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Chapter 5

Feasibility of a Solar Thermal Power Plant in Pakistan

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/55488

1. Introduction

Pakistan has been facing an unprecedented energy crisis since the last few years. The problem becomes more severe throughout the year. The current energy shortage crisis has badly hit Pakistan's economy where hundreds of industries have closed due to lack of electricity to fulfil their requirements. The energy supply and demand gap has risen to 5000 MW [1] and is expected to rise considerably in the coming years as shown in Figure 1. Table 1 shows the existing installed power generation in Pakistan.

Pakistan has a huge potential in renewable energy especially solar energy to fill this gap if utilized properly. Pakistan, being in the Sun Belt, is ideally located to take advantage of solar energy technologies. This energy source is widely distributed and abundantly available in the country. Pakistan receives 4.45- 5.83 kWh/m^2/day of global horizontal insolation as an annual mean value, with 5.30 kWh/m^2/day over most areas of the country [2, 3]. This minimum level of solar radiation (4.45 kWh/m^2/day) is higher than the world average of 3.61 kWh/m^2/day [4] which shows that Pakistan lies in an excellent solar belt range. Pakistan has six main insolation measuring stations, namely Karachi, Islamabad, Lahore, Quetta, Peshawar and Multan and 37 observatories distributed fairly well over the entire country, recording sunshine hours as shown in Table A in Appendix. From the sunshine hours data it can be seen that most of the cities mentioned receive more than 250 sunshine hours a month.

2006 energy policy has resulted in few practical steps taken for utilizing the abundantly available solar resource in Pakistan. A Solar Water Heating System has been installed in a Leather Industry for first time in Pakistan. The system, using 400 m^2 Evacuated Collector tubes, provides heated water at 70 to 80 ^{o}C (at least 10 degree rise to the incoming water) to the already used boiler system, thus saving 33% of the cost. The Project was funded by Higher Education Commission (HEC) under University-Industry Technological Support Program (UITSP).

Solar water heating technology is relatively mature technology in Pakistan but its higher capital cost compared to conventional gas heaters has limited its use so far. This technology is widely recommended by a number of public sector organizations in northern mountains where natural gas is limited and difficult to supply. The solar water heaters are now being commercially produced in the private sector.

More than 2000 low cost solar cookers are used in Pakistan for cooking purposes. Similarly, solar dryers are used in Gilgit and Skardu (Northern part of Pakistan) to dry large quantities of fruits such as apricot and transport and sell them later in the urban areas, thus bringing economic prosperity to the area.

Fresh water unavailability in large parts of Baluchistan, Sind and southern Punjab is a critical issue. Two solar desalination plants consisting of 240 sills each with a capacity of 6000 gallons of seawater/day have been operational at Gawadar in Baluchistan province. A number of such schemes are under active consideration by local governments in Baluchistan and Thar [5].

The need for constructing solar power plants has been realized both at federal and provincial governments. The government of Sindh recently signed a Memorandum of Understanding with German company Azur Solar for building a 50 MW solar power plant at Dhabeji in District Thatta. The firm Azur Solar will initially set up a 60 kW solar power station to provide free electricity to backward 'goths' (Villages), schools and basic health centres of Badin.

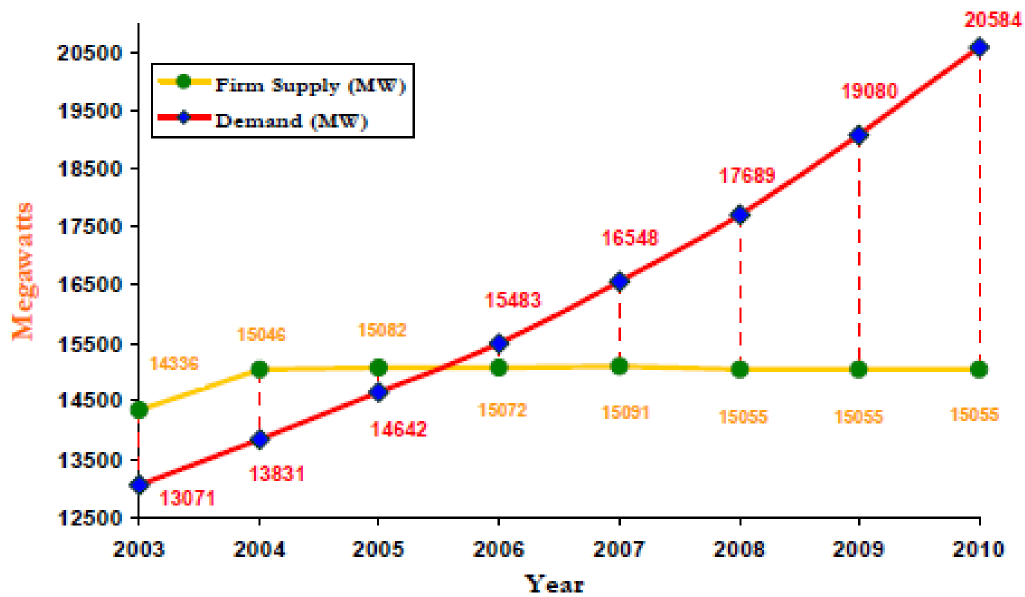

Figure 1. Generation capacity and demand forecast [6]

Both, technical and economical feasibility of a 50 MW solar thermal power plant using Stirling-Dish (SD) technology in Jacaobabad in Sindh Province of Pakistan is analysed in this chapter. The performance and environmental aspects of Stirling dish for power generation with and without solar energy is examined, discussed and compared. The solar data was collected from Bureau of Meteorology (BoM) of Pakistan and Life cycle cost analysis is performed to determine the economic feasibility of the solar thermal power plant. This study reveals that Jacobabad falls within the high solar energy belt and has minimum radiation energy of 4.45 kWh/m²/day (which is higher than the world average of 3.61 kWh/m²/day) to produce electricity, even during the low sunshine and cloudy days. The study concluded that solar thermal power plant in Pakistan is feasible using solar Stirling dish technology.

Type of Generation	Installed Capacity (MW)	Derated / Dependable Capacity (MW)	Availability (MW)	
			Summer	Winter
WAPDA Hydro	6444	6444	6250	2300
GENCOs	4829	3580	2780	3150
IPPs	6609	6028	5122	5402
Rental	285	264	250	250
Total	18167	16316	14402	11102

Table 1. Existing installed generation capacity in Pakistan [1]

2. Solar stirling engines

Solar thermal electric power generating systems have three different design alternatives, as follows;

- Power tower: a solar furnace using a tower to receive the focused sunlight
- Parabolic trough collector: focus systems that concentrate sun rays onto tubes located along the focal line of a parabolic shaped trough.
- Parabolic dishes: focus systems where sun light is reflected into a receiver at the dish's focus point [7, 8].

High optical efficiency and low start-up losses make dish/engine systems the most efficient (29.4% record solar to electricity conversion) of all solar technologies [9]. In addition, the modular design of dish/engine systems make them a good match for both remote power needs in the kilowatt range as well as hybrid end-of-the-line grid-connected utility applications in the megawatt range as shown in Figure 2 [9].

Solar Stirling engines can be classified into two categories;

- Free Piston Stirling engines: are those which have only two moving parts i.e. the power piston and the piston, which moves back and forth between springs. A linear alternator extracts power from the engine through power piston. Electricity is produced internally and therefore, there is no need for sliding seal at the high pressure region of the engine and no lubrication is required too [10].
- Kinematic Stirling engines: are those in which both the power piston and displacer (expansion and compression pistons) are kinematically (mechanically) connected to a rotating power output shaft.

Kinematic engines work with hydrogen as a working fluid and have higher efficiencies than free piston engines. Kinematic sterling engines have sealing problems and complicated power modulation. Sealing problems can be avoided by integrating a rotating alternator into the crankcase [10]. The power modulation can be sorted out by; (a) Varying the piston stroke (b) varying the pressure level of the working space [10].

Free piston engines have simple design as there is no connection between power piston and displacer. There is no need for working fluid make-up system being hermetically sealed as is required in the case of kinematic Stirling engines [11]. Free piston engines work with helium and do not produce friction during operation, which enables a reduction in required maintenance.

The solar Stirling engine is environment friendly as the heat energy comes from the sun and therefore almost zero emission. Similarly emissions from hydrocarbons combustion are very low as the fuel is burnt continuously at almost atmospheric pressure compared to the interrupted combustion in diesel and petrol engines. The quantities of CO produced and of unburnt hydrocarbons HCs are very low due to (i) the combustion of fuel in a Stirling engine occurs in a space surrounded by hot walls under adiabatic conditions and (ii) the latitude in the choice of air to fuel ratio. But unfortunately, the more efficient combustion of a Stirling engine results in relatively more CO_2 produced compared to an equivalent internal engine. Similarly the formation of NO_x are lower due to the short residence time of the gases at the high temperature, lower peak temperatures than in internal combustion engine and the continuous combustion. The emission of NO_x can be further reduced: (a) by recirculation of part of the flue gases along with incoming combustion air and (b) lowering the flame temperature. Stirling engine is intrinsically cleaner than all current heat engines in terms of emission of toxic or other polluting substances [11].

Figure 2. General description of Stirling EuroDish system [12]

http://dx.doi.org/10.5772/55488

3. Stirling-dish solar electric power generating system

Stirling-Dish (SD) systems are small power generation sets which generate electricity by using direct solar radiation. The capacity of a single unit is typically between 5 and 25 (50) kW_{el}. This size and the modularity of the single units qualify the Dish-Stirling system for very flexible applications. They are ideal for stand-alone or other decentralised applications [13]. The size of the solar collector for Stirling Dish is determined by the desired power output at maximum insolation levels (1 kW/m^2) and the collector and power conversion efficiencies. A 5 kW Stirling Dish system requires a dish of ca 5.5 m, in diameter, and a 25 kW system requires a dish of ca 10 m in diameter [10]. The schematic diagram of solar Stirling dish system is shown in Figure 3. The parabolic concentrator reflects the solar radiation onto a cavity receiver which is located at the concentrator's focal point. The heat exchanger (receiver) absorbs the solar radiation and thus heats the working gas (Helium or H_2) of the Stirling engine to temperatures of about 650° C. This heat is converted into mechanical energy by the Stirling engine. An electrical generator, directly connected to the crankshaft of the engine, converts the mechanical energy into electricity (AC). A sun tracking system rotates the solar concentrator continuously about two axes to follow the daily path of the sun to constantly keep the reflected radiation at the focal point during the day [13].

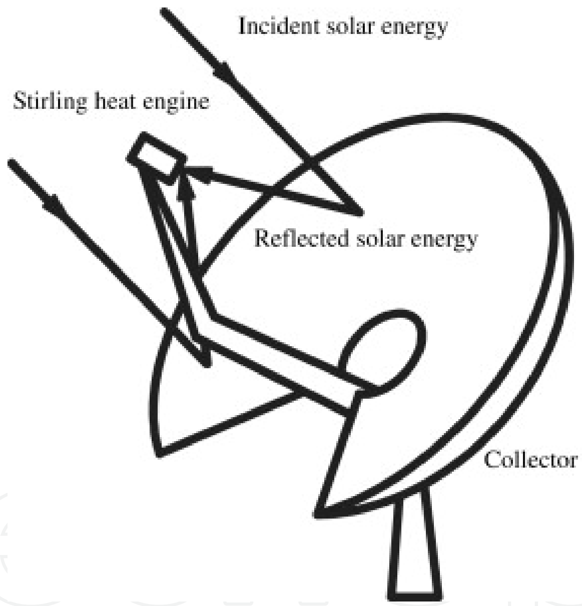

Figure 3. Schematic diagram of solar Stirling dish system [14]

4. Results and discussion

4.1. Technical feasibility

A SD solar electricity system of 25 kW with design characteristics shown in Table 2 was used for analysis in this study [10]. Stirling Dish has the ability to operate earlier and later every day and can also be functional in cloudy conditions when solar energy is < 2 kWh/m^2. Another advantage of SD is it can generate power between passing clouds due its low thermal inertia. Jacobabad's Latitude is 28°18/ N, Longitude is 68°18/ E and elevation is 55m. Jacobabad is among the hottest and the most arid areas of Pakistan, having weather conditions quite similar to those of a desert where direct normal insolation is high (1735 kWh/m^2/year) [15] as shown in Table 5 coupled with low land cost, which is really cheap compared to international costs of land in Europe or USA.

Design Characteristics of a solar electricity system SD 25 kW	
Concentrator	
Glass area	91.01 m^2
Aperture area	87.67
Focal length	7.45
Glass type	No. 82 commercial grade float. Thickness 0.7mm
Radius of curvature	599. 616, 667, 698"
Waviness	<0.6mr
Reflectivity	>90%
Module dimensions	11.89 mH, 11.28 W
Module weight	6.934 kg
Stirling engine (kinematic)	
Engine dry weight	225 kg
Displacement	380 cc
Engine dimensions	66 cm W, 71 cm H, 58 cm L
Number of pistons	4 double acting
working fluid	H_2 or He
working fluid pressure	20 MPa
Operating temperature	720°C
Power control	Fluid pressure
Cooling	Water/forced air fan
Output power	27 kW (max), 22 kW (rated)
Rated power efficiency	38-40%
Power conversion unit	
Weight	>680 kg
Alternator	Induction, 1800 rpm
Alternator efficiency	92-94 %
Electrical power	480 V, 60 Hz, three phase
Gross power rating	25 kW at 1000 W/m^2
Peak net power efficiency	29-30%
Minimum insolation	250-300 W/m^2
Dimensions	W=168 cm, H=122 cm, L=183 cm

Table 2. Design characteristics of 25 kW solar Stirling Dish [12]

NOAA Code	Statistics	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
0101	Temperature Mean Value	F	59.2	64.2	74.8	86.4	94.8	98.4	94.8	91.8	88.5	82	71.8	61.5	80.7
0109	High Temperature Mean Daily Value	F	72.7	77.4	88.3	100	110	112	105	101	98.6	95.5	86.2	75.4	93.5
0110	Low Temperature Mean Daily Value	F	45.9	50.9	61.3	72.1	80.1	84.9	84.6	82.9	78.5	68.5	57.4	47.7	76.9
0615	Precipitation Mean Monthly Value	Inches	0.1	0.3	0.4	0.1	0.1	0.2	1.5	1.1	0.5	0.1	0	0.2	0.4
0101	Temperature Mean Value	C	15.1	17.9	23.8	30.2	34.9	36.9	34.9	33.2	31.4	27.8	22.1	16.4	27.05
0109	High Temperature Mean Daily Value	C	22.6	25.2	31.3	38	43.1	44.3	40.6	38.2	37	35.3	30.1	24.1	34.15
0110	Low Temperature Mean Daily Value	C	7.7	7.7	16.4	22.3	26.7	29.4	29.2	28.3	25.9	20.3	14.1	8.7	19.95
0615	Precipitation Mean Monthly Value	mm	3.1	7.1	10.3	2	1.7	4.7	36.8	26.3	11.2	2.3	1.2	3.7	9.2

Table 3. Climate average weather data for Jacobabad [16]

The Jacobabad's 10 years sunshine hours data was provided by Pakistan Meteorological Department as shown in Table 4. It can be seen from Table 4 that there are very good sunshine hours throughout the year and the average sunshine hours is 9 for a month. It is slightly less than that of National Renewable Energy Lab NREL total sunshine hours [17] but even then it is highly suitable for a solar power plant.

JACOBABAD SUNSHINE HOURS PER MONTH												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2000	213.3	248.1	240.8	273.7	364.1	361.2	330.0	307.4	297.8	308.5	241.6	245.2
2001	269.7	207.8	266.0	261.6	342.1	303.1	209.2	315.4	290.3	287.2	287.4	249.6
2002	238.5	207.4	242.0	263.2	330.7	342.4	300.6	240.6	281.7	300.1	243.3	239.9
2003	200.8	194.0	222.4	128.3	298.2	320.0	228.6	270.1	211.5	294.7	254.2	233.5
2004	200.8	194.0	255.0	128.3	262.2	275.6	270.3	256.3	237.5	318.2	294.5	238.1
2005	200.8	194.0	218.7	128.3	298.5	328.6	341.9	333.4	284.5	313.3	271.7	264.4
2006	216.0	193.9	251.8	247.4	341.9	331.4	312.7	251.2	307.7	310.9	221.4	203.2
2007	213.4	200.0	293.0	319.0	385.5	331.5	313.0	341.5	343.5	335.0	289.5	270.5
2008	171.0	254.5	279.0	273.5	359.0	288.0	323.0	341.5	328.0	315.5	289.0	258.5
2009	164.7	255.9	289.1	320.6	252.0	252.0	269.0.	372.0	281.2	309.5	285.3	247.4

Table 4. Jacobabad sunshine hour's data [3]

It is the hottest location in Pakistan as the temperature is around 45 to 50^{o}C in summer and10 to 25^{o}C in winter as shown in Figure 4. Temperature data given in Table 3 also shows a low temperature mean value of 19.95^{0}C, high temperature mean value of 34.15^{o}C and Temperature mean value of 27.05^{o}C very good hot conditions at Jacobabad [16], which are highly conducive for a solar thermal power plant.

Direct normal insolation data from National Renewable Energy Lab (NREL) USA, shown in Figure 5 and Table 5, was compared with the data from BoM (Pakistan) for assessment of the Jacobabad site. It can be seen that there is not a huge difference between the NREL data and the data received from Pakistan Bureau of Meteorology.

Month	Monthly DNI (kWh/m^2)	Average Day Length (Hours)
January	114.42	10.4
February	127.37	11
March	149.65	11.8
April	165.61	12.7
May	169.83	13.4
June	177.66	13.8
July	168.32	13.6
August	131.59	13
September	157.78	12.2
October	154.77	11.3
November	115.63	10.6
December	102.98	10.2
Monthly Average	144.63	12
Annual Total	1735.56	

Table 5. Average Direct Normal Insolation data for Jacobabad [15]

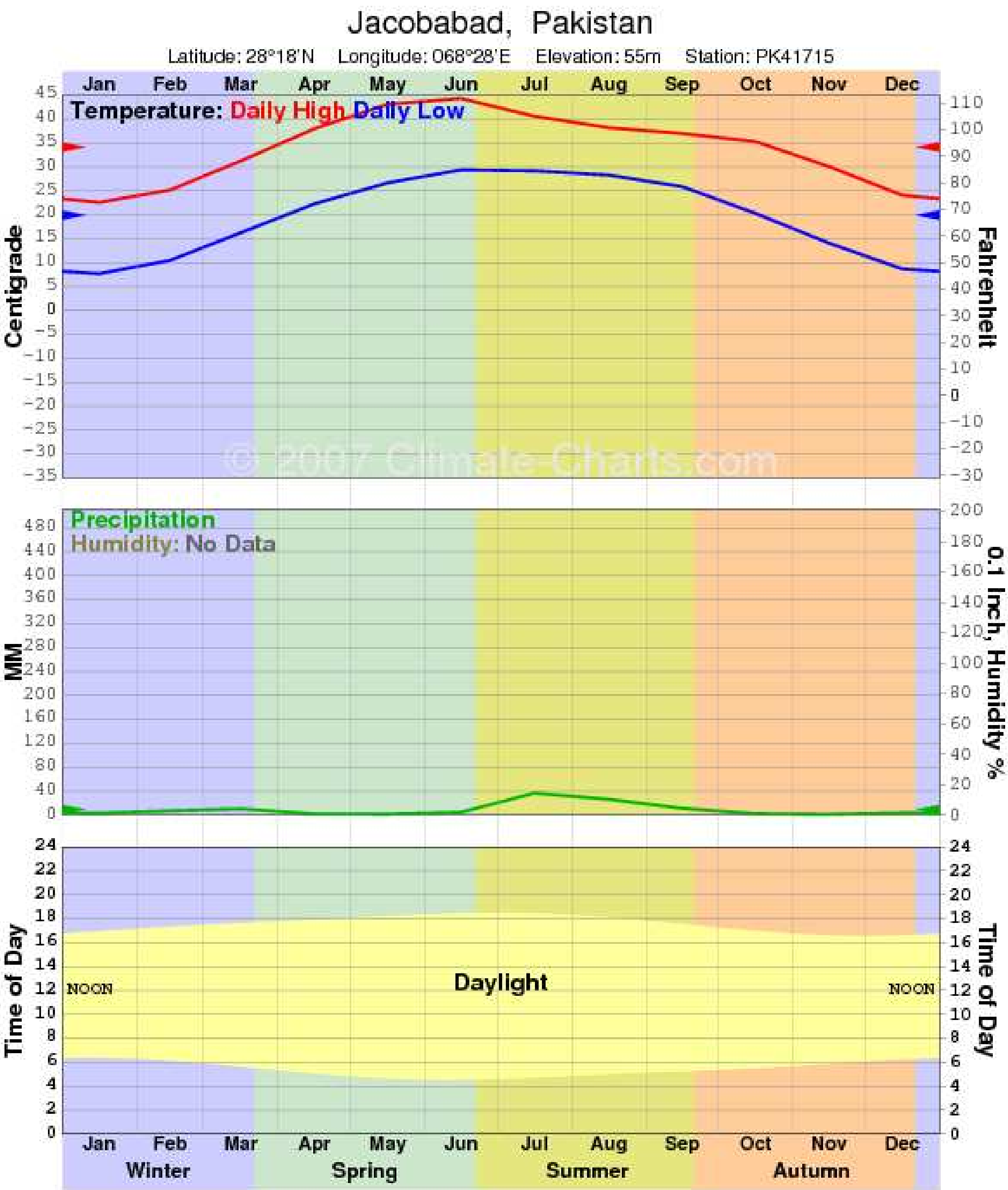

Figure 4. Jacobabad daily temperature – daylight chart [16]

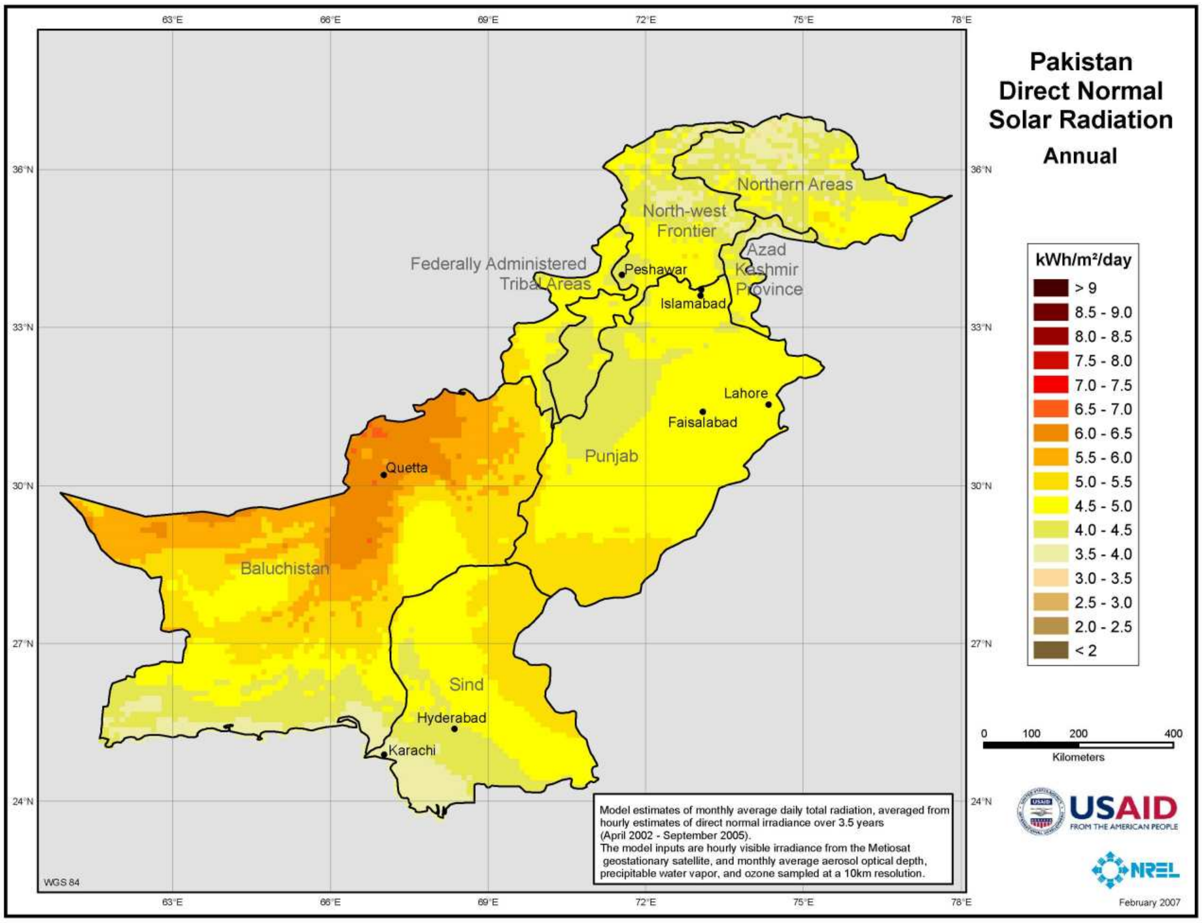

Figure 5. Pakistan annual direct normal solar radiation [17]

By comparing the sun shine hours of these cities available data, it was seen that sun shine hours in Jacobabad are more than other cities as shown in Table A1 of Appendix.

4.2. Economical feasibility

The selected economic indicators for this analysis are: Levelized cost of electricity, net present value (NPV) and total payback period (Tpb) [14].

$$C_L = \frac{I+O}{E_1 \sum_{t=1}^{n} \frac{1}{(1+k)}} [\$/kWh] \tag{1}$$

where I, O E_1, k and n are values of investment, operations and maintenance, energy produced by the plant in the first year (taken as the average annual energy produced), discount rate and number of years envisaged as the plant life time. Therefore, levelized cost is the total cash flows of a plant divided by the energy produced over the lifetime of a plant. It has been assumed that land is provided by the government. The operation and maintenance costs (O&M) cost in Pakistan for a solar thermal power plant is $ 0.001/kWh [18]. The energy inflation is considered to be negligible. We assume 60% sunshine hours are available throughout the year for electricity production to account for cloudy conditions and other miscellaneous factors. We shall use a discount rate of 10% for this analysis. The assumption and data used for the analysis is shown in Table 6, a [19]

Assumptions and data used	
Technical data	
Total power (MW)	50
Annual solar radiation (kWh/m^2)	1735
Annual generated electricity (MWh)	18970
Discount rate	10%
Lifetime (years)	25
System purchase price (US$/kWh)	4540[a]
Fixed cost	
Procurement of equipment (M$)	227
Transport & Installation (M$)	3[a]
Other costs (M$)	3[a]

Table 6. Assumptions and data

Net present value (NPV) which represents the discounted cash flow over the lifetime of a plant can in general be stated as

$$NPV = (1\text{-}T)\ (E - O)\ \text{-}\ I \tag{2}$$

Where T is marginal tax rate, E is income of the plant, O is O&M costs and I is initial investment.

Total payback period is the ratio of the initial capital investment I to the net income (difference between the value of the energy produced in the first year of operation, E_1, and the sum of the expenditure on operation and maintenance in the first year, O_1,

$$T_{pb} = I/(E_1 - O_1) \tag{3}$$

Quantity	Calculated Value
Value of investment	233 million US $
O&M Costs	0.475 million US$
Levelized electricity cost	24.4 cents/kWh
Sale price	60 cents/kWh
Net present value	22 million US$
Payback Period	23 years

Table 7. Summary of calculated quantities for a 50 MW solar thermal power plant

Solar dish technology can be a promising technology which can be deployed in Pakistan in small scale projects producing 25 kW electricity for remote areas, especially, in Sindh and Baluchistan and Federally Administered Tribal Areas (FATA), where there is enough solar potential for producing electricity through dish technology. Jacobabad has a great potential for a solar power plant based Stirling dish. The solar insolation is in the required limits which is more than 1700 kWh/m^2/year coupled with prolonged sun shine hours in those areas make this technology a viable option for producing electricity. Cost analysis shows that this technology is viable although it is expensive at the moment compared to fossil fuels based electricity. The prices will become competitive if the government of Pakistan withdraws the subsidies on fossil fuels and allocate it to solar based electricity. The calculations show that cost of electricity generation is higher than the existing water, natural gas and fossil fuels based generation which is 3 to 12 USD cent/kW [20] and therefore, government subsidy is necessary to make it competitive in the market. If government can provide subsidy on renewable power then it will attract more investment both at local and international level.

5. Conclusions

Pakistan has a huge potential for solar energy potential especially very high in Quetta and Karachi where a solar thermal power plant is viable. Government of Pakistan has to take strong policy and marketability measures that will establish and strengthen this environment friendly technology in the country. Solar power has very little impact on environment. This makes it one of the cleanest sources of power generation available to mankind. An operating solar power plant produces no air and noise pollution. Furthermore there is no hazardous waste produced in the production of electricity and it also does not require and transportable fuel. The use of solar electric systems is also known to reduce local air pollution. This results in the reduction in the use of kerosene and other fuels for lighting purposes. Solar power systems also help in the abatement of CO_2 gases.

Jacobabad is one the hottest place in the country and therefore, has the potential to have solar power plants installed there. Analysis for Stirling dish shows that it is feasible to install such systems there as the insolation is suitable for a solar power plant. The sunshine hours are also good coupled with good infrastructure i.e. transmission lines, natural gas and coal are in close proximity and easy access to national highway makes it an ideal place for a solar thermal power plant. Gawadar and Karachi ports are in the range of 500 to 700 km and also 132/220 kV transmission lines pass through the area for grid connectivity of the power produced by this plant. A positive net present value coupled with a reasonable payback period of 23 years indicates that this plant is a good option.

Appendix

LAHORE SUNSHINE HOURS DATA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	170.9	218.5	258.3	297.3	250.9	237.6	223.2	278.6	256.6	286.9	209.2	237.8
2001	185.8	234.1	277.5	247.4	308.0	244.9	217.2	284.4	263.2	253.3	250.5	198.3
2002	197.8	210.6	258.9	258.9	321.5	288.1	252.0	228.7	241.1	261.3	235.7	205.6
2003	111.9	204.8	234.9	279.7	319.8	245.4	254.0	230.5	236.9	277.0	345.6	225.0
2004	164.2	285.6	285.4	244.1	321.2	280.5	259.3	218.6	251.0	227.2	206.7	203.3
2005	210.3	150.7	220.7	271.9	285.4	292.1	206.9	258.5	238.5	285.6	255.1	227.3
2006	199.8	201.6	237.5	288.0	304.1	276.9	209.5	210.2	248.1	269.2	203.5	195.1
2007	234.9	138.1	260.7	308.5	298.8	250.2	236.4	226.2	223.3	284.7	215.8	217.3
2008	199.9	204.0	264.2	269.9	192.7	192.7	202.5	211.3	255.6	248.9	221.4	176.4
2009	185.2	220.3	238.5	276.2	310.5	308.7	252.9	228.0	273.5	217.5	147.1	189.1

ISLAMABAD SUNSHINE HOURS DATA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	141.1	197.9	255.9	293.5	316	268	235.6	273.6	259.5	258.9	185.7	183.6
2001	208.8	201.1	253.5	246.9	325.3	249.5	219.7	263.3	288.3	242.6	217.3	181.7
2002	202.2	155.4	252.1	259.2	323	307	317.7	181.9	267.1	245.7	201.7	191
2003	205.7	155	191	246.3	299.4	281.7	258.6	251.2	201.2	285.5	211.2	155.6
2004	115.3	224.9	252.6	169.9	313	275	270.5	224.2	248.6	221.2	202.5	157
2005	164.7	100.5	148.1	186.5	390.2	273.5	249.6	265.2	191.1	256.9	216.6	182.6
2006	142.7	154.7	209.7	246.9	315.1	264.1	192.5	208.8	242.8	245.7	163.9	146.1
2007	201.6	116.6	190.3	299.6	291.2	----	244.2	240.4	229.3	278	191.6	165.2
2008	175.5	205.6	245.6	307.8	224.1	224.1	228.7	231.4	244.3	244.4	255.9	199.7
2009	169	170.9	175.7	246.1	338.1	281.1	314.8	273.1	259.3	265.3	218.4	196.5

PESHAWAR SUNSHINE HOURS DATA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	148.3	225.1	204.0	275.3	277.2	250.2	253.2	270.4	253.3	258.4	194.5	131.5
2001	202.6	230.9	243.4	242.2	303.7	288.4	218.5	277.5	252.1	247.3	238.5	157.1
2002	204.1	155.8	222.7	246.7	305.0	280.3	285.8	189.8	243.4	248.1	203.3	140.2
2003	174.9	157.7	194.1	246.5	281.1	297.0	272.1	244.1	224.0	291.4	235.0	173.3
2004	135.6	227.8	259.1	214.2	314.5	303.0	249.3	272.6	249.4	227.3	213.3	137.8
2005	171.1	115.6	169.0	233.4	250.4	252.3	295.9	269.6	271.2	264.1	216.2	172.4
2006	148.6	156.1	172.2	256.5	289.5	----	124.7	148.6	254.2	222.2	163.8	124.5
2007	213.4	116.8	211.3	277.1	249.5	253.3	287.1	219.8	198.1	188.7	134.1	172.4
2008	150.2	173.8	197.6	255.1	248.6	248.6	226.2	221.2		221.6	177.8	176.3
2009	152.6	155.3	165.5	204.8	270.0	241.9	266.5	247.5	237.9	232.8	181.3	158.8

JACOBABAD SUNSHINE HOURS DATA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	213.3	248.1	240.8	273.7	364.1	361.2	330.0	307.4	297.8	308.5	241.6	245.2
2001	269.7	207.8	266.0	261.6	342.1	303.1	209.2	315.4	290.3	287.2	287.4	249.6
2002	238.5	207.4	242.0	263.2	330.7	342.4	300.6	240.6	281.7	300.1	243.3	239.9
2003	200.8	194.0	222.4	128.3	298.2	320.0	228.6	270.1	211.5	294.7	254.2	233.5
2004	200.8	194.0	255.0	128.3	262.2	275.6	270.3	256.3	237.5	318.2	294.5	238.1
2005	200.8	194.0	218.7	128.3	298.5	328.6	341.9	333.4	284.5	313.3	271.7	264.4
2006	216.0	193.9	251.8	247.4	341.9	331.4	312.7	251.2	307.7	310.9	221.4	203.2
2007	----	200.0	293.0	319.0	385.5	331.5	313.0	341.5	343.5	335.0	289.5	270.5
2008	171.0	254.5	279.0	273.5	359.0	288.0	323.0	341.5	328.0	315.5	289.0	258.5
2009	164.7	255.9	289.1	320.6	252.0	252.0	269.0.	372.0	281.2	309.5	285.3	247.4
	177.8	102.2	258.4	283.6	318.2	315.0	298.6	331.7	312.0	310.8	259.6	223.2

MULTAN SUNSHINE HOURS DATA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	197	242.4	270.2	285.3	263.1	234.6	237.9	306.6	275.3	292.8	229.5	222.3
2001	193.6	220.3	293.7	256.9	249.2	213.3	253.2	291.7	278.9	278.1	246.5	233.7
2002	221.7	200	270.1	253.6	280	261	239.2	265.8	255.8	275.8	206.1	219.7
2003	187.6	207.5	228.6	292.1	277.1	269	224	249.3	252	290.8	228.7	180.4
2004	143.1	207.7	287.4	227	252.3	240	234.1	222.4	263.3	236	228.5	205.2
2005	214	127.1	248.1	295.1	284.3	268.8	266.5	279.2	268.6	300.9	252.2	293.6

2006	190.9	161.3	259.6	278.3	249.4	265.8	234	244.2	270.9	259.7	198.6	214.4
2007	233.3	145.4	250.3	295	245.6	----	----	280.7	262.3	293.4	222.5	215.2
2008	190.6	221.2	282.2	273.9	246.9	246.9	289.4	227	268.7	253.4	251.7	180.7
2009	208.9	201.3	239.4	278.3	298.3	263.4	218.5	274.5	272.3	273	172.6	209.1

HYDERABAD SUNSHINE HOURS DATA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	263.0	274.9	282.6	219.6	309.8	179.7	197.7	233.6	248.4	298.7	275.4	278.8
2001	284.2	254.1	276.8	291.2	285.0	158.5	100.4	192.4	275.7	296.5	276.1	263.8
2002	271.2	259.5	273.7	288.1	303.3	250.3	187.5	191.3	282.2	276.0	260.8	254.8
2003	252.6	240.2	259.7	288.0	286.1	222.2	122.4	202.1	255.8	250.0	262.9	247.6
2004	263.0	275.1	313.2	265.9	273.6	216.4	199.3	189.1	271.1	250.4	260.6	244.9
2005	264.9	209.1	291.1	295.1	316.7	293.1	247.1	259.0	245.7	310.6	272.4	272.6
2006	262.8	251.8	289.1	291.2	308.1	258.3	144.8	180.3	271.5	292.5	265.0	242.3
2007	267.9	251.4	280.0	323.4	320.7	260.2	198.9	247.0	280.3	313.5	281.0	264.5
2008	230.1	265.5	291.7	286.9	293.3	184.1	151.6	242.8	249.6	293.5	277.9	212.2
2009	233.0	253.9	296.2	303.2	301.8	275.0	233.0	274.0	290.7	297.3	259.6	227.8

Table 8. Sun Shine Hours Data[3]

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References

[1] Water & Power Development Authority of Pakistanhttp://www.wapda.gov.pk/htmls/power-index.html,June 09, (2012).

[2] Alternative Energy Board (AEDB)Power sector situation in Pakistan, Alternative Energy Board (AEDB), Deutsche Gesellscharft fur Technische Zusammenarbeit (GTZ) GmbH, September (2005).

[3] Pakistan Meteorological DepartmentGovernment of Pakistan, May (2010).

[4] Raja, I. A, & Twidell, J. W. Statistical analysis of measured global insolation data for Pakistan, Renewable energy: (1994). , 4(2), 199-216.

[5] World Energy CouncilRenewable energy in South Asia: Status and prospects. London, UK; November (2000).

[6] Private Power Infrastructure BoardMinistry of Water & Power Govt. of Pakistan

[7] Klaiss, H, Kohne, R, Nitsch, J, & Sprengel, U. Solar thermal power plants for solar countries- technology, economics and market potential. Appl Energy (1995). , 52, 165-83.

[8] Marketaki, K, & Gekas, V. Use of the thermodynamic cycle Stirling for electricity production. In: Proceedings of the 6th Panhellenic Symposium of Soft Energy Sources, (1999). , 283-290.

[9] Overview of solar thermal technologies by Centre for renewable energy resourcesU-SA, May (1997).

[10] Teocharis TsoutsosVasilis Gekas, Katerina Marketabi, Technical and economical evaluation of solar thermal power generation, Renewable Energy 28 ((2003). , 873-886.

[11] Hargreaves, C. M. The Philips Stirling engine. Amsterdam: Elsevier Science, (1991).

[12] De Graaf, P. J. Multicylinder free-piston Stirling engine for application in Stirling-electric drive systems. In: Proceedings of the 26th Intersociety Energy Conversion Engineering Conference- IECEC '91. Boston, MA, USA, (1991). , 5, 205-210.

[13] Schlaich Bergermann und Partner GbREuroDish-Stirling System Description, Schlaich Bergermann und Partner GbR, Structural Consulting Engineers, Stuttgart June (2001).

[14] Li YaqiHe Yaling, and Wang Weiwei, Optimization of solar-powered Stirling heat engine with finite-time thermodynamics, Renewable energy 36 ((2011). , 421-427.

[15] Waqas NasrUllah Khan ShinwariFahd Ali, and A.H. Nayyar, Electric power generation from solar photovoltaic technology: Is it marketable in Pakistan? The Pakistan Development Review 43: 3(Autumn (2004). , 267-294.

[16] ClimateGlobal Warming, and Daylight Charts and Data; http://www.climate-charts.com/Locations/php,August (2010).

[17] National Renewable Energy Lab; http://wwwnrel.gov/analysis/tech_cap_factor.html, National Renewable Energy Lab USA, September (2010).

[18] Policy Framework and Package of Incentives for Private Sector Power Generation Projects in PakistanPrivate Power Cell, Ministry of Water and Power, Government of Pakistan, (1994). Annexure I, , 1.

[19] In the fieldEPRI Estimates Performance, Costs for Solar Thermal Plants, http://mydocs.epri.com/docs/CorporateDocuments/EPRI_Journal/Spring/1025049_InTheField.pdf,EPRI Journal Spring (2012).

[20] National Electric Power Regulatory AuthorityGovernment of Pakistan, http://nepra.org.pk/tariff_ipps.htm,November (2012).