Simulation and Economic Analysis of Photovoltaic Rooftop System on the Female Dormitory

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Abstract. Solar energy is an ordinary type of renewable energy accustomed to produce electricity. However, the photovoltaic system may confront risks and uncertainties for operation. King Mongkut©s University of Technology North Bangkok, Rayong campus (KMUTNB), situated in an area which is suitable for photovoltaic installation, plans to expand their alternative energy proportion. This research focuses on the design and economic feasibility of the photovoltaic rooftop system on the female dormitory. By using the System Advisor Model (SAM) program simulation, the total capacity of the panels is found to be about 198.23 kWp with a total electricity production of about 281.827 MWh per year. The economic results revealed that the photovoltaic rooftop system has the potential to produce electricity at a competitive price. The cost of energy is obtained for 0.1297 USD per kWh throughout the project's life, meaning that the project would serve as a means of reducing 3,535.7327 tons of carbon dioxide equivalent.

1 Introduction

Population growth and economic development leads to an increase in energy consumption from human life and industrial production, causing the government to provide sufficient energy sources to cover their local demand [1]. In terms of electricity, the energy supply is, therefore, the main basis for national development which is heading for lighting and production process in the industry. The main component of electricity production in Thailand is natural gas and its price fluctuates based on world oil prices. It will have to bear the high cost of production even if Thailand has some resources used to produce electricity, but it is not enough for domestic demand. Importing electricity from neighboring countries is one opportunity, nevertheless, it is a security risk in energy management coming about the energy crisis [2].

Renewable energy, therefore, plays an essential role in the mitigation of energy shortage and carbon dioxide emission. The production gases from fossil fuel combustion are the main reason for the greenhouse effect which conduces to global warming and environmental impacts [3]. By the electricity industrial structure, although Thailand has high renewable energy potential such as solar energy, wind energy, biomass, and so on, Thailand still has a small proportion of renewable energy usage for electricity generation compared to developed countries [4]. The government encourages the use of renewable energy sources for electricity production to reinforce economic and energy security for the country [5].

Solar energy is more common than other types of renewable energy, corresponding to the solar intensity potential with approximately 17 to 20 MJ/m^2 day [5]. The photovoltaic system for an electricity generator is a worthwhile way to reduce energy costs [6], however, the photovoltaic system may be subject to risks and uncertainties in the processes such as a lack of sunlight for generating electricity, operation and financial risk [5]. This research aims to introduce the photovoltaic system at King Mongkut's University of Technology North Bangkok, Rayong Campus (KMUTNB) as a way to discover the potential of electricity generation, to assess the economic feasibility, and to calculate the potential of carbon dioxide emission reduction. The results of the analysis can produce guidelines for the planning of an increase in renewable energy usage proportion and to determine the appropriate decisions taking into account energy and environmental sustainability.

2 The Female Dormitory at KMUTNB, Rayong campus

2.1. Location

The female dormitory is represented by the building models of KMUTNB, Rayong campus. For economics analysis of the solar rooftop installation, the physical data must be collected from the location of the female dormitory taken from Google Earth™ with coordinates 12˚41'49˚N 101˚03'13˚E. The location and pictures of the female dormitory are shown in Figure 1.

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Fig. 1. The female dormitory map, left is location generated from Google Earth™ and right is pictures on real location.

2.2. Determination of Effective Roof Surface Area

Area of the female dormitory is determined using Google Maps™. The effective roof area for mounting of PV modules is estimated from a blueprint and direct measurement. The real picture is shown as Figure 2.

Fig. 2. Roof of the female dormitory used in simulation and the orientation of PV panels.

The shading factor is one of the parameters considering PV system performance. This research chooses the 3D Sun-Path software to access overall shading for four seasons of the year. The 3D Shade Calculator program in System Advisor Model (SAM) [7] is applied to calculate shading loss every sixty minutes from active surface areas. The shading simulation is shown in Figure 3.

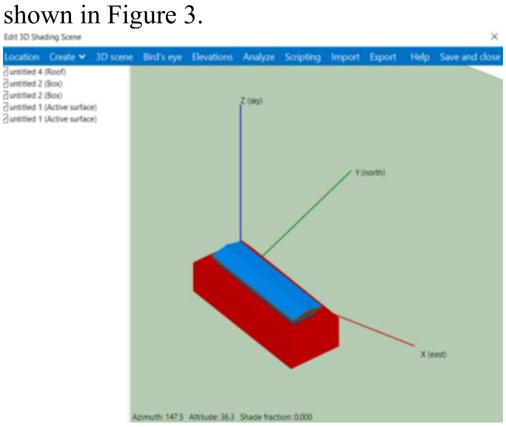

Fig. 3. The shading simulation of the female dormitory generated by 3D Shade Calculator program.

The active surface areas are divided into two parts. The first orients at 20-degree azimuth and another orients at 200-degree azimuth. Each of the roofs is tilted at 11 degrees from the horizontal.

3 Methodology

3.1. Grid-Connected PV System Simulation

The grid-connected PV system is simulated using the System Advisor Model (SAM). Each side of the roof surface areas are used as much as possible for mounting of PV panels aligned to the roof tilt and orientated for the female dormitory. The technical parameters i.e., ground coverage ratio, DC wiring losses, and system degradation rate are given in the default values from the software database. The solar radiation and air temperature are based on Typical Meteorological Year data information (TMY 2007 to 2016) from the Photovoltaic Geographical Information System by the European Commission [8].

3.2 Economic Analysis

Economic analysis is a process in which the strengths and weaknesses of the project’s performance are assessed. The technical performance, energy yield and performance ratio including energy production are common parameters for PV system evaluation. The analysis of PV rooftop system performance was carried out by SAM software.

3.3 Greenhouse Gas Emission Reduction

Emissions of greenhouse gases (GHG) arising from human activities are a very considerable driver of observed climate change leading to a global warming situation. Alternative energy, notably solar energy, is one way to reduce GHG emissions from traditional electricity production. For the calculation of the quantity of GHG gas emission reduction, this parameter compares the electricity from the solar system (E_{Solar}) with carbon dioxide emissions in terms of Grid Emission Factors from conventional electricity generation ($EF_{Grid,y}$) is shown in (1) where ($EF_{Grid,y}$) is Thailand Grid Emission Factor for solar energy production project which is equal to 0.5664 tCO_2/MWh [9].

$$CO_{2\ \text{emission reduction}} = E_{\text{Solar}} \times EF_{\text{Grid,y}} \quad (1)$$

4 Results and Discussion

4.1. Energy System Design and Production

The solar energy resources and the meteorological data at KMUTNB, Rayong campus are shown in Table 1. This data taken over a year period from PVGIS, reveal the total value of global horizontal radiation was 1,858.9 kWh/m^2. The total of diffuse horizontal radiation was 853.91 kWh/m^2. Also, the average air temperature was 27.9 °C.

Table 1. The average monthly radiation and air temperature.

Interval beginning	GlobHor kWh/m².mth	DiffHor kWh/m².mth	T Amb °C
January	166.9	59.86	26.8
February	162.0	59.69	27.1
March	194.1	72.66	28.9
April	174.7	73.99	29.4
May	147.7	78.24	28.6
June	150.7	78.58	28.7
July	154.2	78.81	27.5
August	146.9	82.85	27.8
September	141.2	75.81	27.6
October	125.3	71.10	26.9
November	134.2	64.80	27.4
Year	1858.9	853.91	27.9

The global radiation was significantly higher during January to April, while the monthly radiation is significantly overlooked with diffuse components from March to October. It can be identified that dry season is during January to April, and rainy season is during May to September, such as it regularly followed in this region.

The model outcomes indicate that the daily average of global radiation was 5.09 kWh/m^2, while the daily average of scatter radiation was 2.34 kWh/m^2. The air temperature was found to vary from 26.8 – 29.4 ˚C.

Although the season period is faithfully associated to the PV application, it is likely unstable caused by global warming or climate change.

The PV module and inverter specification calculated the system performance and economic analysis are shown in Table 2. The PV system use multi-crystalline silicon module from Suntech Power Company Model STP330-24/Vfw with the area value 1.94 m2 and the capacity amount 330.38 watts. The inverter from Huawei Technologies Company Model SUN2000-100KTL has capacity amount 100 kW with 880 – 1,200 voltage.

Table 2. PV module and inverter used in the analysis.

PV Module	
Model	SunTech Power STP330-24/Vfw
Cell Material	Multi-c-Si
Module Area	1.94 m^2
Module Capacity	330.38 DC kW
Efficiency	16.9 %
Inverter	
Model	Huawei Tech SUN2000-100KTL
Unit Capacity	100 AC kW
Input Voltage	880 – 1200 v DC
DC to AC Ratio	0.99
AC Losses	2 %

The total area of the female dormitory's roof of KMUTNB, Rayong campus was found about 1,164 m^2 for panels' installation. From the area value of PV module, the total quantity is 600 modules with total capacity of rooftop installation found about 198.23 kWp. So, the 100-kW capacity of inverter is used for this system amount 2 devices.

Then the Sketch-up software application is used to draft and generate the dormitory model for calculation. The effective surface area for PV panels depends on various dimension and specification [10]. Thus the simulation is beneficial for considering PV rooftop installation. Figure 4 is shown as a real picture comparing with an effective surface area generated by the software.

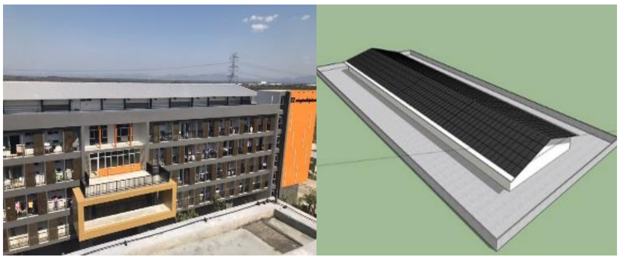

Fig. 4. The real picture of the female dormitory comparing with the simulated rooftop.

The annual energy production as of PV system simulation at KMUTNB, Rayong campus is presented by Figure 5. The energy production at first year is 281,827 kWh and performance ratio is 0.77. Additionally, the energy yield at first year is 1,421.72 kWh/kW.

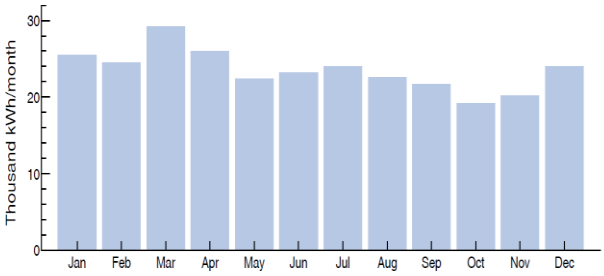

Fig. 5. Monthly energy production.

4.2. Economic Analysis

The benefit and cost of the PV rooftop system to be installed are shown in Table 3. The total revenue throughout project life from electricity saving is 1,355,534 USD. The installed cost is 178,916 USD. The total operating expense is 96,925 USD. The construction loan is 100% of installed cost with 6.3145% of interest rate and 30% of annual tax rate.

Table 3. Benefit and cost analysis of PV rooftop system.

Benefit (USD)	
Electricity Saving	1,355,534
Cost (USD)	
Installed Cost	178,916
Operating Cost	96,925

The project analysis based on the benefit and cost of electricity production from the PV rooftop system with 25 years of project lifetime, annual discount rate around 6.31%, and the power purchase agreement (PPA) price is 0.193 USD/kWh. The economic performance is analysed using five parameters such as payback period (PP), net present value (NPV), internal rate of return (IRR), benefit cost ratio (BCR), and cost of energy (COE).

Table 4. The PV Rooftop system analysis.

Economic Analysis	Value
Payback Period	4.28 years
Net Present Value	257,110 USD
Internal Rate of Return	19.21 %
Benefit Cost Ratio	2.08
Cost of Energy	0.1297 USD/kWh

Table 4 depicts the economic analysis outcomes. The annual cash flow becomes positive in the fifth year, so the payback time of the system is 4.28 years. The NPV over the project lifetime is found as 257,110 USD and the IRR at the end of project is 19.21%. Additionally, the BCR is calculated as 2.08. Finally, the levelized COE is 0.1297 USD/kWh.

In accordance with the value, it has been seen that the PP is high when compared with the discounted cash flow, the NPV is relatively small but it is positive. The IRR is higher than in many other projects which on average show an IRR of about 15%. The BCR have a value more than 1. These reveal that the PV rooftop system simulation is a cost-effective investment, although it handles the bank loan throughout project. Nevertheless, a low value of the levelized COE points out that the project has economical value for investment.

4.3. GHG Emission Reduction Analysis

Electricity generation using PV system is a clean method which does not emit greenhouse during operation. GHG emission reduction can be use Thailand Grid Emission Factor for solar energy production project following the equation 1. The amount of first year GHG emission reduction is 159.6268 tCO_2 and the overall GHG emission reduction is 3,535.7327 tCO_2.

5 Conclusions

This research presents design and economic analysis of PV rooftop system on the female dormitory at King Mongkut's University of Technology North Bangkok, Rayong campus. The simulation outcomes show that the system capacity is 198.23 kWp. The overall energy production is 6,242,466 kWh with energy yield in first year around 1,422 kWh/kW. The low value of levelized COE indicate that high potential for increasing in production capacity. The economic evaluation is in a good condition that supporting the project sustainability. Furthermore, GHG emission is a measure of global warming while the project can be reduced to 3,535.7327 tCO_2. It can be and therefore it is concluded that this project can improve energy stability and be environmentally friendly.

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