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Identification of Potential Solar Power Production Areas of Pakistan Through Cost Benefit Analysis

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***Abstract*—**The adequate supply to the increasing demand for electric power generation is constricting due to ever increasing trend in the costs of electricity and the diminution of conventional energy production sources. Economic theory, alternatively, suggests for renewable energy sources such as solar photovoltaic (PV) system and biogas turbines for energy production. Comparatively, a PV system produces electric power costly, at first, to set up; over the years, it has recompense over non-renewable sources available for commercial use. The cost of management and maintenance of a PV system is relatively small in relation to wind and bio gas energy technologies as PV system has longer life time. This research identifies areas for potential solar power production and its venture points in the scale of solar PV grid based on favorable financial analysis of the costs other than non-renewable energy producing means. The comparison is provided on the tool of cost-benefit analysis and the effects on environment by using data taken from sources of Economic Survey (2015-16), WAPDA, and different thermal power stations. The findings have strong policy implications for installation of PV systems on identified potential areas for solar power production based on favorable economic factors of costs and benefits to encounter increasing energy demands with environment friendly attribute of no sulfur oxides waste in the air of green Pakistan.

Index Terms— Discount rate,Discount factor, Discounted operation and maintenance cost, Discounted Replacement cost, Inflation,Levelizedcost, Photovoltaic (PV) Systems.

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1 INTRODUCTION

Pakistan has enormous potential in the realm of renewable energy, in particular solar energy to plug the gap between demand and supply when used suitably. Pakistan's co-ordinates are preferably situated in the Sun Belt that's why it is favorable to take benefit of the solar energy technologies. Solar energy is available widespread in bulk over the co-ordinates of the country. Pakistan's co-ordinates receive 4.45-5.83kWh / m² / day of the global horizontal insulations. Most areas of the country receive an annual average with 5.30kWh / m² / day. In the country slightest level of the solar irradiations, 14.45kWh / m² / day, is more than average global irradiations3.61kWh / m² / day, this indicates that Pakistanis situated in the solar belt. Six main solar irradiation measuring stations are situated in Pakistanthat isMultan, Peshawar, Islamabad, Quetta, Lahore and Karachi and 37 observatories are fairly well distributed over the entire co-ordinates of the country which measures the sun shine hours. The above mentioned cities receive more than 250 hours of the sun shine per month. Pakistan co-ordinates receive world highest solar irradiations; it is perfect for solar thermal and photovoltaicapplications. The certain regions of the central Punjab and southern Quetta valley receive maximum sun light. The annual direct normal radiations in many parts of the Balochistan are in range 6.5kWh / m² / day to 7.5kWh / m² / day. In southern Punjab and northern Sindh annual direct normal solar radiation is in range from 5 to 5.5KWh / m² / day and around 4.5 to 5 kWh / m² / day in the rest of Pakistan [1].

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Table 1 The Annual Direct Normal Solar Radiation for CSP of four provinces of Pakistan [2].

Province	Irradiation (Min) KWh/m²/day	Irradiation (Max) KWh/m²/day
Balochistan	7	7.5
Southern Punjab	6	7
Northern Sindh	5	5.5
KPK	4.5	5

Monthly average solar irradiation of capital cities of four provinces of Pakistan.

Table 2 Monthly average solar irradiation of capitals of four provinces of Pakistan [2].

Capital of Province	Irradiation (Min) KWh/m² /day	Irradiation (Max) KWh/m²/day
Quetta	3.6	7.56
Karachi	2.4	6.31
Peshawer	3.39	6.31
Lahore	2.8	6.28

Pakistan is constructing solar power plants in, Punjab, Balochistan, Azad Kashmir and Sindh. The project is formed by International Renewable Energy Agency, China (IREA), and the private sector of Pakistan. Pakistan has also set a target to add approximately 100,000 MW electricity through renewable energies by the year 2030 beside replacement of 5% diesel with bio-diesel by year of 2016 and 10 % by 2025[3].

2. METHODOLOGY

The technique/tool of cost benefit analysis has been used to compare PV system and fossil fuel sources of energy production in Pakistan.

2.1 Formulae For Comparative Calculations

For PV system the following formulae has been employed for comparative calculations. All the following formulae have been taken from “Guidelines for the economic Analysis of Renewable Energy Technology “byInternational Energy Agency,OECD/IED [4].

Cost of investment

$$I = \sum_{t=1-P}^{0} I_t \cdot \Gamma^t$$

HereI is total investment in a year and Pis number of years andΓ is discount factor and is given by.

$$\Gamma = \frac{(1+e)(1+\text{h})}{(1+k)}$$

For calculation of discount factor discount rate is taken as 10%,rate of inflation h is taken as 6.8%,real increase in prices of capital goods e is taken as 3.7% and real rate in the prices of input energy $e_f$is taken as 11.4% as per Economic Survey of Pakistan Finance Division Islamabad.

Operations and maintenance cost

$$O = \sum_{t=1}^{n} O_{Annual} \cdot (\Gamma_o)^t$$

O is operation and maintenance cost, n is number of years.

Replacement cost

$$R = \sum_{t} R_t \left(\frac{1+h}{1+K_n}\right)^t$$

Here h is the inflation rate t is number of years.

Fuel input energy

$$F = E_{Annual} \times C_{Fuel} \cdot \sum_{t=1}^{n} \Gamma_f^t$$

Levelised cost

$$C_L = \frac{\text{I} + \text{O} + \text{R} + \text{F}}{E_1 \cdot \sum_{t=1}^{n} \frac{1}{(1+k)^t}} \quad [\$/\text{kWh}],$$

I is investment cost,O is operation and maintenance cost, R is replacement cost,F is fuel inputand E_1 is the energy produced by the plant in the first year of plant operation.

2.2 15 Mw Solar Photovoltaic Power Plant

Solar power station has long life span and free from fuel cost. A solar power plant for small commercial and residential scale is most considerable. For commercial installations of solar photovoltaic system it requires large area where solar photovoltaic system receives high level of solar insulations for bulk amount of power generation. The area chosen for solar power system must be near to power distribution center to avoid the transmission lines losses. In Pakistan some areas such as Baluchistan, Southern Punjab and northern Sindh has high level of solar irradiations. We consider a 15MW solar power station to calculate and analyses the economic viability of its parameters and the data available in this respect is solar insulations data of Jacobabad which is the hottest place similar to desert.

Table 3 Data for average radiation of Jacobabad on monthly basis [5].

Month	Average Daily Radiation on a Horizontal Surface(W/m2)	Average Day Length (Hours)
January	380	10.4
February	423	11
March	497	11.8
April	550	12.7
May	564	13.4
June	590	13.8
July	559	13.6
August	537	13
September	524	12.2
October	514	11.3
November	384	10.6
December	342	10.2
Average	489	12

Solar Photovoltaic cells efficiency is 14% to 15 % thus the power exerted is E_f,15%× 496= 74.4 watt per meter square.

2.3Cost Of Investment

Photovoltaic cell of a square meter produces 48 Watts, for generation of 150 Watts we require 3.1 Square of Photovoltaic power cell. For a 15MW photovoltaic power station installation we require 150 Watts 66666 solar panels which require quarter helf area of a kilo meter. The price of Solar penal per watt in Pakistan's local market is $ 7[1].We need 105 million dollars given a huge investment cost, it is reasonable to assume that an investor will stagger the total investment over a period of five years, P=5 years, investment per year is $21 million. To calculate the construction cost we use the following formula.

$$I = \sum_{t=1-P}^{0} I_t \cdot \Gamma^t$$

From the above formula we have discount factor

$$\Gamma = \frac{(1+e)(1+\mathrm{h})}{(1+k)}$$

P = required time for solar power plant construction.
Γ = discount Factor.
h = Inflation rate.
e = increase rate of capital goods.
k =the best rate that can be purchased from alternative investor.
From the above equation the total cost of the solar power plant construction is I= 104.83 million dollars.

2.4Power Generated By Solar Photovoltaic Plant

Using the data of the table of solar radiations of Jacobabad to extract 15 MW solar power we recorded the 12 hours in a day. Due to some seasonal variations and day light cloudy days we have assumed 10 hours of one day. The average day lights hours available for Jacobabad taken as 10 hours in day to generate electrical energy solar power system.so, calculating electrical energy production for average 10 hours in a day in Jacobabad for 15MW solar power plant thus we have 365×10 hours×15MW/1000=54750000KWh. We assume that this solar power station has required not more than 10 % of maintenance outages of the plant. So 10% is 547.5 Kwh the remaining in a year it is expected to generate 49.275 MWh, 15MW solar power plant will generate total annual electrical energy as 49.275 MWh / year so far thermal power station that run on Furnas oil having 60% of capacity factor is to produce energy

Annual plant capacity =Energy produced per year/60%×365×24

15MW×60%×365×24= Energy produce per year.

So E_{annual} would produce energy in a year is E_{annual} =78.84 GWh.

2.5Operations and Maintenance Cost

The Maintenance and operation cost of labor is $.010 per kilo watt hour in US whereas the cost of labors is very small in Pakistan as compared to US.As per power policy 2015 of Pakistan it is 0.1 cent cost per unit energy generated [1] so we take .001$ per kilo watt for solar power station is

O_{annual}=49.275× 10 ^ 3 kWh x $ 0.001 / kWh = $ 49.275.

Total operations and maintenance cost

$$O = \sum_{t=1}^{n} O_{annual} \cdot (\Gamma_o)^t$$

Where O is annual cost of the operations and maintenance

$$\Gamma_o = \frac{(1+e_o)(1+h)}{(1+k)}$$

Where n is 30 years for the operation and Maintenance of plant, e_0 is the Annual increase in maintenance and operation costs that is 6.8%. h is inflation rate that is 6.8%. Thus discounted maintenance and operation cost after 30 years is O = 1.92$ million.

2.6Replacement Cost

Determining the replacement cost over the project life time has no certain ways. The solar cells system has longer life span but due to some external nature elements in a desert like environment corrode the system that needs replacement. It is assumed that over a life period of 30 years of solar power plant only 30% of the equipment would be replaced. So at the base year the value of the cost of the investment I×30%/30 = I/100 where I=104.83 millions .Now equation

$$R = \sum_t R_t \left(\frac{1+h}{1+K_n}\right)^t$$

that gives the value of discount which is R=$35.35 million.

2.7Levelised Cost

This formula is sued to find and calculate theLevelisedcost

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

In the above formula cost of investment is I, Operation and Maintenance cost is O, Fuel input is F, Energy generated in the first year of the plant is E, Discount factor is K and life span of the plant is n ; putting all the said values in the above levelised cost formula we got the levelised cost of the 15MW solar power plant is 16.26 cents per Kilo watt hour.

Table 4 Calculated parameters of 15 MW Solar Photovoltaic Power Plant

	15MW PV Plant
Discounted Value of the Investment	104.83 m$
Operation and Maintenance cost	1.92 m$
Discounted Replacement Cost	35.35 m$
Input fuel Energy Cost	–
Levelised Cost	16.26 cents/kWh

3. 15 MW POWER PLANT BASED ON FOSSIL FUEL

We shall compare the financial cost and advantages of the PV power plant with the fossil fuel power plant.

3.1 Cost of Investment

The cost of construction of the fossil fuel power station depends on the type of the power plant. The Diesel, Furnas oil and combined cycle power plant has bit high cost. HUBCO a largest fossil fuel run power station with the capacity of 1292 MW which produce 1 Mega Watt of power production at the rate of 1.37 $ million [6], so the installation cost of 15 Mega Watt power generation is I = 15 ×10^6× $ 1.37 I = $ 20.55 million.

3.2 FuelInput

The equation that calculates the input energy

$$F = E_{annual} \times C_{Fuel} \cdot \sum_{t=1}^{n} \Gamma_f^t$$

requires the values of the amount of annual energy, increase in the real rate of prices and values of unit price of the input energy. Having assumption that 60% capacity factor at contemporary and given values of unit price of unit energy, annual amount required for energy and increase in prices of real rate of input energy of 15 MW power station is anticipated to produce energy in a year about 78.84 GWh. while calculating the input energy cost we consider that the power station is run on high quality refined Furnas oil. The calorific value that quoted 43 G joules/tone equivalent to that 1 KWh which is produced by .084kg of Furnas oil can helps to estimate the amount of oil required for generation of one KWh. The price of oil is Rs 11,195 per ton as per current year 2016 .At the exchange rate of Rs 100 to united state dollars the fuel charges for generation of KWh energy from thermal power station which costs Rs.3.134 or 5.2 cents respectively that is running at Furnas oil. HUBCO power station claims its plant efficiency is 37% [7] that is reducing down the fuel charges to 4.2 cents per Kilo watt hour. Our choice that is 4.2 cents per KWh so CFuel =0.042.

The value of increase in the prices of input fuel that has been taken by the average of the value of the increase in fuel prices by Govt of Pakistan over a Past ten years which is 11.4% .The cost of discounted input fuel is reformulated as

$$F = E_{Annual} \times C_{Fuel} \cdot \sum_{t=1}^{n} \Gamma_f^t$$

Where the value of E_{Annual}=78.84 Gwh, C_{ruel}=0.042 is the value per unit of the fuel charges. So e_{f} = 0.114 and the input energy discounted value over thirty years is to be F_{aunal}= $85 million dollars. When the value F_{Anual} =$ 85 million exclude the inventory cost and transportation cost of the fuel.

3.3 Operations and Maintenance Cost

So far the operation and maintenance cost is concerned it is estimated that 0.007 / KWh as an operation and maintenance cost of the thermal power station that is run at fossil fuel in United States .As per energy policy of Pakistan 2016 where labor cost is so cheap the operation and maintenance cost is estimated $ .001 per KWh [8]. In this respect the maintenance and operation cost of the 15 MW power station is about to be

O_{Annual}= 78.84 x 10^6 kWh x $ 0.001 / kWh = $ 78840.

$$O = \sum_{t=1}^{n} O_{Annual} \cdot (\Gamma_o)^t$$

The equation for operation and maintenance Cost calculates the total discounted value of Maintenance and operation cost that is O = $ 2.9 million.

3.4 Replacement Cost

We assume the 50% of the capital of the equipment would need to be replace over the life time of 30 years of the power station that replacement is evenly spaced over the plant life

R_t=I*50%/300=50I/3000 = 50*20.55 x 10^6/3000

R_t= 342500.

Put the value of R in equation 3.4 that is

$$R = \sum_t R_t \left(\frac{1+h}{1+K_n}\right)^t$$

So in this way discounted replacement cost is R= $5.5 million. Putting the values of Investment cost, replacement cost, fuel input cost and operation and maintenance cost in equation 3.1 the value of levelised cost CL we achieve is 12.24 cents/kwh. The difference in Levelised cost is not so high still financier feel contented to invest in thermal power station.

3.5 Levelised Cost

From the formula of the Levelised cost the fossil fuel power station is calculated as 12.24 cents/KWh.

Levelised cost is simulated using MATLAB functions and m-file to make economic model more flexible while calculating the Levelised cost for solar power plant energy and thermal power plant energy.

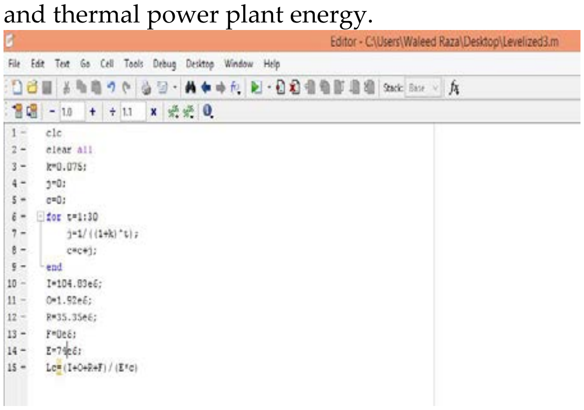

Figure 1 MATLAB coding for solar power plant Levelised cost.

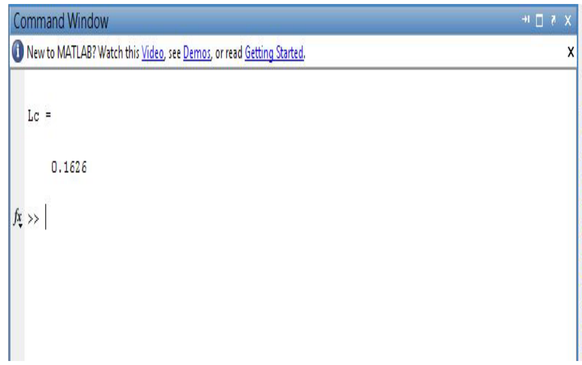

Figure 2Levelised cost calculated for solar power plant.

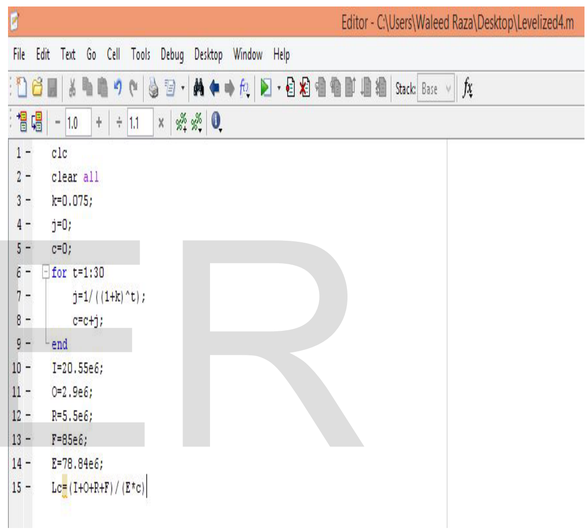

Figure 3 MATLAB Coding for Thermal power plant energy calculations.

Figure 4Levelised cost calculated for solar power plant.

Table 5 Calculated parameters of 15 MW of Solar and Fossil Fuel based power plant.

Parameters	15MW Solar plant	15MW Thermal plant
Cost of Investment	104.83m$	20.55m$
O & M Cost	1.92m$	2.9 m$
Replacement Cost	35.35m$	5.5 m$
Fuel	-	85m$
Levelised Cost	16.26 cents/kWh	12.24 cents/kWh

Using MATLAB functions and m-file we can calculate the parameters; cost of investment, operation and Maintenance cost, Levelised cost and Fuel consumption cost of Fossil fuel power plant and all the parameters of the Solar Power plant to compare cost benefit analysis of potential solar power production of different areas of Pakistan.

4. CONCLUSION

Sensitivity Analysis

Obviously the Levelised cost has a greatest contribution from installation cost of the Photovoltaic plant to generate electricity. If this steep installation cost of the Photovoltaic plant comes down to near about 5.3 per watt, the Levelised cost of solar Photovoltaic plant would come at par with that of the electricity from thermal power plant run on fossil fuel. The lower costs of investment of installation of the Photovoltaic power plant make it more attractive and profitable.

4.1 Amorphous Si technology

The Photovoltaic panels of the Amorphous silicon systems (a-Si and a-SiH) are certainly available at cost near about $3.5 per watt, as in our calculations by National Association of Regulatory Utility Commissioners NARUC, a PV cell importing company, the per watt cost including storage Batteries, Convertors and Installation charges is $ 7 .So Amorphous silicon systems (a-Si and a-Si H) will decrease the cost of investment to great extent.

4.2Indigenous production

The production of the photovoltaic cell at indigenous level reduces the cost to great extent. A one KW of photovoltaic panel including other components if imported can cost about Rs 500,000 while the cost of crystalline silicon photovoltaic cell panel produced indigenously by National Institute of Silicon Technology NIST is around Rs 375,000.This can, obviously, reduce 25% capital cost if produced locally. The 25% capital cost of investment reduction brings the Levelised cost of the PV panel at par with fossil fuel power generation.

4.3 The Concentrator technology

Concentrating the solar energy on Photovoltaic cells by using large mirrors can reduce the number of the solar cells in a panel this reduce the cost accordingly. At contemporary several experimental projects has made using concentrator with photovoltaic cells to produce electricity. The concentrator's technology collects the sun light from large area and concentrate it on a small area using Lenses and mirrors. A cheap and efficient system having photovoltaic panels and concentrators (Lenses, Spherical and parabolic mirrors) heat sink and fans forming the cooling system. The tracking system either one dimensional or two dimensional will increase efficiency more enough. The projects where the concentrator technology used the higher efficiencies 25% to 30% have been achieved[9]. So the capital investment cost has been reduced to 50%.In dry and hot climatic regions such as Texas, Saudi Arab, California and Madrid (Spain) the solar photovoltaic concentrator technology has been used, the data of the experiment and projects from these regions can be used on Pakistan as well.

4.4 MPPT Technology

Maximum power point tracker can also increase the efficiency to great extent, so in this respect the MPPT technology will marvelously decrease the investment cost.

4.5 Excluding the import Tax

Excluding the import Tax over the import of the solar panels from China and Germany having the higher efficiencies will decrease the investment cost to great extent.

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