

Original Research Paper

Feasibility Study on Solar Power Plant Utility Grid under Malaysia Feed-in Tariff

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Abstract: In Perlis, Northern Malaysia, a solar power plant with an energy capacity of 5 MWp began selling energy to Tenaga Nasional Berhad in January 2013. Upon obtaining Feed-in Tariff approval from the Sustainable Energy Department Authority of Malaysia, the power plant will produce energy with a Feed-in Tariff of RM 0.874 for every kWh for 21 years according to the Renewable Energy Power Purchase Agreement. However, the output of solar plants is unpredictable. Investors commonly estimate the output of solar PV power generation from simulation results based on irradiation data proposed in simulations. However, estimates of potential solar generation from simulated analyses may not be accurate and thus exert negative financial impacts to investors. Therefore, comparing estimated output results from simulations with the actual output from solar PV power generation is important. The aim of the present study is to identify the error between the simulation and actual performance of solar PV power generation over the twelve months of 2013. Sensitivity analysis of Feed-in Tariff degression was also performed to study the impact of the performance error on the economic aspect of energy generation.

Keywords: Solar Power, Plant Utility Grid, Feed-In Tariff, Malaysia

Introduction

The environment and energy crises are major issues worldwide. The release of greenhouse gases, especially CO₂ from power generation using coal, gas and steam, depletes the ozone layer and creates more pollution. Shortages in fossil fuels and increasing energy demands also contribute to the energy crisis. The world depends on fossil fuels as primary sources of energy. Some projections indicate that the global energy demand will triple by 2050 (MP, 2011). Globally in 2010, 86.9% of the total energy usage involved fossil fuels, where 33.5% of the energy usage was from crude oil, 23.8% was from natural gas and the remaining was from coal. On the other hand, 5.22% was from nuclear energy, 6.46% was from hydroelectric energy and 1.3% was from renewable energy (BP, 2011).

In Malaysia, the Primary Energy Demand (PED) is represented by natural gas 60.3%, coal 30.4%, hydroelectric power 5.4% and crude oil 1.1% (Daud, 2010). Major concerns in using fossil fuels as primary energy have been expressed. GHG emissions and fossil

fuel depletion, for example, are among the major issues in fossil fuel usage. In Malaysia, researchers estimate that 339 million tons of CO₂ will be produced by 2030. According to the APEC (2009), the energy sector is the biggest contributor of CO₂ emissions (GHG, 42%) to the atmosphere at, followed by the transportation sector (28%) and the industrial sector (20%). The Malaysian government has grown increasingly concerned about GHG emissions and fossil fuel depletion. When the energy demand increases, GHG emissions and the demand for fossil fuels increase accordingly. In 2009, Malaysia introduced the National Green Technology Policy, which is designed to mitigate issues of security, energy efficiency and environmental impact while addressing the rising energy demand.

Given that environmental protection concerns are increasing worldwide, both new energy and clean fuel technologies are being intensively pursued and investigated. Most renewable energy sources, including wind, micro-hydro, tidal, geothermal, biomass and solar, are converted into electrical energy for delivery either directly to the

utility grid or to isolated loads (Canale *et al.*, 2009; Mercure and Salas, 2012).

Solar energy technologies, including solar heating, solar Photovoltaic (PV) cells, solar thermal electricity and solar architecture can make significant contributions toward solving some of the most pressing energy problems currently faced by the world. PV technology has been proven to generate electricity from solar energy easily. Malaysia is a country in which renewable energy is widely promoted because of its tropical location. The country receives an average solar irradiation of 400-600 MJ/m² per month and thus has potential for establishing large-scale solar power generation plants (Mekhilef *et al.*, 2012).

The solar potential and Feed-in Tariff (FiT) rate offered by the Malaysian government to energy producers is expected to attract more investors to the renewable power generation sector, which in turn will help the government achieve its objective of promoting clean technology. The Malaysian government is keen to develop solar energy as a significant source of energy in the country. According to the 10th National RE Goals, a large allocation of funds has been allocated to the implementation of solar PV systems, as shown in Fig. 1.

The size of a power supply system exerts an important function when generating electricity in far-flung areas at a reasonable price. PV systems and other renewable energy systems are excellent options for producing energy at low-to-medium power levels in remote areas because of easy scaling of the input power source (Chamboulegron, 1986; Enslin, 1990). The main feature of PV systems is that they can produce electric power without harming the environment. PV systems achieve this by directly transforming a free inexhaustible source of energy, namely, solar energy, into electricity.

Continuing decreases in the cost of PV arrays and increases in their efficiency also promote the use of PV generating systems (Zweibel, 1990; Hussein *et al.*, 1995).

PV systems may be categorized as a grid-connected PV systems, stand-alone PV systems, or building systems. In grid-connected applications, DC power from solar cells runs through an inverter, which feeds the power back into the distribution system. Grid-connected systems have proven their worth in natural disasters by providing emergency power capabilities during utility power interruptions. While the PV power generated by this type of system is generally more expensive than utility-provided power, the use of grid-connected systems is increasing (Penick and Louk, 1998; Quesada *et al.*, 2011). Various technologies, such as silicon PV (crystalline silicon and nanocrystalline), thin film solar cells (amorphous silicon, cadmium telluride, gallium arsenide and copper indium gallium deselenide) and concentrated PV (multifunction cells), are used to produce PV cells. Of these technologies, researchers have found that multicrystalline outputs and monocrystalline cells have the highest output range (between 12 and 17%) (Sick and Erge, 1996).

PV systems are known to present varying seasonal patterns that depend on temperature and solar irradiation. PV system outputs vary because of the different temperature coefficients of the voltage and current output. To simplify the work of manufacturers, PV modules are rated at standard test conditions of a solar irradiation of 1000 Wm⁻², fixed spectrum and sun-spectrum at air mass of 1.5 (AM = 1.5). The electric power generated by a solar PV array fluctuates depending on the operating conditions and a number of field factors, such as the sun's geometric location, irradiation levels and ambient temperature (KeTTHA, 2011).

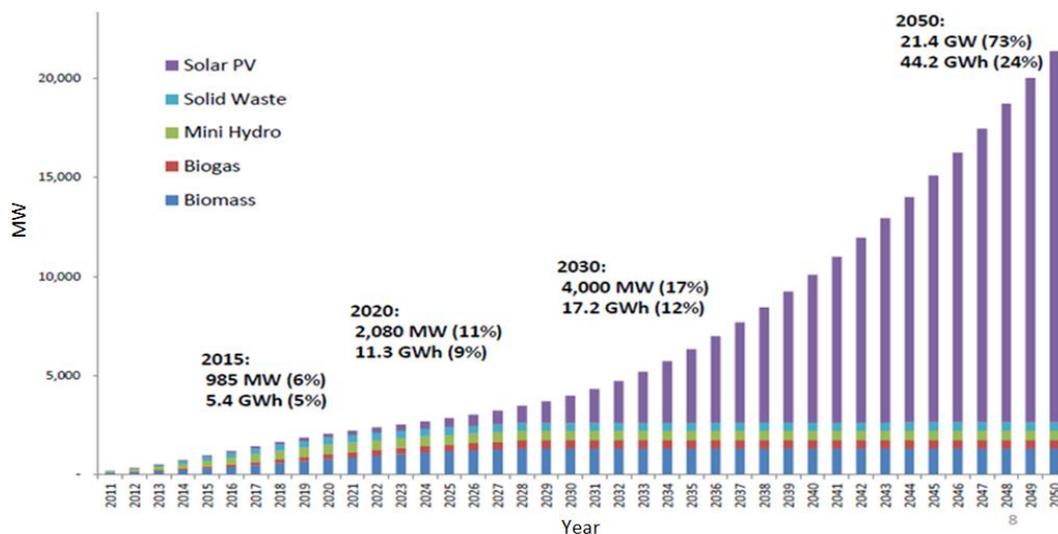


Fig. 1. National renewable energy Goals of the Sustainable Energy Development Authority (SEDA) (Source: Sustainable Energy Development Authority Malaysia)

The study initially reviewed the performance of previous solar PV power generation systems but found that a large number of studies on this topic and a detailed review are beyond the scope of this research. Mondal and Sadrul Islam (2011) conducted a case study in Bangladesh where they identified the potential location of grid-connected solar PV in 14 districts. The study analyzed the feasibility of 1 MWp solar PV using HOMER optimization software. However, this study was discontinued because of very high investment costs. Thus, a comparison based on actual performance and the results of simulation analysis could not be performed to confirm findings.

Another solar PV performance analysis was conducted by Sharma and Chandel (2013). Performance analysis of a 190 kWp solar PV power plant installed in Khatkar-Kalan, India, was carried out and simulation estimations were found to be in close agreement with the actual measured results with an uncertainty of 1.4%. This estimation was performed using PVSYST software. Detailed analysis of the plant's economic feasibility, however, was not performed.

To promote green energy, many countries have introduced the concept of Feed-in Tariff (FiT) for renewable energy. The FiT scheme has been proven successful in accelerating RE deployment, reducing carbon emissions and creating jobs in different countries, such as Germany, Italy, Spain and Thailand (Chua *et al.*, 2011). FiTs are RE payments of electricity in kilowatt-hour (kWh). FiT promotes exportation of electricity as a form of investment. The concept of FiT, according to the Ministry of Energy, Green Technology and Water, obliges Distribution Licensees (DLs) to buy the electricity produced from renewable sources from feed-in approval holders and sets a feed-in rate. DLs thus pay for each unit of renewable electricity supplied to the grid for a specific duration (GPS, 2012).

FiT was introduced to encourage more people to invest in renewable energy sources. The introduction of FiT is set to change Malaysia's electricity production through RE. Domestic and industrial users will be able to generate renewable electricity (i.e., solar power) through RE and sell it back to the national power grid at a premium rate (NEB, 2008). Solar PV power generation is still new in Malaysia and thus requires a large initial investment.

Therefore, feasibility studies focusing on the economic impact of the initial costs of solar PV power are necessary. The first solar power plant under the FiT scheme was inaugurated on March 28, 2012 by Cypark Resources Berhad. The power plant had a total investment of RM 100 million and a capacity output of 8 MWp (GPS, 2012). With the successful construction of this solar power plant, the Malaysian government achieved a significant milestone in promoting clean energy in the country. Given that the development of

large solar power sources in Malaysia requires large investments and that solar generation power plants under the FiT scheme are a new concept, prospective investors were initially doubtful. The fact that case planning-based simulations were not completely parallel with actual expectations also caused doubt. In the present study, we analyzed differences between simulation analysis results and actual production to identify sources of discrepancies. By identifying the difference percentage, investors are likely to feel more confident about investing in the renewable energy generation sector of Malaysia. The study objective is to determine the technical and economic feasibility of solar power plant generation in Malaysia.

Methodology

In this study, the solar PV power plant, located in Perlis, Malaysia (latitude 6°24' North and longitude 100°8' East), uses poly-crystalline panels, as shown in Fig. 2. An install capacity of 5 MWp was used as the case study. Information for economic analysis, such management planning stage and price of materials (e.g., solar PV modules, inverters and land acquisition), was gathered from a consulting solar PV company (Mega Jati Consult Sdn. Bhd). The FiT rates in Malaysia are shown in Table 1.

Several design tools to model and simulate the performance of PV power generation systems are available in the market. The present study was implemented so that actual results can be compared with the analysis of simulation software. The study also presents an overview of the extent of GHG emissions and economic impact of a degression of 8% per year of FiT, as offered by Malaysia. By studying FiT degression, an indicator of future investments in RES in Malaysia may be obtained to ensure that the objectives of the country are achieved.

Simulation software has been developed to estimate the performance of a solar power plant and assist system designers and installers (Henrion *et al.*, 2013). HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone and distributed generation applications (Homer Energy). Three main tasks can be performed by HOMER: Simulation, optimization and sensitivity analysis. HOMER was developed by the United States National Renewable Energy Laboratory and is specifically designed to analyze and optimize renewable energy industry systems, as applied by (Mondal and Sadrul Islam, 2011; Bhattacharjee and Dey, 2014).

HOMER is mostly used for studying, sizing and analyzing the performance of PV grid-connected systems. It is useful for determining several aspects in terms of finance, such as net present value and cost of energy.



Fig. 2. Solar power plant (Perlis, Malaysia)

Table 1. FiT rates

Renewable energy	Installed capacity (Mwh)	Cost (RM)	Effective period (Years)	Annual degression rate
Solar PV	5	0.874	21	8%

The variation of input parameters, such as FiT or solar radiation can be performed to identify the different outputs for each input. In this study, HOMER was used to predict the total monthly and yearly energy output of a 5 MWp grid interactive component of the PV plant.

The study is divided into two parts: The technical analysis and the economic analysis. The difference between the actual and simulated PV outputs of the solar plant was examined and analyzed to identify the error. Cost analysis refers to the total system cost, which includes initial and maintenance costs. The annual cost was calculated to determine the life cycle cost and payback period. All costs were based on real prices used in the development of the solar power plant.

Technical Analysis

Measurement of Actual Data

The actual data, such as solar radiation and energy production, were collected based on site measurement to compare the actual performance of the system against HOMER simulation. The solar PV power plant was equipped with the latest Supervisory Control and Data Acquisition System (SCADA), as shown in Fig. 3.

Parameters such solar radiation and electrical energy production were recorded and averaged at 15 min intervals by the data logger. The recorded data were stored in a computer system using an RS232/RS485 peripheral interface with a SCADA communicator through a computer.

Simulation Data

Solar Radiation

Solar radiation is radiant energy that can be converted into electrical energy by solar PV panels. This

parameter input was important to ensure the success of solar PV power generation because every location on earth receives different amounts of solar radiation. In HOMER, the data were generated by adding the latitude and longitude of the solar plant location.

Modeling of the Solar PV Power Generation

In this study, the SEDA-approved grid connected to the solar PV system was 5 MWp. All of the energy produced by the solar PV power plant was injected into the grid system without any limit from the utility provider (Tenaga Nasional Berhad). HOMER simulation was based on the maximum output and all electrical instruments, such as the solar PV and inverter, were calibrated accordingly to meet the maximum output (Fig. 4).

Solar PV Array

The kilowatt (kW) capacity was determined using HOMER. Based on a maximum output of 5 MWp, the size of the solar PV was 5 MW (Fig. 5). In terms of economic analysis, the capital cost for the solar PV was RM 38,550,048.00. The projected cost covered all components except for the inverter. Other parameters considered in this study were slope degree, derating factor, ground reflector and solar PV lifetime; these parameters were proposed by HOMER.

The cost of replacement was assumed to be the same as the initial costs. Another parameter to be considered is Operation and Maintenance (O& M), which is reflected by the salary of one Electrical Charge man amounting to RM 48,000.00 per year.



Fig. 3. SCADA system used for monitoring and recording purposes

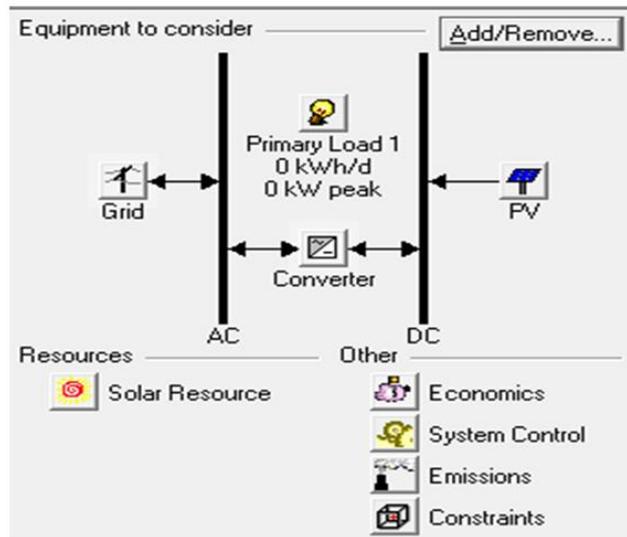


Fig. 4. Solar PV grid-connected system modeling by HOMER

Enter at least one size and capital cost value in the Costs table. Include all costs associated with the PV (photovoltaic) system, including modules, mounting hardware, and installation. As it searches for the optimal system, HOMER considers each PV array capacity in the Sizes to Consider table.

Note that by default, HOMER sets the slope value equal to the latitude from the Solar Resource Inputs window.

Hold the pointer over an element or click Help for more information.

Costs			
Size (kW)	Capital (\$)	Replacement (\$)	O&M (\$/yr)
5000.000	38550048	38550048	48000
(.)	(.)	(.)	(.)

Sizes to consider	
Size (kW)	
0.000	
5000.000	

Properties

Output current AC DC

Lifetime (years) (.)

Derating factor (%) (.)

Slope (degrees) (.)

Azimuth (degrees W of S) (.)

Ground reflectance (%) (.)

Advanced

Tracking system

Consider effect of temperature

Temperature coeff. of power (%/°C) (.)

Nominal operating cell temp. (°C) (.)

Efficiency at std. test conditions (%) (.)

Cost Curve

Fig. 5. Parameter input for solar PV generation

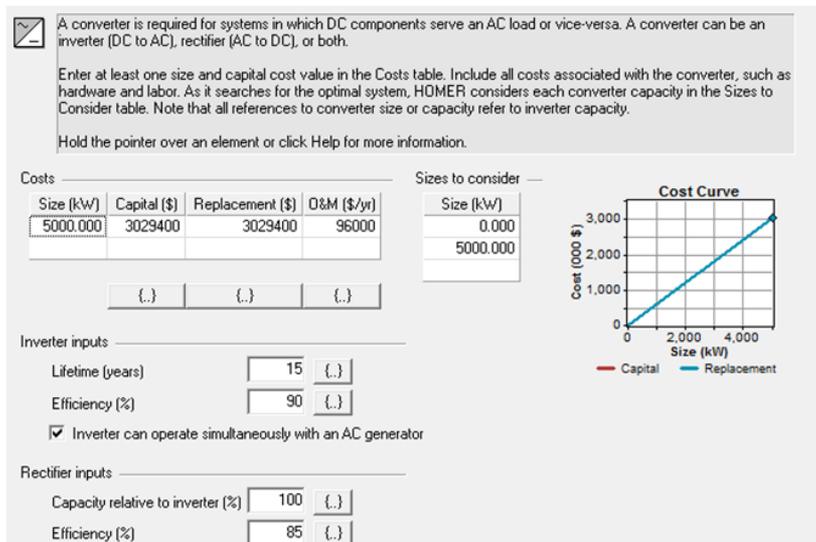


Fig. 6. Parameter inputs for the inverter

Table 2. FiT Rates in Malaysia (KeTTHA, 2011)

Description of qualifying renewable energy	Fit rates (RM per kWh)		
	2011	2012	2013
(a) Basic FiT rates having installed capacity of:			
Up to and including 4 kW	1.2300	1.2300	1.1316
Above 4 kW and up to and including 24 kW	1.2000	1.2000	1.1040
Above 24 kW and up to and including 72 kW	1.1800	1.1800	1.0856
Above 72 kW and up to and including 1 MW	1.1400	1.1400	1.0488
Above 1 MW and up to and including 10 MW	0.9500	0.9500	0.8740
Above 10 MW and up to and including 30 MW	0.8500	0.8500	0.7820
(b) Bonus Fit rates having the following criteria			
Use as installation in buildings or building	+0.2600	+0.2600	+0.2392
Use as building materials	+0.2500	+0.2500	+0.2300
Use of locally manufactured or assembled solar PV	+0.0300	+0.0300	+0.0276
Use of locally manufactured or assembled solar	+0.0100	+0.0100	+0.0092

Inverter Model

Given that the output signal from solar PV is DC current, installing the inverter to change the DC input to AC output before entering the grid system was necessary. Based on the maximum output from solar PV (5 MW), the inverter capacity was expected to be the same. The proposed lifetime of the inverter is 15 years. Another parameter proposed by HOMER was efficiency, which is 90%, as shown in Fig. 6. The cost for this inverter was RM 3,029,400.00.

Grid Model

HOMER can be used to model the system used in grid-connected or stand-alone systems. The capacity of this plant was above 1 MW and could reach 10 MW. The power plant began to sell energy on January 2013. The FiT approved by SEDA was RM 0.874, as per Table 2. To secure investments, all of the energy produced by the solar PV plant was allowed to enter the grid without any limit to maximize the income from solar generation.

Analysis of GHG Reduction

HOMER can simulate GHG reductions of the solar PV plant. In this study, the emission setting was proposed by HOMER. Emission factors for grid power were set by HOMER as 632 g/kWh for CO₂, 2.74 g/kWh for SO₂ and 1.34 g/kWh for N₂O. Based on GHG simulation results, these values were analyzed to study the CO₂ reduction target proposed by the Malaysian government, which is 145,000,000 tonnes by year 2030 (Mendoca *et al.*, 2009).

Economic Analysis

The economy presents a crucial function in the development of large scale solar power plants because of the complex interplay of incentives and various supply demand factors that impact the owner. The major components of the system cost include the price of solar panels, inverter and infra work. To analyze economic implications, the total investment required to create a

solar PV power plant must be determined. To ensure the adherence of our economic analysis to Malaysian economic conditions, actual costs must be obtained and real figures must be presented to investors. In the construction of solar power plants, the material cost of solar panels and inverters is not the only expense. Costs involved in mounting the structure, transformer and high-tension switchgear, as well as land acquisition or management costs, must also be considered. Malaysian Ringgit (1 MYR = 0.30 US Dollar) was used as the main currency for this study. The total actual cost obtained from investors was RM 41,579,448.10. Detailed prices are shown in Table 3 and Fig. 7.

The costs and benefits of the proposed solar PV system throughout its lifetime were analyzed and assessed by HOMER using the following financial indicators.

Net Present Value (NPV) represents the life cycle cost of the system. The calculation assesses all costs occurring within the project lifetime, including initial set-up costs, component replacements within the project lifetime, maintenance and fuel. Future cash flows are discounted to the present. HOMER calculated NPV according to the following Equation 1:

$$NPV (RM) = \frac{TAC}{CRF} \quad (1)$$

where, TAC is the total annualized cost (\$) (the sum of the annual costs of each system component). The Capital Recovery Factor (CRF) was calculated as:

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

where, N is the number of years and “i” is the annual real interest rate (%).

Cost of Energy (CoE) is the cost of generating electricity. The Life Cycle Cost (LCC), unit cost and payback period criteria were used and the LCC was obtained using the formula below:

$$LCC = C_{capital} + C_{O\&M} + C_{replacement} - C_{salvage} \quad (3)$$

The capital cost ($C_{capital}$) of a project includes the initial $C_{capital}$ for the equipment, system design and installation. The $C_{capital}$ is usually considered as a single payment made on the first year of the project. The maintenance cost ($C_{O\&M}$) is the sum of all O&M costs incurred yearly. Examples for O&M costs include operator salary, inspections, insurance and property tax. The replacement cost ($C_{replacement}$) is the sum of equipment replacement costs incurred over the lifetime of the system. A good example of a $C_{replacement}$ expense is the battery, which requires replacement once or twice during the entire lifetime of the system.

These costs normally occur at specific predicted years and the entire cost is often covered by the predicted yearly expenses. Finally, the salvage value ($C_{salvage}$) of a system refers to its net worth in the final year of the life-cycle period. Assigning a $C_{salvage}$ of 20% of the original cost for mechanical equipment that can be moved is a common practice. The $C_{salvage}$ can be modified depending on other factors, such as obsolescence and equipment condition [46]. After calculating the LCC, the unit CoE produced by the system can be calculated as follows:

$$CoE = \frac{LCC}{\sum_1^n E_{pv}} \quad (4)$$

Table 3. Detailed cost for 5 MWp solar power generations

Description	RM	(%)
Management cost	3,694,156.70	9
Land acquisition	2,200,000.00	5
Building, infra and civil work	13,312,500.00	32
Solar modules	12,100,000.00	29
Inverters	3,029,400.00	7
Installation cost	5,423,244.50	13
Electrical equipment and Assc	1,363,574.90	3
Others (Legal Fees/General)	456,572.00	1
Total	41,579,448.10	100

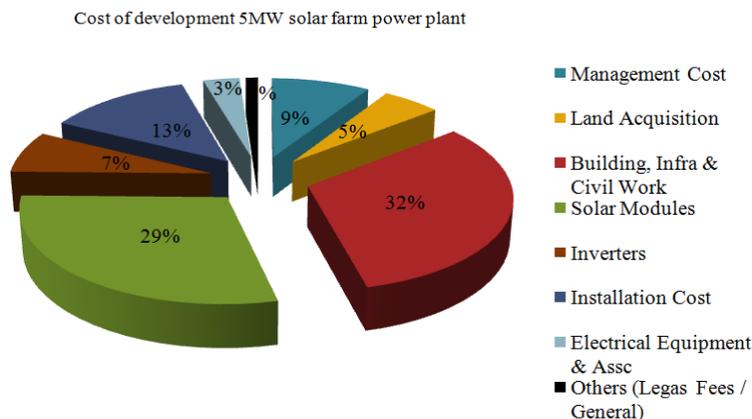


Fig. 7. Percentage of costs in the development of the 5 MWp solar power generation

The material cost of solar panels and inverters is not the only expense encountered during the construction of solar power plants. Costs involved in construction, such as electrical tools (step-up transformers, high-tension switchgears, or cables), land acquisition and management costs must be considered.

Simple Payback Period (SPP) represents the number of years required for the cash flow to equal the total investment. The basic assumption of the SPP method is that the more quickly the cost of an investment can be recovered, the more desirable the investment is. The equation for SP is given below:

$$\text{Payback period} = \frac{\text{Initial Investment}}{\text{Cash In Flow Per Period}} \quad (5)$$

Degression Analysis of FiT in Malaysia, the tariff degression per annum set by SEDA is 8%. The FiT rate is different for each year. In this study, the degression of FiT was estimated by HOMER for two years: For 2014, where the FiT is projected at RM 0.804 and for 2015, where the FiT is projected at RM 0.739. Degressions of FiT were set as sensitivity values. The analysis using FiT rate after two years, from 2014 to 2015, was performed for comparative purposes; the FiT rates of 2014 and 2015 and the degression of FiT were shown to investors to spark interest in investing in solar PV generation in the next two years. Degression analysis used constant values of capital cost because of the uncertainty in future market prices.

Results and Discussion

Technical Analysis

The technical aspect of our study is discussed in this section. Technical indicators were analyzed and solar irradiance, technical performance, energy production and GHG emissions are discussed. The variation in monthly average of solar radiation on the tilted PV modules indicates that solar radiation is minimum during July (4.070 kWh/m²), which reflects a 22.10% error. The maximum actual solar radiation measurement in March (6.335 kWh/m²) was compared with the simulation results in February (6.134 kWh/m²). The predicted yearly irradiance was 5.27 kWh/m² and the measured value was 6.66 kWh/m². Comparison of solar resource inputs from HOMER and the measured irradiance shows that solar radiation is maximum from February to April and minimum from May to July. The average yearly solar irradiance error percentage was 20.88%, as determined by the HOMER output. All comparisons of solar radiation are summarized in Table 4 and Fig. 8.

To compare the measured and predicted outputs of the solar plant, the normalized energy yield (kWh/kW_p) was calculated. The measured total normalized energy output for the year 2013 was 1358.11 kWh/kW_p, whereas the predicted yearly output was 1390.22 kWh/kW_p. Results of the estimation of energy yield using HOMER software were in close agreement with the actual measured results; an uncertainty of only 2.31% was obtained. Comparisons of technical performance are summarized in Table 5.

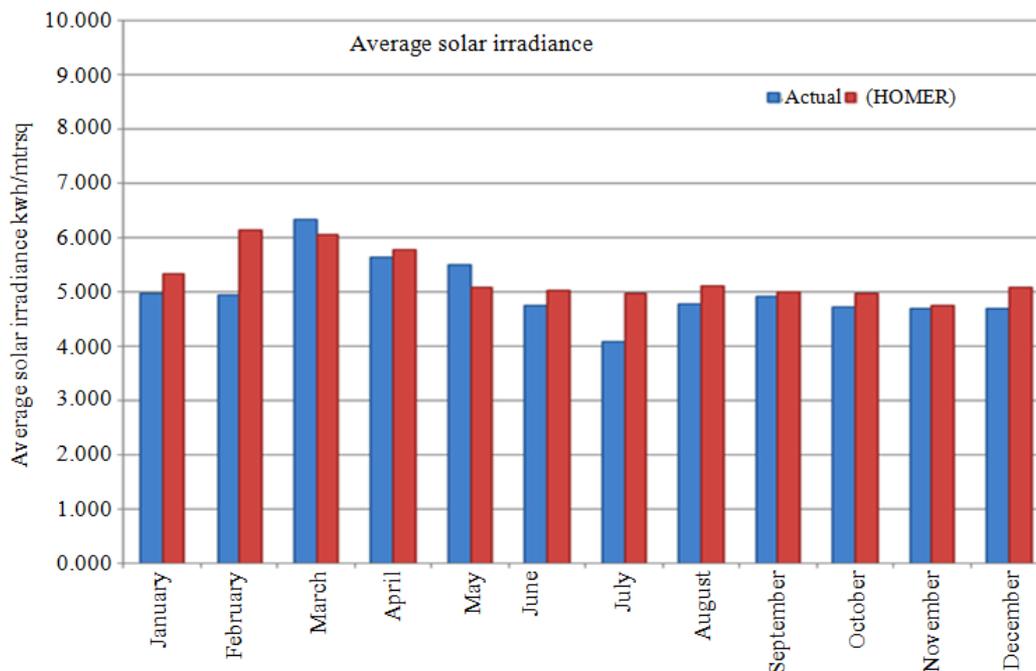


Fig. 8. Actual solar irradiance data versus simulation results

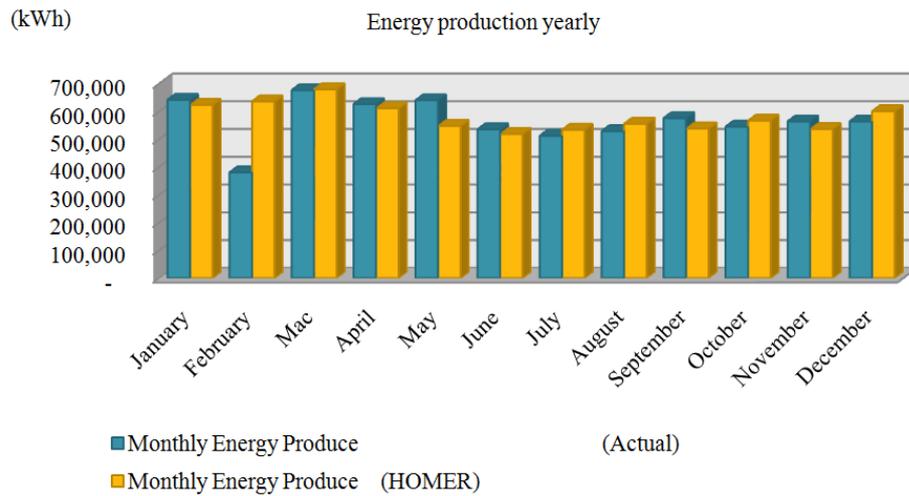


Fig. 9. Bar chart of energy production

Table 4. Summary of solar radiation

Month	Actual (kWh/m ²)	(HOMER) (kWh/m ²)	Error (%)
January	4.956	5.329	-7.53
February	4.941	6.134	-24.15
March	6.335	6.053	4.46
April	5.640	5.759	-2.11
May	5.505	5.078	7.76
June	4.749	5.010	-5.50
July	4.070	4.970	-22.10
August	4.774	5.106	-6.95
September	4.899	4.994	-1.93
October	4.704	4.978	-5.81
November	4.692	4.757	-1.38
December	4.692	5.083	-8.33
Total annual	59.959	63.251	
Monthly average	6.660	5.270	20.88

Table 5. Summary of technical performance

Technical parameters	Actual data	HOMER results
Average annual power output (kWh/year)	6,790,560.00	6,951,076.00
Peak power of the install PV (kWp)	5000	5000
Yield factor (kWh/year/kWp)	1,358.11	1,390.22
Capacity factor (YF/8760)	15.50%	15.87%

Table 6. Summary of energy production

Month	Monthly energy produce (Actual) (kWh)	Monthly energy produce (HOMER) (kWh)	Error (%)
January	641,870	623,771	2.82
February	380,500	636,260	-67.22
March	676,260	679,757	-0.52
April	626,260	611,631	2.34
May	640,230	548,205	14.37
June	535,610	518,798	3.14
July	512,120	534,042	-4.28
August	529,020	555,548	-5.01
September	575,810	538,527	6.47
October	545,220	566,801	-3.96
November	563,830	536,680	4.82
December	563,830	601,056	-6.60
Total Annual	6,790,560	6,951,076	-2.36

The measured monthly normalized yield was highest for March (135.25 kWh/kWp) and the predicted normalized yield was maximum for March (135.95 kWh/kWp). Therefore, an error of 0.518% was obtained. The plant supplied 6.79 GWh of energy during the year 2013, whereas the total annual energy yield predicted by HOMER was 6.95 GWh, which indicates an error of 2.35%. All comparisons of energy production are summarized in Table 6 and Fig. 9.

Calculations of the annual reduction in estimated GHG emissions yielded values of 4,393,080 kg/year for CO₂, 19,046 kg/year for SO₂ and 9,314 kg/year for N₂O. Based on this yearly reduction of GHG emission for the twenty one year, the objective of Malaysia target in CO₂ reduction in year 2030 is not achievable which is 57.17% from 145,000,000 tons when this plant reach 2030.

Economic Analysis

The economic aspect of our study is discussed in this section. Analyzing the economic aspect of power generation is important because it gives investors the necessary information for gauging the success of renewable energy investments in Malaysia. Here, economic indicators, including the NPV and CoE and SPP period are discussed.

Net Present Value and Cost of Energy

The NPV for this project is RM 26,628,810.00 and its CoE is RM 0.329/kWh, as shown in Fig. 10. A negative

NPV is an indicator of the total profit of this project. Based on our analysis, we believe that the project will be profitable and attract investors to invest in solar PV generation. A negative CoE indicates income as renewable energy production for every kWh.

Simple Payback Period

As described previously, the payback period for solar power generation is 10 years, as indicated in Fig. 11 and 12 and Table 7. The cash inflow is negative for the first nine years to recover the initial capital cost. Investments begin to turn a profit starting from the tenth year to the twenty-fifth year.

Sensitivity Analysis

To explore possible discrepancies in the results caused by key parameter variations, sensitivity analysis was performed for important parameters, such as FiT degression, initial investment cost, project lifetime and electricity export cost. CoE production varied between 0.194 and 0.329 RM/kWh with a FiT degression rate of 8% per year. Results of sensitivity analysis of NPV varied significantly in terms of FiT rate (e.g., RM 26,628,810.00, RM 20,958,466.00 and RM 15,693,144.00), as shown in Fig. 13. The FiT degression rate implies that investor profits will eventually decline. This decrease in profit will surely cause anxiety to prospective investors in solar PV generation in the years following 2013.

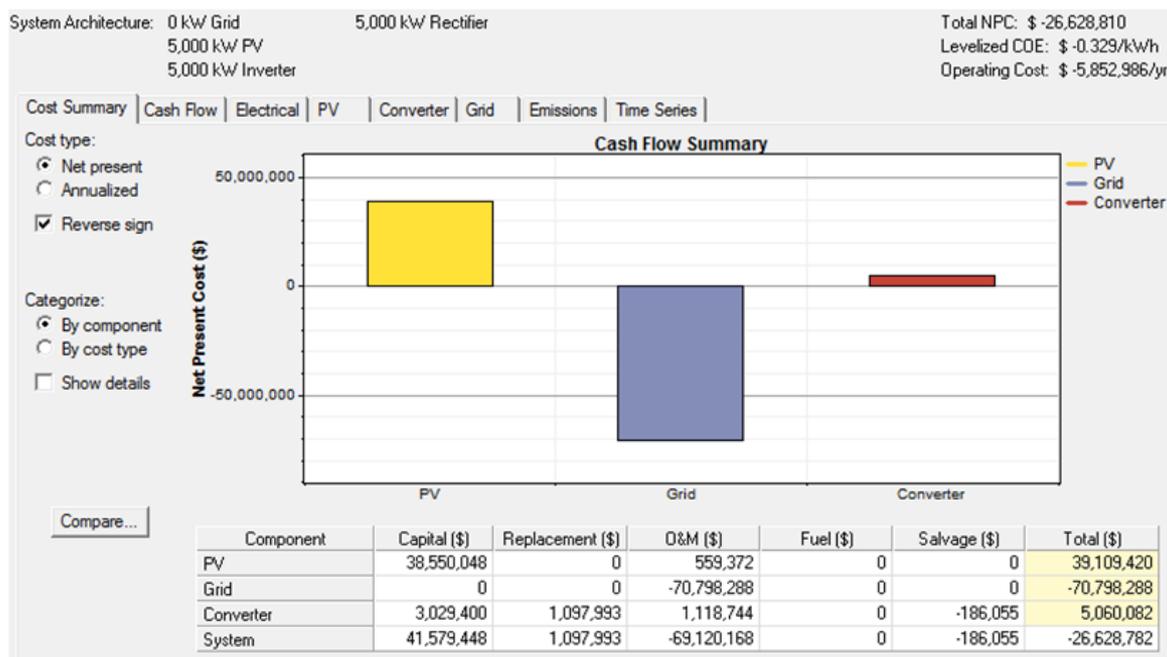


Fig. 10. Net present value analysis and cost of energy (Malaysian Ringgit, RM)

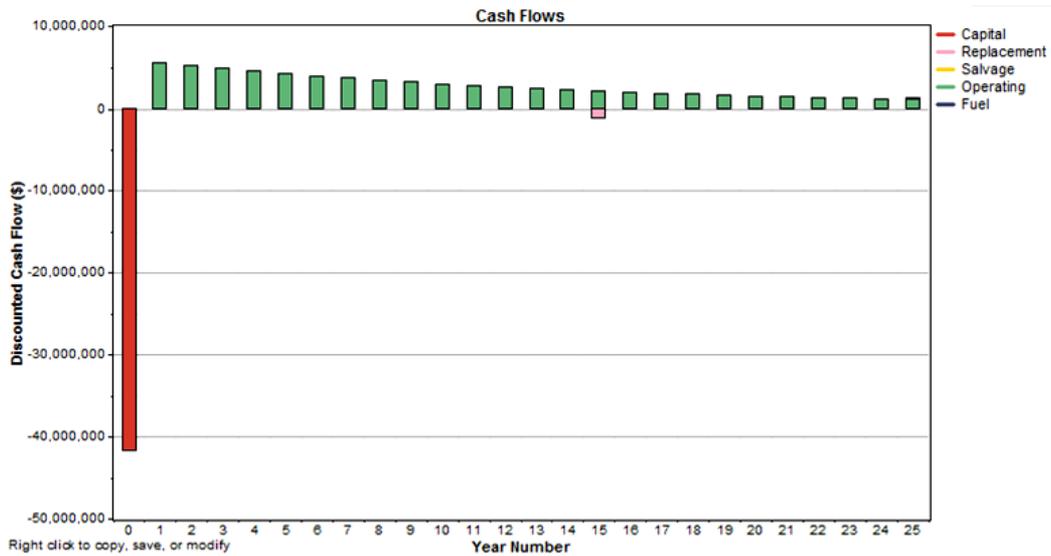


Fig. 11. Discounted of cash flow

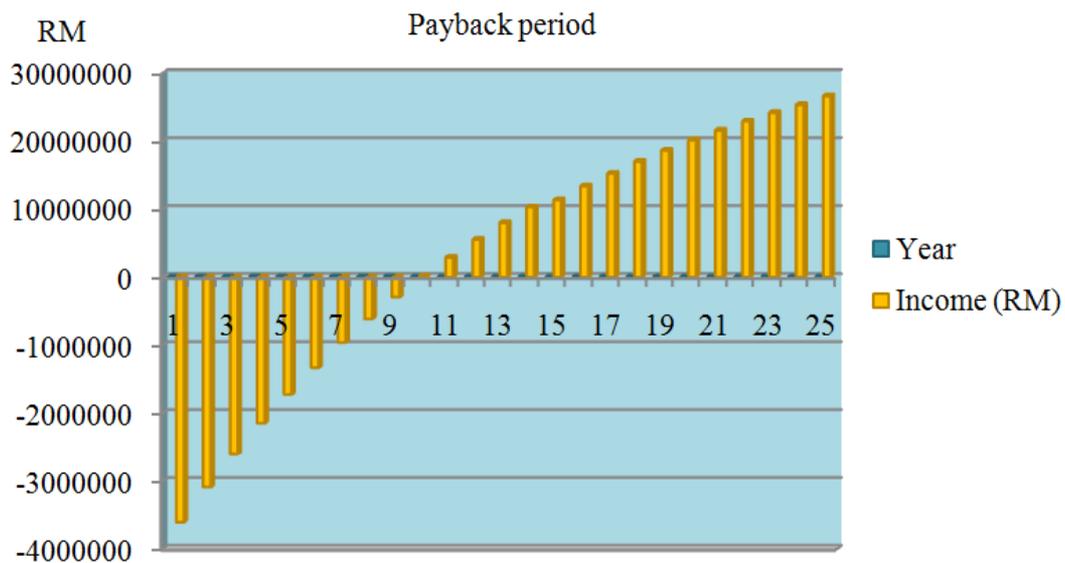


Fig. 12. Simple payback period analysis (Malaysian Ringgit, RM)

Rate 1 Sellback (\$/kWh)				PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)
0.874				5000	5000	0	\$ 41,579,448	-5,852,986	\$ -26,628,810	-0.329
0.804				5000	5000	0	\$ 41,579,448	-5,366,411	\$ -20,958,466	-0.259
0.739				5000	5000	0	\$ 41,579,448	-4,914,591	\$ -15,693,144	-0.194

Fig. 13. Sensitivity analysis based on degression of FiT

To acquire a better understanding of the solar power plant performance, performance parameters evaluated for the Perlis solar power plant were compared with the reported performance parameters of solar power plants at various locations (Table 8). The annual average energy

yield of the solar power after twelve months of continuous operation is 1390.22 kWh/kWp. This annual average yield is comparable with the annual average energy yield of solar power plant systems at other locations, which confirms the suitability of solar power generation in Perlis.

Table 7. Simple payback period analysis (Malaysian Ringgit, RM)

Year	1	2	3	4	5
RM/Year	5,543,215.00	5,180,575.00	4,841,658.00	4,524,914.00	4,228,891.00
Cumulative (RM)	5,543,215.00	10,723,790.00	15,565,448.00	20,090,362.00	24,319,253.00
Year	6	7	8	9	10
RM/Year	3,952,235.00	3,693,677.00	3,452,035.00	3,226,200.00	3,015,140.00
Cumulative (RM)	3,952,235.00	7,645,912.00	11,097,947.00	14,324,147.00	17,339,287.00
Year	11	12	13	14	15
RM/Year	2,817,888.00	2,633,540.00	2,461,252.00	2,300,236.00	1,051,760.00
Cumulative (RM)	44,476,428.00	47,109,968.00	49,571,220.00	51,871,456.00	52,923,216.00
Year	16	17	18	19	20
RM/Year	2,009,115.00	1,877,677.00	1,754,838.00	1,644,036.00	1,532,744.00
Cumulative (RM)	54,932,331.00	56,810,008.00	58,564,846.00	60,204,882.00	61,737,626.00
Year	21	22	23	24	25
RM/Year	1,432,471.00	1,338,758.00	1,251,175.00	1,169,323.00	1,278,879.00
Cumulative (RM)	63,170,097.00	64,508,855.00	65,760,030.00	66,929,353.00	68,208,232.00

Table 8. Performance comparison of PV systems in different countries

Location	Rated capacity (kWp)	Energy yield (kWh/kWp)	References
Perlis, Malaysia	5000.00	1358.11	Present study
Crete, Greece	171.36	1336.40	(Tiwari and Dubey, 2010)
Dublin, Ireland	1.72	885.10	(Ayompe <i>et al.</i> , 2011)
Khatkar-Kalan, India	190.00	812.76	(Mondal and Sadrul Islam, 2011)
Warsaw, Poland	1.00	830.00	(Pietruszko and Gradzki, 2003)

A brief analysis of such studies is summarized in Table 8. Based on our comparison, we conclude that Malaysia has the best potential for solar PV power generation among the four countries studied (Greece, Ireland, India and Poland).

Conclusion

In this study, performance and economic effects of a 5 MWp solar PV plant installed at Perlis, Malaysia, was conducted. Comparison of the energy yield of solar power plant systems in Malaysia with other systems installed at different locations worldwide shows that the energy yield of the solar PV plant in Malaysia (1358.11) kWh/kWp is higher than those of other countries. The comparative study confirms the suitability of Malaysia as a solar power plant location. Estimations of energy yield using HOMER software are in close agreement with the actual measured results and showed an error of 2.31%. The FiT degression rate (8%) will reduce income from solar power generation according to our sensitivity analysis. This predicted income reduction may worry investors and prevent them from investing in solar power generation. The lack of investment will result in failure to achieve the objectives of the Malaysian government, particularly in the renewable energy sector.

Author's Contributions

M. Pauzi M. Kassim: Participated in all experiments, coordinated the data-analysis and contributed to the writing of the manuscript.

Karam M. Al-Obaidi: Participated in all

experiments, coordinated the data-analysis and contributed to the writing of the manuscript.

M. Arkam C. Munaaim: Participated in all experiments, coordinated the data-analysis and contributed to the writing of the manuscript.

Abd. Mokhti Salleh: Designed the research plan and organized the study.

Ethics

We guarantee the truth of all data and the originality of this paper.

References

- APEC, 2009. APEC Energy and Demand Supply Outlook. 4th Edn., Ecomomic Review.
- Ayompe, L.M., A. Duffy, S.J. McCormack and M. Conlon, 2011. Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. *Energy Conver. Manage.*, 52: 816-825. DOI: 10.1016/j.enconman.2010.08.007
- Bhattacharjee, S. and A. Dey, 2014. Techno-economic performance evaluation of grid integrated PV-biomass hybrid power generation for rice mill. *Sustainable Energy Technol. Assess.*, 7: 6-16. DOI: 10.1016/j.seta.2014.02.005
- BP, 2011. BP stastical review of world energy outlook. British Petroleum.
- Canale, M., I. Fagiano and M. Milanese, 2009. KiteGen: A revolution in wind energy generation. *Energy*, 34: 355-361. DOI: 10.1016/j.energy.2008.10.003

- Chamboulegron, I., 1986. A third world view of the photovoltaic market. *Solar Energy*, 36: 381-386. DOI: 10.1016/0038-092X(86)90085-X
- Chua, S.C., T.H. Oh and W.W. Goh, 2011. Feed-in tariff outlook in Malaysia. *Renewable Sustainable Energy Rev.*, 15: 705-712.
- Daud, M., 2010. Future for nuclear in Malaysia, presented at mosti energy forum Malaysia, sheraton imperial. Kuala Lumpur, Malaysia.
- Enslin, J.H.R., 1990. Maximum power point tracking: A cost saving necessity in solar energy systems. Proceedings of the 16th Annual Conference of IEEE Industrial Electronics Society, Nov. 27-30, IEEE Xplore Press, Pacific Grove, CA pp: 1073-1077. DOI: 10.1109/IECON.1990.149286
- GPS, 2012. Cypark integrated energy park in Malaysia starts supplying solar power to grid. GPS.
- Henrion, T., K. Ponweiser, D. Band and T. Telgen, 2013. Dynamic simulation of a solar power plant steam generation system. *Simulat. Modell. Practice Theory*, 33: 2-17. DOI: 10.1016/j.simpat.2011.12.009
- Hussein, K.H., I. Muta and T. Hoshino and M. Osakada, 1995. Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions. *IEE Proc. Generat. Transmiss. Distrib.*, 142: 59-64. DOI: 10.1049/ip-gtd:19951577
- KeTTHA, 2011. Handbook on the Malaysia feed in tariff for promotion of renewable energy. KeTTHA, Sustainable Energy Development Authorot.
- Mekhilef, S., A. Safari, W.E.S. Mustafa, R. Saidur and R. Omar *et al.*, 2012. Solar energy in Malaysia: Current state and prospects. *Renewable Sustainable Energy Rev.*, 16: 386-396. DOI: 10.1016/j.rser.2011.08.003
- Mendoca, M., D. Jacobs and B.K. Sovacool, 2009. Powering the Green Economy: The Feed-in Tariff Handbook. 1st Edn., Earthscan, London, ISBN-10: 1844078574, pp: 208.
- Mercurie, J.F. and P. Salas, 2012. An assesement of global energy resource economic potentials. *Energy*, 46: 322-336. DOI: 10.1016/j.energy.2012.08.018
- MP, 2011. Global challenges facing humanity. Millennium Project.
- NEB, 2008. Ministry of energy, green technology and water. National Energy Balance, Malaysia.
- Mondal, M. and A.K.M. Sadrul Islam, 2011. Potential and viability of grid-connected solar PV system in Bangladesh. *Renewable Energy*, 36: 1869-1874. DOI: 10.1016/j.renene.2010.11.033
- Penick, T. and B. Louk, 1998. Photovoltaic power generation. Report submitted to Gale Greenleaf.
- Pietruszko, S.M. and M. Gradzki, 2003. Performance of a grid connected small PV system in Poland. *Applied Energy*, 74: 177-184. DOI: 10.1016/S0306-2619(02)00144-7
- Quesada, B., C. Sanchez, J. Canada, R. Royo and J. Paya, 2011. Experimental results and simulation with TRNSYS of a 7.2 kWp grid-connected photovoltaic system. *Applied Energy*, 88: 1772-1783. DOI: 10.1016/j.apenergy.2010.12.011
- Sharma, V. and S.S. Chandel, 2013. Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India. *Energy*, 55: 476-485. DOI: 10.1016/j.energy.2013.03.075
- Sick, F. and T. Erge, 1996. Photovoltaics in Buildings: A Design Handbook for Architects and Engineers. 1st Edn., James and James, London, ISBN-10: 1873936591, pp: 287.
- Tiwari, G.N. and S. Dubey, 2010. Fundamentals of Photovoltaic Modules and Their Applications. 1st Edn., Royal Society of Chemistry, Cambridge, U.K., ISBN-10: 1849730202, pp: 402.
- Zweibel, K., 1990. Harnessing Solar Power: The Photovoltaics Challenge. 1st Edn., Plenum Press, New York, ISBN-10: 0306435640, pp: 319.