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Electric Power Generation from Solar Photovoltaic Technology: Is It Marketable in Pakistan?

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Solar photovoltaic systems are prohibitively expensive in terms of installation costs. Power from them is also available intermittently—only when energy from the sun is available. On the other hand, PV systems are free of the ever-rising costs of input fuel. They also incur much less operation and maintenance costs and are supposed to have a longer lifetime than, for example, a fossil fuel power plant. Thus using solar-PV power looks uneconomical in the short term, but may be profitable in the long term. It is, therefore, interesting to identify the factors that can make investment in solar PV power generation acceptable.

This paper carries out a financial analysis of installing a 10 MW solar photovoltaic power generation plant for sale of electricity to a grid. It compares the levelised cost of this mode of energy generation as compared to a fossil fuel plant. It also calculates the cost of electricity generation and tariff for power from this plant. It then identifies the factors that can make the investment in a grid-scale solar PV plant more favourable than investment in other conventional and non-renewable sources.

1. INTRODUCTION

The energy demand in Pakistan is likely to increase steadily. Consequently, the current level of dependence on fossil fuel for electricity production will come under severe strain because of the high depletion rate of the fuel. Currently over 70 percent of the total electricity generation in the country is from fossil fuels, as shown in Table 1 below for the year 2000-2001. In the year 2000-2001 alone, the total fossil fuel consumption in electricity generation amounted to 11.94 million tons of oil equivalent (TOE).

The fossil fuel resources, however, are not expected to last for many years. In fact at the current rate of use of oil and gas for electricity generation, the existing oil reserves, if put to produce electricity only, can last for a little over six years only, and the gas reserves for about 75 years. According to some estimates, a large hydroelectric potential—to the tune of around 30 gigawatts—exists, which is likely

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Table 1

Gross Generation of Electricity by Source in Pakistan for the Year 2000-2001[1] *(GWh)*

Resource Type	Energy Produced Gigawatt-Hours	Percent of the Total Energy Produced in the Year
Hydel	17,194	25.24%
Nuclear[2]	1,997	2.93%
Coal	241	0.35%
Oil	26,904	39.50%
Natural Gas	21,780	31.97%

to form the backbone of future electricity generation. But there are issues—environmental as well as political—that make large-scale dams controversial. The mini- and micro-hydel plants, besides being too far removed from the national grid, add up to a small net generation, serving only some local communities. Even with a greater focus on microhydel plants, the benefit will remain confined mainly to the northern mountainous areas.

Among the various renewable energy options, wind and solar energy stand out for a larger and possibly grid-scale potential. Wind energy potential is currently being charted out by a state agency and in view of the sharp drop in installation costs, may help attract private investment in power generation. The potential is however likely to remain significant only in the coastal areas, mostly far away from the national electricity grid, and perhaps only to the tune of a couple of gigawatts.

Solar energy being in abundance almost all over the country is justifiably seen as the ultimate resource to tap. Although mainly supplemental in nature, it is also a resource that addresses the problems of atmospheric pollution and climate change. A number of projects aiming at different modes of utilisation of solar energy have been initiated over the years by a number of state-run organisations in Pakistan, but have failed to make any significant contribution.

Photovoltaic (PV) is one of the many ways of using solar energy, and PV cells are the means to convert incident sun energy directly into electricity. Attempts have been made in Pakistan both at installing small-scale photovoltaic power generators and at creating an indigenous PV fabrication capability. The indigenous fabrication facility exists only at the state-run National Institute of Silicon Technology whose capabilities remain at pilot scale. Water and Power Development Authority (WAPDA) ventured into installing imported PV panels for small-scale power

[1]Statistics taken from *Pakistan Energy Yearbook 2001* published by Hydrocarbon Development Institute of Pakistan, Ministry of Petroleum and Natural Resources, Government of Pakistan, Islamabad, January 2002.

[2] This includes energy from the Chashma Nuclear Power Plant that started supplying electricity in early 2001.

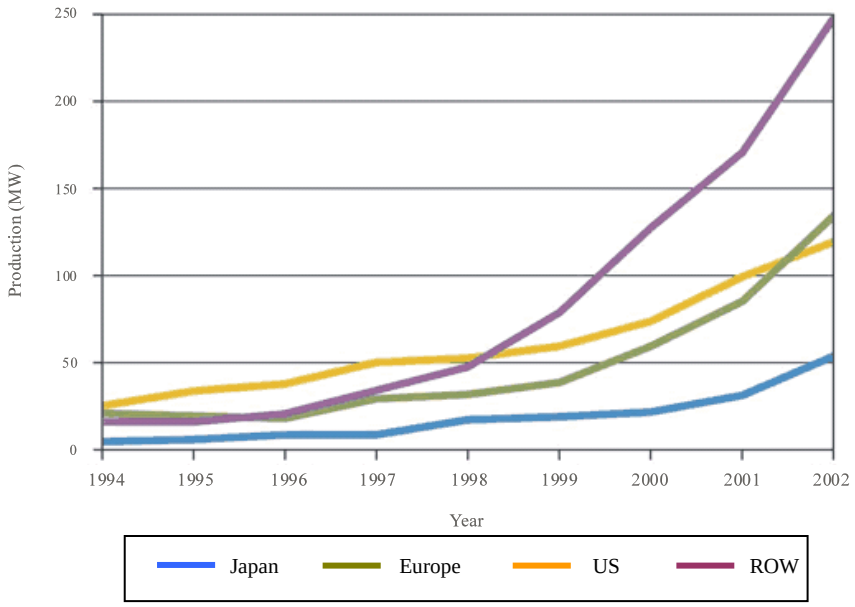
generation, but failed to sustain it. Imported solar modules are available in the open market in Pakistan, but at exorbitant prices.

Clearly then, the PV solar energy technology in Pakistan could neither be sustained at the user level, nor has it been attractive to prospective investors. It would therefore be interesting to find ways that could make solar energy technology marketable in the country. Among the host of factors that form an answer to this question, one is the economic viability.

In this study we look into the economic viability of a PV cell-based power plant as compared to a fossil fuel plant. One basic objective of this study is to compare investment in a solar PV plant as against that in a thermal power plant.

Photovoltaic cell production and installation have both increased worldwide in significant manner in the past decade. The most recent available data clearly shows a many-fold increase in these areas in the Far East and in Europe, although only a modest increase in North America and the rest of the world. Figure 1 shows the PV panel production magnitudes (in megawatts of installed capacity) from 1994 to 2002.[3] The rate of increase has been the largest in Japan. The total PV cell and

Fig. 1. World Solar Photovoltaic Cell/Module Production (in Megawatts of Production Capacity), Both Consumer and Commercial, from 1994 to 2002.



Source: PV News, Vol. 22, No. 3, 2003.

[3]From Paul Maycock, *Renewable Energy World*, July-August 2003.

module production all over the world stood at over 560 MW in the year 2002 which was a 43.8 percent increase over the production in 2001.

Clearly the increase reflects a rising trends towards installing solar panels not only for domestic electricity generation, but also for grid-scale production. Often PV plants are considered at the level ranging from kilowatts to at most a few megawatts. But since the per watt installation cost of a utility scale PV plant is hardly any different from that of a domestic scale one, grid-scale production, particularly in countries that have larger insulation, seems to be a viable option. The world has in fact seen a rapid rise in the grid-scale domestic and commercial PV installations. While grid-scale solar PV power generation was at the most 1 MW in 1990, it grew to 270 MW in 2002, experiencing a rise of 70 MW in the last year alone.

Fossil fuel thermal power plants are a good investment if they are 10 megawatts or higher in power rating. Solar PV plants of 10 megawatts have not so far been common but, given the above facts, are being increasingly considered. This study will therefore consider a 10 megawatt solar PV power plant and will calculate the economic factors that may be of concern to potential investors. It will then compare the investment in it in comparison to that in a thermal power plant.

2. METHODOLOGY[4]

Given the possibility of investing in one of two energy production ventures, a means to measure the choice that would give better returns is the *levelised cost* C_L defined by

$$C_L = \frac{I + O + R + F}{E_1 \cdot \sum_{t=1}^{n} \frac{1}{(1+k)^t}} \text{ [\$/kWh]}, \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2.1)$$

Here I, O, R, F are discounted values of investment, operations and maintenance, replacement and input fuel respectively, E_1 is the energy produced by the plant in the first year (taken as the average annual energy produced), k is the discount rate and n is the number of years envisaged as the lifetime of the plant. Levelised cost is thus the total cash flows of a project divided by the discounted energy produced over the lifetime of a project.

The various quantities that go into defining the levelised cost are defined below. In all of these, the year the plant starts producing energy is taken as the zeroth year.

The value of an asset changes with time because of (1) the opportunity cost of the capital, (2) inflation and (3) the increase in prices without any change in the quality or quality of the goods.

[4]All the formulae have been taken from "Guidelines for the Economic Analysis of Renewable Energy Technologies" by the International Energy Agency, OECD/IEA, 1991.

The discounted installation cost for a plant that takes P years for its construction is

$$I = \sum_{t=1-P}^{0} I_t \cdot \Gamma^t \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (2.2)$$

where the discount factor

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

takes into account, inflation through the rate h and real increase in prices of capital goods through the rate e. The discount rate k—the opportunity cost of capital—is defined as the best rate of profit that can be earned on an alternative investment.

The production of energy incurs operational and management costs that are also to be discounted over the period of operation. The discounted value of the operational and maintenance cost after n years of operation is

$$O = \sum_{t=1}^{n} O_{annual} \cdot (\Gamma_o)^t , \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (2.3)$$

where O_{annual} is the annual operational and maintenance cost, and

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

now contains e_o as the annual real increase in the operations and maintenance costs.

With time, many components of the plant would need replacement. For a replacement cost R_t in year t ($t<n$) in zero year dollars, the discounted replacement cost over the lifetime of the project is

$$R = \sum_t R_t \left(\frac{1+h}{1+k_n} \right)^t \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (2.4)$$

Fossil fuel plants also accrue **cost of input energy** that changes in time too. In principle the discounted input fuel costs F are to be evaluated in a way similar to the above:

$$F = F_{annual} \cdot \sum_{t=1}^{n} P_t \cdot \Gamma_f^{\,t}, \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (2.5)$$

where F_{annual} is the annual amount of required fuel (input energy), P_t is the average price per unit of input energy purchased in the tth year and

$$\Gamma_f = \frac{(1+e_f)(1+h)}{(1+k)}.$$

If e_f is the average real rate of increase in the fuel prices, then the price P_t in year t can be taken as the value per unit of the input energy in the first year.

Parameters Values

Discount rate k: For most public and private sector analysis, one uses a 10 percent discount rate, but some private investors sometimes have a more pessimistic approach and they use 15–20 percent discount rates to evaluate the return on their investment. In this analysis we shall use a 10 percent discount rate, which is probably the best interest rate one can obtain from a bank. The official Government of Pakistan rate now is 7.5 percent.

Rate of inflation h: For most public sector investments in Pakistan, the inflation rate considered is 3-4 percent. In general, however, the average rate of inflation over the last ten years, as documented in the Government of Pakistan's economic surveys[5], has been 6.8 percent. To keep our estimations more favourable to an investor, we shall take this value of the inflation rate.

Real rate of increase in prices of capital goods, e: The average real rate of increase in the prices of manufactured goods over the last ten years, as listed in the Economic Survey,[6] has been 3.7 percent.

Real rate of increase in the operations and management costs, e_o: We shall take this to be the same as the average rate of inflation, that is, 6.8 percent.

Real rate in the prices of input energy (fuel), e_f: The average rate of increase in wholesale prices of fuel, as documented in the Economic Survey,[7] is 11.4 percent.

An observation is in order here. Equation (2.5) requires using both inflation and the real increase in prices of fuel in calculating the discounted value of input fuel. This however enormously inflates the discounted input fuel prices which has an adverse impact on the levelised cost of energy from thermal power plants. It can be argued that the real increase in fuel prices plays a major part in inflation. Hence taking both the increase in fuel prices and inflation would amount to counting the impact twice. Only one of the two should suffice. The rate of increase in the real price of fuel being larger than the discount rate, one should consider the former and ignore the latter in Equation (2.5).

[5]Government of Pakistan. *Economic Survey 2000-2001*. Economic Adviser's Wing, Finance Division, Islamabad.

[6]*Ibid*, Statistical Appendix, p. 7.

[7]*Ibid*, Table 7.1, p. 7.

3. A 10 MEGAWATT SOLAR PV ELECTRICITY-GENERATING PLANT

Photovoltaic solar power plants are known to be prohibitive in capital costs, but the advantage of not incurring any fuel costs, and a longer lifetime may in the end make it competitive over the plant life-time when all the costs in generating electrical energy are together taken into account.

PV power plants are usually considered for smaller distribution areas, consuming kilowatts to megawatts, although it has been estimated that the economy of scales lowers the capital cost of commercial scale plants by a small margin.[8] But as mentioned above, grid-scale installations are increasingly coming into consideration.

Installing commercial scale [megawatt] solar PV power plants would require placing solar cell panels over a very large area, and can be viable only in a region which receives a high level of insulation for most part of the year. The area must also be close to the national grid to avoid large transmission losses. Pakistan's vast desert regions in the southern Punjab or the northern and eastern Sindh appear quite suitable in this respect.

We will consider installing a 10 MW photovoltaic power plant in a desert region of Pakistan. The insulation data is available for Jacobabad,[9] as in Table 2. Jacobabad is among the hottest and the most arid areas of Pakistan, having weather conditions quite similar to those of a desert. We shall therefore assume that the Jacobabad data is suitable for studying installation of such a plant. This is a conservative assumption in that the insulation is likely to be higher in deserts.[10]

Maximum efficiency of a common silicon solar PV cell is around 15 percent, so the power density that can be extracted from the incident solar flux is

$$489 \times 15\% = 73.3 \text{ W/ m}^2$$

Roughly two-thirds of the total area of a panel consists of photovoltaic cells. So a one meter square PV panel can generate about 48 watts from the incident flux. Thus, in order to produce 100 W of electricity from solar cells in an area like Jacobabad, the required area of a PV panel should be about 2.1 square meters.

[8]Herzog, A. V., T. E. Lipman, and D. M. Kammen (2001) "Renewable Energy Sources". In, OUR FRAGILE WORLD: Challenges and Opportunities for Sustainable Development, forerunner to the Encyclopaedia of Life Support Systems (EOLSS), Volume 1, Section 1 (UNESCO-EOLSS Secretariat, EOLSS Publishers Co. Ltd.)

[9]Khan, Nasim A, "Solar Energy Guide and Data Book for Pakistan", College of Electrical and Mechanical Engineering, 1986.

[10]It has been estimated that Balochistan receives on the average 19-20 MJ/m^2 per day with the day length taken as 8 to 8.5 hours. This makes the incident power about 650 W/m^2. Our estimate is conservative in the sense that it is 25 percent lower than this. See http://www.worldenergy.org/wec-geis/publications/reports/renewable/country_reports/chap_2_6_2.asp.

Table 2

The Monthly Average Radiation Data for Jacobabad, Pakistan[11]

Month	Average Daily Radiation on a Horizontal Surface (W/ m^2)	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

The installation of a PV cell power plant of 10 MW capacity would require a total of 100,000 PV panels of 100 watts each for which the required total area of PV panels would be about a quarter of a square kilometre. This gives an idea of the size of the power plant.

PV cells are usually sold in Pakistan at the rate of $ 7 per watt along with storage batteries, converters, and installation charges.[12] A 10 MW plant would therefore cost around 70 million US dollars.[13] One must also consider economy of scales, as is indicated by the following quote from a US Department of Energy document.[14]

> "Small, single PV-panel systems with built-in inverters that produce about 75 watts may cost around $900 installed, or $12 per watt. A 2-kilowatt system may cost $16,000 to $20,000 installed, or $8 to $10 per watt. At the high end, a 5-kilowatt system that will completely offset the energy needs of many conventional homes may cost $30,000 to $40,000 installed, or $6 to $8 per watt. These prices, of course, are just rough estimates."

[11]*Ibid*, pp. 78–83.

[12]National Association of Regulatory Utility Commissioners [NARUC] and Prices from Trillium (a company importing PV cell panels in Pakistan).

[13]http://www.solarbuzz.com.

[14]From *A Consumer's Guide to Buying a Solar Electric System*, U.S. Department of Energy, September 1999, http://www.nrel.gov/ncpv/pdfs/26591.pdf.

Moreover, recent trends in grid-scale power production from PV cells indicate a substantial decrease in costs. With the increase in the production of PV modules from a total of 17.4 MW in 1995 to 251MW in 2002, the pre-subsidy price has reportedly dropped from US$11/W in 1996 to $6/W in 2002.[15] The factory prices for single and polycrystalline silicon modules have decreased to between US$2.90 and $3.25, and amorphous silicon modules were are reportedly being sold at prices of $2.00-3.00 per watt.[16]

We shall, however, consider in this analysis the installation cost of PV modules to be $7 per watt, and shall at the end consider the impact of these reduced costs.

We thus assume that 70 million dollars is the total capital investment.[17] To avoid further complications in the economic calculations, we are considering only the cost of PV cell panels and their installation, and assuming that the connection to the national grid costs and the civil construction costs will be quite low as compared to the cost of PV cells.[18]

Pakistan has a very limited capacity of producing PV cell panels. National Institute of Silicon Technology (NIST) is the only establishment involved in PV cell production, and that too on a pilot scale. An investor in a PV power plant will have to import the modules from major manufacturers abroad. Most manufacturers have a production capacity of around 5–10 MW annually,[19] but the capacity of some (e.g. Sharp Co. Japan) has now increased to over 120 MW a year. The total PV module production capacity world-wide has increased to over 550 MW a year. On the use side, the grid-connected residential and commercial installation in the year 2002 alone has been to the tune of 270 MW. A 10 MW solar PV plant will therefore not be an unusual venture.

Given the huge investment cost, it is reasonable to assume that an investor will stagger the total investment over a period of five years (P=5 in Equation (2.2)), investing $14 million a year.

The various discounted costs that go into calculating the levelised costs are tabulated below for a PV plant and a fossil fuel thermal power plant.

3.1. Discounted Cost of Investment

The total discounted construction cost,[20] calculated from Equation (2.2), when the

[15]Maycock, p. 84.

[16]Maycock p. 90.

[17]Quoted from A Consumer's Guide to Buying a Solar Electric System, U.S. Department of Energy, September 1999, http://www.nrel.gov/ncpv/pdfs/26591.pdf.

[18]This is a "standard" assumption as the cost of connectivity to the grid is low when the plant is located near the national grid. Furthermore, grid connections are usually provided by the Government to the private investors. This was also the case in 1994 policy in which this was part of incentive package offered to the investors.

[19]http://www.solarbuzz.com/.

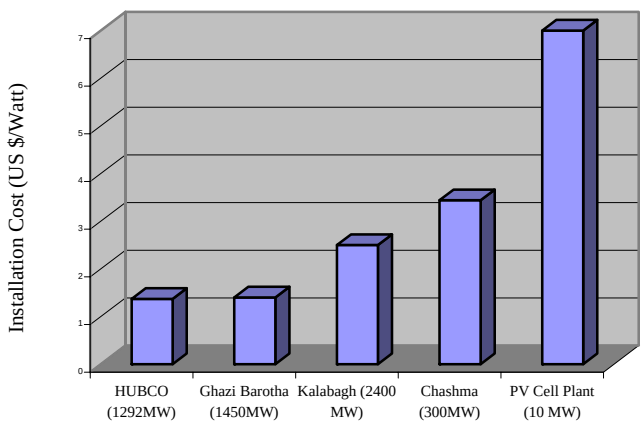
[20]As noted in Section 2, the base year in this formulation is taken to be the start of the plant operation.

investment is taken to be equally divided over each year of the installation period, is

$$I = \text{US\$ } 69.06 \text{ million}$$

Therefore, as far as an investor is concerned, the cost of installing a 10 MW PV cell power plant will be 69.06 million US$. In contrast, the Kalabagh Dam power plant, which has been abandoned for the present, was planned to have a generation capacity of 2400 MW. It was going to cost around 6 billion dollars. The construction cost per watt of electricity generation capacity would therefore have been around $2.5/ W. The cost of the 300 MW Chashma Nuclear Power Plant was 1.033 billion US dollars. For it, therefore, the capital cost was about 3.44$ per watt of the installation capacity. A comparison of these generation costs is given, together with other indicators, in Figure 2.

Fig. 2. Construction/Installation Costs in US$ per Watt of Electricity Production Capacity.



In the following we intend to add to this elementary estimate of the capital cost for the plant an analysis that brings out costs over the life-time of the plant, the need for including fuel costs and operational and maintenance costs to complete the picture. As the fossil fuels deplete, the costs would continue to rise, and the operational and maintenance costs of, for example, a nuclear power plant are prohibitively high. In contrast, the operational skills for a PV power plant will be much less demanding. In addition, there are long-term adverse effects of other large projects like hydroelectric dams. It would be interesting to see also, in a future analysis, if such adverse effects could be quantified and brought up in a comprehensive analysis.

3.2. Total Value of Electricity Produced by the PV Cell Plant

The total energy in a year from this 10 MW PV cell plant can be calculated by using the data in Table 2 for average monthly insulation in Jacobabad. This average value of the incident solar power and its availability for utilisation is assumed to have taken into account the cloudy days and the variation in the incident solar flux due to seasonal variation round the year. Also, although the daylight is recorded to be available on the average for 12 hours a day, we assume that for power generation purposes it is available for only ten hours.

The energy generated by each 100W panel in a year for an average of 10 hours a day is $0.1 \times 10 \times 365 = 365$ kWh.

This is possibly an over-estimation because this assumes that there are no maintenance outages. We assume that solar PV plants are robust enough to not require such outages of no more than 10 percent. Discounting for this, a 100W panel is thus expected to generate a total of about 330 kWh of electrical energy in a year.

Total annual electricity generated by a 10 megawatt plant would be

$$330 \text{ kWh} \times 10^7 = 33 \text{ GWh/ annum}$$

In comparison, a 10 MW furnace oil thermal power plant working at 60 percent capacity factor is expected to produce 52.56 GWh of energy a year.

3.3. Total Discounted Operational and Maintenance Costs

The operational and maintenance cost of PV solar modules has been estimated as \$0.005/kWh.[21] This is however in the US. The labour cost in Pakistan is usually much smaller, particularly for low-skilled maintenance jobs. The 1994 Power Policy[22] takes the O&M cost of thermal power plants as equivalent of 0.1 cent per unit of energy produced. The skills required in operating and maintaining a solar PV plant are expected to be much lower. Yet we take the O&M cost for PV plant to be also \$.001/kWh. So the annual operational and maintenance costs are

$$O_{annual} = 33 \text{ x } 10^6 \text{ kWh} \times \$0.001/\text{kWh} = \$\ 33{,}000.$$

The discounted operational and maintenance cost over the 30-year lifetime, from Equation (2.3) is therefore

$$O = \$\ 1.82 \text{ million}$$

[21]Data from National Association of Regulatory Utility Commissioners [NARUC].

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

3.4. Discounted Replacement Cost

There is no certain way to determine the replacement costs over the project lifetime. Assumptions will have to be made. Although the solar cells usually have a long lifetime of their own, but because the modules are subject to the elements of nature, which are expected to be rather harsh in a desert environment, we assume that 30 percent of the equipment would need replacement over the 30-year life of the plant. We also assume that this is equally spaced in time so that the yearly replacement cost is $I*0.3/30 = I/100$. Discounted over the plant lifetime, Equation (2.4) gives the replacement cost as

$$R = 13.7 \text{ million dollars}$$

Putting all these numbers in Equation (2.1), the levelised cost of producing electricity from a 10 MW solar PV plant comes to 27.2 cents/kWh. (Table 3.)

Table 3

Summary of the Calculated Quantities for a 10 MW Photovoltaic Electricity Generation Plant

Quantity	Calculated Value
Discount Value of the Investment	69.06 million US dollars
Discounted Operation and Maintenance Cost	1.82 million US dollars
Discounted Replacement Cost	13.73 million US dollars
Levelised cost	27.2 cents/kWh

We shall next consider similar costs for a fossil fuel power plant of the same size to be able to compare the two costs, hoping to find reasons why PV plants are not attractive in the market.

It may however be noted that the environmental advantages of the solar power plant have not been considered in the above. There are other factors also to which the costs involved in the solar power plants are sensitive. These will be considered in Section 5.

4. A FOSSIL FUEL-BASED POWER PLANT OF 10 MW CAPACITY

Whenever a power plant based on renewable energy sources is proposed, it is compared with a fossil fuel based power plant to compare the financial and environmental advantages and disadvantages. We therefore consider a fossil fuel power plant, so that the economic indicators can be compared with PV cell power plant. All the economic values are pre-tax both in the case of the PV cell plant and the fossil fuel power plant.

4.1. Cost of Investment

The construction cost of a fossil fuel power plant is normally taken to be around 1$ per watt of electricity production capacity. The cost varies depending on the type of plant. Gas fired combined cycle plants cost the least while diesel and oil-fired combined cycle plants cost a little higher. The variation is however less than 10 percent. HUBCO, a large fossil fuel power plant of 1292 MW installed generation capacity, quotes that installing a 1 megawatt fossil fuel power production facility would cost around $1.37 million dollars.[23] The construction delay may have pushed up the cost and offset any reduction due to the economy of scales. It therefore seems reasonable to take $1.37 per watt as the installation cost of a thermal power plant. Thus the total installation cost of a 10 MW plant will be $13.7 million.

The construction period is taken to be around 5 years. We divide the total estimated cost of the power plant equally in three years. Discounted cost, determined by Equation (2.2), thence comes to

$$I = \$13.5 \text{ million}$$

4.2. Discounted Sum of Input Energy Expenses

Equation (2.5) requires the annual amount of energy required, the unit price of input energy, and the real rate of increase in prices of the input energy.

Assuming a 60 percent capacity factor, the 10 MW plant is expected to produce 52.56 GWh of energy a year.

To evaluate the cost of input energy we assume that the plant is run on refined furnace oil.[24] The amount of oil needed to generate a kWh can be estimated from its calorific value, which is quoted as 43 gigajoules per tonne,[25] equivalent to saying that 1 kWh is produced by 0.084 kg. of furnace oil. With a standard efficiency of 30 percent, a thermal power plant would produce a kWh from 0.28 kg. of furnace oil. The current (year 2001) price of furnace oil is Rs 11,195 per tonne.[26] Thus fuel charges for producing a kWh from a thermal power plant running on furnace oil will be Rs 3.134, or 5.2 cents at the exchange rate of Rs 60 to a US dollar. HUBCO claims 37 percent efficiency for its combined cycle power plant. With that efficiency, the fuel charges come down to 4.2 cents per kWh. The average fuel cost claimed by various private power producers running their plants on the refined furnace oil are given in Table 4. These average to 4.11 cents/kWh. Our choice of 4.2 cents/kWh is close to it.

[23]http://www.hubpower.com/.

[24]Natural gas combined cycle plants incur less fuel charges, while high speed diesel plants incur more than the furnace oil, *Energy Year Book 2001*, Table 5.11, p. 62.

[25]*Pakistan Energy Yearbook 2001*, Hydrocarbon Development Institute of Pakistan, Ministry of Petroleum and Natural Resources, Government of Pakistan, p. 82.

[26]*Pakistan Energy Yearbook 2001*, Hydrocarbon Development Institute of Pakistan, Ministry of Petroleum and Natural Resources, Government of Pakistan, p. 39.

Table 4

Input Fuel Charges for RFO based Thermal Power Plants

Power Station	Installed Capacity (MW)	Average Fuel Cost (Ps/kWh)	Average Fuel Cost (Cents/kWh)*
AES, Lalpir	362	305.60	5.09
AES, PakGen	365	288.44	4.81
Gul Ahmed	136	123.56	2.06
HUBCO	1292	237.26	3.95
Japan Power	135.6	280.46	4.67
Southern Electric	117	280.12	4.67
Tapal Energy	126	211.44	3.52

Source: Energy Year Book 2001, Table 5.11, p. 62.

*Excahnge rate taken as Rs 60 to a US$.

The rate of increase in the price of input fuel has been taken by averaging the increase in fuel prices in general over the past 10 years as given out by the Government of Pakistan.[27] It comes to 11.4 percent.

The discounted input fuel cost is calculated using Equation (2.5), which in itself is reformulated now to

$$F = E_{annual} \cdot c_{fuel} \cdot \sum_{t=1}^{n} \Gamma_f^t$$

With E_{annual} = 52.56 GWh, the per unit fuel charge c_{fuel} = \$0.042, e_f = 0.114, and h and as given above in Section 2, the value of input energy discounted over 30 years comes out to be

$$F_{annual} = \$\ 81.1 \text{ million.}$$

This value excludes the transportation and inventory costs of the fuel.

4.3. Operational and Maintenance Costs

The operational and maintenance cost of a fossil fuel based plant in the United States of America is estimated at \$0.007/ kWh.[28] In Pakistan, however, the labour being cheaper, the Energy Policy[29] of 1995 estimated it as \$0.001/kWh. We have discussed this above. So the annual operational and maintenance costs of a 10 MW thermal power station are likely to be

$$O_{annual} = 52.56 \text{ x } 10^6 \text{ kWh x } \$0.001/\text{ kWh} = \$\ 52{,}560.$$

[27]Government of Pakistan. *Economic Survey 2000-2001*. Economic Advisers Wing, Finance Division, Islamabad, Statistical Appendix, Table 7.1, p. 79.

[28] Data from National Association of Regulatory Utility Commissioners [NARUC].

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

Equation (2.3) for the total discounted value of the operational and maintenance costs gives

O = \$ 2.9 million

Which is about 20 percent of the capital cost.

4.4. Discounted Replacement Costs

Assuming again that 50 percent of the capital equipment would need replacement over the 30 year lifetime of the plant, and that the replacement is spread evenly over the plant life. The discounted replacement cost would be

R= \$ 4.5 million

It must be mentioned here that had the rate of inflation been included in addition to the real increase in fuel prices in the calculations, the levelised cost of energy from the thermal power plant would have climbed up to over 60 cents a unit.

Thus, taken over the life-time of the plants, the difference between the levelised costs is not that big (Table 5). Nevertheless, for an investor, it is still more profitable to invest in a thermal power plant—unless the levelised cost of energy from a solar plant could be brought down in some manner. In order to see how this could be done, we look at the sensitivity of the levelised costs on the quantities like investment cost and discount rate, etc.

Table 5

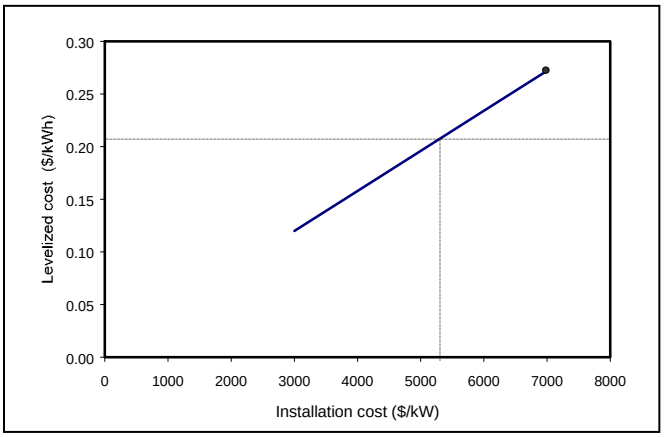
A Comparison of the Values of Various Quantities Calculated for 10 MW Solar PV and Thermal Power Plants

	10 MW Solar PV	10 MW Thermal
Discounted Value of the Investment	69.06 m\$	13.5 m\$
Discounted Operation and Maintenance Cost	1.8 m\$	2.9 m\$
Discounted Replacement Cost	22.88 m\$	4.5 m\$
Input Energy Cost	–	81.1 m\$
Levelised Cost	27.2 cents/kWh	20.6 cents/kWh

5. SENSITIVITY ANALYSIS

Clearly the largest contribution to the levelised cost of electricity from a solar PV plant comes from the exorbitant installation cost. If this somehow comes down to about \$5.3 per watt, the levelised cost of solar PV electricity would come at par with the electricity from a fossil fuel thermal plant (Figure 3). Any lower installation cost would make investment in a solar PV plant more profitable.

Fig. 3. Dependence of the Levelised Cost of Electricity from a Solar PV Plant on the Installation Cost. The dot represents the values in Table 5, and the horizontal dotted line shows the levelised cost of a thermal power plant, as calculated above. The figure thus shows that if the installation cost of a solar PV plant is brought down to about 5.3 $/W, the investment would be as good as that in a thermal power plant.

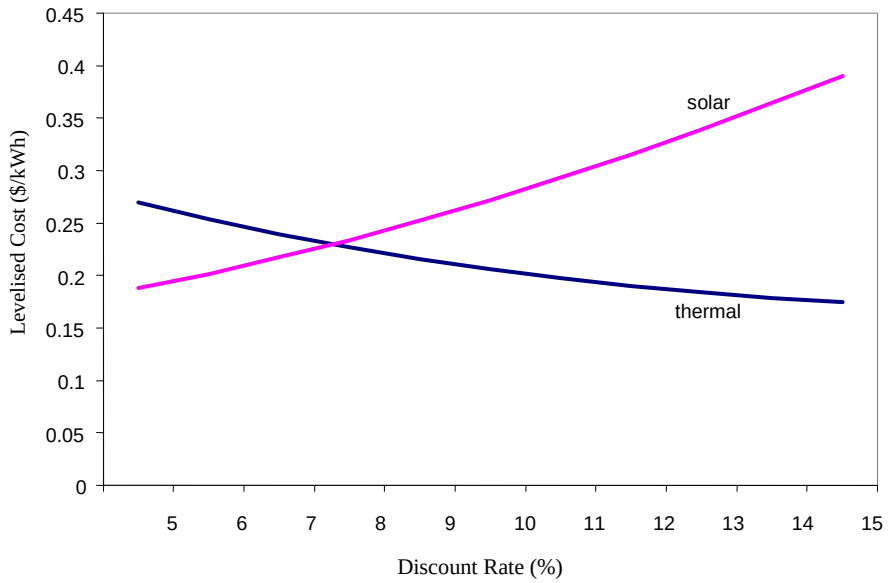


Japanese PV industry has been aggressively seeking export markets and in the process has brought down its prices from $11/W to $6.5/W in 2002.[30] We do not know the trends since then. It is possible that the prices may have come down even further.

Discount rate is another variable that can act as a handle in the analysis. Quite recently the Government of Pakistan reduced the discount rate from 10 percent to 7.5 percent. Discount rate is a variable that has an interesting effect on the levelised cost of the two technologies. In the case of solar PV systems, a reduction in discount rate decreases the levelised cost while for a fossil fuel thermal power plant, the reduction increases the levelised cost of energy, as shown in Figure 4, his is understandable because in the former case the levelised cost is predominantly determined by the installation cost, while for the latter, the input fuel charges dominate the calculations. While a smaller discount rate reduces the discounted installation cost, it increases the discounted cost of input fuel, hence the opposite effect. This implies that there can be discount rates below which the levelised cost of energy from a solar PV plant would become less than that from a thermal power plant. This crossover, as shown in Figure 4, is roughly at a discount rate of 8 percent, which means that at the discount rate of 7.5 percent that the government of Pakistan has now fixed, investment in solar PV system is already more profitable than in a thermal power plant.

[30]Maycock, p. 94-95.

Fig. 4. The Dependence of the Levelised Cost on Discount Rate for Solar PV and Fossil Fuel Thermal Power Plants.



Alternatives

5.1.1. Amorphous Si Technology

Amorphous silicon systems (a-Si and a-SiH) are indeed available at an installation cost near $3.5 per watt but then they have a much shorter lifetime, would incur a high replacement cost and almost zero salvage value.[31] In fact, in spite of the installation cost being reduced by half, these factors raise the cost of electricity generation from amorphous silicon PV plants to a higher value.

5.1.2. Indigenous Production

Indigenisation of PV cell production can reduce the cost. Importing a set of 1kW PV cell panels and other components costs[32] around Rs 500,000, while at the National Institute of Silicon Technology (NIST), which has a pilot facility of producing crystalline silicon PV cell panels, it costs[33] around Rs 375,000. There is thus a possibility of at least 25 percent reduction in the capital cost if the panels are

[31]They also have smaller conversion factor, but in our financial analysis is based on the cost of a 1kW panel and not on the number of cells contained in that panel.

[32]Private communication from M/S Trillium, Rawalpindi, a company involved in import of PV cell panels.

[33]Private communication from Dr. Parvaiz Akhtar, Chief Research Officer, PCRET.

manufactured locally. In the above calculations, a 25 percent reduction in the capital investment already brings the levelised cost it at par with thermal power electricity.

5.1.3. The Concentrator Technology

Using large mirrors to concentrate solar energy on PV cells can reduce the number of PV cells required in a panel, in turn reducing the cost proportionately. Many experimental projects have recently proven the practicality of using solar concentrators in combination with PV cells to produce electricity. Solar concentrators work by collecting sunlight from a large area and concentrating it onto a small area with the help of mirrors and lenses. The PV cell panels are integrated into a very cheap and efficient system by adding a concentrator (a parabolic or spherical mirror, or a lens), a cooling system (using heat sinks, and fins), and a sun-tracking system (one or two dimensional). In projects where concentrators have been used, efficiencies as high as 25–30 percent have been achieved.[34] Capital costs have been reduced and in some cases system costs have been reduced by more than 50 percent.[35] Solar concentrators for PV cells have been used in quite hot and dry climatic areas like Saudi Arabia, Madrid (Spain), Texas, and California, so the available data from the experimental projects in these areas can be applied to Pakistan as well.

A study based upon the EUCLIDES (European Concentration Light Intensity Development of Energy Sources) Prototype predicts that for a grid connected PV cell concentrator system of size 10 MW, the initial capital cost would be at 3.3 $/W of peak capacity. This is more than 50 percent less than the cost on flat PV cell systems. But this is a predicted figure assuming that the process of manufacturing and installing of the parts involved in a concentrator type PV cell power plant would be on a mass-scale and streamlined. Nevertheless, a cost of installation reduced to $3.5 to a watt makes the solar PV technology very competitive.

6. CALCULATING TARIFF FOR A 10 MW PV CELL ELECTRICITY GENERATING PLANT

Sections 4 and 5 clearly establish a case for investing in PV cell plant. Although, the difference in levelised cost of the two investments is large, however, the sensitivity analysis done in Section 5 shows how this difference can be reduced. A reduction in installation cost, using a low discount rate, investing in cheap solar PV technology and indigenisation of technology can give an edge to investments in solar power plants comparable to fossil fuel plants.

[34]Test, Rating, and Specification of PV Concentrator Components and Systems, (C-Rating Project), Book 1, "Classification of PV concentrators", http://www.ies-def.upm.es/ies/CRATING.

[35]Eldon C. Boes and Luque, Antonio, Photovoltaic Concentrator Technology. In Thomas B. Johansson, Henry Kelly, Amulya K. N. Reddy and Robert H. Wiliams (eds.) *Renewable Energy: Sources for Fuels and Electricity.* Washington, D.C. and Covelo California: Island Press, 1993.

The question that arises here is that if one is to invest in solar cell PV plants at all then at what price the investor should sell the electricity to the distribution utility/company. The price should be attractive enough for the investor, but should not be too high to be marketed. It would therefore be interesting to find out the cost of electricity generation and hence a suitable tariff rate for electric power from such a plant. This will also help determine the cash flow to the PV power utility.

7. METHODOLOGY[36]

The methodology given in Section 2 only calculates factors required for a levelised cost analysis. To do a detailed investment analysis one must also know various other factors like discounted value of energy produced in the life time of the plant, plant's salvage value, depreciation cost, Net Present Value, and payback time of the investment. The methodology for calculating these factors is given below.

The **discounted value *E* of the total energy produced in *n* years** is given by

$$E = \sum_{t=1}^{n} E_{annual} \cdot (\Gamma_e)^t , \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (7.1)$$

where E_{annual} is the value of the electricity produced every year, and

$$\Gamma_e = \frac{(1+e_e)(1+h)}{(1+k_n)}$$

and e_e is the annual real increase in the price of energy.

Salvage value. A plant after a certain period of operation has a salvage value of its capital investment. This is usually estimated at the start of the project, and then gets discounted similar to other economic parameters. The discounted salvage value after *n* years of operation is evaluated by the formula

$$S = S_n \cdot \left(\frac{1+h}{1+k_n} \right)^n , \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (7.2)$$

where S_n is the salvage or resale value of the plant in the year "*n*" as estimated in the zeroth year.

Depreciation cost. A plant gets depreciated in value with use. Often an accelerated depreciation is allowed as an incentive for investment. For a **depreciation expense** D_t in year *t* and a depreciation period of *d* years, the discounted depreciation is

[36]All the formulae have been taken from "Guidelines for the economic analysis of renewable energy technologies" by the International Energy Agency, OECD/IEA, 1991.

$$D = \sum_{t=1}^{d} D_t \frac{1}{(1+k_n)^t} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (7.3)$$

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

$$NPV = (1-T)\cdot\{(E+S)-(F+O+R)\}+T\cdot D-I \qquad \ldots \quad \ldots \qquad (7.4)$$

The expenses on the project are subtracted and the revenues from the projects and the salvage value are added, weighted suitably by the marginal tax rate T. All the quantities are discounted as defined above.

One important economic parameter is the **pay-back time** T_{PB} of the initial investment in an energy project. This is usually defined as 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, as well as on the input fuel, F_1);

$$T_{PB} = \frac{I}{E_1 - O_1 - F_1} \text{ years} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (7.5)$$

7.1. Objective of the Analysis

For an individual investment, the basic principle for determining suitability is that the Net Present Value be positive. In principle, any positive NPV assures a profitable business. NPV can be calculated easily if the unit price of energy from an investment is known. On the other hand, if the unit price of energy from an investment is not already fixed or known, because of which one cannot evaluate the discounted value E of the energy produced, or NPV, the principle of positive NPV provides a convenient way to determine price of energy. We take as cost of energy production the value that makes the net present value zero (a break-even situation where the capital is returned with a gain that is only equal to the discount rate), and the unit price of energy as that which includes a reasonable mark-up on the cost. Thus, if x cents per kWh of energy renders NPV zero then x is the cost of energy production. And if 20 percent is regarded as a reasonable mark-up rate then 1.2 times x will be the price, which the producer will charge the buyer for each kWh sold. This is the principle that will be used below to find the reasonable unit price of energy. But first we shall look at the NPV and the Pay-back Time using the tariff rate that is usually paid to the independent power utilities.

7.2. Fixed Sale Price Results

Total annual revenues from this generation would depend upon the agreed tariff for the purchase of power by the distributor. The state electric power

distribution utility WAPDA (Water and Power Development Authority) currently purchases electricity from independent power producers at an average rate[37] of 5 cents (Rs.3.00)[38] per unit (kWh), so total value of electricity produced by the PV cell plant in a year would be

$$E_{annual} = 33 \times 10^6 \text{ kWh} \times .05 \text{ \$/ kWh} = \text{US\$ } 1.65 \text{ million/ annum}$$

The lifetime of a solar PV cell is very large compared to that of other electricity production sources. While a hydroelectric or a nuclear power plant has a designed lifetime of about 30 years—and likewise for a fossil fuel thermal power plant—that of a solar plant can be easily 50 years. We shall however take the lifetime of the latter to be also 30 years, and reflect the larger lifetime in its large salvage value.

Discounted Value of the Energy Produced

The discounted value of the energy produced from a PV cell plant over the lifetime can be calculated using Equation (7.1). With the value E_{annual} of the annual energy production estimated at US$ 1.65 million, and the real rate of increase in the price of electricity taken as that of the capital goods, the discounted value E of the energy produced over 30 years comes to

$$E = 55.1 \text{ million dollars}$$

This is the discounted value of the revenue that the PV cell plant would generate during its lifetime of 30 years.

Discounted Salvage Value

Next, we estimate the discounted salvage value of the PV cell plant after 30 years of operation. If properly maintained, 50 percent of the solar cells can be sold at the rate of its initial cost, as crystalline silicon PV cells are very resilient and can sustain their usefulness through very tough weather conditions. So, using Equation (7.2) the salvage value is estimated to be

$$S = 14.4 \text{ million dollars}$$

Discounted Depreciation Cost

Even though crystalline PV panels are taken to be very resilient, allowing accelerated depreciation forms a standard incentive for investment. We assume that a

[37]The tariff rate for private power producers has a complicated structure. The average tariff for the first ten years is 6.1 cents a unit up to the capacity factor. However, not all IPPs sell power at this rate. It has been negotiated with some to 4 cents a unit while others are still allowed to charge over 6 cents a unit. In our estimation, we assume an average tariff of about 5 cents a unit.

[38] At the current exchange rate of Rs 60 to a US$.

30 year depreciation can be allowed, implying that the entire initial investment will be depreciated to a zero value after 30 years. We also assume a uniform depreciation. That is, the depreciation each year is $I/30$, and we then discount depreciation over 30 years using Equation (7.3). It comes to

$$D = 21.9 \text{ million dollars}$$

Net Present Value NPV, Cost of Electricity Generation, and the Electricity Tariff

We are now in a position to evaluate after tax NPV for the plant using Equation (7.4). The tax rate to be used for this purpose is assumed to be 30 percent, almost the highest tax rate in Pakistan, although investment incentives could include lower tax rates. With the values above, the net present value of the plant comes to

$$NPV = -31.1 \text{ million dollars}$$

a rather high negative value. We keep in mind the basic principle that an investment is attractive only if it gives rise to a positive net present value. The price of 5 cents a unit clearly does not make investment in a solar PV plant viable. Another indication is the payback time as calculated from Equation (7.5). It comes to **43 years**, much higher than the lifetime of 30 years considered here.

Thus we need to find out a just cost and sale price. For a viable investment in any venture the after tax NPV must be positive. We take the zero of NPV to define the energy production cost and add 20 percent on it as mark-up to get the energy sale price. The cost of producing a unit of energy that makes NPV zero is given from Equation (7.4) by

$$c = \frac{I + (1-T)(O+R-S) - T \cdot D}{(1-T) \cdot u \cdot \sum_{t=1}^{n} \Gamma_e^{\,t}} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (7.6)$$

where u denotes the number of energy units produced in a year. Substituting the values from above, we get the **cost of electricity generation** from a PV plant equal to **9.03 cents per kWh**. With a mark-up of 20 percent allowed on this cost, the **tariff** comes to **10.83 cents a unit**. The total **revenue** generated over 30 years would be **119 million dollars**, and the **net present value** would be come close to **14 million dollars**. The plant will **pay back** the investment in **20 years** or so. The results of this analysis are summarised in Table 6.

These number are, expectedly, sensitive to the values of various parameters that go into the enumeration. The sensitivity analysis below identifies the factors that can provide a handle to encourage investment in PV power technology in the country.

Table 6

Summary of the Calculated Quantities for a 10 MW Photovoltaic Electricity Generation Plant

Quantity	Calculated Value
Discount Value of the Investment	69.06 million US dollars
Discounted Operation and Maintenance Cost	1.82 million US dollars
Discounted Depreciation Cost	21.9 million US dollars
Discounted Replacement Cost	22.88 million US dollars
Salvage Value	14.43 million US dollars
Cost of Production of a Unit of Electricity	9.03 cents/kWh
Sale Price of a Unit of Electricity	10.83 cents/kWh
Total Discounted Revenue Over 30 Years	119.39 million US dollars
Net present Value	13.92 million US dollars
Payback Period	19.5 years

8. SENSITIVITY ANALYSIS

The costs calculated in Section 7 are dependent on

(1) Investment cost
(2) Tax rate
(3) Discount rate
(4) Depreciation rate.

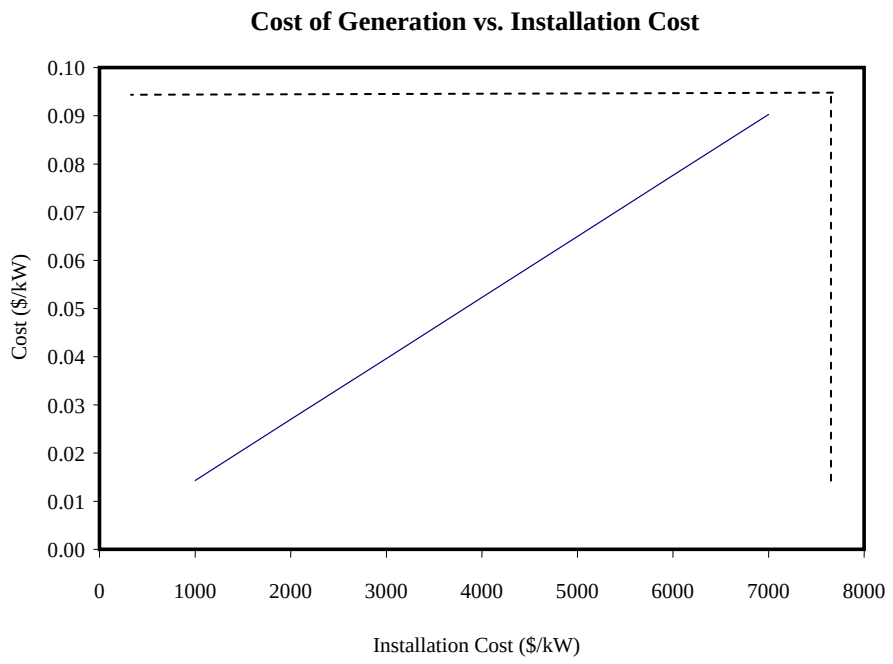
We shall look at the sensitivity of the generation cost or the electricity sale price to these factors one by one.

8.1. Investment Cost

The dependence on investment cost should be the most sensitive factor in determining the generation cost, and hence the sale price of energy, the tariff. This is seen for the solar PV plant in Figure 5 below.[39] The variation is linear and has a large slope. The current installation cost of US$7 to a watt translates in the analysis of this study to an electricity generation cost of 9.03 cents a kWh, as displayed by the dotted lines. Independent power producers in Pakistan are currently allowed on the average to charge a tariff of 5 cents a unit on the electricity they sell to WAPDA. In our formulation, the tariff of 5 cents amounts to a generation cost of 4.17 cents a unit. It can be seen from Figure 5 that in order for the tariff for electricity from a PV

[39]In all the figures in this section, only the cost of generation of a unit of electricity is considered. The electricity tariff, i.e., the unit sale price, as mentioned in the text, is assumed at 1.2 times the cost.

Fig. 5. Dependence of the Energy Generation Cost on Initial Investment.

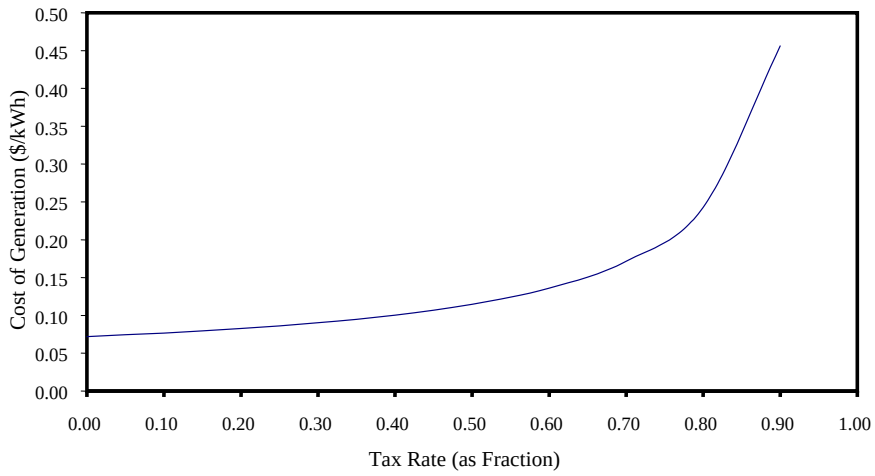


plant to be 5 cents a unit, the installation cost must come down from $7 a watt to about $3.35 a watt. In the sensitivity analysis done for the levelised cost calculations we have discussed in detail the alternatives available to reduce initial installation cost and how adoption of these alternative can lead to a lower cost of production.

8.2. Tax Rate

Tax rate is an important parameter the dependence on which can provide clues to the policy interventions that would encourage investment in the technology. Figure 6 shows that the cost of generation is fairly mildly dependent on the tax rate up to about 50 percent, and rises rapidly after about 70 percent. We have chosen a tax rate of 30 percent. Giving a tax benefit by reducing it to 20 or even 10 percent would change the cost of generation from 9.03 cents a unit to only 8.26 and 7.67 cents respectively, which are hardly near the desired 4.17 cents. Figure 6, in fact, shows that increasing the tax rate to 40 percent or 50 percent would not increase the generation cost dramatically.

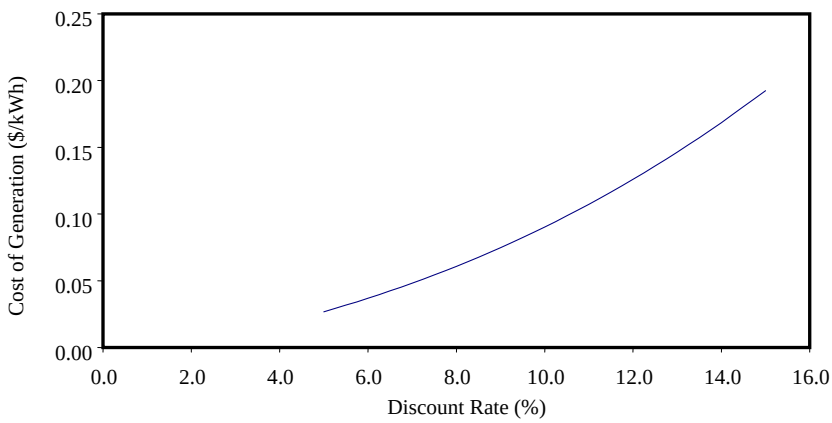
Fig. 6. Dependence of the Electricity Generation Cost on the Tax Rate.



8.3. Discount Rate

Discount rate is a taken as a useful handle with the state to encourage investment. A dependence of the generation cost on discount rate would show where and how the incentives for investment in solar PV technology could work. Figure 7 below shows the pattern of dependence. We have taken the rate of 10 percent. For the generation cost to be reduced from 9.03 to the desired 4.17 cents a unit, the discount rate will have to come down to about 5.7 percent. The government has recently announced a reduction in discount arte to 7.5 percent. Given everything else the same, this step alone will help reduce the generation cost to about 5.42 cents a unit.

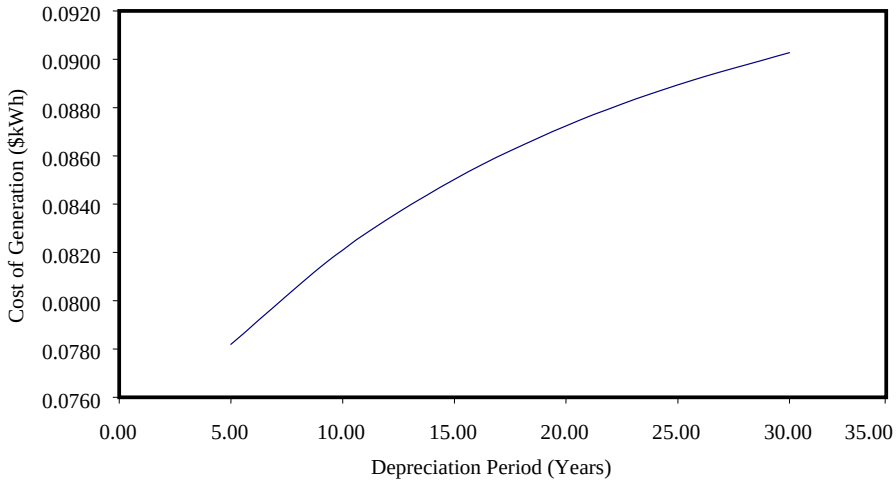
Fig. 7. Dependence of the Generation Cost on Discount Rate.



8.4. Accelerated Depreciation

We now consider the sensitivity to the time over which an accelerated depreciation of the plant is allowed as an incentive. This is shown in Figure 8. An interesting aspect of this result is that the effect on the cost of generation is very little for depreciation time. Insofar as the incentive is meant to reduce the cost of generation, allowing an accelerated depreciation dramatically to, say, five years would not produce the desired results. The cost of generation for a five year depreciation period is 7.82 cents/unit, which is nowhere near the desired value of 4.17 cents.

Fig. 8. Generation Cost as a Function of Depreciation Period.



9. CONCLUSIONS AND POLICY RECOMMENDATIONS

The Ad Hoc Expert Group Meeting on Commercialisation of Renewable Energy Technologies and their Technology Transfer, organised by ESCAP in Bangkok 22-24 September 1999, emphasised the need for private sector participation in renewable energy projects. The experts suggested that: 'To motivate the private sector into renewable energy development, it will be necessary to promote an enabling policy framework which will include an appropriate power purchase agreement, access to technologies and fiscal and other benefits'. It is clear that the main initiative for promotion of commercialisation of renewable energy technologies has to come from governments. International and regional organisations can only play a catalytic role, particularly in terms of capacity building and promoting regional and sub-regional cooperation.[40]

[40]http://www.worldenergy.org/wec-geis/publications/reports/renewable/future_development/future_development.asp.

Marketability of solar PV technology for grid-level power generation would be determined by the cost of generated electricity and a secure and reasonable return on investment. Among the variables that can significantly affect the cost of electricity there are some that can be used as a policy tool to create a suitable environment for investment into the solar PV technology. These are (i) installation costs, (ii) discount rate, and (iii) accelerated depreciation.

It is very clear that if it had not been for a larger capital involved in installing a PV cell power plant, it would have been a very clear winner in the economic comparisons. The installation costs can come down by encouraging

(i) solar collector technology,
(ii) indigenisation of the technology, and
(iii) giving duty relief on import of technology.

Using solar collectors with photovoltaic cells in itself is sufficient to cut down the investment costs by half and consequently bringing solar PV power production at par with a fossil fuel plant.

Local generation of PV cells on a commercial scale can bring about a substantial decrease in the capital prices involved in PV cells production, further decreasing the levelised cost of energy. The only organisation that indigenously produces *Si* photocells is the National Institute of Silicon Technology, which only has a pilot scale production facility. Even then it is able to produce PV cells at a cost that is two-thirds of the cost of an imported system. Enhancing the capability of NIST will in the long term prove very cost effective. In addition, if NIST can extend its capabilities to that of producing radiation collector based PV panels, the grid-scale solar power generation technology will look extremely attractive to an investor.

Further, a reduced discount rate, as has recently been announced by the government, can be greatly helpful. It is already enough to make investment in solar PV system more attractive than in a fossil fuel thermal power plant.

Though the culture of PV electricity in the country has been mainly of small household or building units—a few hundred watts to a few kilowatts—it is time to break out of this thinking and plan for setting up grid-size solar PV plants. This will be in direct accordance with the Kyoto Protocol and the UNFCCC's (United Nations Framework Convention on Climate Change) CDM (Clean Development Mechanisms). Though the price on the carbon abatement has been kept high in this discussion because the tremendous potential social and economic development opportunity provided by such a project. To gain REC points, any Annex 1 country can be convinced to invest in such a project under CDM. But connecting such a power plant to the national grid will provide opportunity for others to follow suit and justifying the expenditure on connection to the national grid because of its size will set an example for other countries. By setting a precedent of large PV cell based power plants, prices of PV cells can be brought down by a large margin, as this

would provide opportunity and resources to people working in this field to invest in R & D activities, bringing down the prices consequently.

As hinted above 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 kerosene and other fuels for lighting purposes.[41] Solar power systems also help in the abatement of Carbon-di-oxide gases. It is said that the carbon emissions are offset by 6 tons over a twenty year life time of a solar power system.[42]

One could argue here that setting up a large-sized solar power plant will be enormously risky. Since, investors are not risk-neutral therefore they may want a risk premium on their investments. The risk in renewable energy investments stems primarily from the fact that it will have to function in a world where most energy companies use fossil fuel. So when crude oil prices fluctuate, the prices for thermal electricity fluctuate with it. In a falling crude oil price scenario, the renewable energy producers will find it extremely difficult to compete with other energy companies. In order to boost investor confidence one may suggest that like other IPPs working in the county GoP or its relevant department(s) like WAPDA may sign long term power purchase agreement (PPA) with renewable energy investors. This will safeguard the interests of the renewable investors and help to make investment in this area less risky.

In the end, it needs to be emphasised that market-based economic systems tend to have short-term outlook. The high capital cost of renewable energy technologies and long gestation are not attractive for private sector financing, which has many other competing uses for the money. This is especially problematic under the new regime of liberalisation and privatisation.[43] *Although, the initiative in investments on renewable energy technologies ought to come from the public sector, this will be difficult to achieve especially under the new scenario of liberalisation and privatisation. One therefore suggests that GoP needs to adopt two pronged approach to promote investments in renewable energy sector. Firstly, it needs to offer subsidies to "green energy producers". Secondly, GoP must promote public private partnerships to promote green energy investments.*

[41] http://www.self.org/shs_envir.asp.
[42] *Ibid.*
[43] http://www.worldenergy.org/wec-geis/publications/reports/renewable/issues_barriers/chap_ 3_5.asp.