Technical and Economic Potential of Solar Energy on Rooftops: A Case Study at Lampang Rajabhat University, Thailand

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DOI: https://doi.org/10.52939/ijg.v20i2.3069

Abstract
This paper presents an assessment of the potential of solar rooftops, and an analysis of the feasibility of investing in rooftop photovoltaic systems for the buildings at Lampang Rajabhat University. The ArcGIS solar radiation analysis tool was used to prepare the solar radiation maps. The derived solar radiation values were then used to evaluate the viability of investing in rooftop photovoltaic (PV) systems, considering factors that included Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PB) through project analysis and evaluation. According to the analysis, 23 buildings could be fitted with a solar rooftop, and 4,106 solar panels would cover 8.29% of the roof area. Southerly oriented pitched roofs had high solar radiation; nevertheless, slopes steeper than 40° reduced the radiation. Flat roofs with solar panels that were oriented southward and inclined at around 15° were found to be effective. When the PV-potential value was compared with the PV output value, a 0.19% difference between the values was observed. After we adjusted the PV-potential value in the PV-potential areas, the solar energy potential was determined to be 1,540,389.14 kWh per year. This potential could result in a 42.73% reduction in the total electricity cost at the university. Furthermore, the system's financial and environmental analyses revealed that the discounted PB would be 9 years and 6 months, with a reduction of 791.44 tCO_2eq/year. These findings could be used to guide the university in developing a policy about the installation of a rooftop PV system, reduce fossil fuel consumption, and increase self-generated clean energy. These indicators are critical milestones for the university toward becoming a green university and achieving the Sustainable Development Goals

Keywords: Solar Rooftop, Solar PV System, Solar Radiation, Geographic Information System, CO_2 Emission

1. Introduction

The demand for electrical power has continued to increase over the past year due to the country's economic expansion and warmer weather conditions. The production and utilization of renewable energy is one solution to this problem. The university can reduce its energy consumption and produce energy for its own use. There is an operation for becoming a Green University that manages energy and climate change by increasing the ratio of renewable energy to university consumption following the UI Green Metric criteria. Universities are a group of electricity users who have high electricity costs and tend to use more electricity. An energy consumption proportion of 40–60% of the power is used in air conditioning systems [1]. Campus buildings have high electricity usage during the daytime; this is consistent with the ability to produce solar power, which can only be produced during the daytime. Therefore, the installation of rooftop photovoltaic (PV) systems is an appropriate way to create an alternative energy source. Thailand is considered to have potential for producing environmentally friendly electricity from solar energy.

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

Therefore, it is suited to using solar energy as an alternative for generating electricity. Over the past several years, the technology for producing solar energy has improved greatly and now offers lower costs and better efficiency [2]. Lampang Rajabhat University (LPRU) had a high demand for electrical energy. The university's electrical energy consumption in 2018 was 3,562,815 kWh. During the past five years (2017–2021), LPRU's electricity consumption has decreased on average by 5.76% of the power costs because the university has implemented measures for reducing energy usage. It also participated in The Energy Block Grant Project of the Department of Alternative Energy Development and Efficiency to promote the use of renewable energy in government agencies in the fiscal year 2017. It received budget support to install a rooftop PV system having a capacity of 300 kW and 944 solar panels on the roof of a building, which represented an area of 1,836.7 m^2 or 1.91% of the roof area. In addition, a considerable amount of rooftop space is still available for the installation of solar panels to produce electricity for university use but has not yet been put to good use.

An assessment of solar energy potential on rooftops can be done by determining the roof area with which to estimate the number of solar panels. The capacity of a rooftop PV system can then be estimated by multiplying the number of panels by the maximum power of each panel [3]. The literature review revealed that software plays a pivotal role in the assessment of electricity generation in a solar PV system and in calculating energy output. To effectively employ this software, it is imperative to provide precise geographic coordinates that can determine the annual solar radiation levels within the study area. Additionally, the software requires the detailed technical specifications of the solar panels utilized in the research [4]. For example, PVsyst software is used to design and simulate PV systems and to evaluate the potential of PV systems [5]. RETScreen software estimates the amount of electricity produced, the financial analysis of a project, and the reduction in greenhouse gas emissions [6]. In the same way as System Advisor Model (SAM) software [7] and Hybrid Optimization Model for Electric Renewable (HOMER) software [8] and [9]. The electrical power is estimated using PVGIS software, and the estimation is compared with the electricity production data recorded for one year for the previously installed PV system. A slight discrepancy was found between the recorded data and the evaluation results for electrical power [10]. In addition, another study developed tools that could be used instead of RETScreen and SAM software for estimating the electrical power produced by PV systems. These tools used annual solar radiation values to estimate solar energy potential [11] and Artificial Neural Network (ANN) models were developed for estimating solar radiation with high accuracy in any weather [12].

The concept of "Net Zero Carbon" and the transition to sustainable energy stem from the pressing challenges of climate change and environmental degradation. Extracting and burning fossil fuels cause significant environmental damage. Transitioning to solar energy, which constitutes a sustainable and non-polluting alternative, can mitigate these adverse effects and safeguard natural ecosystems. Solar energy can be easily converted into electricity through the usage of photovoltaic (PV) systems. Geoinformatics ability to identify optimal locations for solar energy installations by analyzing solar radiation and estimating energy potential facilitates achieving potential energy production at specific locations [13]. An accurate assessment of PV potential requires a spatial analysis of available resources, which is most easily completed within a Geographic Information System (GIS) [14]. GIS has been utilized for database management, visualization, rooftop extraction, shading analysis, solar radiation modeling, and spatial analysis. Additionally, GIS-based methods can be applied differently according to the scale of the study area [15]. These are the main advantages of GIS in providing a precise estimate of the energy produced for each panel installation by considering the position of the sun, as well as the orientation and tilt of the solar panels.

Solar radiation plays a crucial role in evaluating solar energy potential and the capacity to generate electricity from solar cells [16]. The electricity output of a PV system relies on both the solar radiation level and the extent of sunlight exposure. This study presents a spatial analysis methodology utilizing GIS to assess the projected solar energy yield following the implementation of rooftop PV systems. This approach capitalizes on high-resolution Digital Surface Model (DSM) data acquired through Unmanned Aerial Vehicle (UAV) technology. This dataset facilitates a detailed evaluation of solar radiation on rooftops at a pixel-level resolution (0.01 m^2), enabling precise identification of optimal locations for solar panel installation. Additionally, spatial analysis techniques are employed to evaluate solar energy potential within the study area. The assessment of solar rooftop potential serves as a basis for analyzing the economic feasibility of investing in rooftop PV systems.

The outcomes of this study offer valuable insights for deciding on the installation of rooftop PV systems at LPRU, aiming to reduce energy expenditures, elevate the proportion of renewable energy utilization within the university, and diminish reliance on electricity sourced from fossil fuels—a significant contributor to climate change and global warming.

2. Materials and Methods

2.1 Case Study

This study aims to assess the technical potential of a rooftop PV system and to evaluate the viability of investing in a solar rooftop PV system. LPRU has an area of 1.08 km^2 and is located in Lampang Province, Northern Thailand (18°14′02″ N latitude and 99°29′15″ E longitude) (shown in Figure 1a). There are 52 buildings in use on campus. The solar radiation intensity in Thailand in 2020 at the Lampang Meteorological Station was measured at 5.05 kWh/m^2-day. In the year 2017, the database of solar radiation intensity was located at LPRU, and the solar radiation value was 4.90 kWh/m^2-day. From UAV photogrammetric surveys and the use of automatic aerial image processing software to create orthophoto (Figure 1b) and DSM (Figure 1c) with a resolution of 10 cm/pixel and a rooftop area of about 96,186 m^2 having an installation area of 1,836.61 m^2 PV, which is 1.91% of the total area.

Figure 1c shows a DSM derived from UAV photogrammetric surveys. This DSM boasts both high resolution (0.1 m) and accuracy, attributes crucial for precise mapping. While DSMs can be constructed using either LiDAR or UAV technology, UAV-based surveying encounters limitations when covering extensive areas due to constraints such as limited battery capacity, resulting in short flight duration (approximately 20 minutes), and restricted remote control range [17]. When surveying small areas, unmanned aerial vehicles are commonly utilized to create DSMs that necessitate high spatial accuracy and resolution [18]. DSMs provide significant input data for Solar Radiation Analysis tools within ArcGIS software, as they provide essential surface data like slope and aspect, influencing solar radiation and facilitating accurate solar energy estimations [19].

LPRU installed solar PV systems on the roofs of seven buildings (Figure 2), using polycrystalline solar panels that had a maximum power of 320 watts. The panels had a width of 992.7 mm, a length of 1,972.7 mm, and 944 panels. The electricity production by the installed PV rooftop system (the PV output) in 2021 was reported to be an average monthly output of 31,732.43 kWh, and a total yearly output of 380,789.18 kWh. The PV output production of each building is shown in Figure 2. This value is compared with the PV-potential value obtained from calculations to determine the error, which was calculated as the percentage difference between the PV-potential and PV output values. In Thailand, to install solar panels for maximum efficiency, the panels should be oriented toward the south and tilted approximately 15° to receive continuous solar radiation throughout the day as the sun moves from the east to west.

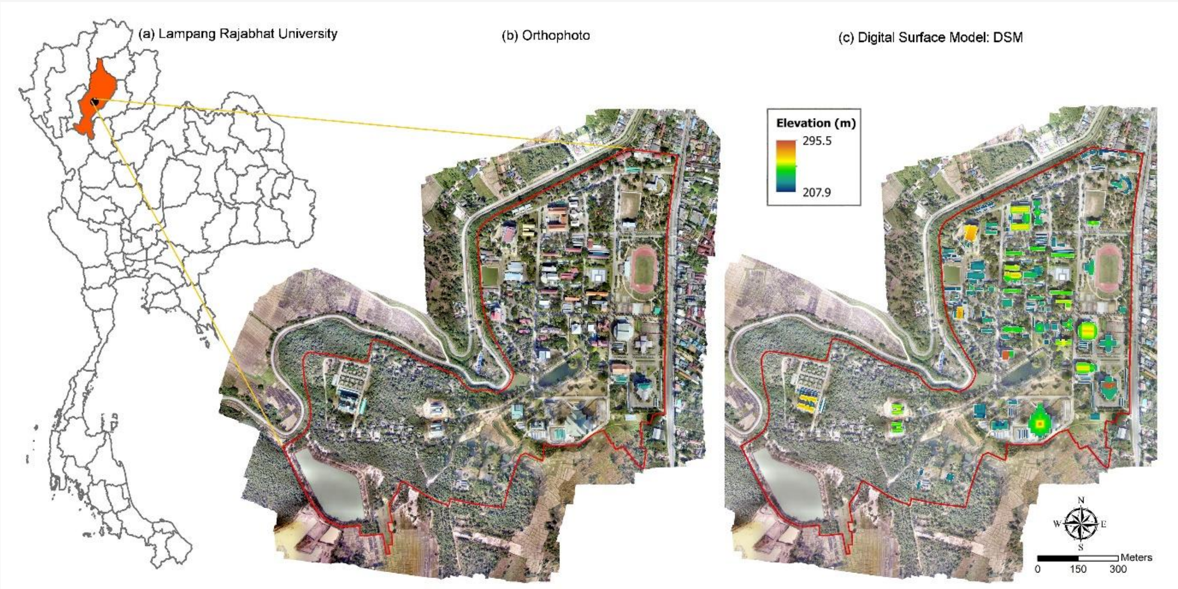

Figure 1: (a) LPRU location, (b) orthophoto, and (c) rooftop DSM from UAV

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

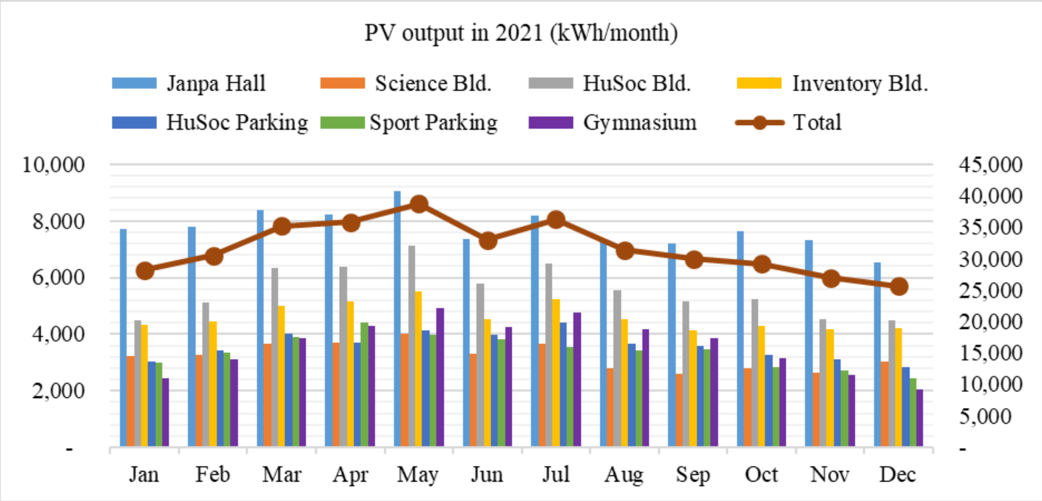

Figure 2: Monthly PV output in the year 2021

The roof of the building where the solar panels are installed must be free of shadows from other buildings or tree cover. Most of the building roofs in LPRU are installed with panels attached to the roof-mounted, which are installed on roofs that face south, and the solar panels are tilted to match the slope of the roof. The installed PV rooftop system has a slope between 9° and 23°. The HuSoc Bld. Rooftop is a flat roof with solar panels that can be set to face south and tilted at 15°. The panels installed on the roofs of Janpa Hall (slope 17.5°), and the HuSoc Bld. (slope 15°) produced 37.09 and 35.15 kWh per panel, respectively. The panels installed on the roof of the Gymnasium building had the lowest power production of 28.28 kWh per panel, because they were in the shadow of the trees beside the building.

2.2 Solar Radiation Analysis

The rooftop DSM (Figure 1c) was input data to point solar radiation analysis tool in the ArcGIS 10.3.1 solar radiation analysis model. Different essential parameters such as latitude, elevation, slope and aspect, viewshed, sky map, sun map, and atmospheric conditions in terms of aerosol content-induced transmissivity are considered in small-area solar radiation modeling. The modeled output dataset represents global radiation or the total amount of incoming solar radiation in kWh/m^2-day calculated pixel by pixel in the DSM [16]. The result is a solar radiation map in which each pixel shows the average monthly solar radiation on rooftops in 2021, ranging between 19.520 and 150.877 kWh/m^2, as shown in Figure 3. Analysis of the rooftop solar radiation map revealed that roofs facing south in Thailand receive significantly higher solar radiation compared to those facing other directions. This phenomenon stems from Thailand's position above the equator, causing the sun to consistently rise from the east and indirectly shine towards the south. Consequently, installing solar panels facing south is optimal to receive continuous solar radiation throughout the day. Mapping solar radiation on building rooftops aids in identifying areas suitable for installing solar power generation systems and determining the optimal direction and slope for panel placement, ensuring minimal shading from neighboring buildings or trees [20]. From our solar radiation analysis, we found that the solar radiation on the installed panels averaged 4.92 kWh/m^2-day, which is similar to the solar radiation data for the LPRU area mentioned above.

According to the 2021 monthly solar radiation analysis, solar radiation is high from May to July, and it is low from December to January. This is due to the daily changes in the position of the sun in the sky throughout the year. Rooftop solar radiation maps help identify building rooftop areas that have potential for collecting solar energy by installed solar panels. Considering the solar radiation value and the appropriate tilt angle of the solar panel greatly increases the power generation capacity of the solar panel [21] and [22]. Flat roofs are suitable for the installation of solar panels that are oriented toward the south and tilted approximately 15°. Pitched roofs must slope toward the south or southeast and the roof slope must not exceed 40° to enable the solar panels to receive sunlight at their full efficiency. In light of the above considerations, 23 buildings show promise for the installation of solar rooftop PV systems, with 4,106 solar panels, representing an area of 7,977 m^2, a total capacity of at least 1,300 kW.

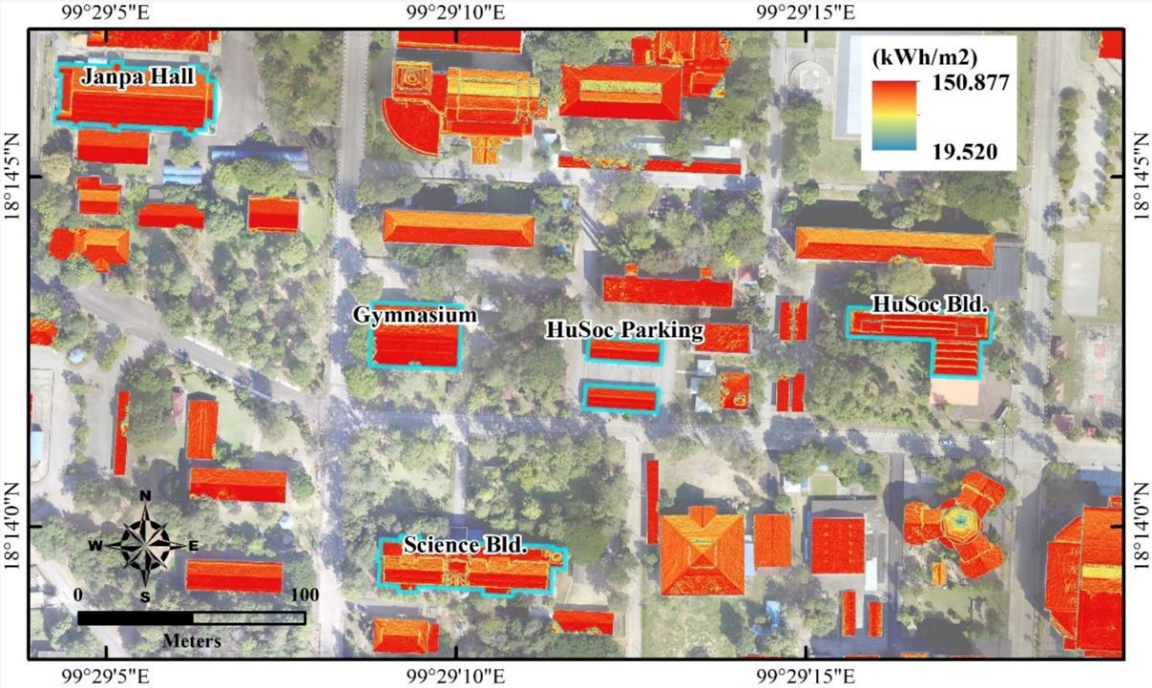

Figure 3: Rooftop solar radiation map for LPRU

2.3 Rooftop PV Technical Potential Assessment

2.3.1 Rooftop PV energy production simulation

A rooftop solar radiation map where each pixel represents a solar radiation value is used to calculate the production of electrical energy that is expected from solar panels on the roof of the building. The raster calculator tool in ArcGIS is used to estimate the electrical energy produced by the PV system [23], as shown in Equation 1:

$$E = A \times R \times H \times PR$$

Equation 1

where E is the energy that is produced by the PV system in kWh; A is the total area of PV panels in m^2; H is the average solar radiation on the PV panels in kWh/m^2; Performance Ratio (PR) is very important to an evaluation of the quality of a PV system because it guarantees performance regardless of the orientation or inclination of the panel. PR includes all the loss coefficients (between 0.5 and 0.9), and R is the efficiency of the solar panel given by a ratio %; this ratio is given for the standard testing conditions: radiation = 1000 watts/m^2, cell temperature = 25°C, wind velocity = 1 m/s, air mass = 1.5.

In this simulation, E was the pixel area of 0.01 m^2; H was the solar radiation value of the pixels; PR is the conversion efficiency from DC to AC, which was considered to be 85% (0.85); R is the efficiency of the Solartron Solar Module SP320 solar panel at a maximum power (P_{max}) of 320 watts, and the area of the solar panel is 1.958 m^2. The efficiency of the solar panel was calculated as 16.34% according to Equation 2:

$$Efficiency\ (\%) = \left(\frac{P_{max}}{Area\ x\ 1000}\right) \times 100$$

Equation 2

2.3.2 Percentage error (%Error)

The percentage error (%error) was calculated as the difference between the PV-potential and PV output values as a percentage, as shown in Equation 3. The solar energy potential was subtracted from the %error, and the resulting solar energy potential matched the PV output value.

$$\%Error = \left|\frac{PV - potential\ value\ -\ PV\ output\ value}{PV\ output\ value}\right| \times 100$$

Equation 3

Economic potential assessment is an analysis of the worthiness of investment in the installation of a solar rooftop PV system. The worthiness of the project is measured by comparing the benefits received with the costs or expenses across the project. This research uses three criteria to measure the worthiness of the project: Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PB).

2.4 Rooftop PV Economic Potential Assessment

2.4.1 NPV

The NPV refers to the difference between today's value of cash inflow and the cash outflow over the lifetime of a project or business. The NPV of a project is measured, as in Equation 4, during a project's planning phase to analyze its profitability [24].

$$NPV = \sum_{t=0}^{n} \frac{Revenue_t - Cost_t}{(1+d)^t}$$

Equation 4

where n is the number of years of economic analysis; t is the year variable in each summation; d refers to the discount rate; $Revenue_t$ is the PV system revenue in year t; and $Cost_t$ represents the system cost in year t.

2.4.2 IRR

The IRR refers to the value of the discount rate at which the NPV of the cash flow of a particular investment is zero. This rate is measured to investigate the profitability of a potential investment [24]. IRR is measured using Equation 5.

$$IRR : NPV = \sum_{t=0}^{n} \frac{Revenue_t - Cost_t}{(1+d)^t} = 0$$

Equation 5

2.4.3 PB

A PB refers to the time needed for an investment return to offset the amount invested in terms of profits or net cash flow. PB is measured using Equation 6.

$$PB = E + \frac{B}{C}$$

Equation 6

where E is the year immediately preceding the year of recovery; B is the amount left to be recovered; and C is cash inflow during the year of final recovery in THB/year.

The rooftop PV economic potential assessment uses rooftop PV potential to analyze project costs and benefits and to prepare a cash flow schedule across the life of the project. The analysis parameters are shown in Table 1, and the net benefits obtained are calculated according to investment decision criteria, including NPV, IRR, and PB.

3. Results and Discussion

The rooftop solar energy map was derived from the rooftop solar radiation map and spatial analysis. We used the ArcGIS zonal statistics tool with Equation 1 to compute the electrical energy generated by the solar cell power generation system to determine the PV-potential value. This value represents the cumulative electrical energy of individual pixels in two designated areas of the rooftop solar energy map: 1) the PV-installed area, and 2) the PV-potential area. The output of solar energy assessment, which is the annual total of solar energy on the rooftops, was in the range of 0.333–2.513 kWh. The PV-potential area represents the area of a building's roof that is suitable for the installation of solar panels. The identified rooftop PV-potential areas of buildings in LPRU included the specific sections of rooftops oriented southward that could receive continuous solar radiation throughout the day and at a maximum tilt of 40°, and it included flat-roofed buildings as well, as shown in Figure 4.

Additionally, the study revealed a direct correlation between the electricity output of solar panels installed on flat-roofed buildings and the solar radiation received, surpassing that of panels installed on pitched roofs.

Table 1: Parameters used in economic potential assessment

Parameters	Values	Remarks
Project lifetime	25 years	Lifetime of solar panels
Technical lifetime of invertor	10 years	Replace at year 11
Solar cell degradation	0.5%/year	
Discount rate	2.693%	Average 10-Year Government Bond Yields from 2012–2021
Energy charge (Peak)	4.2097 THB/kWh	PEA—Provincial Electricity Authority
Energy charge (Off-Peak)	2.6295 THB/kWh	
Proportion of the number of days (Peak:Off-Peak)	68%:32%	
Average Ft of 2012–2015	0.2325 Baht/kWh	Ft is fuel adjustment cost at the given time
An increase in electricity tariffs	2.25% per year	
PV-potential value	1,540,389.14 kWh/year	Form calculation
Average system cost	35.16 THB/kWh	Average system cost of solar rooftop project in LPRU

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Figure 4: Rooftop solar energy map for PV-installed and PV-potential areas

Table 2: Percentage error of the PV output and PV potential in the PV-installed area

Bld. name	**Solar radiation (kWh/m^2)**	**PV output**		**PV potential**		**%error**
		(kWh)	**(kWh/panel)**	**(kWh)**	**(kWh/panel)**	
Janpa Hall	148.23	7,715.56	37.09	8,318.78	39.99	-
HuSoc Bld.	148.14	5,554.10	35.15	6,309.94	39.94	0.14
Science Bld.	145.01	3,223.44	34.29	3,673.18	39.08	0.14
HuSoc Parking	148.11	3,592.17	33.26	4,317.64	39.98	0.20
Inventory Bld.	149.39	4,629.21	33.07	5,676.41	40.55	0.23
Sport Parking	146.66	3,398.45	31.47	4,275.45	39.59	0.26
Gymnasium	148.41	3,619.51	28.28	5,149.94	40.23	-
Monthly average	147.71	4,533.20	33.23	5,388.76	39.91	0.19

Nevertheless, roofs with slopes exceeding 40° experience diminished solar radiation, thereby reducing the efficiency of solar electricity production [25]. The solar rooftop potentials were calculated only from the PV-potential area. If all rooftop areas were included, it might lead to overestimation or underestimation [26]. The average monthly solar radiation on the PV-installed area was 147.71 kWh/m^2, and it was 143.40 kWh/m^2 on the PV-potential area. The PV-potential value was calculated from the solar radiation value, and the amount of electricity generated from the PV system varied according to the solar radiation. The PV potential value was calculated and then compared with the PV output in the PV-installed area to determine the %error. The results show that the average monthly PV-potential value, which is 5,388.76 kWh and 39.91 kWh/panel, is higher than the average monthly PV output value, which is 4,533.20 kWh and 33.23 kWh/panel, as shown in Table 2.

Normally, the electrical power produced by a solar panel varies with the amount of solar radiation the panel receives [27]. Meanwhile, the PV-potential value is calculated from the solar radiation value obtained from the analysis under clear-sky conditions [28]. Although the equation employed to estimate the electrical energy produced by the PV system, the effects of the atmosphere on solar radiation were considered. The air mass is set to 1.5, which is the standard value used to estimate the absorption of solar energy and the effect of the atmosphere on solar radiation. The assessed results of solar energy potential still deviate from the actual power produced.

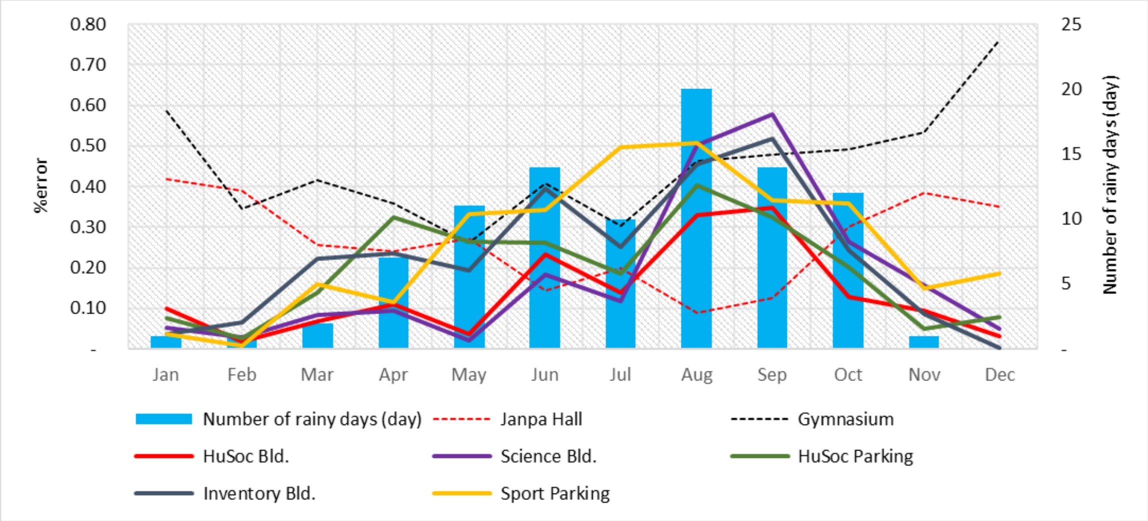

Figure 5: Percentage error and comparison of the number of rainy days in the year 2021

The %error is the difference between the PV output value and the PV-potential value. This period has a large error, especially from June to October, which is the rainy season, and the many clouds in the sky reduces the sun's radiation on the solar panels. As a result, the solar panels generate less energy. For the Janpa Hall and Gymnasium buildings, the %error differs from that of other buildings (Figure 5) and does not consider the average error. Therefore, the %error for the evaluation of the PV-potential value in this study was 0.19 (Table 2), and this was the %error we used to improve the PV-potential value of the PV-potential area so that the value obtained from the calculation was as close to the PV output value as possible.

In the assessment of the solar energy potential, the PV-potential value exceeded the PV output value. The PV-potential value was compared with the PV output value from the rooftop PV system that had already been installed to calculate the %error. The factor that caused the PV-potential value to be higher than the PV output value was the cloudy weather during the rainy season [29]. The roof surfaces had different slopes and orientations, and the reflections and shadings from nearby objects caused the solar panels to produce less electricity [30] [31].

3.1 Solar Energy Potential

The PV-potential areas could accommodate 4,106 solar panels or 7,977 m^2 from a total of 23 buildings. In the solar energy calculations, the monthly rooftop PV-potential value reached its peak value between March and October, because this included the summer period (March to May) and the rainy season (June to October), which are characterized by high solar radiation. Conversely, the PV potential decreased during the period from November to February, which corresponds to winter, when solar radiation is reduced. The %error was more pronounced during August to October due to the rainy season. In Thailand, the rainy season runs from June to October, with August to October being the period of heaviest rainfall. During this time, the increased cloud cover had a significant impact on solar radiation, which resulted in decreased power generation from the PV systems. Finally, the PV-potential value was computed by subtracting %error to the resulting solar energy potential matched the PV output value, as shown in Figure 6.

Table 3 presents a total of 23 buildings that were identified as having potential for the installation of a PV system on their rooftops. The maximum solar energy potential was 148,533.04 kWh per year (a capacity of at least 122 kW) for Bld.43; the next-highest was 116,091.45 kWh per year (a capacity of at least 99 kW) in Bld.47 (location as shown in Figure 4); the minimum was 29,704.13 kWh per year (a capacity of at least 26 kW) in Bld.29. Additionally, the total yearly PV-potential value was 1,540,389.14 kWh. The total yearly PV-potential value is used to analyze the costs and benefits of installing rooftop PV systems to further analyze the financial feasibility of the project. This study used the %error to improve the PV-potential value. The resulting solar potential assessment matched the actual electrical energy as closely as possible. This method was developed in past studies for model validation. By comparing the expected production of electrical power with the actual electrical energy produced [4], the solar energy potential of the building's roof was assessed before the solar panels were installed.

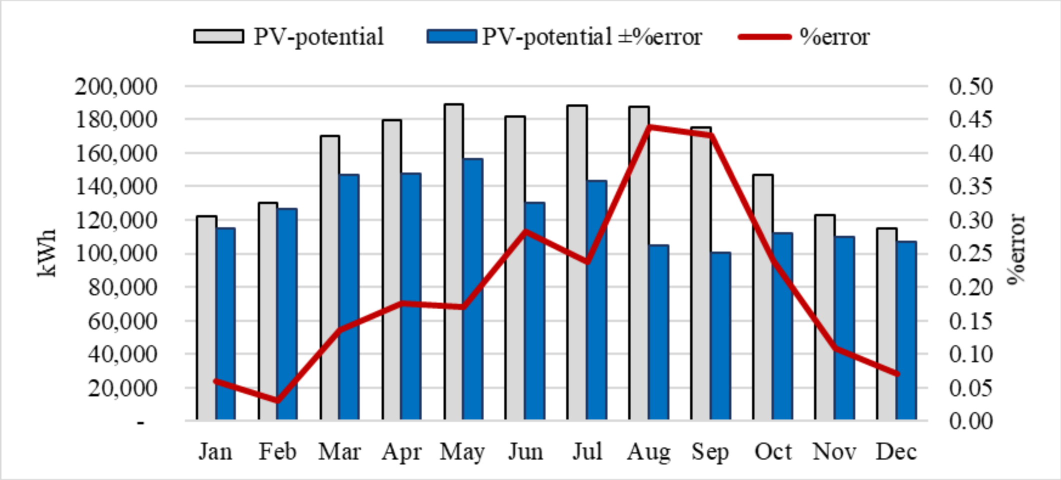

Figure 6: Monthly rooftop PV-potential value in PV-potential area

Table 3: Solar energy potential of PV-potential area

Bld. No.	Panel	Capacity (kW)	Yearly total of PV potential (kWh)	Bld. No.	Panel	Capacity (kW)	Yearly total of PV potential (kWh)
43	384	122	148,533.04	4	140	44	50,508.50
47	312	99	116,091.45	17	133	42	46,685.60
52	307	98	111,668.66	51	120	38	45,723.14
46	288	92	110,583.47	6	116	37	45,329.91
45	293	93	110,156.77	33	120	38	45,318.22
38	277	88	105,873.13	41	116	37	44,513.59
8	218	69	83,369.12	2	100	32	38,140.70
48	215	68	80,482.00	3	100	32	37,878.77
42	180	57	63,317.18	5	100	32	37,518.32
1	140	44	52,620.29	7	92	29	34,486.11
50	138	44	51,030.66	29	84	26	29,704.13
F1	133	42	50,856.36	Total	4,106	1,303	1,540,389.14

This was then compared with the actual energy produced after the solar panels were installed. Assessment methods were used to evaluate the reliability and efficiency of the solar energy potential [32]. This is important because the amount of electricity produced by a PV system is an important factor in deciding to use solar energy and to invest in a PV system [33].

3.2 Economic and Environmental Potential

The feasibility analysis of investment in a rooftop PV system indicated a favorable NPV over the project's 25-year lifespan. The IRR of 11.48% surpassed the project's discount rate, which was represented by the Weighted Average Cost of Capital (WACC). Moreover, the project exhibited a remarkably short PB of 9 years and 6 months, which is well below the project's entire duration. These results strongly affirm the financial soundness of the project, as shown in Table 4.

The proportion of reduction in greenhouse gas emissions from rooftop PV systems. It is an environmental benefit that is gained from using solar energy to reduce the greenhouse gas emissions due to the production of electricity from fossil fuels. According to data for the amount of carbon dioxide (CO_2) emissions from the power plants of the Electricity Generating Authority of Thailand, the amount of CO_2 emissions per unit (kWh) is 0.5193 $kgCO_2/kWh$. Therefore, the electrical power supplied by a rooftop PV system on a building at LPRU that produces 380,789 kWh per year can reduce emissions by 197.74 tCO_2eq/year. If the project is carried out in a PV-potential area, it will be able to produce 1,540,389 kWh of electricity per year, which reduces greenhouse gas emissions by 799.92 tCO_2eq/year. The ratio of renewable energy produced to the university's energy consumption will increase to 53.29% (Table 4).

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) | © Geoinformatics International

Table 4: Financial and environmental benefits of the project

Benefit	PV system installed	PV system project	Total
Number of solar panels	944	4,106	5,050
Capacity (kW)	300	1,300	1,600
Solar energy potential (kWh/year)	380,789.18	1,540,389.14	1,921,178.31
Cost of investment (million THB)	17.997	54.16	72.157
Present rooftop area (%)	1.91	8.29	10.20
Proportion of renewable energy (%)	10.56	42.73	53.29
NPV (THB)	-	72,239,291	-
IRR (%)	-	11.48	-
PB (year)	-	9.457	-
CO_2 emission (tCO_2eq/year)	197.74	799.92	997.67

The results of evaluating the financial worthiness of investing in rooftop PV systems using NPV, IRR, and PB showed that the project was worth the investment with a PB of 9 years and 6 months. This study did not compare the calculated PB with the actual installation PB. The actual installed PV system had a PB that was slightly faster than the calculated data [34]. This is due to external factors that affect installation costs and the constantly changing amount of power produced. In particular, the technology developed for rooftop PV systems will produce higher efficiency. Most importantly, the lower cost of installing a solar rooftop PV system results in a faster break-even point or PB. However, installing solar panels on a roof that is not covered by shadows, and orienting the solar panel in the appropriate direction will help the PV system produce higher electrical power and bring about an increase in the Performance Ratio and IRR, respectively [35]. Including considering the installation of solar panels to get the right angle of inclination and price of solar panels to maximize energy production and reduce the cost of solar power production [36].

4. Conclusions

When a rooftop PV system is installed, it is essential to carefully consider the solar panel's orientation and tilt to ensure that it aligns optimally with the sun's position throughout the year, which will maximize its electricity production efficiency. Our assessment of solar energy generation potential on rooftop structures reveals that the PV-potential value surpasses the actual PV output value, particularly during the rainy season when panels generate significantly less power, which is partly due to the shading effects of nearby trees or buildings. Consequently, weather-related factors and the building's surroundings diminish the solar panels' electricity production efficiency. To address this, we subtracted the calculated %error from the PV-potential value to bring the evaluations closer to the actual PV output value. Moreover, the methodology for assessing the rooftop PV system's potential detailed in this document is adaptable for use in various other regions and contexts, and the %error is calculated from the specific solar panel parameters employed in the study.

In this paper, we apply geoinformatics to estimate solar radiation using GIS and visualize it on a solar radiation map to delineate feasible areas for solar energy on rooftops. However, GIS is effective for assessing various potentials: physical potential (solar radiation on the rooftop), geographic potential (available rooftop area considering the orientation, tilt of the solar panels, and shadows), and technical potential (visualizing and assessing solar energy power output). Additionally, economic and environmental potentials are presented (the feasibility of investment in a rooftop PV system and the amount of CO_2 emissions reduction). These research findings provide guidance for leveraging existing building rooftops as a clean energy source and making decisions regarding the installation of rooftop PV systems. However, an assessment of solar power production results is not sufficient to meet the university's energy needs, and may result in the proportion of clean energy produced increasing to just 42.73%. If energy-saving measures or practices for reducing energy consumption are carried out simultaneously, these efforts align with the overarching goals of reducing the university's energy expenses, decreasing fossil fuel dependence, and increasing the proportion of generated clean energy on campus. Achieving these objectives serves as a crucial benchmark for the university's commitment to becoming a green institution and achieving Net Zero Carbon status. In the future, related research will continue to improve and develop through the integration of artificial intelligence (AI) and geographic information systems (GIS), known as AI GIS.

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This amalgamation of AI technology and various GIS processes, such as spatial data analysis algorithms (GeoAI), combines the power of AI technology with spatial data analysis capabilities offered by GIS. This integration enables more sophisticated analysis and decision-making in various fields, including managing energy effectively by utilizing advanced forecasting techniques to predict energy generation from renewable sources and energy demand patterns.

Acknowledgements
The authors would like to extend my sincere thanks to Lampang Rajabhat University for facilitating gathering and providing essential data for this research.

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