weather dataset utilized as the baseline for calculating the generated energy. The details are as follows: 1 Ban Ku Ku MN81 SYN: The name of the meteorological dataset for the project's installation site ("Ban Ku Ku"). 1990 (reference year): Indicates that the weather data used to simulate the first year of operation (Year 1) is derived from historical data from the calendar year 1990. Years simulated: 1, 6, 16, 21, 25: Indicates that instead of performing detailed computations for every single year, the system executes a full simulation for key milestone years (Years 1, 6, 11, 16, 21, and 25). The values for the

intermediate years are then interpolated to reduce processing time. Simulation Results (Ban Ku Ku MN81 SYN). This table displays the performance forecast for the system for each consecutive year across the 25-year timeline. Year: Represents the chronological year of operation, from Year 1 to Year 25. System output (kWh): Represents the cumulative annual electrical energy the solar PV system is projected to generate, measured in kilowatt-hours (kWh). Notably, this value decreases annually; for instance, the output starts at 329,664 kWh in Year 1 and falls to 301,134 kWh by Year 25. This downward trend is a direct consequence of the preconfigured 0.4% annual module average degradation. (Figure12)

PR (Performance Ratio): A metric used to assess the overall efficiency of the solar PV system by comparing the actual energy produced against the theoretical ideal yield (accounting for solar irradiance and temperature, without system losses). A higher PR value (closer to 1 or 100%) indicates superior system performance and minimal losses. It can be observed that the PR begins at 0.786 (or 78.6%) in the first year and continuously declines to 0.718 (or 71.8%) by Year 25, aligning with the reduction in system output and reflecting panel degradation.

PR loss %: Displays the percentage decrease in the PR value relative to the first year (which serves as the 0% baseline).

Example: Year 2 (-0.4%) indicates that the PR value in the second year has decreased by 0.4% compared to Year 1.

By Year 10 (-3.2%), the PR has dropped by 3.2% from the baseline.

By Year 25 (-8.7%), at the project's conclusion, the system's overall efficiency (PR) is projected to experience a total cumulative loss of 8.7% compared to the first year.

Ban Ku Ku MN81 SYN			
Year	System output	PR	PR loss
	kWh		%
1	329664	0.786	0%
2	328501	0.783	-0.4%
3	327338	0.78	-0.7%
4	326175	0.777	-1.1%
5	325012	0.775	-1.4%
6	323850	0.772	-1.8%
7	322672	0.769	-2.1%
8	321495	0.766	-2.5%
9	320318	0.763	-2.8%
10	319141	0.761	-3.2%
11	317963	0.758	-3.5%
12	316773	0.755	-3.9%
13	315583	0.752	-4.3%
14	314392	0.749	-4.6%
15	313202	0.746	-5%
16	312012	0.744	-5.4%
17	310809	0.741	-5.7%
18	309605	0.738	-6.1%
19	308402	0.735	-6.4%
20	307198	0.732	-6.8%
21	305995	0.729	-7.2%
22	304780	0.726	-7.5%
23	303564	0.723	-7.9%
24	302349	0.721	-8.3%
25	301134	0.718	-8.7%

Figure 12: Meteo used in the simulation

Overview Summary: This section provides a long-term performance forecast (25 years) for the "Ban Ku Ku" solar PV project, based on the core assumption that the solar panel efficiency will decrease at an annual average rate of 0.4%. The results demonstrate that both the energy

generation (System output) and the system's overall efficiency (PR) will continuously decline throughout the project's lifespan. By the conclusion of Year 25, the system will generate less energy, and its overall efficiency will drop by approximately 8.7% compared to the first year of operation. These

data are critically important for assessing the project's long-term financial viability and energy production performance. P50-P90 Evaluation (Solar PV System Yield Probability Assessment): The foundational concepts are detailed as follows: P50 (Probable 50%): Represents the forecast energy yield that the system is expected to equal or exceed with a 50% probability; simply put, it is the median or expected average production value. P90 (Probable 90%): Represents the conservative forecast energy yield that the system is expected

to equal or exceed with a 90% probability. P95 (Probable 95%): Represents the highly conservative forecast energy yield that the system is expected to equal or exceed with a 95% probability. PXX (Probable XX%): As the "P" value increases (e.g., P90, P95), the probability of meeting or exceeding that target becomes higher, but the corresponding projected electricity volume becomes lower. This framework is essential for evaluating risk and analyzing worst-case scenarios. (Figure13)

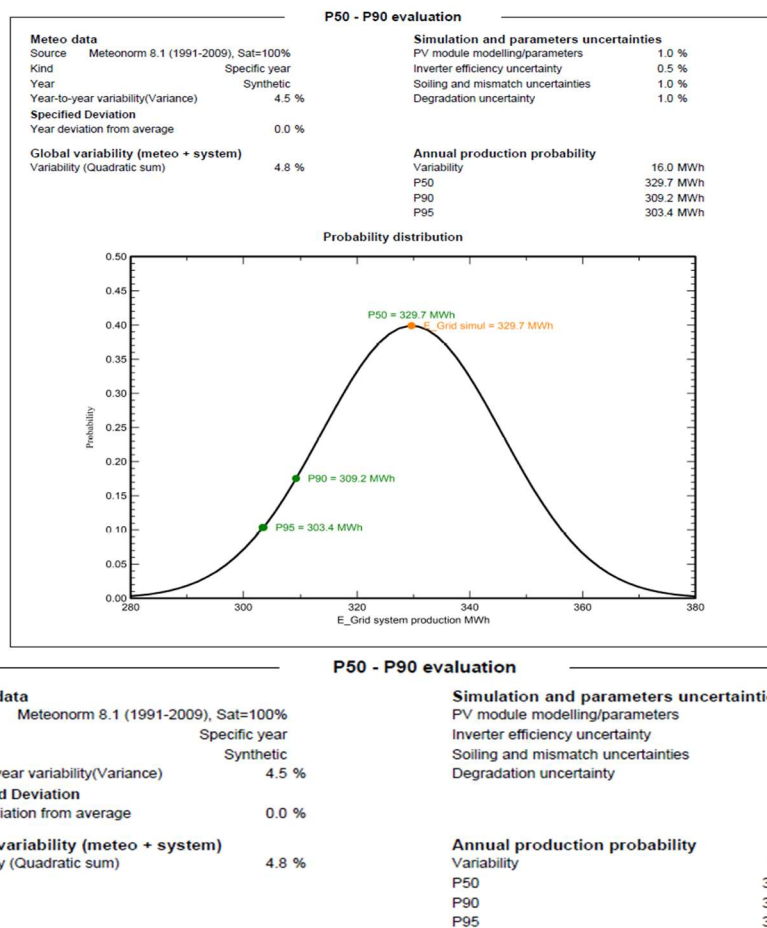


Figure 13: Energy generation decline throughout lifespan of 25 years

Meteorological Data: This section describes the weather data used in the simulation. Source: Meteonorm 8.1 (1991–2009) – This is the climate database utilized, referenced from historical data spanning 1991 to 2009. Kind:

Synthetic – Indicates that the data functions as a "synthetic year," representing the long-term climatic average rather than historical records of any single specific calendar year. Year-to-year variability: 4.5% – This is a highly critical statistical figure, meaning

that the annual solar irradiance fluctuates with a statistical deviation of $\pm 4.5\%$ from the long-term mean. Put simply, some years will be sunnier than average, while others will be cloudier.

Simulation and Parameters Uncertainties: This section itemizes the specific uncertainties (or potential error margins) associated with the simulation model and hardware components:

- PV module modelling/parameters (1.0%):** Uncertainty derived from the solar panel's technical specifications.
- Inverter efficiency uncertainty (0.5%):** Uncertainty regarding the performance and conversion efficiency of the inverters.
- Soiling and mismatch uncertainties (1.0%):** Combined uncertainty arising from dust accumulation and electrical mismatch between modules.
- Degradation uncertainty (1.0%):** Uncertainty surrounding the long-term degradation rate of the panels.

Global Variability (Meteo + System): This parameter integrates all individual fluctuations into a single comprehensive value:

Variability (Quadratic sum): 4.8% – This figure is calculated by mathematically combining the weather variability (4.5%) with all system-related uncertainties listed above using a statistical root-sum-square method (quadratic sum). This 4.8% represents the total uncertainty threshold for the project.

Annual Production Probability: This is the definitive summary and ultimate outcome of the yield assessment:

Variability (16.0 MWh): The 4.8% total global variability translated into electrical energy units (megawatt-hours), calculated as: $329.7 \text{ MWh} \times 4.8\% \approx 16.0 \text{ MWh}$.

P50 = 329.7 MWh: The expected base case (Expected Case). This means there is a 50% probability that the project will generate more than 329.7 MWh per year, and a 50% probability it will generate less. It serves as the standard median value for baseline evaluations.

P90 = 309.2 MWh:

The conservative estimate with high statistical confidence (Conservative Case). This indicates a 90% probability that the project's annual yield will equal or exceed 309.2 MWh, leaving only a 10% probability that production will fall below this line.

Financial institutions and investors heavily rely on this P90 figure to evaluate project revenue stability and risk, as it represents a highly secure threshold.

P95 = 303.4 MWh: A highly risk-averse threshold, indicating a 95% probability that the project's energy yield will exceed this value.

Summary: The project is forecast to generate an expected average of 329.7 MWh per year, with a highly reliable minimum floor production of 309.2 MWh per year.

Probability Distribution Graph:

X-Axis (Horizontal): Represents the cumulative annual electricity generation from the solar PV system (E_{Grid} system production) measured in MWh.

Y-Axis (Vertical): Represents Probability Density.

Key Plots on the Curve:

- Orange Dot:** Represents the P50 value (expected mean production) at 329.7 MWh, where the cumulative probability of meeting or exceeding this yield is exactly 50%.
- Green Dot:** Represents the P90 value at 309.2 MWh, where the cumulative probability of meeting or exceeding this yield is 90%.
- Lower Green Dot:** Represents the P95 value at 303.4 MWh, where the cumulative probability of meeting or exceeding this yield is 95%.

Application and Implementation: The P90 value is predominantly used by investors and financial institutions during underwriting and due diligence for solar energy projects. It offers a more pragmatic, risk-adjusted, and conservative view compared to the optimistic P50 median by accounting for worst-case system uncertainties and weather variables. Structurally, P50 yields the highest energy value, followed by a lower value for

P90, and the lowest for P95. This adheres to the foundational statistical principle: to achieve higher certainty (lower risk), the guaranteed target yield must be adjusted downward. The system is expected to generate an average of 329.7 MWh/year (P50). There is a 90% confidence level

that the system will produce at least 309.2 MWh/year (P90).

There is a 95% confidence level that the system will produce at least 303.4 MWh/year (P95). (Figure 14)

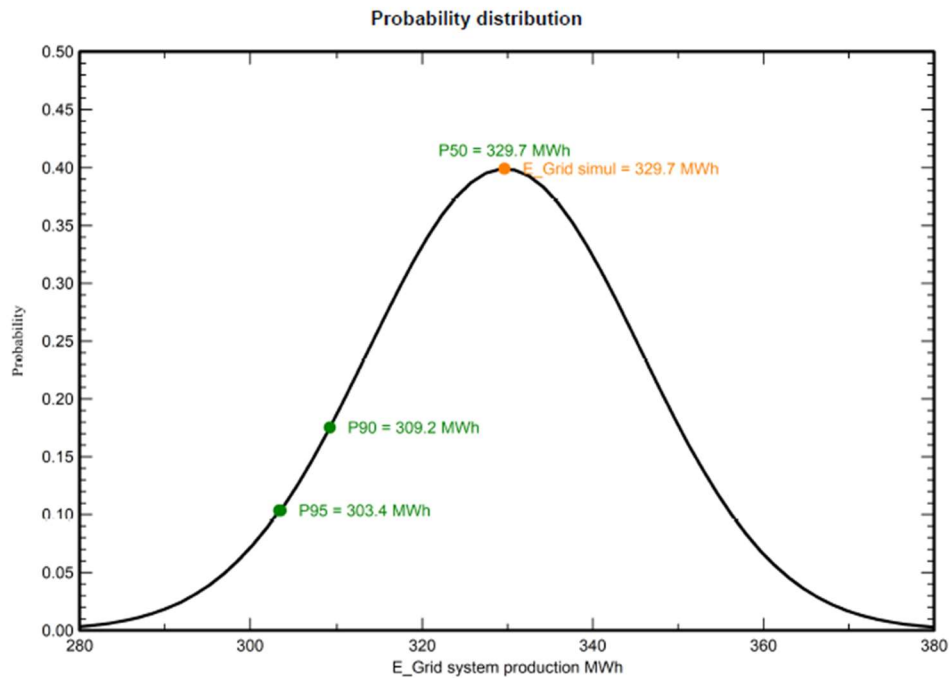


Figure 14: Probability distribution of generation from the solar PV system

Conclusion

The creation of a 3D Solar System Simulation Model for the buildings and surrounding areas of Mission Hospital Phuket was conducted using PVsyst Photovoltaic Software Version 7.3.1. This process involved collecting and simulating meteorological data, site-specific characteristics, and various system parameter inputs. The energy production was subsequently analyzed under the Grid-Connected System configuration, followed by a technical evaluation aimed at maximizing installation and operational efficiency.

The annual electricity production simulation results are summarized as follows: (1)

Produced Energy: 329,664 kWh/year (kilowatt-hours per year). (2) Specific Production: 1,475 kWh/kWp/year (annual energy yield per kilowatt-peak of installed capacity).

Performance Ratio (PR): 78.56%. PV Field Orientation: Fixed planes configured across 4 distinct directions. Horizon: Free Horizon, indicating no surrounding landscape obstacles to obstruct horizontal sunlight. Sheds Configuration: Comprises 352 rows of identical solar PV modules with identical electrical specifications. Models Used: Transposition (Radiation Calculation): Perez Model.

Diffuse Sky Radiation: Perez, Meteonorm separate model. Circumsolar Radiation: Meteonorm

separate model. Near Shadings: Evaluated using the Linear Shadings calculation method. User's Needs: Configured as an "Unlimited load (grid)," denoting a grid-connected system with continuous grid backup. Ultimately, the findings of this research serve as a practical guideline for assessing the actual feasibility of solar power system installations within the Thai context.

Acknowledgement

The research team coordinates their highest gratitude to Mission Hospital Phuket and Empower Green Co., Ltd. for their kind assistance in providing the data and supporting this research study.

Reference

- Chonticha Thongbuntho, Kulapa Kuldilok, and Sansanee Wangvoralak. (2024). Investment Analysis of the Solar Cell for White leg Shrimp Farmers. *Journal of Social Science Panyapat*. 6(1):447-460
- Jakpattanajit, C. (2020). Simulations of floating solar cell system in Bang Pra basin Chonburi province. *Kasetsart Engineering Journal*, 33(109), 1–8.
- Ouaychai Wongrat, Pichat Rattanaboontawee, Sitthut Madee and Adisak Thongchuay. 2020. Thailand Calculation of break-even point for solar panel installation for public buildings Bangkhen Subdistrict, Mueang District, Nonthaburi Province. *Industrial Technology, Faculty of Industrial TechnologyPhranakhon Rajabhat University*.3(1):31-38
- Phra Jamlong Philaphan and Pakdee Pusing. 2019. Solar Cells: Change to Energy. *Journal of Research and Development Institute, Rajabhat Maha Sarakham University*. 6(2):525-536
- Pholnak, C., Waewsak, J., Cheewamongkolkarn, S., & Nutongkaew, P. (2017). Efficiency evaluation of 3 kW photovoltaic rooftop and grid connected system by using PVsyst programmed modeling simulation. *ASEAN Journal of Scientific and Technological Reports*, 20(3), 210–219.
- Praphitthar, T., & Sirisamphanwong, C. (2020). Assessment of the technical performance and investment economics of the photovoltaic rooftop of the BTS Sky Train Station. *Engineering & Technology Horizons*, 32(1), 49–54. *
- Thipsupawong, T., Wongpanyo, W., Wichanpol, B., In-ai, K., & Wongchai, W. (2022). Performance simulation of a grid-connected rooftop photovoltaic system of Mae Moh Subdistrict Municipality, Lampang Province. *Uttaradit Rajabhat University Journal*, 17(1), 81–94. *
- Wongpanyo, W., Kamjainak, P., Wongchai, W., Thongphaen, R., & Thipsupawong, T. (2024). Spatial feasibility study for photovoltaic power system installation: A case study of Mae Moh District, Lampang Province. *CRMA Journal*, 22(1), 131–142. *
- Uptegrove, Chriss Allen. (2025). "Solar Photovoltaic Applications in Residential Buildings and Shrimp Aquaculture Farms in Thailand." *International Journal of Science and Innovative Technology*, 8(2), 20–23