
Feasibility of a Solar Thermal Power Plant in Pakistan

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Additional information is available at the end of the chapter

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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/m²/day of global horizontal insolation as an annual mean value, with 5.30 kWh/m²/day over most areas of the country [2, 3]. This minimum level of solar radiation (4.45 kWh/m²/day) is higher than the world average of 3.61 kWh/m²/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 m² Evacuated Collector tubes, provides heated water at 70 to 80 °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.

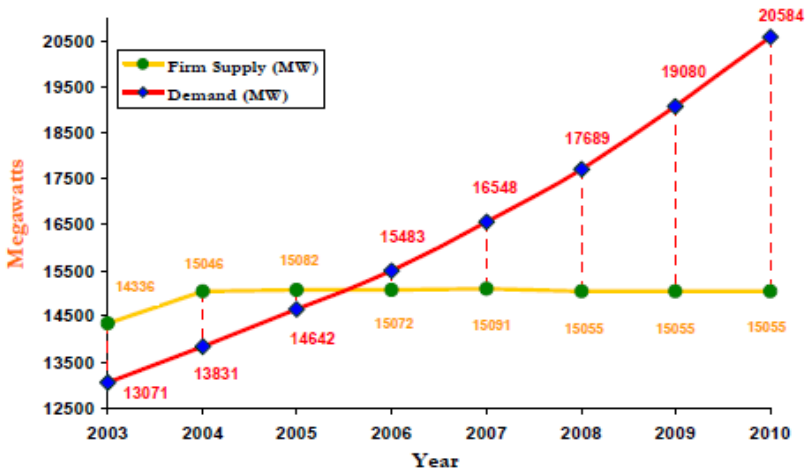


Figure 1. Generation capacity and demand forecast [6]

Both, technical and economical feasibility of a 50 MW solar thermal power plant using Stirling-Dish (SD) technology in Jaccobabad 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 CO₂ 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]

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/m²) 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 H₂) 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].

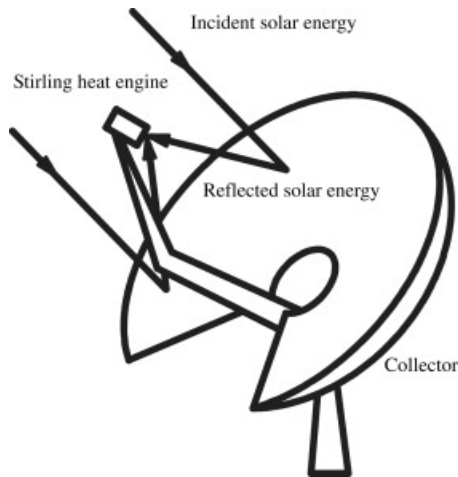


Figure 3. Schematic diagram of solar Stirling dish system [14]

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 $< 2 \text{ kWh/m}^2$. Another advantage of SD is it can generate power between passing clouds due its low thermal inertia. Jacobabad's Latitude is $28^{\circ}18' \text{ N}$, Longitude is $68^{\circ}18' \text{ E}$ 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 ($1735 \text{ kWh/m}^2/\text{year}$) [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°C in summer and 10 to 25°C in winter as shown in Figure 4. Temperature data given in Table 3 also shows a low temperature mean value of 19.95°C, high temperature mean value of 34.15°C and Temperature mean value of 27.05°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]

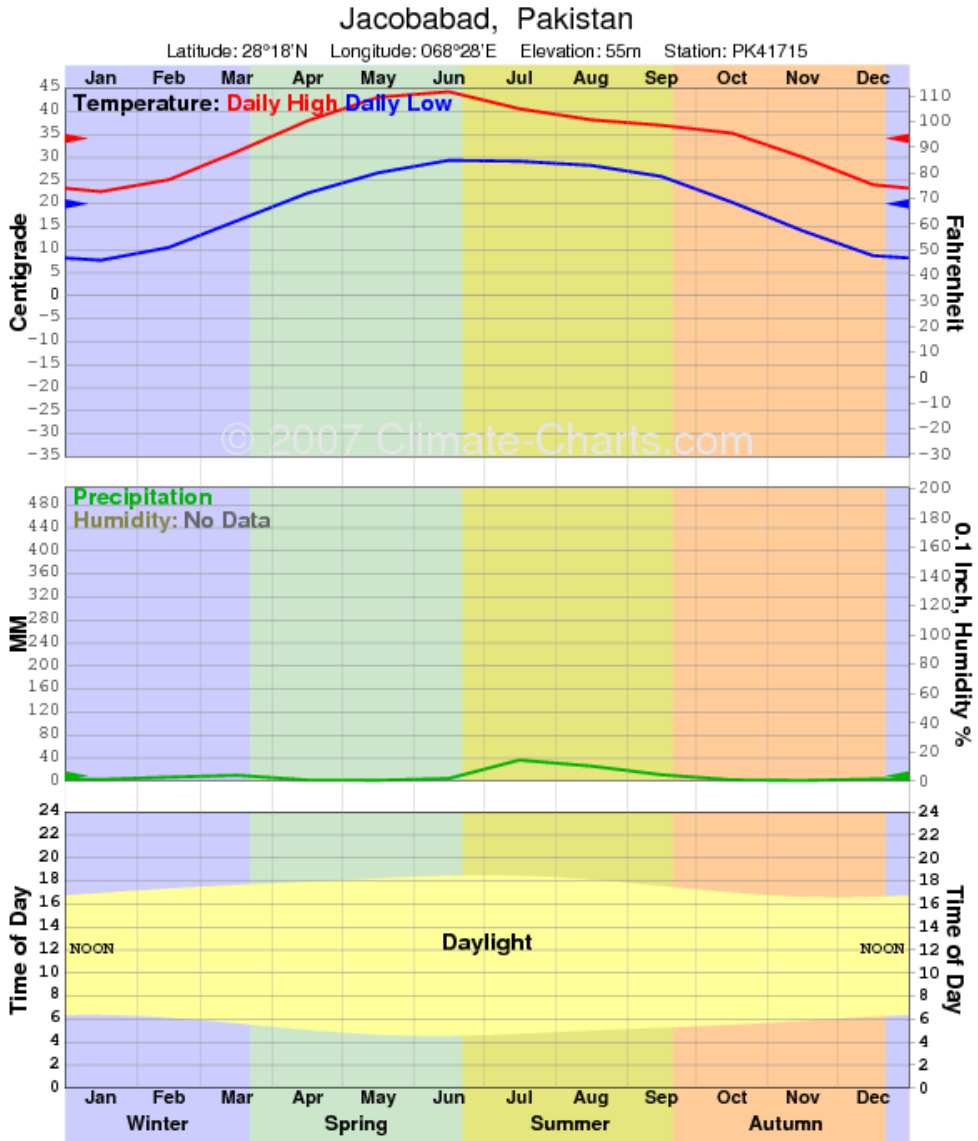


Figure 4. Jacobabad daily temperature – daylight chart [16]

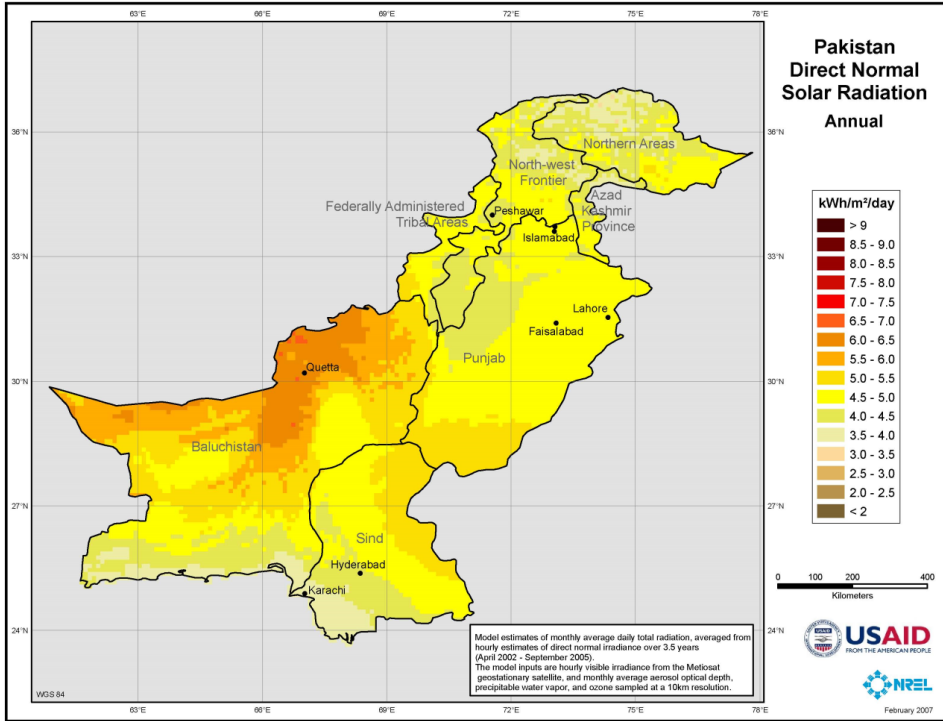


Figure 5. Pakistan annual direct normal solar radiation [17]

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].

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

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

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

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, E₁, and the sum of the expenditure on operation and maintenance in the first year, O₁,

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

| 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/m²/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 CO₂ 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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