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# A Review on Feasibility Assessment of Solar Photovoltaic Systems

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## ABSTRACT

Many researchers in the field of renewable energy have conducted a lot of studies and investigations to discover the financial practicability and feasibility of applying photovoltaic solar energy systems. It is of great necessity to carry out feasibility studies of implementing solar photovoltaic (PV) projects in various locations to generate electricity in order to reduce the dependency on the limited resources to generate electrical energy, in addition to alleviate the issue of dangerous greenhouse gases (GHGs) and carbon dioxide ($CO_2$) emissions. The purpose of this paper is to review the works performed on the assessment of solar photovoltaic based projects depending on economical, environmental and technical perspectives. Perceptions addressed by each research work on the utilization of computer simulation software to examine the potential of solar energy and economic indicators in evaluating the viability were analyzed.

**KEYWORDS:** Viability, Economic indicators, Ret Screen, Energy payback time, Homer, Life cycle cost, NPV

## 1. INTRODUCTION

Currently researchers and environmentalists are critically deliberating on the changes in world climate and global warming problems. The reason being of social change, industrial development and increment in global population which leads to the escalation in necessity of electricity exclusively through the traditional way of generating electricity using the resources from the earth such as natural gas, oil, fossil based fuel and coal. As a result, dangerous greenhouse gasses and carbon dioxide emissions have been amplified. This environmental threat drives researchers, energy utility companies and policy makers to find ways to substitute traditional fossil fuels with renewable energies such as photovoltaic, wind, hydro, geothermal, biomass, biofuels and tides [1, 2, 3]. Research work done on estimating the feasibility and financial practicability of implementing renewable energy systems in various countries comes in to play. Therefore, a comprehensive survey on the literatures in assessing the viability of solar photovoltaic projects is presented in this paper.

## 2. REVIEW ON EVALUATING THE PRACTICABILITY OF SOLAR PV PROJECTS

Economical, environmental and technical examination of building integrated grid-tied solar photovoltaic systems in Malaysia has been carried out by Lim Yun Seng., et al. (2008). Fiscal feasibility of installing solar PV systems was analyzed using the key economic indicator of net present value (NPV) under the present governing and commercial frameworks in Malaysia. In addition, sensitivity analysis on the input parameters of selling price and subsidy has been carried out (Figure 1) and it was found that the fiscal return on the investment of the solar PV systems cannot be made under the present regulatory and commercial contexts even for the government offered subsidy rate of 70 percent of the PV capital. Hence, the authors concluded that in order to stimulate PV installations, a better tariff of PV electricity should be offered to the PV proprietors by the government and the utility companies. Reduction in the amount of GHGs emissions by installing the solar PV systems was also analyzed and presented with numerous data as an indication of benefits to the government, utility companies and PV owners. In order to show the extent of benefits that the solar PV systems can bring to the environment, energy payback time (EPBT) has been calculated for various technologies and different locations in Malaysia. Based on EPBT results, they recommended using thin film solar module technology in Malaysia. Power losses and voltage rise issues on the distribution grid associated with solar PV systems and as well the maximum demand charge was determined with the aid of Matlab simulation model and the results were shown. They concluded that through the penetration of solar PV systems, there is a reduction of energy losses and maximum demand charge too, and voltage rise issues may not be a major concern to the power utility companies [4]. Potential and practicability of grid-tied solar photovoltaic power system in Bangladesh was estimated by Md. Alam Hossain Mondal and A.K.M. Sadrul Islam (2011). In this study,

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GeoSpatial toolkit, National Aeronautics and Space Administration, Surface meteorology and Solar Energy (NASA SSE) solar radiation data and Hybrid Optimization Model for Electric Renewables (Homer) software was utilized to examine the potential of solar energy. Financial viability of suggested 1 MW grid tied solar PV system was assessed utilizing RetScreen (Renewable Energy Technologies Screen) computer software application for fourteen prevalent sites in Bangladesh. Economic feasibility indicators of NPV, internal rate of return (IRR), cost of energy (COE), benefit-to-cost (B/C) ratio and simple payback period was assessed. Highest and lowest electricity production was attained from Dinajpur and Barisal solar PV system of around 1844 MWh and 1653 MWh per year respectively. Most and worst suitable locations for the installation of 1 MW grid tied solar PV power system in Bangladesh have been found. In addition, sensitivity analysis of some key parameters of electricity export rate, project lifetime, discount rate and initial investment cost was performed. B/C ratio and simple payback period for all the considered 14 sites in Bangladesh is shown in Figure 2. Authors concluded that based on the analysis of all the economic indicators, the establishment of the suggested solar PV system in all the sites at Bangladesh was favorable. As per the results shown, implementing the proposed solar PV system, minimum of 1423 tons/year of GHGs emissions can be circumvented [5].

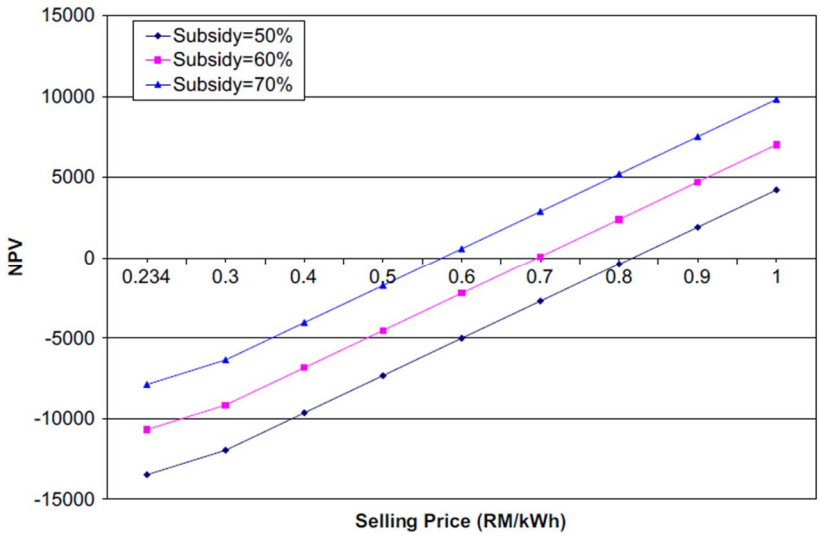


**Figure 1.** NPV as a function of PV rate under different subsidies [4]

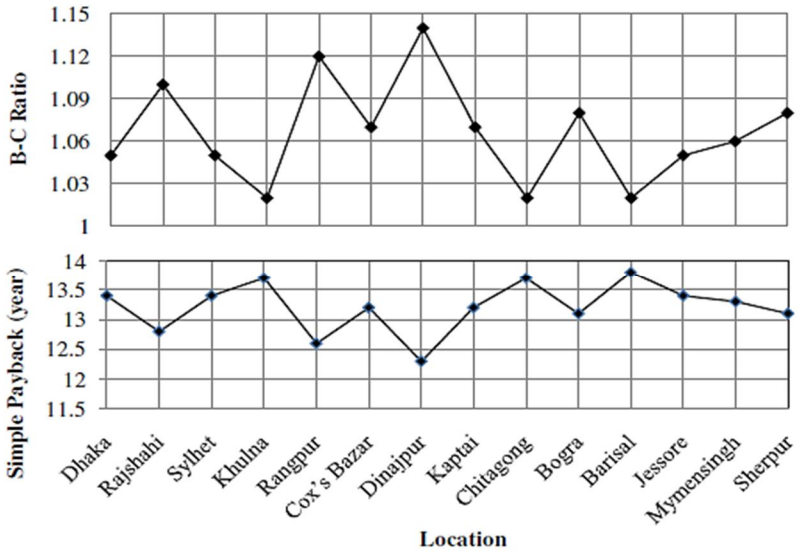


**Figure2.** Simple payback and B/C ratio of 1 MW solar PV power system for 14 sites, Bangladesh [5]

Insight into the projected energy, economic and environmental performance of 1.72 kWp pilot trial rooftop mounted PV system in Dublin, Ireland was provided by Lacour Ayompe., et al. (2010). RetScreen4 software has been used to obtain the long-term monthly average daily total in-plane solar insolation values. Economic indicators of performance ratio, net present value, PV electricity cost and as well emission of greenhouse gases has been analyzed by employing different scenarios and the results were shown [6]. Alireza Hajiseyed Mirzahosseini and Taraneh Taheri (2012) carried out the environmental, technical and financial feasibility study of 12 kW solar power plant installed at Islamic Azad University, Iran. RetScreen simulation software was used in this research. Economic analysis was done considering three main scenarios, according to the targeting of energy subsidies. One of the scenarios was about the reduction of greenhouse gasses. Results about the cash flows over the project life, IRR, simple payback and equity payback time (return positive cash flow) has been shown for all the considered scenarios. Cash flow for the first scenario of average price for the central grid electricity of 3.75 Cents/kWh and not considering any credit for the reduction of greenhouse emissions is displayed in Figure 3. The study concluded that regional government policy clearly helps promote PV system adoption in Iran [7]. Sam Koohi Kamali and Dr. Saad Mekhilef (2009) evaluated the PV solar energy installations connected to the Malaysian electrical grid system based on economic and environmental perspectives. Using Homer software, the simulation of two types of system configuration such as grid/renewable energy system (RES) and only RES was conducted by these authors for construction situated in the city of Kuala Lumpur, Malaysia. Profitability of a PV structure has been found by calculating the parameters of net present cost (NPC), renewable fraction (RF) and lifetime. Applying different values of sellback rate, interest rate, initial cost incentives or subsidy rate and project lifetime, various scenarios were proposed in this study. In addition, evaluation done on the environmental benefits of grid connected solar PV systems. As per the results, it might be gratifying to implement a grid connected RES in the Kuala Lumpur construction sites [8].

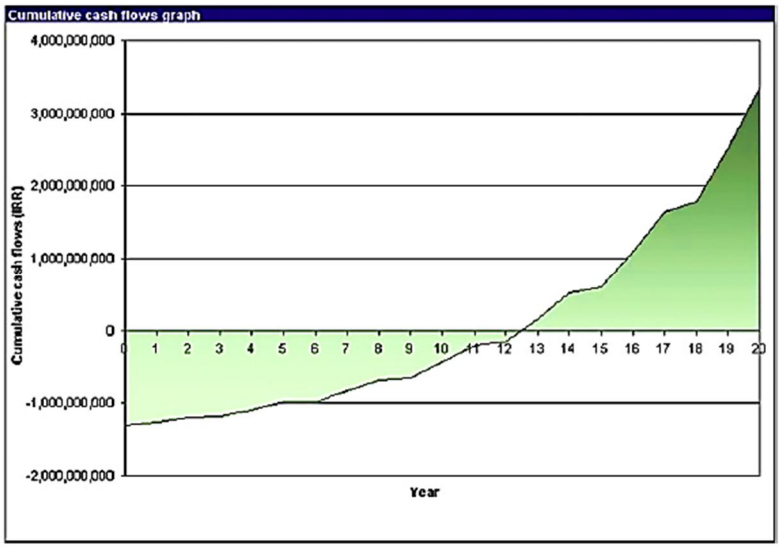


**Figure3.** Cash flows over the project life of the first scenario [7]

Techno-economic feasibility of solar PV-grid connected energy system in a location called Jos, North East Nigeria was investigated by Muyiwa S. Adaramola (2014) using the Homer software. Economic indicators of levelized cost of electricity (LCOE) and NPC was found and also the effects of the cost of PV system and global solar radiation were determined. As per the conclusions drawn from this study, development of photovoltaic grid connected systems (PVGCS) in the north-eastern part of Nigeria was economically viable [9]. Economic evaluation of PVGCS for companies situated in Flanders (Belgium) was piloted by Amaryllis Audenaert., et al. (2010). The author conducted the economic study using generic Excel model, which incorporates the dimension of taxation. Classical evaluation criteria of net present value, internal rate of return, payback period, discounted payback period, profitability index, yield unit cost, yield unit revenue and break-even turnkey cost was calculated. Sensitivity analysis on the three most influential variables of initial investment cost, discount rate and the energy price was also performed and the results were shown. Change in discount rate and its effect on the NPV as a sample of the author's work is presented in Figure 4 and it was clear to see that the greater the discount rate, the lesser the NPV [10]. In numerous solar regions within Tennessee's poultry industry, United States, Ernest F. Bazen and Matthew A. Brown

(2009) examined the influence of the grants, alternative energy programs and other incentives on the feasibility of solar PV systems. Authors estimated the solar energy output using the internet-accessible software model, PVWATTS Version 2 which was developed by National Renewable Energy Laboratory (NREL). Discounted and undiscounted payback period, B/C ratio as well as the net present value and IRR have been analyzed. Results were estimated by varying each parameter from its base value in the sensitivity analysis. From the study, they found out that it would be economically favorable, if incentive exceeding current levels before adoption of solar PV systems [11].

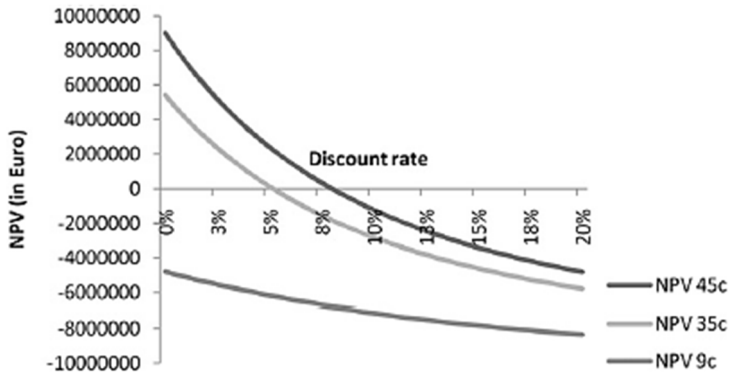


**Figure4.** NPV discount rate spectrum [10]

Renewable energy generation and fiscal assessment of a 5 MW PV based grid tied power plant over Saudi Arabia was analyzed by Shafiqur Rehman., et al. (2007). In this study, RetScreen software was utilized to analyze the viability in 41 locations. Financial indicators of years-to-positive cash flow, annual life cycle savings (ALCS), cost of renewable energy production, profitability index (PI), internal rate of return, simple payback period and net present value were assessed. They found out that the global solar radiation varies between a minimum of 1.63 $MWh/m^2$/year at Tabuk and a maximum of 2.56 $MWh/m^2$/year at Bisha while the mean remained as 2.06 $MWh/m^2$/year. Annual renewable energy generation per annum by the 5 MW installed capacity differed in the midst of 8196 and 12,360 MWh whereas the average remained as 10,077 MWh/year. They also found out that Bishah was the favorable location for the development of PV generating station and Tabuk, the unfavorable site in Saudi Arabia for the solar PV installation based on the analysis of the above mentioned economic indices. In addition, as per the ecological perspectives, 8182 ton of greenhouse gases can be evaded. COE or renewable energy production cost that has been calculated by the author for all the 41 locations using the RetScreen model is portrayed in Figure 5 [12]. A 1 MW grid-connected PV system was studied and analyzed by Wei Yee Teoh., et al. (2012) using the energy modeling software of Homer. The financial practicability of the system was also examined using the NPC and COE in a small industry region of Malacca, Rembia-Krubong located in Malaysia. Simulation, optimization and sensitivity analyses for different configurations of PV modules and inverters were done in this paper. Three types of solar PV modules with different output powers (165 W, 225 W and 315 W) and two inverters with dissimilar power capacities of 250 kW and 500 kW were taken into consideration. Simulation results were compared for grid standalone (without renewable energy fraction) and grid-connected PV systems. Emission of the GHGs by each system has been compared and the results were shown (Table 1). Even though the net present cost of the system was comparably higher to grid standalone supply, the outcomes of this research verified that the grid connected PV system is favorable in the long run [13].

**Table 1.** Pollutant emission [13]

| Pollutant | Emissions (kg/year) | |
|---|---|---|
| | Grid stand-alone | Grid connected PV |
| Carbon dioxide | 3,630,438 | 2,728,111 |
| Carbon monoxide | 0 | 0 |
| Unburned hydrocarbons | 0 | 0 |
| Particulate matter | 0 | 0 |
| Sulfur dioxide | 15,740 | 11,828 |
| Nitrogen oxides | 7,697 | 5,784 |
| Total emissions | 3,653,875 | 2,745,723 |


**Figure5.** Cost of energy (COE) [12]

Economic and environmental studies were performed on grid connected PV system in the city of Zaragoza, Spain by Jose L. Bernal-Agustin and Rodolfo Dufo-Lopez (2006). Profitability of a PV installation was found using the net present value and payback period and as well the environmental benefits of grid tied PV systems have been evaluated with the energy payback time. Impact of parameters such as energy sale price, cost of the installation, annual energy production, maintenance and insurance cost, inflation, interest rate as a function of subsidy on NPV and payback time was determined. Influence of selling price on the net present value is displayed in Figure 6, in which the NPV increases with prices slightly greater than the current one. Contaminating emissions that can be circumvented was estimated considering three circumstances and the results were shown as tables and figures. The study concluded that with the current price, investment is cost-effective but with higher payback time. Results have shown that in order for shorter return times and to attract investors, sale price of the energy or incentives should be increased [14]. Life cycle cost (LCC) analysis of the solar based stand-alone PV system to provide the required electricity for a typical single residential home in Malaysia was presented by Abdulateef, J., et al. (2012). Solar Energy Park located at University Kebangsaan Malaysia in Bangi, Malaysia was used as the base case scenario. PV array, battery, maximum power point tracking (MPPT) controller and inverter sizing analysis was done. They calculated the life cycle cost of the PV system as $65,912.46, annualized LCC (ALCC) as $5,351.61/year and unit electrical cost (cost of 1 kWh) as $0.34/kWh. In order to make revenue, PV suppliers were not encouraged to sell the electricity not lower than $0.34/kWh. Using the life cycle cost method, they concluded that it would be beneficial to electrify a remote household using PV systems and appropriate for enduring investments, specifically if the initial cost of the solar PV systems is reduced and their efficiencies are improved [15].

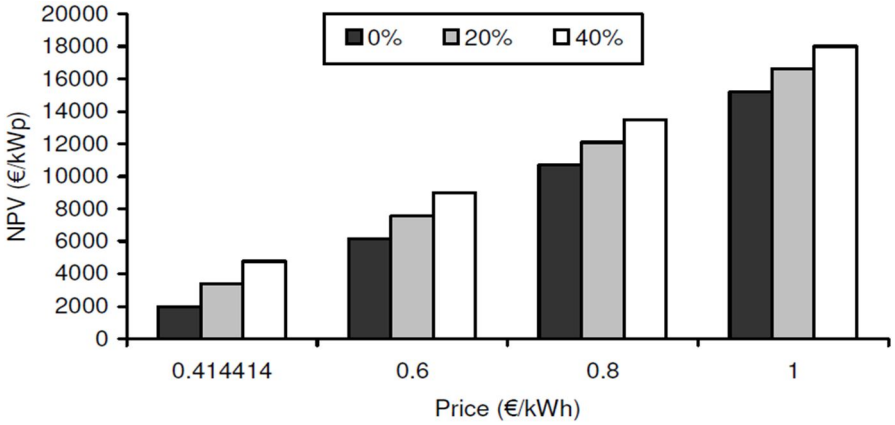


**Figure 6.** Comparison of NPV as a function of subsidy and sale price of the energy [14]

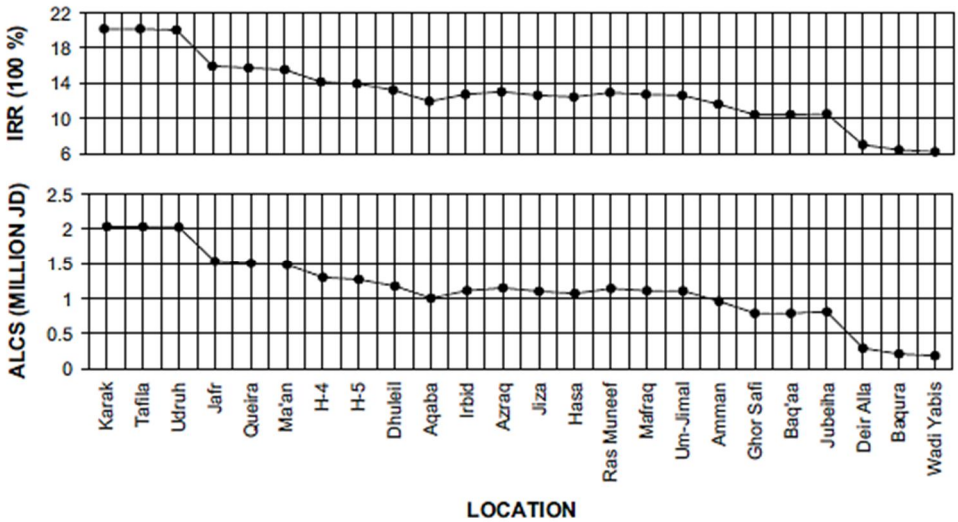


**Figure7.** Internal rate of return and annualized life cycle savings for all sites [16]

Viability of proposed 5 MW grid tied solar photovoltaic power station in Jordan was assessed by Eyad S. Hrayshat (2009). Evaluation and analysis of the proposed plant's electricity generation and financial practicability for 24 locations in Jordan has been performed by making use of the RetScreen software. Indicators such as years-to-positive cash flow, annual life cycle saving, internal rate of return, cost of energy, simple payback period, net present value and B/C ratio has been calculated. It was determined that the sunshine duration of the proposed grid tied solar PV power plant varied in the midst of 8.47 and 9.68 h/day; with an average value of 9.07 h/day and around 3311 sunshine hours per year. Too, annual electricity production differed between 6.886 and 11.919 GWh/annum; with a median amount of 9.46 GWh per annum depending on the location. Most and worst appropriate locations for the solar PV power plant's establishment in Jordan have been found from this study. Sample results of annualized life cycle saving and internal rate of return for the entire 24 sites are exhibited in Figure 7. Analysis using all the fiscal indicators revealed that Tafila and Karak were the most appropriate locations for the solar PV power plant's establishment and Wadi Yabis was the unfavorable site. Additionally, in accordance with the results of GHG emission reduction analysis, if the suggested 5 MW solar photovoltaic power station implemented in any part of Jordan, an average of 7414.9 tons/year of GHG emissions can be mitigated [16]. The life cycle cost analysis on a stand-alone photovoltaic system to provide the required electricity for a single residential household in Faridabad, India were examined by Sheeraz Kirmani., et al. (2010). Usage of PV systems to electrify the rural sites of India was beneficial as per the results shown by this author [17]. Utilizing Homer software, the techno-economic viability analysis of a grid tied solar PV power system to supply a single residential load located near Siliguri, West Bengal, India was analyzed by Bidisha Roy., et al. (2014). Two modes of grid connected and stand-alone systems has been studied and compared. Fiscal indicators such as cost of energy, NPC, pay-back period and environmental emissions were calculated and also the sensitivity analysis on government subsidy was performed. They concluded that despite of the high capital cost; implementation of solar PV systems is highly gainful for a long run and would lead to economic, social and environmental benefits [18].

**Table 2.** IRR, NPV and Discounted payback period [19]

| Sharp 235 W Mono | | | | CareyGlass Solar 185 W Mono | | | |
|---|---|---|---|---|---|---|---|
| **Peak Power (kWp)** | **IRR (%)** | **NPV (€)** | **Discounted payback (years)** | **Peak Power (kWp)** | **IRR (%)** | **NPV (€)** | **Discounted payback (years)** |
| **3.055** | < 0 | -11810 | ∞[a] | 6.105 | < 0 | -21312 | ∞ |
| **6.110** | < 0 | -21318 | ∞ | 3.145 | < 0 | -11620 | ∞ |
| **2.115** | < 0 | -8964 | ∞ | 2.035 | < 0 | -8789 | ∞ |
| **1.175** | < 0 | -5414 | ∞ | 1.110 | < 0 | -5239 | ∞ |

Note: [a] ∞ indicates that the solar PV system cannot reimburse under the specified scenario

Financial study of eight sample grid-connected domestic solar PV systems existing in Ireland was investigated by Zhe Li., et al. (2011). Homer and Microsoft Excel 2007 software programmes was utilized for this study in which IRR, NPV and discounted payback period were evaluated. Effects of the imported electricity price, household

electricity consumption, exported electricity rate, capital grants and mortgage rate were also analyzed. Table 2 indicates the IRR, NPV and discounted payback for eight sample solar PV systems under present Irish situations of incentive exported electricity rate as €0.19/kWh, exported electricity value as €0.09/kWh, imported electricity price as €0.146/kWh and mortgage rate as 4.5%. Based on the conclusions drawn in this study (Table 2), under the existing Irish conditions, domestic solar PV systems were not economically feasible due to its high capital cost [19]. Daut, I., et al. (2011) presented analysis of the peak sun hours (PSHs) of the solar radiation and PV power generation capacity such as daily and annual mean solar radiation and wind speed characteristics in Perlis, Northern Malaysia for the year of 2006. Probability density function of Weibull distribution was utilized to analyze and calculate the wind speed characteristics and wind power generation potential in Perlis. Solar radiation data for the year of 2006 was obtained from Meteorological Station, Chuping Perlis and potential energy generating capacity per annum by the PV systems was calculated as 237.7 $KW/m^2$. Approximately 18,929 GWh can be generated if the entire land in Perlis was occupied with horizontal PV panels. It has been concluded that based on the observation for 24 hours ($9^{th}$ March 2011) 24 V PV and wind power hybrid generation, PV array gives big potential and the wind power gives 10 % of its total output voltage. Figure 8 shows the observation of solar irradiance for 24 hours [20]. Considering the economic and technical perspectives, structure of hybrid solar PV systems were compared by Jalal Addin Sadri and Payam Hooshmand (2012). Hybrid PV systems with other resources of diesel, diesel-battery, wind, fuel cell, wind-fuel cell, fuel cell-battery and fuel cell-wind-diesel-battery has been studied in this research work and the results were shown [21].

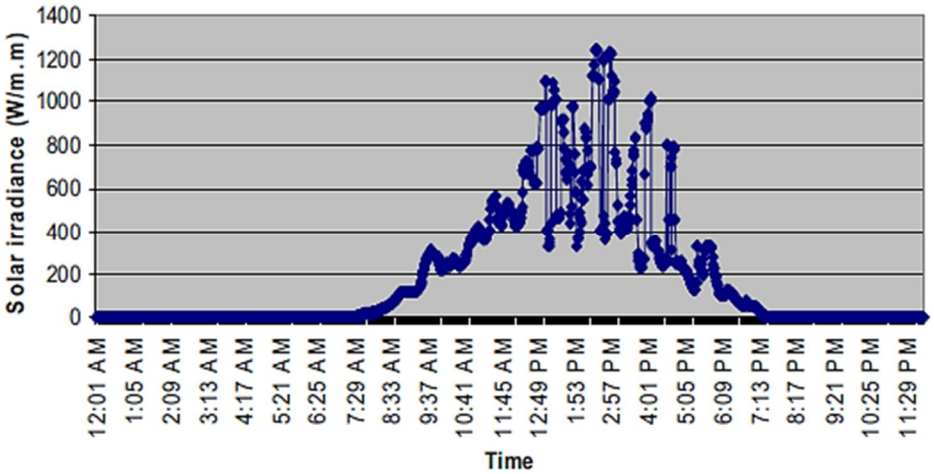


**Figure 8.** Solar irradiance [20]

Life cycle evaluation on a 200 kW roof top solar photovoltaic system was performed in Catalonia (Spain) by Andreas Sumper., et al. (2011). PVsyst, a computer based software package was used for the analysis in this study. EPBT, net energy ratio (NER) and greenhouse gas emission rates were evaluated. Modification of only one of the system variables, that is the level of incident solar radiation, was carried out as a sensibility analysis. As per the conclusion in this study, significant potential for energy savings and $CO_2$ mitigation was offered by PV technology [22]. Elizabeth Harder and Jacqueline MacDonald Gibson (2011) performed cost and benefit analysis of large-scale solar photovoltaic power production in Abu Dhabi, United Arab Emirates by utilizing the RetScreen modeling software in order to forecast the annual energy production, economic viability and GHG emission reductions. NPV, energy production cost, net B/C ratio, IRR, ALCS, number of years to positive cash flow and simple payback period of 10 MW photovoltaic power plant in Abu Dhabi was studied in this paper. Effects of altering key input variables on NPV were also examined. Authors recommended highly to go for additional research as there are limitations to the RetScreen model which requires fixed values for inputs [23]. Cost evaluation of a stand-alone residential photovoltaic power system in Malaysia has been carried out by Vigneswaran Applasamy (2011). RetScreen software was used in this research work. Life cycle costing analysis over a span of 25 years has been analyzed to determine the development cost of the stand-alone PV system and finally to calculate the cost per kilowatt hour (kWh) for the several photovoltaic technologies. They calculated and summarized the cost per kWh for various photovoltaic modules for a standalone system as in Table 3. It has been concluded that the cost of between RM. 1.17 to RM. 1.21 per kilowatt hour is five times more than the present cost of electrical energy distributing to the domestic household in Malaysia, which becomes the main disadvantage in implementing solar PV systems [24].

**Table 3.** Summary of LCC for various PV modules for 1 year [24]

| Module | Cost per kWh (RM) |
|---|---|
| **Mono-crystalline** | 1.17 |
| **Poly-crystalline** | 1.18 |
| **Thin-film** | 1.21 |

Diana Liyanage and Sumedha Rajakaruna (2011) conducted a performance assessment and a cost-benefit study for a grid-connected solar photovoltaic array in Kalgoorlie, Western Australia with two proposed systems, one axis tracking system and horizontal mounting/tracking systems which intended for the dwelling units of a mine site. Payback period, profit and cash flows have been utilized in this research work. In spite of its high capital cost, cash flow analysis during 25 years with the carbon tax of $23/tonne, tariff of 10 cents/kWh, subsidy of $40/MWh (Figure 9), one axis tracking was the most profitable method for installing in large scale commercial solar PV farms. They concluded that the one axis tracking system was evidently more cost-effective than the other one [25]. Feasibility study of design and construction of grid tied solar power plant using photovoltaic cells in the Kingdom of Saudi Arabia (KSA) from the geographic, economic and technical perspective has been done by Al-Ammar, E and A. Al-Aotabi (2010). The feed-in-tariff of the solar station has been estimated by this author, which ranges from 0.216 to 0.24 $/kW/h. Specialized programs of PVSyst and Sunny design have been utilized and the output power that can be generated was found to be in the Riyadh location, which got a high rate radiation specifically in rush hour, as 83.45 GW/h per annum [26]. Jubran, B.A., et al. (2003) had studied the viability of using different photovoltaic systems of grid PV (GPV), stand-alone PV (SAPV), grid PV wind (GPVW) and PV wind (PVW) for supplying the power requirements of small loads under hot climatic conditions in Oman. Simulation program called Homer has been utilized for performing the analysis and selecting the best system. Total net present cost and annual capital cost of each system has been analyzed. They found out that GPVW and SAPV systems were the best to meet the load requirements of window-type air-conditioning system and residential/school applications respectively [27]. Hasan Davari., et al. (2012) designed and carried out the economic analysis of a pilot solar PV project for supplying power for an educational school in Hormozgan Province, Iran. Amount of energy consumption by the school was predicted. Quantity and the type of solar PV system equipment requirements were determined. The entire cost of this project was estimated and compared with the costs related to power supply and consumption through public network and the results were presented [28].

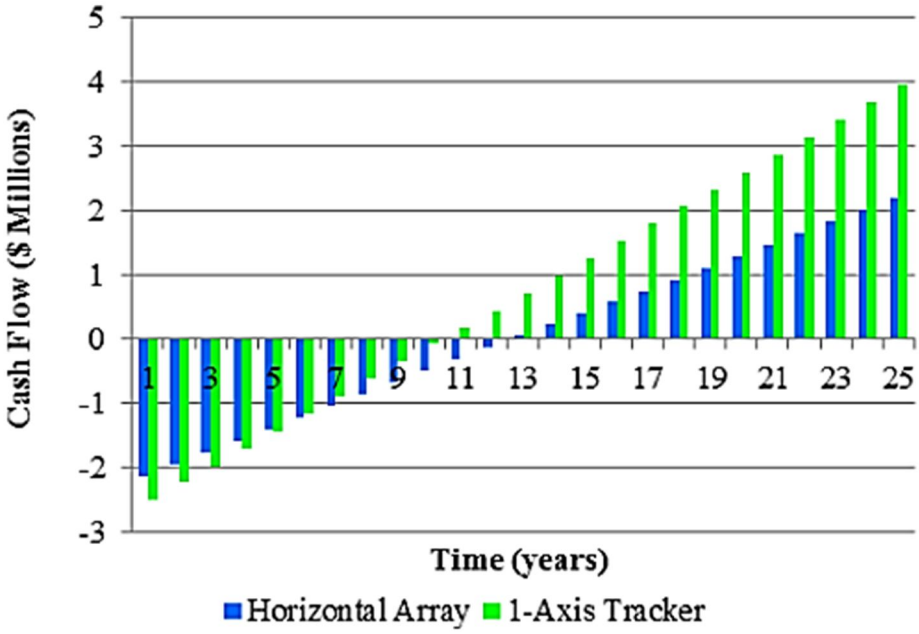


**Figure 9.** Cash flow analysis [25]

## 3. CONCLUSION

This paper critically reviewed the research work done by the prior scholars in assessing the potentials of solar photovoltaic based systems in various regions. Optimization software tools that have been utilized by the authors to assess the potentiality of solar energy were discussed. Fiscal indices of net present value (NPV), simple payback period, cost of energy (COE), energy payback time (EPBT), life cycle cost (LCC), benefit-cost (B-C) ratio, annualized life cycle savings (ALCS) and internal rate of return (IRR), just to name a few, were mostly employed in order to know the financial viability of the solar based projects. It is envisioned that the literature study presented in this paper can be potentially valuable to the researchers, power utility companies, policy makers and investors.

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