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Economic Viability of Photovoltaic Power Plant for Sukkur–Pakistan

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ABSTRACT

Pakistan is confronting severe power shortages which bring out power cuts for several hours in the country. To diminish the shortfall of power, renewable energy sources must be exploited. Therefore, this research focuses on the feasibility of photovoltaic power plant by selecting the best site for installation of the power plant. Monthly average global solar radiations for nine (09) cities of Sindh province were compared and Sukkur was selected for proposed 10 MW PV power plant-based on highest radiations available in the region. For simulation purpose RET Screen software is used. Results have shown that 20.944 GW of energy can be generated using single axis tracking PV at an initial cost of $23.57 M, 40% debt ratio and 9% discount rate, the power plant will generate electricity at a rate of $0.068/kWh. Furthermore, emission analysis indicated that proposed power plant will reduce CO_2 emissions by 8,894 tons/year. It is evident from the study that currently PV based power plants are economically feasible.

Keywords: emissions, economics, RET screen, solar photovoltaic, solar energy, solar tracking

INTRODUCTION

Pakistan is currently facing an electricity shortfall of 5000 MW [1]. Industrial and residential areas of the country are affected by electricity outages [2]. In rural areas, people are facing severe load shedding of 20 hours whereas 14 hours in cities [3]. Due to increase in the population of the country, demand for electricity is also increasing as depicted in **Table 1**. Power sector of Pakistan is heavily dependent on import of fossil fuels. During year 2015-2016 4.98 million metric tons of crude oil was imported, power sector's consumption for Petroleum was 4,446,597 tons and for natural gas consumption was 303,600 mm cft [4]. The burning of fossil fuels has a worse effect on the environment, which results in global warming and ozone depletion. **Figure 1** shows different resources utilized for production of power in Pakistan and it reflects that country's power sector is mainly dependent on fossil fuels. If energy produced from oil increases by 1% then CO_2 emissions in Pakistan will increase by 13.7% which shows adverse effect of energy generated from fossil fuel on environment [5]. In Pakistan 51 million people which makes 27% of total population has no access to electricity [6]. Solar PV can be used as alternative source for supplying electricity to remote villages because of heavy transmission and distribution costs it is almost impossible for

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Table 1. Energy supply and demand in Pakistan (2002-2030) [14]

Year	Supply (GWh)	Demand(GWh)
2002	10.9	10.5
2003	11	11
2004	11.8	11.6
2005	12.8	12.6
2006	12.6	13.8
2007	13.3	15.8
2008	12.4	17.4
2009	13.6	17.9
2010	19.5	24.5
2015	27	36.2
2020	40	54.4
2025	70	80.6
2030	90	113

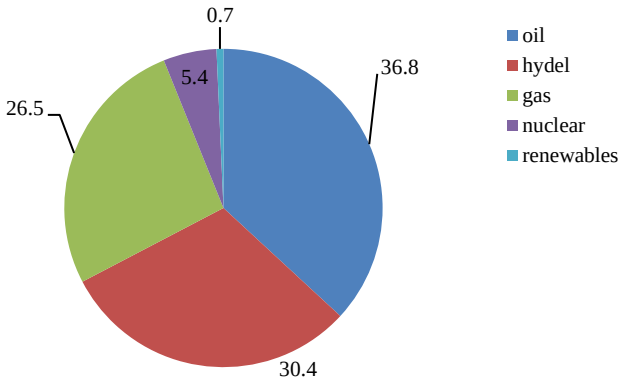

Figure 1. Power generation by source in Pakistan for the year 2015 [15]

autonomous bodies to supply electricity to remote villages through existing infrastructure. If suggested solar PV power plants are installed in different regions of Pakistan it will reduce burden on national grid also will improve country's economy. Pakistan has important role in mitigating global warming as it is member of UNFCCC (United Nations Framework Convention on Climate Change). Major work of UNFCCC includes not to allow global average temperature to rise beyond 2° C and to monitor all global environmental changes. A report of (national GHG inventory 2012) shows an increase in GHG emissions mainly due to power and agriculture sector of Pakistan. According to report 371.4 million tonnes of CO_2 equivalents with 45.8% share of energy sector, 5.2% share of industrial process, 43.5% share of agriculture, 2.6% share of LUCF and 2.8% share of waste sector. Renewable energy resources have potential to replace fossil fuel-based power plants which produce GHG emissions hence renewable energy power generation will mitigate climate change [7]. Renewable energy resources are advantageous in diversifying energy supply markets and reducing GHG emissions, additionally in rural areas renewable energy resources are cost effective source of supplying energy services while creating employment opportunities for [8]. Pakistan has huge potential of solar energy, if utilized for generation of power; it will help in reducing burden on existing fossil fuel-based power plants. Study is a mission to fight against power shortage that country is facing now days. Feasibility study of solar PV power plant was conducted for Sindh province. The study will help to mitigate climate changes, produces CO_2 free power and will show the world how much we are serious towards production of emission free power in our country. Solar PV market is growing rapidly at a rate (30 to 40%) like other technologies due to reduced cost of the solar cell [9]. Solar photo voltaic is becoming a major contributor for supplying energy to the world, in 2008 share of energy supplied by photo voltaic was 5.95 GW, which will reach a share of 11% in the year 2050 [10]. Almost 30 GW of new PV capacity added worldwide in 2011 [11]. One of the major problems with our energy sector is energy security, termed as "continuous supply of energy". There is uniform distribution of renewable energy resources as compare to fossil fuel-based energy resources. Renewable energy resources with good design and management system will reduce imports, diversify supply options and will eventually reduce burden on economy thus enhancing energy security as a whole [12]. Solar PV dominates wind energy in terms of reliability because solar energy has small variation in day hours whereas wind energy is less reliable due to variation in wind speed in small intervals [13].

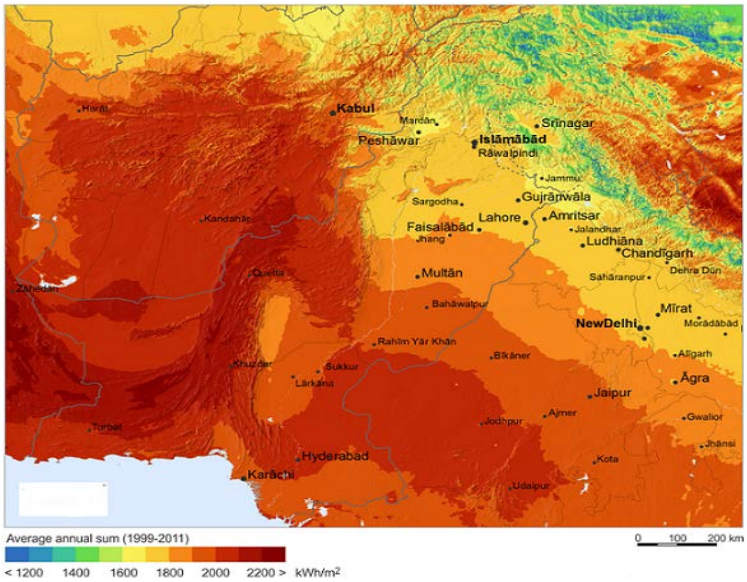

Figure 2. Solar radiation map of Pakistan [20]

Solar Power Potential in Pakistan

Pakistan is a country with huge potential of solar energy. It has solar energy potential of 2900 GW [16]. Pakistan receives about 15.5×10^{14} kWh of solar irradiance each year with most regions receiving approximately 8 to 10 sunlight hours per day [17]. For 10 h a day, average solar radiation intensity ranges from 1500W/m²/day to 2750W/m²/day in Pakistan especially in southern Punjab, Sindh and Balochistan regions throughout the year, hence in an area of 100 m², 45 MW to 83 MW power per month may be generated in the above-mentioned regions [18]. In Pakistan values of GHI is in the range of 200-250 watt/m² with 1500 to 3000 sunshine hours in the year [19]. Solar radiation map of Pakistan is shown in **Figure 2**.

MATERIAL AND METHODS

RET-Screen clean energy project analysis software is a decision support tool provided free of charge. It evaluates the energy production, savings, cost, emission reductions, financial viability, and the risk factor for various type of renewable energy and energy efficient technologies. RET-Screen also includes products, project hydrology and climate database, which helps in comparing the base case and proposed case [21].To access economic viability of solar PV power plant in Sindh province simulation software Ret-Screen is selected. National resources Canada has provided free access to the Ret-Screen software to simulate energy production cost, economic feasibility of solar system, payback period, CO_2 reduction cost and life cycle cost of renewable energy technology [22].To access total energy generated from solar power plant, global solar radiations on horizontal surface, monthly average air temperature and type of tracking systems are used by Ret-Screen software to calculate energy delivered by gird. NASA global solar radiation database is used to collect data for global solar radiations on horizontal surface and monthly average air temperature while fixed tilt solar PV and single axis tracking systems are compared by estimating total annual energy generated by 10 MW solar PV power plan with fixed tilt and single axis tracking system in (09) meteorological regions of Sindh province shown in **Table 2**. Karachi, Hyderabad, Mirpurkhas, Badin, Nawabshah, Sukkur, Larkana, Tharparkar, and Jacobabad regions were selected for study and their solar radiation data was derived from RET Screen climate data base. RET Screen uses NASA surface metrological and solar energy database which provides data for different parameters like average air temperature, radiations on horizontal surface etc as shown in **Table 2**. Ret-Screen results show that Sukkur has highest radiation value 5.35 KWh/m²/day while lowest solar radiations recorded at Larkana were 5.16 KWh/m²/day.

Table 2. Solar radiations data for Nine (09) cities of Sindh Province [15]

City	Elevation (m)	Latitude (Degrees N)	Longitude (Degrees E)	Average ambient temperature (°C)	Radiation-horizontal surface (kWh/m²/d)	Electricity generated (GWh/year)	Capacity Factor
Karachi	22	24.9	67.1	26.1	5.34	16,234	17.6
Hyderabad	26	25.4	68.4	26.5	5.27	15,580	16.9
Mirpurkhas	20	25.5	69	26.7	5.33	16,081	17.5
Badin	7	24.7	68.8	27	5.24	15,734	17.1
Nawabshah	33	26.2	68.4	26.3	5.24	15,909	17.3
Sukkur	51	27.7	68.9	26.2	5.35	16,353	17.6
Larkana	390	28.1	68	23.8	5.16	15,966	17.4
Tharparkar	43	24.7	70.2	27.5	5.2	15,470	16.8
Jacobabad	121	28.3	68.4	25.1	5.17	15,818	17.2

Assessment of Electricity Generation

Pakistan is blessed with ideal sun belt and this energy source is extensively disseminated and richly available in almost all parts of the country [23]. Sukkur is situated on west bank of river Indus at an elevation of 51 m with latitude of 27.7° in North and longitude of 68.9° in East [24]. For Sukkur daily average solar insolation on horizontal surface is 5.35 KWh/m²/day while annual average ambient temperature is 15.7°C [14]. For regions like Sukkur, crystalline PV modules will be better choice because it has high value of direct normal radiations. Thin film photovoltaic modules are suitable for diffused radiation condition. In comparison amorphous or thin film modules age derating value of power for crystalline silicon modules is low, hence there will be small deterioration in electricity generation capacity of PV power plant over a life time [25]. Due to the higher efficiency of crystalline PV modules in comparison with amorphous, Polycrystalline PV module has high cost as compared with monocrystalline module [26]. That's why a moderate technology between amorphous and polycrystalline is considered in this study which is better in efficiency and cost competitive in industry. Mono crystalline silicon modules Si - LPC250SM have been selected from the product database of RET Screen software because it has highest efficiencies and supply power output of 14.5 W/ft² when compared to other available models of same ratings in RET-Screen product database. It has a conversion efficiency of 15.6% which and thermal coefficient of -0.48/˚C [27]. Sukkur receives annual solar radiations of 1950 kWh/m²/year [28]. The average total energy generated by solarPV system for one region was also estimated to 1.73 kWh per day [29]. Solar PV with tracking system have cost advantages over fixed tilt in areas where annual solar radiations values are beyond 1800 kWh/ m²/year. Different losses occur during operation of photovoltaic power generation are calculated by RET Screen, these losses may occur due to module mismatch, dirt deposition on module and conversion from DC to AC. 10% losses are taken for array losses, 5% losses for inverter [25].

Assessment of Financial Viability

RET-Screen financial analysis is carried out using different financial parameters like project life time, inflation rate, debt term, energy escalation cost etc. Capital cost for 10 MW solar PV power plant is taken as $13.5 M [30]. An additional cost of single axis tracking system is taken as $1/W [31]. In order to carry out financial analysis, RET Screen needs input data for capital cost, fuel escalation price, electricity export rate, the rate of return, annual cost which is shown in **Table 3**. To incorporate Solar PV in the country government of Pakistan is providing incentives like income tax exemption and the premium tariff on solar projects, hence income tax and tax depreciation are not considered in the study. Tariff selected for the solar power plant is $ 0.12/KWh keeping in view current tariff of solar PV in Pakistan [21]. For 25 years life period 5% fuel escalation [33] and 40% based on previous literature debt can be taken (30%-70%) [34].

Table 3. PV plant Inputs

Capacity of Power plant	**10 MW**
Tracking system	Fixed Tilt and Single-axis tracking
Module Conversion Efficiency	15.62%
Misc. PV array losses	10%
Inverter losses	5%
Module Temperature Coefficient	0.40%
Project life	25 years (NREl,2012)
Electricity export rate	$ 0.12/kwh (NEPRA,2014)
Electricity export escalation	5% (Khalid et al, 2013)
Debt ratio	40% (NREl,2012)
Inflation rate	8% (Khalid et al,2013)
Discount rate	9% (Khalid et al,2013)

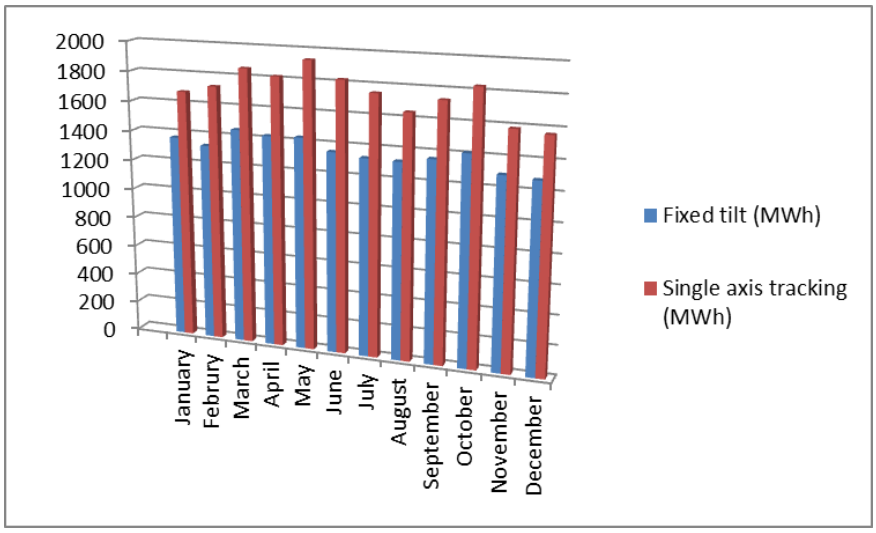

Figure 3. Comparison of Power generation by fixed tilt and single axis tracking solar PV

When comparing fixed tilt solar PV with single axis tracking system, fixed tilt solar PV has low capital as well as O&M cost due to lack of tracking and moving parts. O&M cost which includes inverter replacement and cleaning of solar panels is kept $0.411M/year using a tracker system need replacement and repair cost of a tracking system, which is additional amount hence the O&M cost of single axis tracking solar PV is kept $0.5 M [25].

Assessment of GHG Emissions

In year 2014 in Pakistan, 67.9 TWh of energy was from fossil fuel based thermal power stations [15]. These types of power plants produced harmful gases like CO_2, which is major cause of air pollution and ozone depletion. CO_2 production rate of base case power plants was assumed 0.425 ton_{co2}/MWh. This factor is multiplied with total electricity generated per year, which gives out total GHG reduction per annum.

RESULTS AND DISCUSSION

Simulation results for PV power plant shows that:

- Different tilt angles (i-e $0\text{-}50^0$) were used in energy model data sheet of RET-Screen and maximum output was obtained at 27^0slope hence a tilt angle of 27^0 is considered in study
- At a slope of 27^0 a fix tilt solar PV produces 16.353 GWh/year
- At a slope of 27^0single axis tracking system produces 20.9944 GWh/year
- Power produced by single axis tracking system is 21.9% more as compared to fix tilt solar PV. Comparison of the power generation capabilities of both types of PV systems are shown in **Figure 3**.

From above graph it is found that:

- Maximum output power (i-e 1901 MWh) is obtained in month of May because solar radiation value is highest in May

Table 4. Indicators of financial viability for two types of systems

Indicator	Fixed Tilt solar PV	Single-axis tracking solar PV
Generated power (GWh/year)	16.353	20.944
Additional Cost of tracking system ($/w)	0	1.0
Capital cost (Million $)	13.57	23.57
O&M cost ($/year)	411,140	511,000
Cost of electricity ($/MWh)	87.31	68.17

Table 5. Indicators of financial viability for (09) meteorological location of Sindh province

Location	Capacity Factor (%)	Simple Payback (Year)	Equity Payback (Year)	NPV (US$)	Annual Lifecycle Saving	Benefit to cost ratio	Energy production cost ($/MWh	Net GHG reduction
Karachi	22.4	6.6	5.4	16486467	1678425	3.03	69.78	8745
Hyderabad	21.6	6.9	5.8	15046422	1531820	2.85	72.42	8425
Mirpurkhas	22.,2	6.6	5.5	16204479	1649717	3.0	70.28	8682
Nawabshah	21.9	6.7	5.6	15671481	1595455	2.93	71.25	8564
Badin	21.6	6.9	5.8	15109555	1538247	2.86	72.3	8439
Sukkur	22.8	6.4	5.3	17159360	1746930	3.1	68.6	8894
Tharparkar	21.2	7.0	5.9	14463893	1472515	2.78	73.55	8296
Larkana	22.4	6.6	5.5	16421095	1671770	3.02	69.89	8730

Table 6. Other Indicators of financial viability for Single Axis Tracking System

Output Variable	Output Value (at Sukkur)	Suggested optimum value (Khalid and Junaidi,2013)
Net Present Value	$ 17,303,143	Positive Value
Energy Production Cost	68.17 $/MWh	must be equal to or lower than the tariff
Benefit-cost ratio	3.13	1 >
Internal rate of return on equity	21.3 %	IRR ≥ Required rate of return
Year to positive cash	6	Value < 10 years

- In months like April, June and July there is small variation in solar radiation value. In April value is 6.13 KWh/m^2/d, in June 6.62 KWh/m^2/d, in July 6.12 KWh/m^2/d.
- Lowest radiations 6.4 KWh/m^2/d were recorded in month of January.
- Average output energy is 1716 MWh.

When single axis tracking solar PV is compared with fix tilt solar PV in terms of financial viability it is obvious from values of indicators as shown in **Table 4** that single axis tracking is better choice because it generates least cost energy while in terms of capital, O&M expenditure single axis tracking system is costly Important indicators are shown in **Table 4** it is obvious from values of indicators that single axis solar PV generates least cost energy.

For a single axis tracking PV of 10 MW at a capital expenditure of $13,527,094 and annual O&M cost of $411,140 at Sukkur region equity payback is 6 years while IRR on equity is 21.3% which is greater than required rate of return of 6%. All financial viability parameters which indicates feasibility of solar PV power plant for (09) meteorological locations are shown in **Table 5**.

Table 5 indicates different financial indicators for (09) meteorological locations in Sindh province. Due to highest solar radiations at Sukkur 10 MW solar PV power plant will generate an annual energy of 20.499 GWh/year which is highest energy generated in Sindh. Annual savings from generated energy will be $1746930 for Sukkur region. When 10 MW solar PV plant is installed in Sukkur region its payback period is 6.4 years which is lowest period as compared to when plant is located in other regions, energy generation cost for Sukkur region is lowest as compared to other locations where as total GHG emissions reductions are highest in Sukkur region. Keeping in view all parameters given in **Table 5** it is concluded that Sukkur is best location for 10MW solar PV power plant in Sindh Province.

Indicators shown in **Table 5** are compared with suggested optimum values shown in **Table 6** and it was found that proposed solar power plant is encouraging for installation. Indicators such as IRR and NPV consider profitability over the life of project. Positive value of NPV indicates that project is feasible while IRR is interest yield of project for lifetime. RET screen shows that profitability of projects is affected if miscalculation occurs for these indictors. Benefit to cost ratio shows at what proportion of cost, protect is profitable. A year to positive cash flow is very important indicator as it indicates how quickly investment returns to the investor; hence care should be taken during calculation of these indicators. Emission analysis shows that proposed power plant avoided carbon dioxide production by 8,894 tons annually, which is equivalent to 1,629 cars and light trucks not used.

CONCLUSION

The study focuses on the best site feasibility of photovoltaic power plant in Sindh region. The nine major cities global solar radiations were considered in the province. It is found that Sukkur region have highest solar radiations and it is proposed to be selected for the installation of 10 MW photovoltaic power plant. The simulations of the two systems fixed tilt and single axis tracking at 27^0slope were carried in RET screen. It is observed that single axis PV power plant generates the cheaper electricity and has potential to generate 20.944 GW electric power in a year at Sukkur which is the site with highest solar insolation. The electricity obtained from this clean power source will have capital cost as $ 23.57 M that includes additional cost of tracking as $10 M and the payback period is 6.4 years whereas IRR on equity is 21.3 %. The single axis solar PV energy production cost is less as compared with fixed tilt solar PV. Moreover, the financial analysis shows that currently 10 MW solar power plant is cost effective and is feasible to install in Sukkur region of Sindh province. Furthermore, the plant will help reduce production of 8,894 tons of carbon dioxide per year which is equivalent to 1,629 cars and light trucks not used. This study proposes an alternative solution to cope energy crises, climatic conditions and harness cheap electricity for local community. The study helps policy makers to ponder over the sever environmental challenges being faced and thus leads to the environmental sustainability.

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