Technical & Economic Evaluation of the University of Phayao Solar PV Rooftop System

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Abstract

Educational institutions such as universities are high energy demand groups and tend to increase more their use of electricity every year. This research studied and evaluated the technical and economic potential of a 2 MW solar PV rooftop power generation system at the University of Phayao in Thailand. 13 buildings and two car parks in the university campus were selected for installation of the system. The total installed capacity was 1,998.72 kW. The result of the system simulation showed an average performance ratio (PR) of 79.96% with total electricity generation of 2,784,702 kWh in the first year, leading to a reduction of electricity consumption by 18.6%. An economic assessment was done based on an investment value of 100 million Thai Baht, project life of 25 years, and a system maintenance fee of 0.5% of investment value per year (500,000 Thai Baht per year). These gave a net present value (NPV) of 260 million Thai Baht and a payback period of 13 years. Other socio-economic and environmental benefits were also identified but their economic values were not assessed and as such not included in the economic evaluation.

Keywords:

Solar PV Rooftop System, Performance Evaluation Technical Evaluation, Economic Evaluation, University

1. Introduction

1.1. Energy Situation

Global energy production growth is steadily increasing at an average of 1.2% annually [1], driven by increasing population and economic growth. Energy production is dominated by fossil fuels, as such CO_2 emissions from fossil fuel use continue to rise too. However, there is increasing push to move to low-carbon energy, especially after the signing of the Paris Agreement.

For Thailand, the gross energy consumption increased by 0.8% in 2018 from 2017. It was a 1.8% increase in oil consumption (used mainly in the transportation and communications sectors), a 3.5% increase in coal consumption, a 4.9% increase in petroleum products (i.e.; LPG, propane, and butane) consumption, and a 17.6% increase in imports of electric power [2]. The 2019 forecast is that energy consumption will increase by 2.4% compared to 2018, causing Thailand to import and produce more energy. All these increases Thailand CO_2 emissions.

1.2. Energy Use and Climate Change Impacts

Without reduction of fossil fuel use, global carbon dioxide emissions will increase by 10% over the next 20 years (2040), making global warming a more serious problem.

In 2019, land temperature increased by as much as 1.35 degrees Celsius, while ocean temperature increased by 0.74 degrees Celsius. The average temperature rise for both land and sea was 0.97 degrees Celsius as shown in Fig. 1.

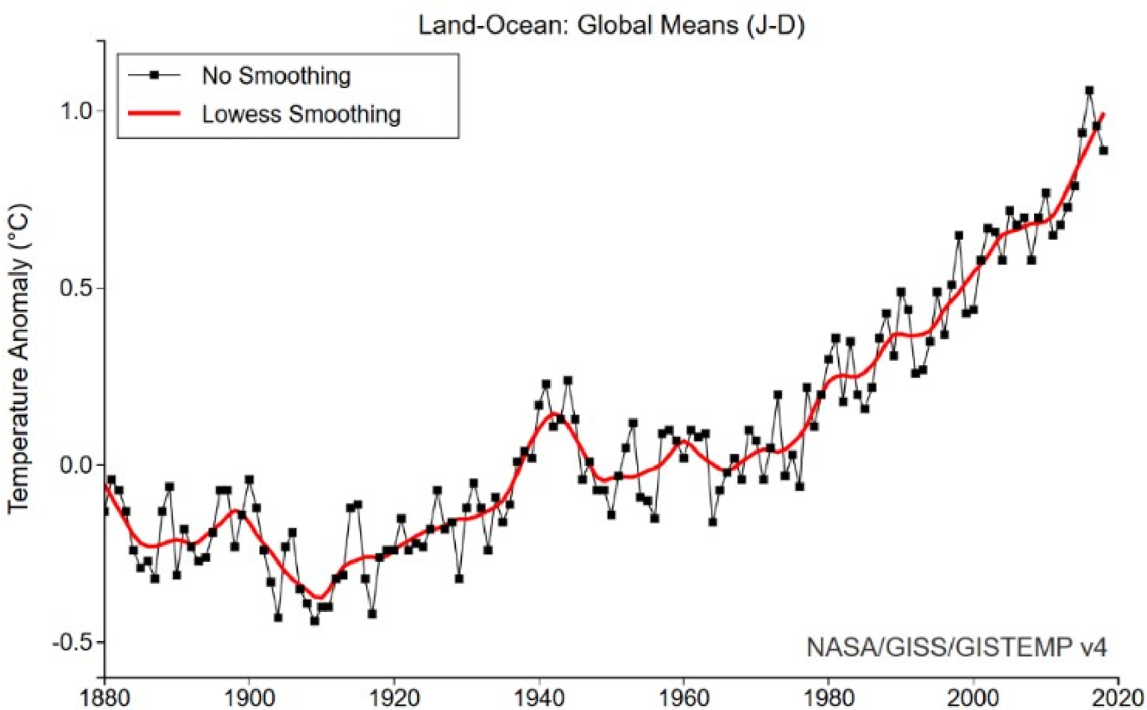

Fig. 1 Average annual land and sea temperatures differing from the land and sea temperatures in 1901 – 2000.

Global warming causing increases in sea temperatures increases the water thermal energy and humidity leading to formation of more and violent storms. The average number of tropical storms and hurricanes that occur in the Atlantic Ocean each year was found to increase from 16 per year in 1920 to 29 per year in 2018.

In 2000, Thailand emitted 210.23 million tons of CO_2 and absorbed 52.37 million tons of CO_2. Thus, Thailand's net CO_2 emission in 2000 was 157.86 million tons. The amount was lower than in 1994, when 202 million tons net of CO_2 was emitted. Of the total CO_2 emission in 2000, power generation emitted 150 million tons or more than 90% of net CO_2 emission. In the energy sector, power generation was the largest emitter of CO_2 (64.2 million tons), followed by transportation at 44.4 million tons, and industry at 30.3 million tons [3].

So far, research has provided a broad picture of the effects of global warming in Thailand. Rainfall across all the regions in the country has a potential to increase by about 10-20%. The rainy season will not change much, although the weather will tend to be warmer due to an increase in maximum and minimum temperatures by 2 degrees Celsius. It is noted that the extent of the effects of climate change can vary from area to area, such as between the east and west coasts in southern Thailand.

The agricultural sector in Thailand is most vulnerable to climate change impact, since most farmers are small landholders in rainfed areas. The shift from annual field crops to permanent trees in recent years further limits the flexibility of changing the cropping system, and hence creates more vulnerability. Research and development in this area has so far not been able to sufficiently address uncertainty issues. Policy development is mostly general, calling for increasing the management capacity of farmers under high-risk situations and for enhancing the climate and early warning systems.

1.3. Thailand Electricity Production and Consumption Trends

Data from the Provincial Electricity Authority (PEA) showed that electricity consumption for Thailand has increased annually from 2015 to 2018 as follows; 3,91%, 5.31% 1.80% and 1.31%. In addition, the base electricity price has also steadily increased from 3.2045 baht per kWh in 2012 to 3.7556 baht per kWh in 2015.

The increasing demand for electricity, its increasing price, and the dependence of Thailand on imported electricity have negatively affected many users in communities, businesses, and government institutions. A new possible alternative for them is to install on-site decentralized renewable energy systems to reduce the use of electricity produced from centralized higher-cost and fossil fueled power plants, including those which are from imported supply sources.

1.4. Electricity Use in Universities

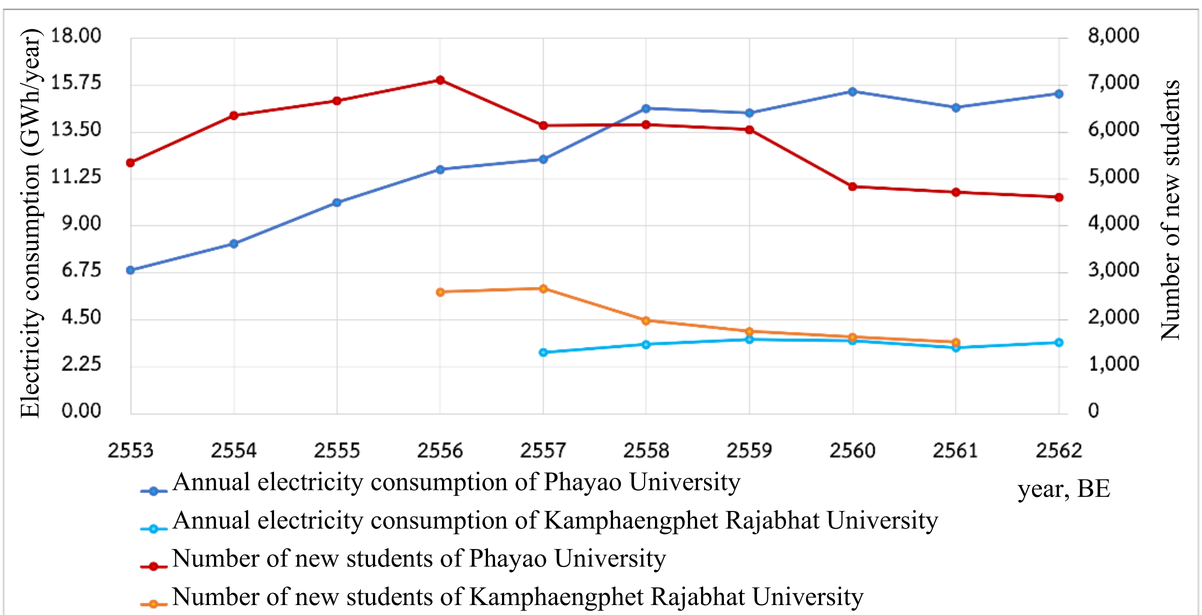

Fig. 2 The university's electric power consumption compared with the number of new students.

Note: Electric power consumption in 2019 is an estimate based on the first 7 months of the year.
Source: The Office of Academic Promotion and Registration of Kamphaengphet Rajabhat University and Center for Information Technology and Communication Services, University of Phayao

Electricity consumption in t universities in Thailand has been increasing annually too even if the student population in some of the universities have decreased in recent years (see Figure 2, the slowdown in Thailand population growth because of low birth rate is one reason for the decrease in student population in several provincial universities). However, owing to increasing use of digital technology for teaching and learning - such as computers, computer networks and servers, to support online instructions and classes –electricity consumption has increased, and as such, the expenditures of the universities for electricity.

This has really put a big financial burden on the universities, because, as mentioned previously, their student population have been decreasing and so is the revenue or income of the universities. As previously mentioned too, an option to save on electricity expenses will be to adopt cheaper on-site decentralized renewable energy power plants and shift non-electricity energy uses to electric power (e.g., petroleum-fueled university vehicles to electric-driven ones).

1.5. Purpose of the Study

Universities should adopt energy-saving measures and one of them, as already mentioned above, is to install cheaper on-site power generation systems to supply solely the electricity demand of the universities. One such type of on-site power generation system, which is renewable and cost-competitive are solar PV rooftop systems. A big advantage of solar PV rooftop systems is that they generate electricity during daytime, which coincide with the operating hours of universities and which is also the time when electricity demand by universities is the highest.

This paper discusses the basis and rationale for which universities in Thailand may install on-site renewable energy power plants, particularly solar PV rooftop power plants. The discussions are based on the analysis of the of economics, and the social and environmental impacts, of the solar PV rooftop power plant installed in the University of Phayao. Universities, like the University of Phayao, are in a good position to promote solar PV rooftop power plants, as an option for universities to reduce electricity expenses, adopt energy saving measures and contribute to the environmental goal of reducing carbon dioxide emissions to mitigate climate change.

2. Analysis of Solar PV Rooftop Power Plant

2.1. Description of the Solar PV Rooftop Power Plant

The 2 MW Solar Rooftop power plant is located inside the university campus is shown in figure 3 and 4. The system is connected to the distribution grid. It is composed of six sub-systems, installed on rooftops of six separate buildings in the university. All these sub-systems are also designed to operate independently or in isolation. This also allow them to operate as a prosumers; satisfy the energy demand of their building first, then export excess electricity production e to another building or to the grid.

This system use multi-crystalline of 320 Watt/ module. Average of solar irradiance is 4.74 kWh/d at Latitude 19.01 North and Longitude 99.95 East. The system is design PV array loss factors as this criteria;

- Array soiling losses 2.5 %
- Thermal loss factor 29.0 W/m^{2}K
- Wiring ohmic loss 1.5 %
- Light induced degradation 2.0 %
- Module Degradation 0.78 % per year

Fig. 3 Overview of University of Phayao.

Fig. 4 Solar PV rooftop installations in the UP Campus.

2.2. Performance of the Power Plant

Data such as Solar Irradiance, Electricity generation, etc. were collected from the on-line electric meter known as PEA-AMR, and which were reported (in kW) every 15 minutes. The yearly average load was analyzed for comparison with the power curve of the solar PV rooftop power plants to be able to determine the suitable installed capacity of the solar power plants. Figure 5 shows that for the average load, the suitable capacity of the power generation system is 450 kW for each sub-system.

However, some buildings may adopt energy saving measures such as turning off lights and appliances during lunch breaks. In this case, the reduction in electricity demand must be considered in determining the future cost-effectiveness of the solar PV rooftop power plant installations and thus, the designed installed capacity.

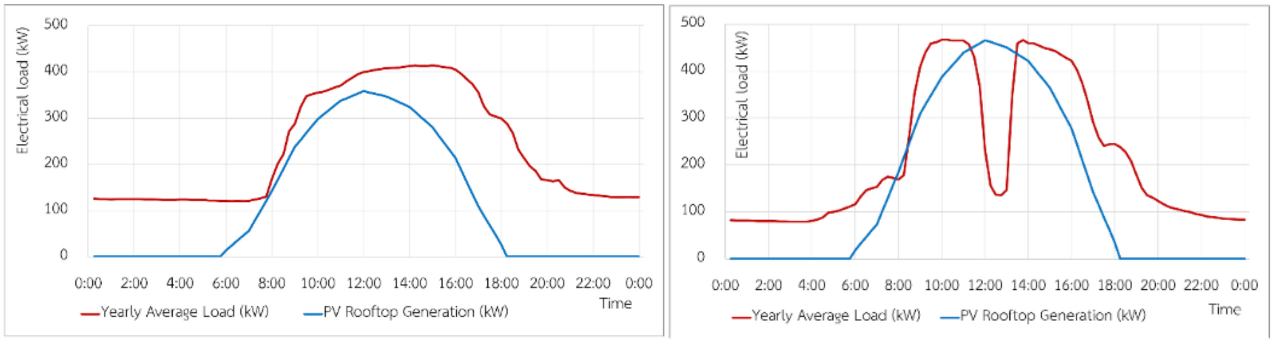

Fig. 5 (left) shows the typical hourly comparison of the power generated from the solar power generation system , with the electricity demand of the building where a solar PV rooftop power plant has been installed ; Fig. 5 (right), shows the typical hourly comparison between the power generated from the solar PV power plant and the electricity demand of the building when energy-saving measures were adopted during lunch breaks.

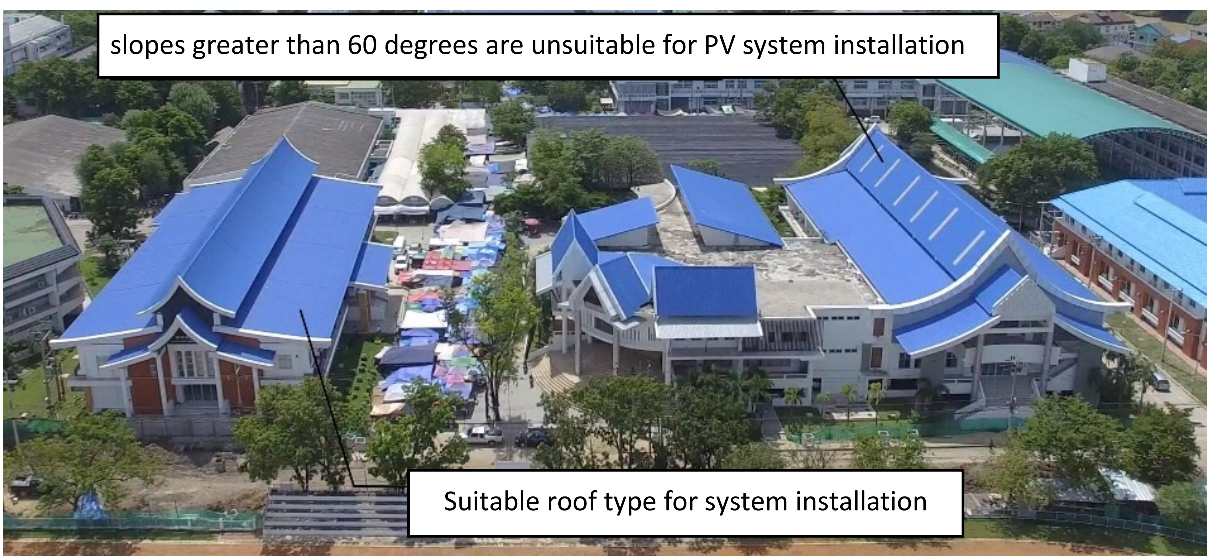

Fig. 6 Shows the roof characteristics of university buildings that are suitable and unsuitable for the installation of the solar power generation system.

Table 1 Electricity Generation for 25 years of project life time.

Year	Degradation (%/ year)	Module Efficiency (%)	Performance Ratio; PR (without correction) (%)	Maximum Electricity Generation (kW)	Electricity Generation (kWh)
1	2.5	100.0	79.98	1,590.3	2,784,702
2	0.7	97.5	77.98	1,550.5	2,695,592
3	0.7	96.8	77.42	1,539.4	2,676,099
4	0.7	96.1	76.86	1,528.3	2,656,606
5	0.7	95.4	76.30	1,517.1	2,637,113
6	0.7	94.7	75.74	1,506.0	2,617,620
7	0.7	94.0	75.18	1,494.9	2,598,127
8	0.7	93.3	74.62	1,483.7	2,578,634
9	0.7	92.6	74.06	1,472.6	2,559,141
10	0.7	91.9	73.50	1,461.5	2,539,648
11	0.7	91.2	72.94	1,450.4	2,520,155
12	0.7	90.5	72.38	1,439.2	2,500,662
13	0.7	89.8	71.82	1,428.1	2,481,169
14	0.7	89.1	71.26	1,417.0	2,461,677
15	0.7	88.4	70.70	1,405.8	2,442,184
16	0.7	87.7	70.14	1,394.7	2,422,691
17	0.7	87.0	69.58	1,383.6	2,403,198
18	0.7	86.3	69.02	1,372.4	2,383,705
19	0.7	85.6	68.46	1,361.3	2,364,212
20	0.7	84.9	67.90	1,350.2	2,344,719
21	0.7	84.2	67.34	1,339.0	2,325,226
22	0.7	83.5	66.78	1,327.9	2,305,733
23	0.7	82.8	66.22	1,316.8	2,286,240
24	0.7	82.1	65.66	1,305.6	2,266,747
25	0.7	81.4	65.10	1,294.5	2,247,255
Total	**-**	**-**	**-**	**-**	**62,098,855**
Average	**-**	**-**	**71.88**	**1,429.2**	**2,483,954**

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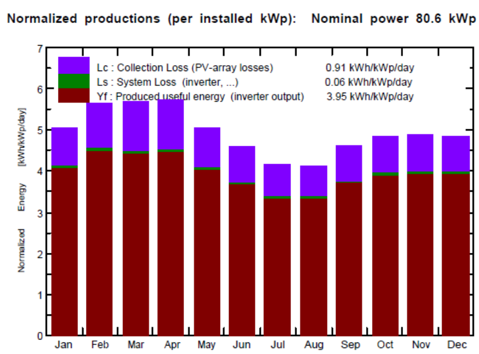
Grid-Connected System: Main results

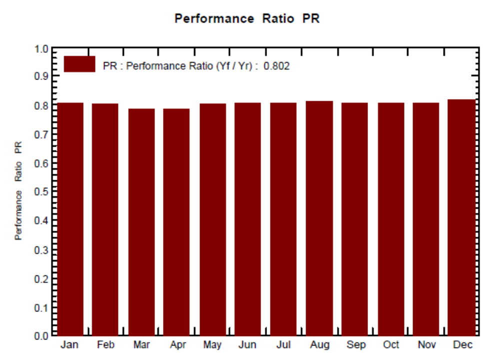
Project : **University of Phayao 2MW**

Simulation variant : **SC1-SC2**

Main system parameters System type **No 3D scene defined, no shadings**
PV Field Orientation tilt 20° azimuth -37°
PV modules Model TP672P-320 Pnom 320 Wp
PV Array Nb. of modules 252 Pnom total **80.6 kWp**
Inverter Model SUN2000_36KTL 400Vac Pnom 36.0 kW ac
Inverter pack Nb. of units 1.8 Pnom total **63.0 kW ac**
User's needs Unlimited load (grid)

Main simulation results
System Production **Produced Energy** **116.2 MWh/year** Specific prod. 1441 kWh/kWp/year
Performance Ratio PR 80.17 %





SC1-SC2

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	133.0	46.81	28.00	156.5	148.1	10.36	10.20	0.808
February	141.8	56.12	31.00	158.2	149.4	10.35	10.19	0.799
March	168.3	74.30	34.00	175.9	166.1	11.31	11.13	0.785
April	173.9	78.58	35.00	171.4	161.7	11.00	10.83	0.784
May	165.6	89.35	33.00	156.7	147.0	10.25	10.10	0.799
June	145.8	83.40	32.00	137.5	128.8	9.05	8.91	0.804
July	138.7	73.77	31.00	128.9	120.9	8.51	8.38	0.806
August	134.2	80.75	30.00	127.9	120.0	8.49	8.36	0.810
September	135.2	71.71	30.00	138.7	130.9	9.13	8.99	0.804
October	139.9	68.38	30.00	150.1	141.7	9.91	9.75	0.806
November	128.1	52.58	29.00	146.4	138.0	9.68	9.54	0.808
December	124.9	46.55	26.99	149.6	141.3	10.00	9.85	0.817
Year	1729.4	822.30	30.82	1797.7	1693.9	118.04	116.23	0.802

Legends:
GlobHor Horizontal global 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

Fig. 7 shows technical design of the 2 MW Solar PV rooftop system.

2.3. Economic Analysis of the Power Plant

The following were the basis and the additional assumptions used in the economic analysis:

- Investment cost of the 2 MW Solar PV Rooftop power plant (include infrastructure and control building) is 100 Million Thai Baht
- Operation and maintenance cost per year is 0.50% of investment cost; 500,000 Thai Baht/ year
- The monetized benefit of this project includes only electricity saving. Other indirect benefits such as a practical laboratory for the university for training/learning, and the environmental benefits such as greenhouse gas emission reduction, were not included.
- Internal Rate of Return (IRR) is applied for a project lifetime of 25 years.
- There were eight scenarios considered for the sensitivity analysis as follows:

Table 2 Eight scenarios of economic analysis.

Scenario	System Performance Ratio (%)	Annual O&M (Baht)	Electricity Tariff Growth (%)	Discount Rate (%)	Degradation Rate in First Year (%)	Degradation Rate Since 2nd Year (% Per Year)
Baseline	80	500,000	1.89	-	2.5	0.7
Scenario 1	80	500,000	1.89	4.00	2.5	0.7
Scenario 2	80	500,000	1.00	4.00	2.5	0.7
Scenario 3	78	500,000	1.89	4.00	2.5	0.7
Scenario 4	78	500,000	1.00	4.00	2.5	0.7
Scenario 5	82	500,000	1.89	4.00	2.5	0.7
Scenario 6	82	500,000	1.00	4.00	2.5	0.7
Scenario 7	PVsyst	500,000	1.89	4.00	2.5	0.7
Scenario 8	PVsyst	500,000	1.00	4.00	2.5	0.7

The installation of the university solar PV rooftop system (500 kW) reduced also the demand from the PEA distribution system. The total reduction is 57,905 kWh per month resulting to r savings in electricity costs per year of 2,987,900 baht (calculated at electricity cost 4.3 baht per KWh).

If the installation cost of the system is 30 million baht (60 baht/watt), the payback period is 10 years. If the installation cost is 22.5 million baht (which is the actual investment cost for the system), the payback period is just 7.5 years.

Table 3 Economic Performance of eight scenarios.

Scenario	NPV (THB)	BCR	IRR (%)	Payback Period (Year)
Baseline	175,948,109	2.76	10.63	9.9
Scenario 1	68,526,560	1.69	5.84	12.6
Scenario 2	53,265,273	1.53	4.87	13.5
Scenario 3	64,118,120	1.64	5.49	13.1
Scenario 4	49,238,365	1.49	4.52	14.0
Scenario 5	72,935,000	1.73	6.19	12.3
Scenario 6	57,292,181	1.57	5.22	13.1
Scenario 7	68,343,552	1.68	5.84	12.7
Scenario 8	53,119,539	1.53	4.87	13.5

2.4. Electrification of Transport and other Energy Uses

With cheaper electricity generated on-site in the university campus from the solar PV rooftop system, further energy cost saving measures can be adopted by electrifying other energy uses such as transport. The university adopted electric shuttle busses and as such, saved on petroleum fuel costs. This has also contributed to more reduction in greenhouse gas emission, which was contributed from the transport sector.

2.5. Environmental Benefits

Using solar power generation system produces a carbon footprint throughout the service life of the solar PV power plant in the range of 15.8 g to 34.8 g of carbon dioxide equivalent per 1 kWh of electricity produced from the system (g CO_2-eq / kWh).

However, this depend on the type of solar panel installed. The use of the solar rooftop PV power plant by the university has reduced the carbon footprint of electricity use by the university to 15.8 g to 34.6 g CO_2eq per kWh of electricity produced. If the Multi-crystalline silicon cells are used, the carbon footprint will be 27.2 g CO_2-eq/kWh.

The carbon footprint or emission factor for total electricity generation in Thailand is 561 g CO_2 / kWh. This total carbon footprint for the electricity sector of Thailand, include a 4.9% share of PV power generation in the total national electricity supply mix.

Installation and use of the solar power generation systems, replaces fossil fuel use, which can greatly reduce carbon emission and thus, the rate of global warming.

2.6. Education, Training & Promotion

The installation and use of the solar PV rooftop power generation system within the university helped in raising awareness among the students and the staff of the university about solar PV systems and renewable energy in general. The solar power plant installations allowed interested students to learn and study about the solar PV design and installation process. This has created a new career path for the students.

The solar power generation system was also useful to the university in using the media and in conducting public relations activities, to promote energy conservation and the use of renewable energy. The plant was also useful in creating awareness and understanding on reducing global warming and about climate change and its impacts. Study tours were hosted for the public, private sector groups, government agencies, particularly for those who are interested in supporting the benefits of solar power plants.

3. Recommendations

3.1. Steps in the Installation of Solar PV Rooftop Systems

Based on the experiences gained from this project, the steps and processes, which may need to be undertaken in installing a solar PV rooftop power plant in a university, are shown in the diagram below. The paper recommends to consider the following these steps in the design and installation of a solar PV rooftop power plant to provide local decentralized solar PV electricity supply systems for a university campus:

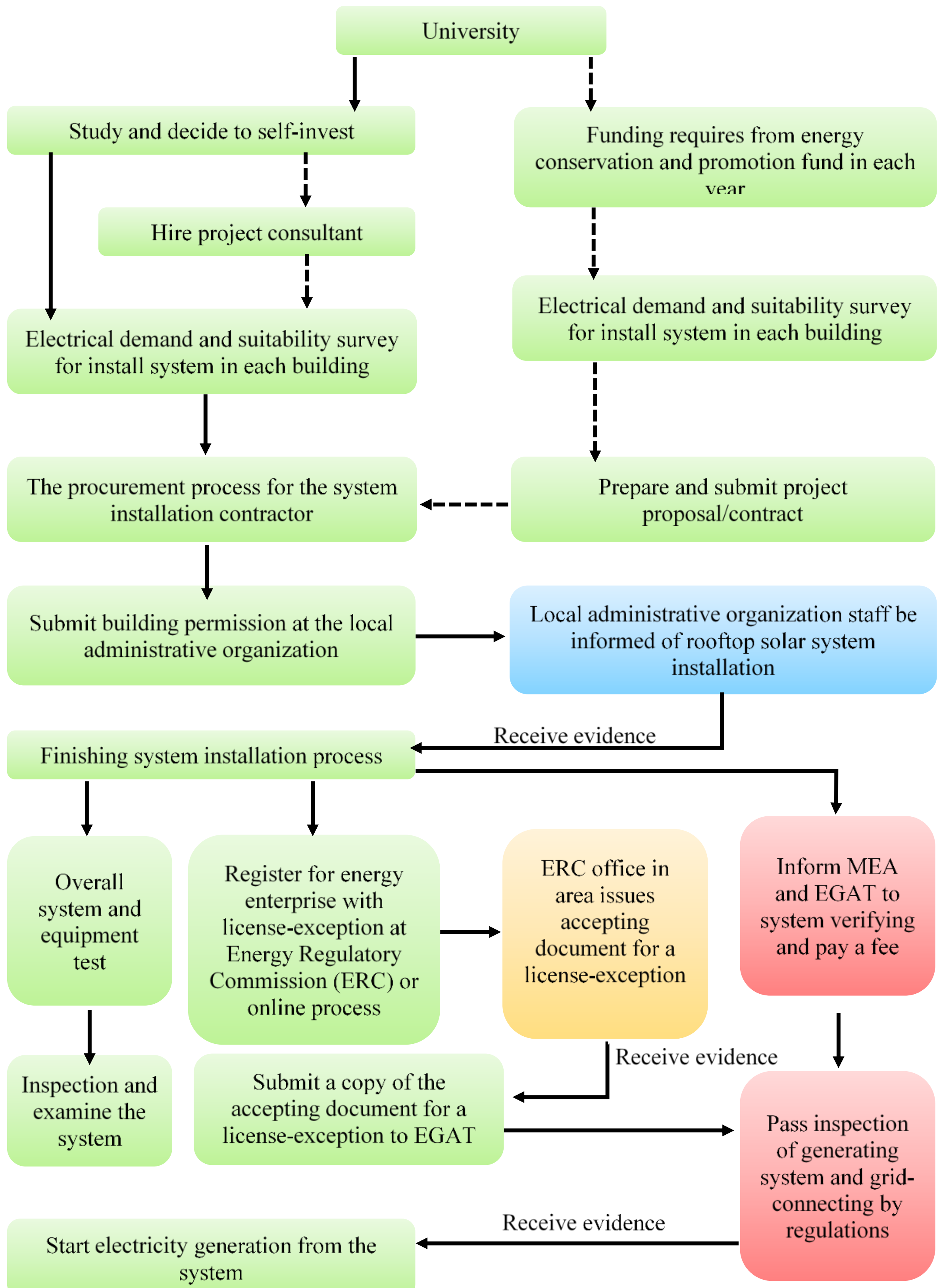


Fig. 8 Diagram showing steps and processes in preparing the installation of the solar power generation system in the university.

3.2. Factors in Installation & Operation of Solar PV Rooftop System

3.2.1. Electricity Consumption Pattern

This is one the primary factor to be considered in determining the designed capacity of the solar rooftop PV power system and in developing a micro-grid management system, through smart grid technologies, to allow prosumer operations. Adoption and the management of a smart grid to allow prosumer operations to improve the economic performance of the power system, is another key objective of this demonstration project on solar PV rooftop system in the university.

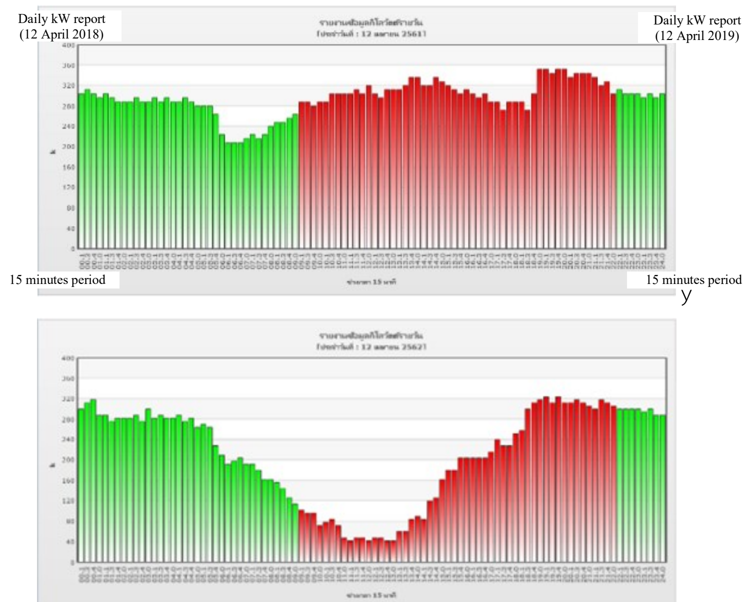


Fig. 9 Comparison of the power demand (kW) from PEA's distribution system before and after installation of the 500 kW system in the University of Phayao (left graph) before installing the system on 12 April 2018, and (right graph) after installation and use of the system on 12 April 2019.

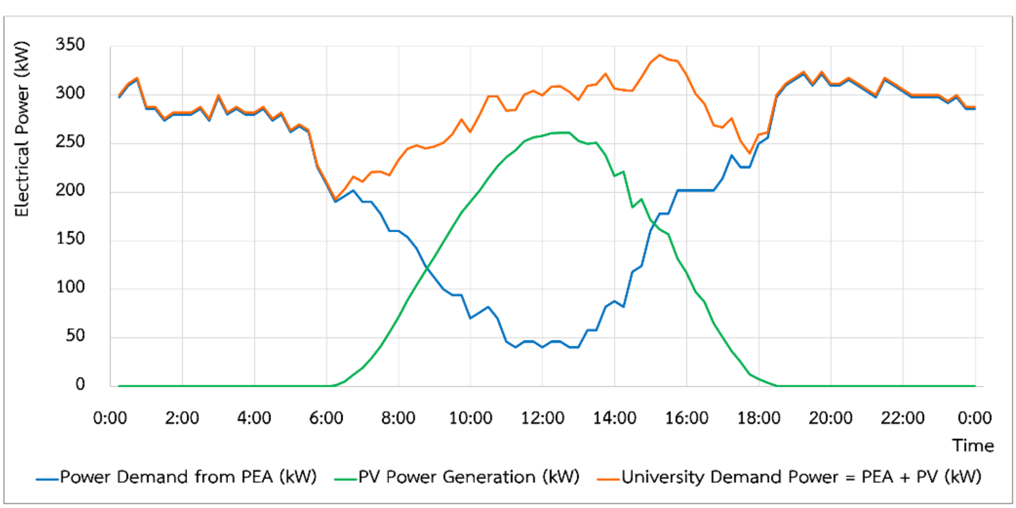


Fig. 10 Comparison of the power demand (kW) from PEA's distribution system / installed power produced from the 500 kW at university in the north of Thailand.

3.2.2. Pattern Shapes of Building Rooftop

In installing solar panels, the direction of panels should be turned towards the south to get sunlight all throughout the day and generate electricity at full capacity. As such, the roof should be facing the south and the slope should not be over 60 degrees. A roof slope greater than 60 degrees will cause the panel to receive less than 20% solar intensity. A survey of roofs and their suitability of all buildings within the university to assess the size of the PV panel installation was conducted. The survey identified rooftop areas that can be shadowed by trees or by other buildings. The results of this survey were then considered in the assessment of electricity production from the solar PV panels.

3.3. Future Considerations – Use of Electric Vehicles

The university introduced the use of electric shuttle buses to replace the petroleum-fueled buses. This has shown the potential for larger energy savings, and greater reduction of CO_2 emission and global warming if applied widely. The overall car market in Thailand in 2019 is expected to expand only 1.8%, but the electric vehicles market may expand by 61%, with total sales 32,000 - 37,000 vehicles. It shows the beginning of the transition to the electrical vehicle society of Thailand. For the world car market, it is expected that in the next 20 years, electrical vehicles will have a s share of more than 50% of all cars and that e the number of electrical vehicles use worldwide will be between 150 - 500 million vehicles.

If the cost of solar PV power continue to decrease and more solar PV power plants are installed to power electric vehicles, the energy cost savings and the reduction of carbon dioxide emissions from transport energy use can really be significant.

4. Conclusion

Solar power generation systems installed on rooftops and connected to the grid can be an important infrastructure for a university to save on their electricity costs and help reduce their overall operating cost. The economic analysis showed that for this solar PV rooftop power plant, the payback period can be 7.5 years, which can be made lower as solar panel costs are getting much cheaper. They also provide on-site real-life laboratory that can be used for teaching and learning. They also provide actual demonstration of the operation and benefits of the solar rooftop power plant that the university can use for media and public relations campaigns to promote energy saving, renewable energy use and also, awareness about reducing global warming and promoting climate action.

Further reduction of CO_2 emissions was also demonstrated by the university by shifting to electric shuttle buses, thus eliminating the use of petroleum fuels in transport. Electricity to power the vehicles was supplied by the solar PV rooftop system. The solar rooftop PV power plant is a renewable energy source and as such, it reduces the carbon dioxide emissions of energy use in the transport sector by the university and help reduce global warming.

With the installation of the solar PV rooftop power plant, the university has begun to undertake other activities and initiatives towards climate actions, which also contribute to sustainable development goals. The solar PV rooftop power plant has become a training base and learning center for the university to promote not only on-site decentralized solar PV systems and electric vehicles, but also new emerging technologies for sustainable development such as green buildings, that are part of "smart city" wherein electricity trading/exchange of energy between residences and business/public buildings – which have become electricity prosumers - are promoted. These are the additional areas of research, development and technology promotion that the university is looking now and into the future.

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