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Original Article

Economic Feasibility Assessment of Solar Photovoltaic Rooftop Installation for Buildings in Northern Thailand

Chatchaphon Ketviriyakit[1], Lakkana Ruekkasaem[2], Keeradit Saipattalung[3*], Pasura Aungkulanon[4]

[1]*Faculty of Industrial Technology, Uttaradit Rajabhat University, Uttaradit, Thailand.*
[2]*Faculty of Science and Technology, Thammasat University, Rangsit Campus, Pathumthani, Thailand.*
[3]*Faculty of Industrial Technology, Phranakhon Rajabhat University, Bangkok, Thailand.*
[4]*Faculty of Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand.*

[*]*Corresponding Author : keeradit@pnru.ac.th*

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Abstract *- Thailand's commitment to renewable energy and reducing carbon emissions has made solar photovoltaic (PV) technology increasingly important, given the country's high solar irradiance and favorable climate. This study examines the economic viability of a 120-kW rooftop PV system for the Uttaradit Teacher Savings and Credit Cooperative building in Northern Thailand. The objectives are to lower energy costs and support Thailand's renewable energy goals. This research assesses the feasibility of the proposed system using financial indicators such as Net Present Value (NPV) and Payback Period, along with an analysis of* CO_2 *emissions reduction across three scenarios: (1) direct calculations using local solar irradiance, (2) energy production simulation with PVsyst software, and (3) comparison with existing PV installations in Uttaradit Province. The findings indicate that the system can generate between 133,793.2 and 190,800 kWh per year, with a payback period of 4.92 to 7.64 years and a positive NPV in all scenarios. The system also has the potential to reduce* CO_2 *emissions by 75.78 to 108.07* tCO_2eq*/year annually. Sensitivity analysis shows the system's resilience to changes in equipment costs, electricity prices, and maintenance expenses, confirming its viability as a sustainable investment. This study highlights the economic and environmental benefits of rooftop PV systems in Thailand's cooperative sector and emphasizes their role in supporting the country's renewable energy transition.*

Keywords *- Solar photovoltaic, Feasibility analysis, Carbon dioxide reduction, Net present value, Payback period.*

1. Introduction

The world's energy consumption remains heavily dependent on fossil fuels for electricity generation due to continual economic and population growth. This has caused severe environmental impacts, particularly greenhouse gas emissions into the planet's atmosphere, which are the main cause of global warming. One way to reduce these impacts is to turn toward using renewable energies such as solar energy, wind energy, and water energy. In addition to reducing greenhouse gas emissions, this will increase sustainable electricity generation capabilities. According to data on Thailand's electricity consumption in 2023, electricity consumption was found to have increased by 3.4%, or a total of 203,923 million units, while electricity consumption in business sectors connected to tourism and services grew by 8.4%, and electricity consumption in hotels increased by 22.5%. Electricity consumption in apartments, guesthouses, department stores, and retail or wholesale businesses increased by 15.0%, 3.7%, 6.9%, and 4.0%, respectively, while household electricity consumption increased by 7.4% and electricity consumption in other sectors increased by 12.7%. On the contrary, electricity consumption in the industrial sector, which has a utilization percentage as high as 42%, declined by 2.6% due to a global economic slowdown, causing export manufacturing to reduce in the first three quarters of 2023. Peak electricity demand occurred on 6 May at 9:41 pm at 34,827 MW, an increase of 5.0% when compared to the previous year. Renewable energy consumption in Thailand continues to grow with support from factors such as government sector support, the development of more effective technology, and heightened environmental awareness.

1. Support from the Government Sector: The Thai government has policies emphasizing renewable energy promotion and reductions to greenhouse gas emissions, such as the Solar PV Rooftop project and community-level or industrial renewable energy power plant projects under the Alternative Energy Development Plan (AEDP).
2. Reduced Energy Costs: The cost of renewable energy technology, such as photovoltaic panels and wind turbines, has significantly declined in the past several years. Photovoltaic panel prices in Thailand dropped by 66%

between 2013 – 2019. This is a key factor enabling growth in solar rooftop installations.

3. Environmental Awareness: People and the industrial sector have become more aware of the importance of reducing carbon dioxide (CO_2) emissions and environmental problems, causing many agencies to turn to renewable energy to reduce environmental impacts.
4. Sustainable Development Goals (SDGs): Sustainable development goals have prompted the government and private sectors to expedite clean energy projects such as wind and solar energy projects in order to reduce dependence on fossil fuels.

Solar PV technology has advanced rapidly in terms of electricity generation efficiency, useful life, and safety standards, making solar PV rooftops more popular while also reducing carbon dioxide emissions from electricity generated by using fossil fuels. Moreover, the 66% reduction in photovoltaic panel prices reduced the payback period of solar rooftop installation from 17-30.3 years in 2013 to 6.1-13.9 years in 2021. The utilization of solar energy for electricity generation in Thailand has been increasingly promoted through national policies. This is evident in the Thailand Power Development Plan (PDP), which serves as the country's long-term master plan for electricity supply to support economic and social development. According to the latest Thailand Power Development Plan 2018-2037 (PDP 2018), a significant target has been set to increase solar power generation capacity to 10,000 MW. This marks a substantial rise compared to the target of 6,000 MW outlined in the previous PDP 2015 (2015-2036).

Uttaradit Province is an area with large solar PV rooftop installation projects such as Toyota Uttaradit Toyota Dealer Company Limited and Uttaradit Rajabhat University. Therefore, the goal of this research is to study the economic feasibility of investment in the solar PV rooftop project for Uttaradit Teacher Savings and Credit Cooperative, Limited, by comparing data in three cases consisting of calculation of electricity generation from photovoltaic panels, simulation with the PVsyst program, and comparisons with installed programs in the area.

The main variables used to assess cost-efficiency consisted of Net Present Value (NPV) and Payback period. The findings will help with the investment decisions of Uttaradit Teacher Savings and Credit Cooperative Limited. This research compares three models to evaluate the feasibility of investing in a solar PV rooftop system. The results provide recommendations and guidelines for the Uttaradit Teacher Savings and Credit Cooperative to make informed decisions about building investments. This study is composed of the following sections: 1) Introduction; 2) Solar Energy Generation Systems; 3) Financial Analysis; 4) Materials and Methods; and 5) Results and Recommendations.

2. Solar Energy Generation Systems

Solar energy generation systems are widely used in diverse forms and are divided into three main categories: on-grid systems, off-grid systems, and hybrid systems. Each system has different special characteristics based on use and technical specifications. On-grid systems are connected to the power transmission cable system. Photovoltaic panels generate Direct Current (DC) electricity transmitted via grid-tie inverters for conversion into Alternating Current (AC) electricity for distribution into home electricity systems. The remaining electricity can be sold back to electricity authorities. Off-grid systems are not connected to power transmission cables or standalone systems. Users can generate and use electricity without being dependent upon electricity authorities.

This type of system is suitable for remote areas without access to electricity, such as mountainous and island areas. Hybrid systems are a mix of on-grid and off-grid systems. Hybrid systems can use electricity from electricity authorities, photovoltaic panels, and batteries. In cases where photovoltaic panels generate excessive electricity, batteries can store electricity for use in periods without sunlight. Although solar energy systems are highly beneficial in clean electricity generation, cost problems were found in previous case studies, particularly from high battery prices, resulting in long payback periods and potential investment cost-inefficiency in some cases. Studies have been conducted on investment in solar energy projects in many countries. For example, a study conducted by Omid Nematollahi and Kyung Chun Kim in South Korea on solar radiation values in various regions of the country found the central and southern regions to have higher capacity for solar energy than the northern regions [1]. In addition, Kassem et al. in Cyprus used RET Screen software to conduct feasibility analyses of 100 MW photovoltaic panels and found the proposed system to be able to generate electricity effectively [2].

In Qatar, Banibaqash et al. studied the feasibility of rooftop PV panel installation for households and organizations by calculating energy generated from photovoltaic panels of different sizes and comparing it with real energy use, finding renewable energy use in this field to have high capacity [3]. In the United Kingdom, Constance and Richards analyzed photovoltaic panel system installation in three-bedroom households and found the payback period for a 4-kW system to be 6-7 years [4].

In Tunisia, S. Farhani et al. studied mixing solar and wind energy in a hybrid system for electricity and hydrogen generation via electrolysis and found the system to be capable of generating hydrogen at a mean of 101.8 kg per day [5]. In Egypt, Mostafa and Aboelezz proposed solar energy use in the industrial sector and found situations with the least environmental impact to have potentially higher costs than other options [6].

A number of relevant studies have been conducted in Thailand. Sopitsuda Tongsopit et al. compared the economics of three potential support schemes for distributed PV self-consumption in Thailand. The PV investment of four customer groups was found to be profitable, with the IRR from 10-17% in the base cases [7]. Suntiti Yoomak et al. concluded that monocrystalline and polycrystalline solar panels can generate nearly the same amount of maximum power. Solar rooftop systems using either type of panel have a payback period of 6.1 years and an internal rate of return (IRR) of 15% [8].

Pathomthat and Atthapol studied the feasibility of photovoltaic panel system installation in buildings in Bangkok and found system installations to help reduce energy consumption in buildings [9], while Krittaphas designed and assessed rooftop photovoltaic panel systems in Rayong Province and found the system to be able to generate 31.49 kWh of electricity per day and reduce carbon dioxide emissions by 643.77 tons over 25 years [10].

Furthermore, Waewsak et al. assessed 1-megawatt rooftop photovoltaic panel systems at Thaksin University, Phattalung Province, and analyzed the effectiveness of technologies and panel angles in energy generation [11].

In addition, Rawait Khamharnphol et al. assessed rooftop photovoltaic panel systems with a capacity of 100 kWh at hospitals in the southern region and found Tha Kuab Thung Hospital to be able to generate electricity with a minimum generation cost of 2.47 baht per kWh [12]. Thanapol Tantisattayakul et al. conducted a feasibility study for the installation of rooftop solar photovoltaic (PV) systems on dormitory buildings at Thammasat University Thailand.

The results show an internal rate of return (IRR) between 15.35% and 18.45% and a payback period of approximately 5-6 years [13]. These studies show the benefit of solar energy in economic and environmental terms, and Thailand still has opportunities for significant growth in solar energy use.

3. Financial Analysis

Investments in solar energy systems, particularly solar PV systems, have garnered significant attention. However, in making decisions to invest in solar energy projects, a thorough financial analysis is required to assess cost-efficiency and Return On Investment (ROI), particularly in the context of the household, industrial, and commercial sectors [14, 15]. Financial analysis is associated with the following factors:

3.1. Investment Cost

The main costs in solar energy system installation consist of photovoltaic panel prices, inverters, batteries (if energy storage systems are installed), installation structures, labor costs, and maintenance expenses. Photovoltaic panel prices have trended downward continually in the past several years, causing overall system installation costs to decline.

3.2. Payback Period

The payback period is time spent to pay back all investments via saved electricity costs or electricity sales into the system. Payback periods can be calculated by comparing the total investment value with expected annual or monthly electricity savings. This calculation helps investors know how long solar energy projects will take to pay back investments spent on installations. The payback period calculation is presented in Equation (1).

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Net\ Cash\ Inflow} \tag{1}$$

3.3. Net Present Value (NPV)

NPV is a financial indicator of investment cost-efficiency with consideration given to monetary value at different times. NPV is calculated from expected future returns deducted from current investment cost. Positive NPV indicates the project is cost-effective in the long term. NPV is an instrument popularly used in project assessments.

An NPV greater than zero indicates that the project has investment cost-efficiency. However, an NPV below zero indicates potential cost-inefficiency in the project, as shown in Equation (2).

$$NPV = \frac{\text{Annual Net Cash Inflow}}{(1+i)^t} - initial\ investment \tag{2}$$

Where:

i = Required return or discount rate

t = Number of time periods

3.4. Sensitivity Analysis

Sensitivity analysis is a financial instrument used in project or investment risk analyses and is performed by testing impacts due to changes in significant variables such as interest rates, income growth rates, or expenses. In sensitivity analysis, each variable is adjusted and analyzed to determine changes in financial outcomes such as net present values or payback periods.

4. Materials and Methods

4.1. Study Area

The main office of Uttaradit Teacher Savings and Credit Cooperative Limited is located at 39, Village No. 5, Ban Koh, Muang, Uttaradit, which is located at latitude 17.596 and longitude 100.092. This cooperative has a total area of 27,200 m^2 and a total usable roof area of 600 m^2.

The Cooperative has over 3,000 members. Due to roof capacity, Uttaradit Teacher Savings and Credit Cooperative, Limited has the opportunity to use solar energy, which, in addition to reducing expenses from using electricity in the grid, can generate supplemental income via electricity sales to the electricity grid, as shown in Figures 1 and 2.

Fig. 1 Top view of location

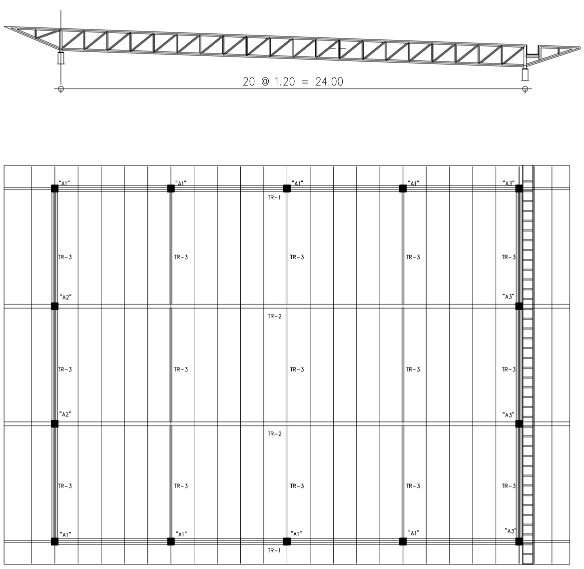

Fig. 2 Installation drawing

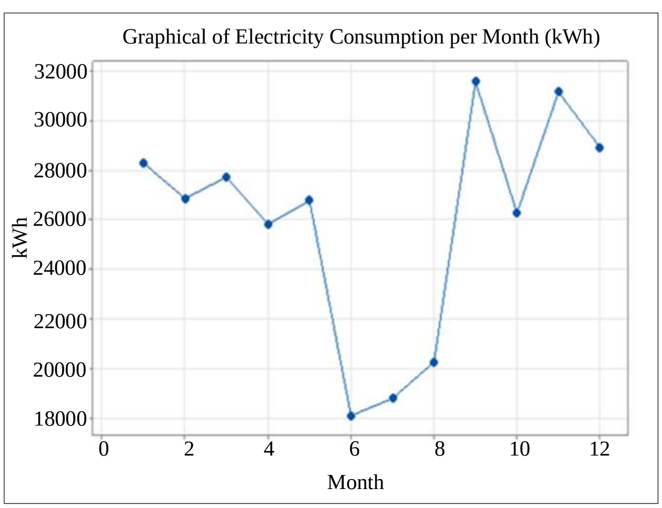

Fig. 3 Electricity consumption per month

4.2. Electricity Generation Information

According to retrospective data concerning electricity consumption from July 2023 to June 2024, electricity consumption was found to have fluctuated seasonally, particularly from March 2024 to June 2024, when Thailand had high temperatures, which raised electricity consumption. The mean electricity consumption per month at the aforementioned time is 240 kWh, as presented in Figure 3. Because the existing rooftop area for solar energy system installation is limited in size, the solar energy electricity generation system design for the aforementioned area must consider these limitations. The analysis found that an installed system with a generation capacity of 120 kWh should be suitable for the roof size of Uttaradit Teacher Savings and Credit Cooperative Limited.

4.3. Solar Energy Electricity Generation System Equipment

In designing a 120-kWh solar energy electricity generation system, the main equipment consists of 216 photovoltaic panels, two on-grid inverters, 216 sets of solar mountings, 2 DC combiner boxes, 2 digital meters, two sets of breakers and fuses, two surge protection devices, cabling, and cost of wiring and installation system, as shown in Figure 4. The single-line diagram of PV modules and solar energy inverters uses monocrystalline PV modules with PV module capacity used in the design of 560 Wp [16]. Both units consist of six sets of parallel strings with 18 sets of PV modules in each string sequentially connected to 60 kW solar energy inverters connected to the main distribution board (MDB) via cables. Both inverters can connect to outside devices via the internet.

The PV inverter specifications are as follows: Model SUN2000-60KTL-M0, manufactured by HUAWEI. The rated AC active power of the HUAWEI inverter is 60 kW, with an MPPT operating voltage range of 200 to 1,000 V. The nominal AC output voltage and current are 400 V and 100 A, respectively. The inverter efficiency is 98.7%. Additional technical specifications for the PV inverter are provided in Table 1, alongside details for the PV modules. The selected photovoltaic module type was chosen based on the energy generated per unit and its surface area ratio (power/surface area: 560 W, P-type mono-crystalline), with a total of 216 units required. Table 1 provides specifications for the 216 PV modules needed to establish the 120-kW station, while Table 2 presents further specifications of the PV panels.

Angle specifications for the photovoltaic panels to receive solar radiation are the major factors affecting effectiveness in generating electricity from solar energy sources [17]. In this study, the angle selected for photovoltaic panel installation was considered by reviewing previous studies concerning suitable position and angle specifications for Thailand, which stated: "the angle at which photovoltaic panels can receive the most sunlight is to face south or Azimuth 0° and by raising the panel to form a tilt angle of 14-16°"[18].

Table 1. Specifications for the PV modules

Manufacturer	HUAWEI
Model	SUN2000-60KTL-M0
Max. Input Voltage	1,100 V
Input Current Per MPPT	22 A
MPPT Operating Voltage Range	200 V to 1,000 V
Efficiency	98.7%
Rated AC Active Power	60 kW
Max AC Output Power	36 kWp
Max. Output Current	100 A
Nominal AC Output Voltage	220V/400 V
Rated Output Frequency	50/60 Hz

Table 2. Specifications for the PV panels

Model	560w P type Mono-crystalline
Type of PV	P type
Maximum Power (Pmax)	560Wp (STC)
Open-circuit Voltage (Voc)	49.82V (STC)
Short-circuit Current (Isc)	14.21A (STC)
Module Efficiency STC (%)	21.68 %
Operating Temperature(°C)	-40°C ~ +85°C
Maximum system voltage	1000/1500VDC (IEC)
No. of cells	144 (6×24)
Weight	28 kg (61.73 lbs)
Junction Box	IP68 Rated

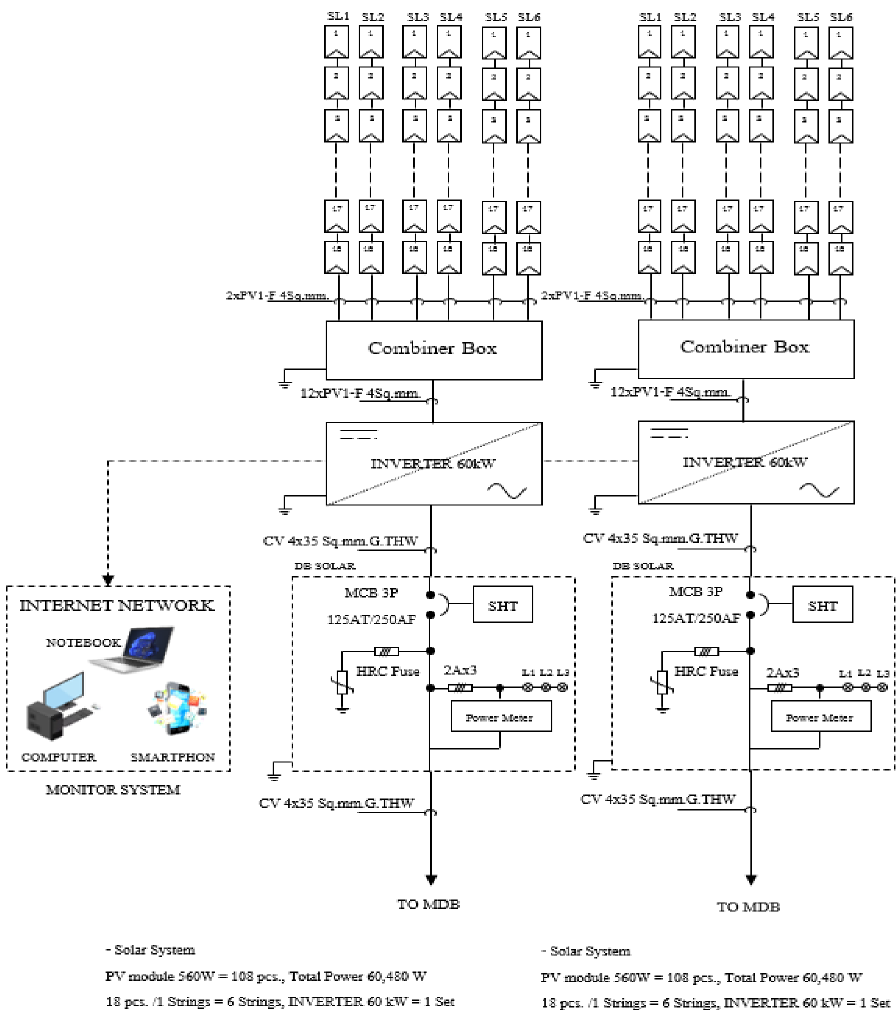

Fig. 4 Electrical wiring diagram of the PV system

This suitable azimuth and tilt angle helps the photovoltaic panels to receive solar energy with full effectiveness throughout the year, particularly in areas with high sunlight intensity. Suitable angles are important in increasing the amount of electricity generated from solar energy while also increasing investment cost-efficiency in renewable energy generation systems [19]. Figure 4 shows a solar energy system frame and information on connections of photovoltaic panels, inverters, junction boxes, checking systems, and the Internet of Things, which provide information on key system components consisting of:

1. Two sets of photovoltaic panels. Each set is divided into multiple strings. These photovoltaic panels are sequentially connected (strings) and fed into junction boxes via 2x(2x4) mm^2 cables.
2. Junction boxes function to collect photovoltaic panel string cables and send signals via 2x(2x4) mm^2 cables to inverters.
3. Two 60 kW inverters are placed behind junction boxes and function to convert Direct Current (DC) electricity generated by photovoltaic panels into Alternating Current (AC) electricity, which can be fed into the grid. Each inverter receives electricity from junction boxes and transmits alternating current electricity via 4x35 mm^2 CV cables.
4. 4.Testing and protection systems. Inverters are connected to the DB SOLAR and SHT system (switch gears or safety switches) and a system for measuring electricity generated by photovoltaic panels.
5. The internet and testing systems are connected to networks with devices such as notebooks, computers, and smartphones for real-time testing. This part shows remote testing systems used to monitor solar power plant efficiency and remotely identify problems or test the effectiveness of the system.
6. Main grid export functions to send generated electricity after electrical meters and switch gears. The system is connected to the Main Distribution Board (MDB). Specific data shows the total energy export from both systems to be 60.4 kW per system (by referring to 15 sets of PV modules per string with a total of 6 strings).

4.4. Method of the Experiment

In this study of solar energy system generation efficiency, the research team divided the study into three models as follows.

Case 1 is a calculation of electricity generation from data on the building's electricity consumption by specifying calculation variables for a 120-kW photovoltaic panel system. Estimates in this case used data on mean sunlight per day, which was approximately six hours. Therefore, a 120-kW solar energy system can generate 720 kWh of electricity per day (120 kW x 6 hours = 720 kWh). When calculated according to the TOU system rate during on-peak times at 5.2 baht per unit, the system was found to be able to save 3,024 baht in electricity fees per day (720 units x 5.2 baht). For year-round electricity generation, the system is expected to be able to generate a total of 190,800 kWh of electricity by calculating from solar energy system functions for 265 days per year, which will help investors significantly save electricity fees and promote sustainable renewable energy use.

Case 2 is a calculation of electricity generation by using PVsyst software, a program popularly used to simulate solar energy system effectiveness. The PVsyst software simulation results are presented in Figure 5, which shows that the solar energy system can generate 183,619 kWh. of electricity per year (kWh/year), which is 85.37% of the system capacity. The parameters of system tilt and azimuth angles equal 15^0 and 0^0, respectively. This indicator shows system effectiveness in real environments.

According to Figure 5, energy generation in months with high solar radiation will be higher, such as in April. Calculation of the mean monthly system performance ratio (PR), including PR for the entire year, had a result of 0.854 or 85.4%.

Case 3 is a calculation of electricity generation from other projects installed in Uttaradit Province. The solar PV rooftop project installed in Uttaradit Province uses the same type of photovoltaic panels by considering one year of installation data and electricity generation information from the PSI Energy application, which enables convenient generation data checking and analysis.

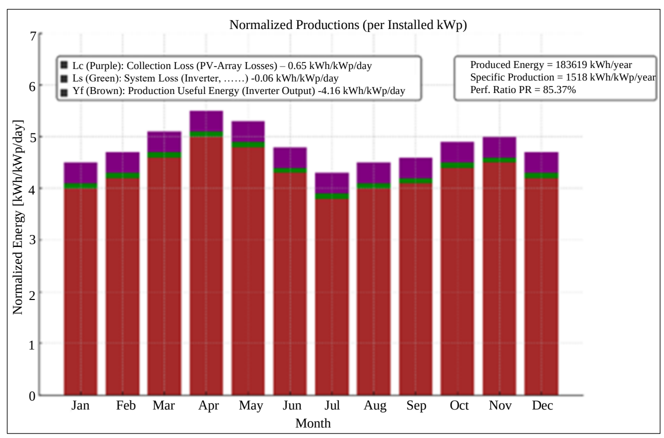

Fig. 5 Output from PVsyst software

Table 3. Monthly energy production for each PV module

Month	Location A (kWh)	Location B (kWh)	Location C (kWh)	Average (kWh)
Jul-23	42.43	48.50	57.67	49.53
Aug-23	39.26	44.80	61.86	48.64
Sep-23	36.18	42.15	61.31	46.55
Oct-23	41.85	48.60	63.04	51.16
Nov-23	42.08	46.68	66.83	51.86
Dec-23	37.40	42.11	63.97	47.83
Jan-24	35.07	45.93	45.54	42.18

Feb-24	39.09	48.25	55.97	47.77
Mar-24	49.31	52.10	66.47	55.96
Apr-24	52.57	48.33	75.09	58.66
May-24	50.60	47.26	68.33	55.40
Jun-24	45.62	45.13	67.07	52.61

Table 3 shows the monthly energy generation data of photovoltaic panels in three locations (Location A, Location B, and Location C) from July 2023 to June 2024. Energy values are measured in kWh. Regarding mean energy generation at each location, the mean monthly energy generation was as follows: at Location A, the mean was 42.88 kWh; at Location B, the mean was 46.46 kWh; and at Location C, the mean was 63.72 kWh.

The month with the lowest energy generation for every location was January 2024, which may be because of reduced sunlight during winter. Changes in energy generation in each month were correlated with weather changes and the amount of sunlight received by each area. According to data analysis using data from Case 3, a project with 220 panels installed will be able to generate 133,793.2 kWh of electricity per year (kWh/year).

5. Results and Recommendations

This study analyzed a solar energy system installation project with investment starting at 4,200,000 baht while covering equipment such as photovoltaic panels, inverters, and other support systems. The project has a useful life of 25 years, according to the manufacturer's warranty. Inverters have a mean useful life of 12 years and will need to be replaced in the 12th year at a cost of 100,000 baht. Inverter effectiveness will decline by 0.8% per year. Solar energy system maintenance expenses are expected to be 10,000 baht per year. In addition, electricity costs are expected to increase by 1% per year. The interest rate used to calculate the current cash value (discount rate) was 7%. TOU system electricity rates at on-peak times were calculated to be 5.2 baht per unit, and the value of the system after the project's expiration was 3% of the investment.

5.1. Economic Analysis

Case 1: The system generates 190,800 kWh of electricity per year with a payback period of 4.92 years and a Net Present Value (NPV) of 8,197,423.83 baht.

Case 2: The system generates 183,619 kWh of electricity per year with a payback period of 5.15 years and a net present value (NPV) of 7,725,647.73 baht.

Case 3: The system generates 133,793.2 kWh of electricity per year with a payback period of 7.64 years and a Net Present Value (NPV) of 4,452,200.92 baht.

5.2. Reductions to Greenhouse Gas Emissions

Solar energy system installation can reduce greenhouse gas emissions when greenhouse gas emissions are set at 0.5664 tCO_{2eq}/MWh [10]. The formula for calculating CO_2 emissions reduction is shown in Equation (3).

CO_2 Emissions Reduction = Electricity Generation (kWh) × Emission Factor (tCO2eq/MWh) (3)

This formula estimates the reduction in greenhouse gas emissions from electricity generation. The result of the three cases is as follows: In case 1, CO2 emissions were reduced by 108.07 tCO_2eq/year; in case 2, CO2 emissions were reduced by 104.00 tCO_2eq/year; and in case 3, CO2 emissions were reduced by 75.78 tCO_2eq/year.

5.3. Sensitivity Analysis

In the sensitivity analysis, factors potentially affecting the project were considered, including equipment costs, electricity costs, and interest rates. These three decision variables significantly impact the investment cost, leading to the following three guidelines.

Guideline 1: Equipment costs increase by 10%, electricity costs increase by 1.5% per year, and maintenance costs increase by 20,000 baht per year. According to calculations, for case 1, the payback period is 5.36 years and NPV = 8,246,483.16 baht; in case 2, the payback period is 5.61 years and NPV = 7,752,754.82 baht; and for case 3, the payback period is 8.39 years and NPV = 4,326,991.06 baht.

Guideline 2: Equipment costs are fixed, the interest rate is reduced to 5.5%, and electricity costs increase by 1.5% per year. According to calculations, for case 1, the payback period is 4.44 years and NPV = 10,897,302.26 baht; for case 2, the payback period is 4.64 years and NPV = 10,323,311.59 baht; and for case 3 the payback period is 6.71 years and NPV = 6,340,642.88 baht.

Guideline 3: Equipment costs are fixed, interest is the same, electricity costs increase by 1% per year, and the project life is reduced to 20 years. For case 1, the payback period is 4.98 years and NPV = 6,920,926.16 baht; for case 2, the payback period is 5.22 years and NPV = 6,497,943.21 baht; and for case 3, the payback period is 7.74 years and NPV = 3,563,050.37 baht.

These cases show flexibility and the impacts of changes in various factors on the project's decision.

6. Conclusion and Recommendations

According to the findings, the installation of solar energy systems for electricity generation is economically and environmentally cost-effective. When considering case studies, the solar energy system capacity of the Uttaradit Teacher Savings and Credit Cooperative, Limited can be identified as having the capacity to generate 133,793.2 to

190,800 kWh per year, and the project's payback period is between 4.92 and 7.64 years, which shows a fast return on investment and capacity to generate long-term profits. Furthermore, the NPV was positive in every case, meaning the project can generate income at a higher level than all investment costs. This project shows good financial returns with short payment periods in many cases. This is a significant advantage, giving investors confidence in returns within a short period of time. The payback period is similar to other solar projects in Thailand, such as those in Phatthalung and Nakhon Si Thammarat provinces.

The analysis confirmed the benefits of the solar PV system and provided guidelines for the committees of Uttaradit Teacher Savings and Credit Cooperative Limited to consider investing in this project. After investing in a solar rooftop system, once the calculated payback period, such as 5 years, has passed, the electricity generated from the PV system can start generating profit. Therefore, this project should be considered an investment [20]. Solar energy system installation will significantly reduce greenhouse gas emissions, particularly Carbon Dioxide (CO_2), a main cause of global warming. Reductions in greenhouse gas emissions will have positive effects on the environment in the long term, enabling organizations to play a role in reducing greenhouse gas emissions according to national and global goals.

The project's sensitivity analysis will help investors assess the impacts of changes in significant factors such as equipment costs, maintenance costs, or electricity fees. Knowledge of these impacts helps investors adapt and plan to manage unexpected situations effectively. Sensitivity analysis is a tool for reducing investment risks, giving investors more confidence in decision-making [21]. Although this project has high starting costs, savings from electricity costs and electricity sales back to the electricity authority will enable fast investment payback. At the same time, investors should consider system maintenance expenses and the replacement of deteriorated equipment, such as inverters, to ensure systems will function continually [22]. Investors should prepare budgetary plans for system maintenance and equipment replacement, such as inverters, in the 12^{th} year to maintain investment efficiency and achieve the desired returns. Renewable energy use at the community level should be further supported, particularly through tax reductions or investment incentives from the government, which will encourage operators and individuals to invest in clean energy. Additionally, investors should use sensitivity analysis to assess risks from various factors and create plans to adapt to changing situations, thereby maximizing the effectiveness of their investment in solar energy systems. Therefore, installing solar energy systems not only helps reduce electricity costs but also promotes sustainability and positive long-term environmental impacts.

This study focused on Uttaradit province, which has specific climatic and solar irradiance conditions. Results may not be directly applicable to other regions with different environmental or economic factors. The sensitivity analysis used fixed rates for electricity price growth and interest rates for the calculations. Future studies could include an economic analysis of solar photovoltaic rooftop systems combined with battery storage for buildings. Additionally, future research could concentrate on technical aspects, such as evaluating the thermal efficiency and environment of rooftop photovoltaic systems and analyzing the data collected after installation using machine learning methods [23].

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