

Technological and Economic Assessment of Solar Photovoltaic Power Generation in Bangladesh *Creating a Vision up to 2020*

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Abstract: This paper presents a policy goal of generating 5 percent electricity demand by 2020 utilizing solar energy especially from a grid-connected PV system in urban areas of Bangladesh. This utilization option requires installation of 2080 MW solar PV generation capacity. Electricity demand has been forecasted using a cointegrating long-run relationship between per capita electricity consumption and per capita GDP. The technical potential from urban areas is estimated by using IEA-PVPS guidelines. It is found that target generation capacity requires only 13 percent utilization of total technical potential. Present installation cost is found US\$ 7.5/Wp which is still very high in the Bangladesh context. An investment decision on a solar PV system is not found to be economically viable with the current electricity tariff rate. The social benefit derived from solar PV generated electricity is estimated as a determinant of the government financial incentive. Based on an estimated social benefit of US\$0.14/KWh, the government can offer 50 percent initial investment cost as financial incentive, which will be reduced gradually. A budget allocation varying from 1 to 2 percent each year starting from 2010 to 2020 will suffice for the implementation target.

1.0 Introduction

In the draft of the Renewable Energy Policy of Bangladesh, the government set a target for producing 10 percent of the electricity demand utilizing renewable energy by 2020. This paper presents a challenging policy goal to produce 5 percent of electricity by 2020 utilizing grid-connected PV system in all urban areas of Bangladesh. Compared to other renewable energy systems, the PV system is one of the best suited for urban areas. Therefore, we need to include urban

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areas when developing a long term sustainable energy system. Bangladesh is located in a very favorable place between 20.34°N and 26.38° latitude and receives solar radiation of 1840 to 1972 KWh/m²/year (Hussain, M. and Huda, A.U, 1996). A limited scale of stand alone solar PV system has been introduced in remote rural areas, where there is no plan/way of transmitting energy through a conventional grid system. Up to May 2005, a 2.872 MWp total solar PV system has been installed all over Bangladesh (Hossain, A.K. and Badr, O, 2006). Government encourages the promotion of PV technology by introducing fiscal concessions to the PV industry, duty free imports of solar products and 100% depreciation in the first year of installed solar products. Around 30 organizations are involved with this system. Thus, Bangladesh is quite ready for grid-connected PV system installation in urban areas.

The life cycle cost of stand alone photovoltaic system calculated by Bhiyan, M.M.H (2000) using net present value analysis was found in Bangladesh 43.40 taka/KWh (Bhuiyan, M.M.H. et. al., 2000). **The life cycle cost of one unit of energy from grids that are 1 km away from a village is much higher than the cost of energy from a PV system.** Thus the use of PV system is economically feasible in rural villages and remote areas of Bangladesh, where grid electricity is not available. Similar economic study based on Net Present Value and the Pay Back Period has been made by Bernal-Agustin, J.L (2006) on a grid connected PV system in Zaragoza, Spain and annual costs of PV installation was found 6.5-7.5 Euro/Wp (Jose, L. B. and Rodolfo D.L. 2006). Here cost of electricity production from grid-connected PV technology has been estimated mainly from urban area using NPV and Pay Back Period and found costly. However, according to Jacson and Oliver, (2000), electricity generated from the PV system is costly compared to conventional electricity, but if we fail to formulate long-term sustainability goals only due to cost, we will be losers and face long term penalties (Jacson, T. and Oliver, M, 2000).

PV system offers a myriad of benefits including power quality, reliability, environmental impacts, convenience, security and employment. Wijyatunga P.D.C and Jayalath, M.S, (2004) studied the

economic impact of power interruptions both planned and unplanned in Sri Lanka and found loss as high as approximately US\$81 million a year, which is approximately 0.65 percentage point of Sri Lanka's gross domestic product (GDP) (Wijayatunga, D.C and Jayalath, M.S., 2004). A 1987 study focusing on the effect of power outages in Pakistan estimated by Adenikinju A.F. (2003) found the direct costs of load shedding to industry during a year, coupled with the indirect multiplier effects on other sectors, resulted in a 1.8% reduction in GDP and 4.2 % reduction in the volume of manufactured exports (Adenikinju, F.A., 2003). This paper focuses on quantifying distributed benefits, avoided cost of unserved energy, avoided loss of investment in large conventional fossil fuel based power plants and environmental externality benefits in the Bangladesh context.

Externality is defined by all the costs or profits that fall on the environment and society as a consequences of an economic activity and that are not included in the price structure of the product that causes them (Jose, L. B. and Rodolfo D.L. 2006). There are differences among the externality costs estimated in different countries. For such differences there are also diverse opinions. Sundqvist, T (2004) found methodological differences as one of the major causes of differences in the results of his study (Sundqvist, T. 2004). Schleisner, L (2000), in his study, found that most of the differences may be attributed to the different background level of emissions in different surroundings and to differences in population size (Schleisner, L. 2000). Considering the above facts the external cost (XC) of power plant in the US which was based on full cost approach and estimated by Roth I.F and Ambs, L.L (2004) is transformed in this study to the Bangladesh context (Roth, I. F. and Ambs L. L. 2004).

Application of subsidy programs in different countries shows that there are some short comings of fixing the same rate over the planned implementation period. Japan pursued the most advanced way of offering subsidy in this regard, which was 50 percent in the initial year and then 10-15 percent reduction each year. However, efficient

promotion programs take into account the consumer's willingness to pay (WTP). Optimal financial incentives would provide only the difference between the system costs and the WTP for the PV system (IEA-PVPS. 2002). The paper is a comprehensive study and covers forecasting electricity generation based on GDP growth rate and estimating the grid-connected solar PV potential in line with fulfilling the national energy policy goal. Again, the investment analysis of solar PV employed Net Present Value and Payback Period method and went for quantifying the social benefits to determine the government strategy in offering incentives.

2.0 Electricity Demand Forecast

A long-run electricity demand model is used, where per capita gross domestic product (PGDP) is analyzed as a main factor in affecting per capita electricity consumption (PCEC) in Bangladesh considering the fact that economic growth has a profound impact on the living standards of people. The study employs the unit root test for the stationarity test of the variables and the cointegration test for identifying the long-run relationship amongst variables, if they exist. The major aim of such a demand projection in this study is to compare with the supply side scenario and especially the contribution of renewable energy in the overall power supply.

2.1 The Model and Data

The long-run electricity demand function for Bangladesh is modeled as follows:

Per capita electricity demand = f (per capita gross domestic product)

The data for this study are taken from the World Development Indicator, 2004-2005, CD-ROM. Historical trends of PGDP and PCEC are jointly presented in Figure 1.

Estimated model:

$$PCEC = -119.031 + 0.589 PGDP \dots\dots\dots (1)$$

$$(-16.065)^{**} \quad (22.058)^{*}$$

Sample range: 1971-2002 $R^2 = 0.942$ $DW = 0.796$

Adjusted $R^2 = 0.939$ $F = 486.565$

* indicate significance at 1% level

Source: Shimada, K and Sayadat, N (2006)

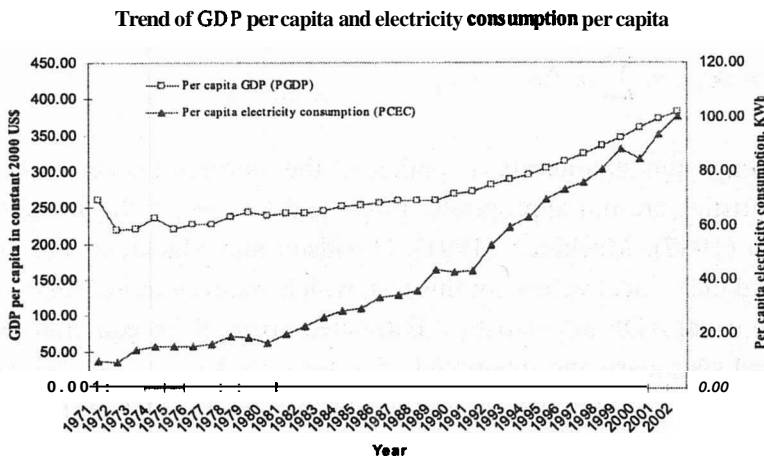


Figure 1: Historical trend of per capita GDP and per capita electricity consumption
 Source: Shimada, K and Sayadat, N (2006)

2.2 Econometric Analysis and Empirical Results

Figure 1 is a plot of the data for PGDP and PCEC from the WDI dataset. These time series are in fact non-stationary time series. Cointegration analysis is a technique used in the estimation of the long-run or equilibrium parameters in a relationship with non-stationary variables. PGDP and PCEC series are non-stationary; thus they are not integrated at level form i.e., not $I(0)$. If both of them are integrated in the same order, i.e., $I(1)$ or $I(2)$ and residuals resulting from their linear combination are stationary, then these two series are cointegrated. Augmented Dickey Fuller (ADF) Unit Root Tests were performed at levels and at the first difference of the variables. From ADF test it is found that both PCEC and PGDP series are non-stationary in their levels but become stationary at first differencing. Thus, it naturally leads to constructing a cointegration test. With these

two variables, a long-run equilibrium relation is presented by OLS as follows:

$$PCEC = a + \beta PGDP + \varepsilon_t \dots\dots\dots (2)$$

Where, the residual ε_t is an estimator of the equilibrium error. For these two variables to be cointegrated the equilibrium error must be stationary. To test the stationarity, the ADF test was applied, which involved the following estimations:

$$\Delta e_t = \alpha e_{t-1} + \sum_{j=1}^q \delta_j \Delta e_{t-j} + v_t \dots\dots\dots (3)$$

For testing non-stationarity hypothesis, the normal Dickey-Fuller (tau)-statistics are not appropriate. Engle and Granger (1987), Engle and Yoo (1987), Mackinon (1991), Davidson and Mackinon (1993) presented the critical values for this test, which are even more negative than the usual ADF tau-statistics. Estimated errors from equation (3) are found stationary and integrated of order zero, i.e., $\rightarrow I(0)$. So we can reject the null hypothesis that the variables PCEC and LGDP are not cointegrated. Thus the estimator of equation (1) is consistent and efficient because it converges faster to the true values of the regression coefficients than the OLS estimator involving stationary variables. Thus equation (1) specifies a long-run equilibrium relationship.

2.3 Long-run Electricity Demand Forecast

Using the long-run equilibrium equation (1), aggregate electricity demand is forecasted (Table 1 and Figure 2). Here, projected GDP growth scenario was based on Millennium Development Goal (MDG) target and short term growth forecast of Medium Term Macroeconomic Framework (MTMF) of the Poverty Reduction Strategy Paper (PRSP). The estimated result is found very much comparable with the forecast of the National Energy Policy, the Power System Development Plan and The World Bank (Table 2).

Table 1: Projected Electricity Demand

Year	2001	2010	2020
Electricity consumption demand, TWh	13.405 (12.483)*	29.206	75.356
Forecast error:			
Root Mean Square Error	6.64	Mean Absolute Percent Error	18.75
Mean Absolute Error	4.64	Theil inequality coefficient	0.066
Forecast interval: Forecasted value $\pm t_{\alpha/2}$.SE of regression			

○* Actual consumption in the year 2001

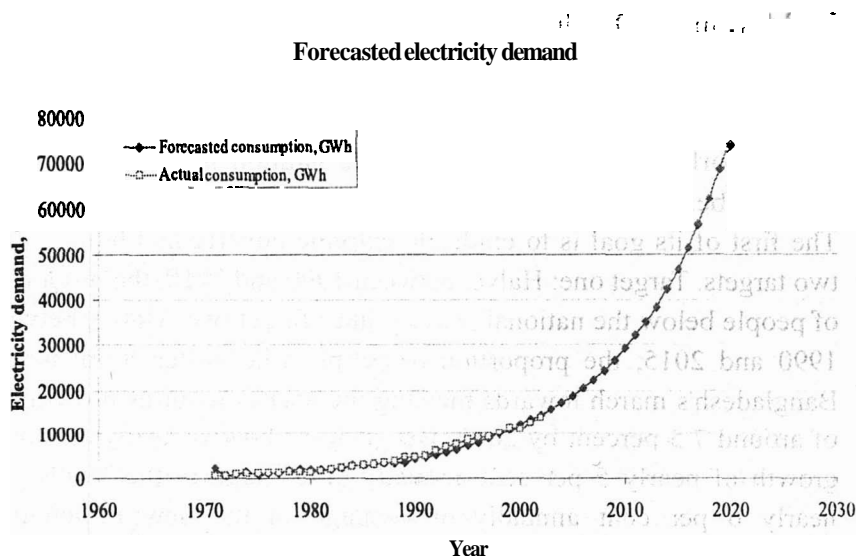


Figure 2: Forecasted electricity demand

Source: Shimada, K and Sayadat, N (2006)

Taking the above projected electricity demand up to 2020, the electricity demand needing to be served by 2020 using solar energy is 3768 GWh (5 percent of projected demand). It is expected that applying energy efficiency measures will lead to lower demand. If this happens in future, the requirement from solar energy will also be reduced.

Table 2: Comparison of Projected Demand with other Projection

Study	2000	2010	2020
This study (2006), TWh	12.212 (11.055)*	29.206	75.356
National Energy Policy (1996) Low Scenario, TWh	18.315	30.994	61.988
Reference Scenario, TWh	19.871	39.750	92.400
Power System Development Plan up to 2020 (2004), TWh (www.powercell.gov.bd/)		39.157 (in 2012)	76.545
World Bank (1996), TWh (Generation capacity required; MW)	15.747 (3908)	31.495 (7816)	62.991 (15632)

(*) Actual consumption in the year 2000

2.4 Millennium Development Goal (MDG) target

Meeting at the United Nations Millennium Summit in September 2000, world leaders agreed a farsighted declaration to meet the needs of the world's poorest people. That declaration gave birth to eight goals to be achieved by 2015: the Millennium Development Goals. The first of its goal is to eradicate extreme poverty and hunger with two targets. Target one: Halve, between 1990 and 2015, the proportion of people below the national poverty line. Target two: Halve, between 1990 and 2015, the proportion of people who suffer from hunger. Bangladesh's march towards meeting the MDGs requires growth rate of around 7.5 percent by 2015. Bangladesh showed steady economic growth of nearly 5 per cent annually on average in the 1990s, and nearly 6 per cent annually on average in the new millennium. Inadequate electricity generation is one of the great impediments of steady economic growth (MDGs: Mid-term Bangladesh Progress Report, 2007). Higher growth requires higher electricity generation and consumption. To serve the projected electricity demand, utilization grid-connected solar PV systems will be of supportive nature and thus will help to achieve the MDGs.

3.0 Grid-Connected Solar PV Potential in Bangladesh

The grid-connected system is the most popular type of solar PV system for residential and commercial buildings in the developed world. In this system, connection to the local utility grid line allows any excess power produced by the system to be sold to the utility, and

electricity will be imported from the utility grid-network outside daylight network through a net metering arrangement. Inverters are used for converting the DC power generated from the PV array to AC power, which is compatible with the local electricity distribution network. IEA PVPS Task 7-4: 2002 (IEA-PVPS T7-4:2002) derived model were used here to assess electricity production potential from the grid-connected PV system in urban areas of Bangladesh.

3.1 Model for Assessing Solar Electricity Production Potential,

The solar electricity production potential (SEPP) is calculated by the following model:

$$SEPP = A \cdot P \cdot U \cdot Y \cdot I \cdot GCE \dots \dots \dots (4)$$

Where.

A: Available floor space per person P: Population size U: Utilization factor
 Y: Solar yield I: Solar insolation GCE: Global conversion efficiency

Source: Technical Report IEA-PVPS T7-4:2002, Page-8.

3.2 Solar Insolation in Bangladesh

Daily average solar insolation in Bangladesh varies between 4 to 6 KWh/m². The maximum amount of insolation is available in the months of March, April and May and the minimum in December to January. The sunlight is abundant throughout the year in all over Bangladesh. Even during the monsoon rainy season, solar insolation is as good as the annual average.

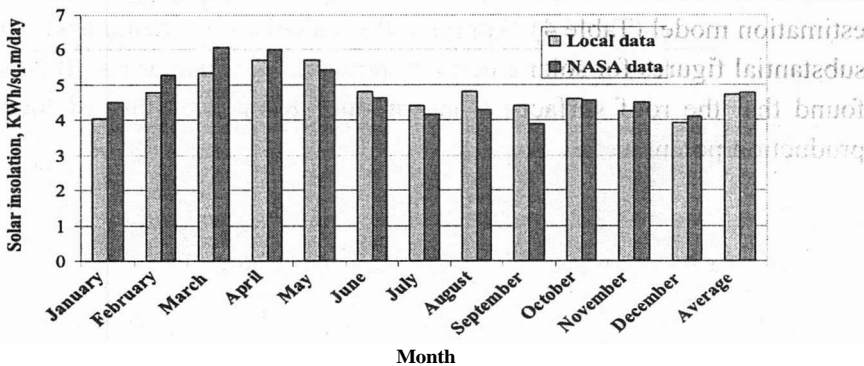


Figure 3: Monthly average daily solar insolation in Dhaka city

Source: Dr. Shahida Rafique, Department of Applied Physics, Dhaka University, recorded from 1988 to 1998 for local data and <http://eosweb.larc.nasa.gov/sse/> for NASA data.

3.3 Average Floor Space in Urban Areas of Bangladesh

To get the sum of all buildings envelope from all the existing buildings in urban areas, all building stock has been calculated. It has been multiplied by average areas per structure. Average area per structure is assumed to be fixed for each year, which is 27.87m² (Statistical Pocket Book of Bangladesh, 2003). Dividing it by the total population, the average ground floor space has been calculated (Table 3). It is assumed that these buildings have suitable orientation and a definite possibility of suitable tilted mounting structure on roofs.

Table 3: Average Floor Space per Person in Urban Areas of Bangladesh

Year	Building stocks (Dwelling units, institutions and others)	Population	Average Floor Space per person, m ²
1981	2413591	13228163	5.09
1991	3789338	20872204	5.06
2001	5855040	28605200	5.70
2010	8782560*	41610000**	5.88
2020	13173840	63590000**	5.77

Source: Population Census, 1981, 1991, 2001 (Population Census, National Report (Provisional), July 2003)

* 5 percent increase from previous year

** UNDP, UNCHS, GoB, RAJUK (1993) and Bhadra and Shamim (2001)

3.4 Estimation results

Results are obtained for urban areas in Bangladesh applying the above estimation model (Table 4). Applying this calculation scheme leads to substantial figures for solar electricity potential in urban areas. It was found that the roof surfaces alone produce 80% electricity of total production potential.

Table 4: Electricity production potential in urban areas of Bangladesh

Year	On roofs, TWh/y	On façade, TWh/y	Total production potential, TWh/y	Electricity demand, TWh/y	Potential/demand (%)
2001	10.239	2.498	12.737	12.483	102
2010	15.367	3.749	19.116	29.206	65
2020	23.046	5.623	28.669	75.356	38

Source: Shimada, K and Sayadat, N (2006)

Parameters used in estimating production potential were the following:

Parameters	2001	2010	2020
Population, million	28.60	41.61	63.59
Average floor space (sq. m/person)	5.70	5.88	5.77
Utilization factor for roof area	0.40	0.40	0.40
Utilization factor for façade area	0.15	0.15	0.15
Solar yield	90%	90%	90%
Solar radiation on horizontal surface, KWh/year	1744.7	1744.7	1744.7
Solar radiation on 90° tilted surface, KWh/year	1135.15	1135.15	1135.15
Global conversion efficiency	10%	10%	10%

Urban areas of Bangladesh have good production potential from solar PV system. The Rural area is not considered due to not having a utility grid connection. Based on the above potential figure, serving 5 percent of the electricity demand by utilizing solar energy in 2020 requires the utilization of a 13% production potential (Table 5).

Table 5: Required Utilization of Solar Energy Potential

Year	Total production potential in Bangladesh including all urban areas, TWh/y	Electricity production required from solar energy, TWh/y	Utilization of total production potential (%)
2001	12.737	---	---
2010	19.116	0.146	0.76
2020	28.669	3.768	13.16

Source: Shimada, K and Sayadat, N (2006)

3.5 Role of Solar PV in Sustainable Development in Bangladesh

Sustainable development is an approach of achieving economic emancipation and development ensuring protection of the environment. Solar energy is considered as sustainable energy that ensures health safety, minimizes pollution, reduces green house gas emission, indicates socially acceptable energy source and enhances durability of economic growth. Green House Gas emission from

Energy Industry of Bangladesh was 4763, 7612 and 13154 Kilo tonne in 1990 to 2000 respectively i.e., emission from energy sector is being almost double in every five year (Rahman, A. *et. al.*, 2003). On the other hand, during a 20 year life time, a 100 MW solar plant would avoid emitting more than 3 million tons of carbon dioxide and 140 tons of nitrogen oxides compared to the cleanest combined-cycle plants available today (Blankinship, S. 2003). Bangladesh is vulnerable to climate change, global warming and sea level rise. Thus, there is a clear opportunity for Bangladesh to participate in worldwide efforts for sustainable development with reducing the vulnerability to climate changes by utilizing solar PV technology.

4:0 Economic Assessment of Supply Option

4.1 Life Cycle Cost Analysis (LCCA)

In project evaluation, life cycle cost analysis (LCCA) is usually used in which all costs arising from owning, operating, maintaining. and ultimately disposing of remnants are taken into account. As it permits inclusion of the impact of the changing economic variables, i.e., interest rates, inflation rate, some other escalation rate and discounted future values, LCCA is used for better comparison with several cost effective alternatives. This study assessed life cycle costs of electricity generation with the following equations.

$$LCC = C + O\&M_{pv} + R_{pv} + FC_{pv} + XC_{pv} - SV_{pv} \dots\dots\dots (5)$$

Where,

- | | |
|---|---|
| <i>LCC</i> : Life cycle cost, | <i>C</i> : Initial capital investment |
| <i>O&M_{pv}</i> : Present value of operation and maintenance cost | |
| <i>R_{pv}</i> : Present value of replacement cost, | <i>FC</i> : Present value of fuel cost |
| <i>XC_{pv}</i> : Present value of external cost, | <i>SV_{pv}</i> : Present value of salvage value |

Source: M.N.El-Kordy, *et. al./Renewable Energy* 25(2002), Page-319
 M.M.HBhuiyan *et.al./Renewable Energy* 21 (2000), Page407

4.2 Cost Comparison of Grid-connected PV System with CCGT

Result of the LCCA shows that the cost of electricity generation from grid-connected PV system is not comparable with the CCGT at the current market price. The cost of electricity from the solar PV system

is found to be nine times higher than the gas fired combined cycle power plant (Table 6).

Table 6: Life Cycle Cost Comparison

	Grid-connected PV system		Combined cycle gas turbine	
	Without external cost	With external cost	Without external cost	With external cost
In BDT/KWh	16.77	16.77	1.83	2.98
In US cents/KWh	24.14	24.14	2.64	4.28

Source: Shimada, K and Sayadat, N (2006)

4.3 Net Present Value (NPV) and Payback Period Analysis

Here NPV and payback period is calculated based on various tariff categories. The subsidy expected to be offered to the investment was considered as a base case for such analysis. NPV is calculated as the difference between the present value of the total avoided electricity bill (or the amount of electricity that can be sold to the utility at present market price) and the present cost of the system (Eq. 6).

$$NPV = -S + \sum_{j=1}^N \frac{Q_j}{(1+i)^j} \dots\dots\dots(6)$$

Where, N : 25 year

Q_j : Annual electricity bill avoided as inflow from the 1KWp PV system

i : Discount rate, and S : Initial investment cost.

Source: J.L.Bernal-Agustin, R. Dufo-Lopez/Renewable Energy 31 (2006), Page-11 10

The NPV should be larger (as cumulative revenue stream is higher than the costs) and always positive. Current electricity tariff rates vary from 2.5 Taka/KWh for residential consumers who consume below 100 KWh/ month to 7.82 Taka/KWh for commercial consumers at peak hour. At the present tariff rate and 7 percent discount rate, the investment in solar energy by residential, commercial and industrial sector is not a viable economic option even after considering the highest rate of subsidy (Figure 4).

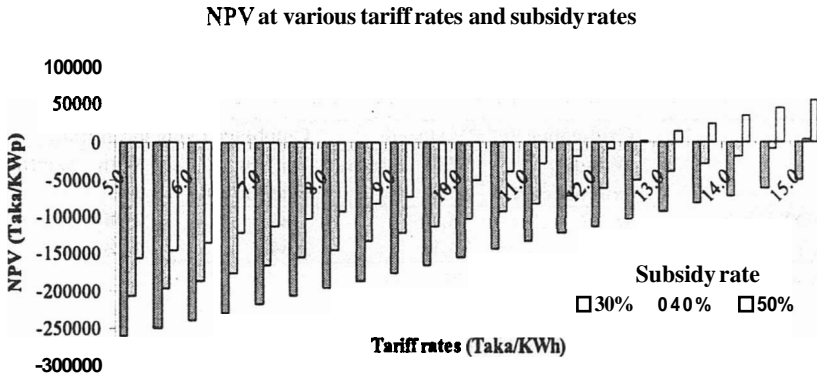


Figure 4: Comparison of NPV as a function of subsidy and electricity tariff rate

Source: Shimada, K and Sayadat, N (2006)

A simple payback period is calculated based on the length of time required for a project's cumulative revenues to return its investment through annual (non-discounted) cash flow (Eq. 7). For a renewable energy project and especially for a solar PV project, it is considered to be worth investing in when the payback period becomes less than the projects life time.

$$P = \frac{C}{A_s} \dots\dots\dots(7)$$

Where, C : Capital Cost and A_s : Annual Savings

Source: Shimada, K and Sayadat, N (2006)

At the existing tariff rate, the highest tariff category residential customer and peak rate of industrial customer are found suitable but not below 25 years even under highest subsidy (Figure 5). At the existing tariff rate, the payback period is found to be suitable for the commercial sector as it is below 25 years in peak demand period under a subsidized scenario. However, rather than the result of financial analysis, we need to give importance on how significant the solar PV system offers non-monetary benefits. Cost should not be the sole criterion in decision making because climate change may become a serious risk (Kannan, R., *et. al.*, 2006).

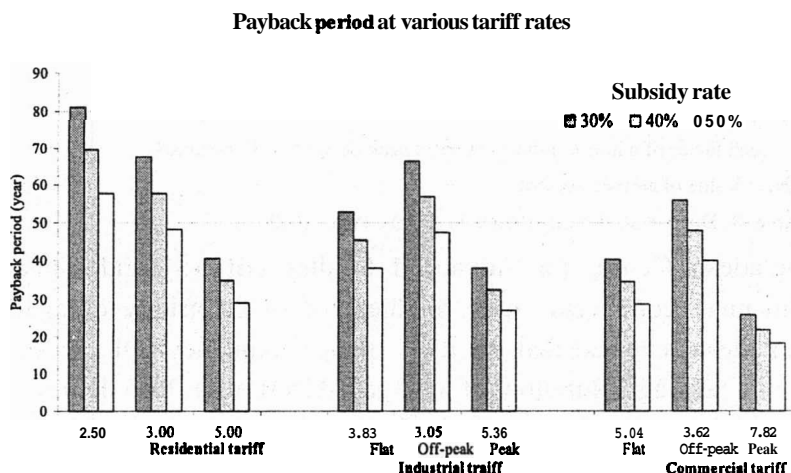


Figure 5: Comparison of payback period as a function of subsidy and tariff rate (Taka/KWh)

Source: Shimada, K and Sayadat, N (2006)

5.0 Valuing Externality Benefits of Grid-Connected PV Systems

A large-scale conventional energy system is now questioned due to its negative externality on society and on the environment compared to new cleaner technology. The comparative high cost of energy from a grid-connected PV system should be considered with its externality benefits. This paper focuses on quantifying distributed benefits, avoided cost of unserved energy, avoided loss of investment in large conventional fossil fuel based power plants and environmental externality benefits in the Bangladesh context.

5.1 Valuing Distributed Benefits

Grid-connected PV system offers substantial benefits in terms of modularity, short lead time, fuel diversity and reduced price volatility, load matching, reliability and resilience, and most importantly reduction of the probability of power failure in the area where it is located. The value of distributed PV benefits can be estimated based on the analysis carried out by Pacific Gas and Electric (PG&E) Company researchers with limited variables (Duke, R. *et.al.*, 2005). As per their study, distributed benefit of increased service reliability (DB_{ISR}) is calculated as follows:

$$DB_{ISR} = OF \cdot ADO \cdot AV_{PV} \cdot LF \cdot VSNL \dots\dots\dots(8)$$

Where, OF : Outage frequency, ADO : Average duration of outage

AV_{PV} : Availability of the PV system (0.33 assumed)

LF : Load factor of a house (ratio to average peak demand, 0.33 assumed)

VSNL : Value of service not lost

Source: R. Duke et al. /Energy Policy 33 (2005), Page- 1922

Bangladesh Centre for Advanced Studies (BCAS) and Unnayan Shamannay conducted study on the cost of electricity outaged in Bangladesh revealed that the daily outage frequency (OF) was 3.56 and the average duration of outage (ADO) was 1.65 hours for commercial units (World Bank, 2000). Sector Assistance Program Evaluation of Asian Development Bank Assistance to Bangladesh Power Sector in December 2003 found that on average, customers are willing to pay around 10% more for guaranteed better service quality (Asian Development Bank, 2003). Thus, the VSNL in this study is taken as 10% more than the average billing rate/KWh to residential customer (i.e., 3.5 Taka/KWh for residential customer).

DB_{ISR} is found 898.908 Taka/KW yr. So the distributed benefit (DB) per KWh of PV electricity generation would be 0.498 Taka/KWh with the following equation.

$$DB = \frac{DB_{ISR}}{O_{PV}} \dots\dots\dots(9)$$

Where, O_{PV} : Annual output from per KWp of installed PV system, which is 1804.7 KWh/KW yr

5.2 Avoided Cost of Unserved Energy

Electricity generation by grid-connected PV system will indirectly help increase the amount of electricity supply to the industry sector and thus will reduce power outages and outage frequencies and, thus, finally the cost of unserved energy in this sector. Generally cost of unserved energy (CUE) is expressed in cost/KWh which is derived from power interruptions, voltage fluctuations and supply harmonics at the end use level. Cost estimated by Bangladesh Power System Master Plan (1995) is taken for avoided benefit estimation. According to the Power System Master Plan, the cost per KWh is around taka

17.00 in the market price of 1995. If inflation, price and cost increment are considered, the cost of electricity will be around taka 25.00/KWh at present (Alam *et. al.*, 2004). CUE in Bangladesh and other neighboring countries are shown in Table 7.

Table 7: Cost of Unserved Energy (CUE) based on production loss method

Country	Macroeconomic cost per KWh	Study
Sri Lanka	US \$ 0.66/KWh For planned outages US \$ 1.08/KWh for unplanned outages	Wijayatunga, D.C.P, 2002
India	US \$ 0.54/KWh	TERI, 2001
Bangladesh	US \$0.8/KWh	World Bank funded study by BCAS and Unnayan Shamannay, 2000
Bangladesh	US\$ 0.42/KWh (Taka 17.00/KWh)	Bangladesh Power System Master Plan, 1995 (Taka 25/KWh in Alam et al. study, 2004)
Bangladesh	US \$ 0.83/KWh for unplanned outages US \$ 0.34/KWh for planned outages	USAID-SARI/Energy program, 2003

Transmission and distribution loss is considered as a major cause for electricity outage in the industrial sector. If standard technical loss of the utilities is considered at best 10%, the rest of the losses (23.71%) are responsible for economic loss. Thus, avoided cost of unserved energy (ACUE) from a 1 KWp PV system can be estimated with the following equation:

$$ACUE = O_{PV} \cdot T \& D_{Loss} \cdot Cost / KWh \dots\dots\dots(10)$$

Where, O_{PV} : Annual PV output per KWp of installed PV system

$T \& D_{Loss}$: Transmission & Distribution Loss rate $Cost/KWh$: Cost of unserved energy

Source: Shimada, K and Sayadat, N (2006)

Thus, the avoided cost per KWh of electricity generated from the PV system would be (= $ACUE/1804.7 \text{ KWh/KW yr}$) Taka 5.927/KWh, i.e., avoided cost of unserved energy would be Taka 5.927/KWh.

5.3 Benefits from Avoided Investment in New Centralized Generation

For estimating benefits from avoided investment in a new centralized generation system, a combined cycle gas turbine (CCGT) power plant is considered. Because 88.9% of electricity generated in 2004 was by natural gas (Annual Report, BPDB, 2003-2004), and CCGT is gradually taking the place of other technology in new power plant

installation decisions. From such a plant avoided capital cost is found to be 0.320 **taka/KWh**, avoided **O&M** cost is found to be 0.669 **taka/KWh**, avoided variable **O&M** cost is found to be 0.111 and avoided fuel cost is found to be 0.772 **taka/ KWh**.

5.4 Benefits from Avoided Externality Cost of Conventional Power Plant

Conventional power plants cause environmental damage and incur social costs which are usually not reflected in their cost structure. Solar PV is being compared considering the facts that solar PV can provide externality benefits by avoiding negative impacts and risks of conventional systems. The external cost (XC) of gas fired power plant in the US which was based on full cost approach and estimated by Roth I.F and Ambs, L.L in 2004 (7.31 US cents for Combined cycle) (Roth, I. F. and Ambs L. L, 2004) is transformed in this study to the Bangladesh context. Externality cost from a power plant is related to site-specificity mainly due to differences in population size and people's willingness to pay, which is related to income level. Thus population density and GDP per capita are included in the following conversion equation. From this equation avoided externality cost is estimated as 1.447 **taka/ KWh**.

$$XC_{Bangladesh} = XC_{USA} \left[\frac{PGDP_{Bangladesh}}{PGDP_{USA}} \right]^{\epsilon_T} \left[\frac{PDENSITY_{BANGLADESH}}{PDENSITY_{USA}} \right] \dots\dots\dots(11)$$

Where, PGDP = Per capita GDP in constant 2000 US dollars, PDENSITY = Population density per square kilometer, and ϵ_T = Income elasticity of willingness to pay for reducing the health hazard. In this estimation, income elasticity of willingness to pay for reducing the health hazard is taken as 1.

Source: Shimada, K and Sayadat, N (2006)

Social benefits from above estimations are found Taka 9.744/KWh (14 **US** cents /KWh) from PV system. Thus, financial incentives from the government to promote this sustainable energy system is worthy,of it. A very basic analysis shows that a 50 percent subsidy arrangement by

the government based on above social benefit makes PV practically competitive with conventional energy generation.

6.0 Results and Discussion

Investment in renewable energy especially of solar and wind may be a luxury for the developed world, but it is a mere necessity for Bangladesh if we consider the demand for new energy generation in the face of energy security issues. Bangladesh needs to look on the support from sustainable energy. Solar energy utilization pattern in Bangladesh shows that the countrywide application of the solar PV system is worthy of investment. Thus, this study is centered on a vision to generate 5 percent of electricity demand in solar energy by 2020.

Electricity demand was forecasted using the simple consumption model based on per capita electricity demand and per capita GDP. The model was based on strong footing as the data were cointegrated. The study forecasted electricity demand of 75.356 TWh by 2020, which is very much comparable with some other important forecasts made by the Ministry itself and the World Bank. Following IEA-PVPS guidelines for estimating the technical potential of solar energy it was found that theoretically, 28.67 TWh of electricity can be produced by 2020 utilizing all available floor space in that period. In economic assessment the life cycle cost of PV generated electricity was found 16.77 Taka/KWh whereas electricity generated from CCGT was found to be 1.83 Taka/KWh, NPV was found to be negative at current tariff rate and payback period was found to be cost competitive only for peak rates of electricity tariffs. The social benefit, on the contrary, that could be accrued from a PV system considering the distributed benefit, avoided loss in investment in conventional power plant, avoided cost of unserved energy and environmental externality cost was estimated and the social benefit was found to be 9.744 Taka/KWh (14 US cents). Based on this social benefit, government could easily offer 50 percent of initial investment costs as a financial incentive for rapid deployment of solar system. To implement the goal of generating 5 percent electricity demand to be served by 2020 utilizing

solar energy, 1.04 million 2KWp grid-connected PV systems or 2.08 million 1KWp grid-connected PV systems would need to be installed by 2020.

6.1 Findings

Major findings of the study can be summarized as follows:

1. Electricity required to be served utilizing solar energy by 2020 - 3768GWh (5 percent of total demand). This amount of electricity can be produced utilizing only 13 percent of the country's technical potential.
2. The cost of electricity generation from a PV system is 16.77 Taka/KWh, which is nine times higher than conventional CCGT power plants and at current tariff rate PV system is not financially viable for individual investment decisions.
3. Benefits from electricity generated by a PV system is found to be substantial (9.744 Taka/KWh) allowing up to 50 percent of government subsidies as investment incentives.

This study is a comprehensive study covering the supply side and demand side of electricity generation as well as benefit estimations and deployment strategies with subsidization technique. In the demand side analysis, a simple model is used and though the result is found to be comparable with other studies, the model could have been much more realistic after inclusion of energy efficiency and conservation measures variables. In the supply side estimation from solar energy, all structures in urban areas are taken as suitable for PV fitting as it is a country wide study. Actually, the age of the building, orientation, shading characteristics, building materials and energy consumption by the residents of the buildings should be considered for micro level studies and more small area specific studies. The benefit estimation requires further study to include more benefits in estimation processes with Bangladesh context. In the case of PV deployment strategy, offering subsidies by the government is presented as one of the major strategies which was based on the above social benefit estimation. Willingness to pay (WTP) is considered vital

for setting this strategy along with the social benefit. Thus, further research should be directed to WTP for a grid-connected PV system. Again, as a source of subsidies, alternative sources of financing should be considered besides government budgetary allocation. The major alternative could be through CDM project financing considering the potential GHG emission reduction potential.

6.2 Recommendations

The following policy recommendations need to be considered as supplementary for expediting the deployment of grid-connected photovoltaic systems in Bangladesh.

1. Enactment of net metering law and other necessary rules and regulations will be a good marketing strategy with minimal financial risks. As well as gradual withdrawal of subsidy from conventional energy system will encourage competitive pricing.
2. Approval of Renewable Energy Policy and establishment of Bangladesh Renewable Energy Development Agency (BREDA) should be in due time according to the 3-Year Road Map for Power Sector Reform.
3. Awareness raising and confidence growing program through demonstration sites on educational buildings and government office buildings. Encouraging community involvement and mass participation program should get overall priority.
4. Taking initiative for establishing solar panel manufacturing plant. It is also mandatory to strengthen the physical and institutional infrastructure to get the full benefit of the PV system.
5. Taking lessons from other countries especially from Asian and neighboring countries and it is needed to obtain fund for implementation through CDM financing.

7.0 Conclusion

Solar, wind and biomass energy are considered as major renewable energy resources for Bangladesh. Due to having a competitive edge over others, solar energy shows that the countrywide application of the solar PV system is worthy of investment. Utilization of this technology is tested and already crossed the experimentation phase in our country. Now it needs government's direct initiatives to be exploited to its full potential.

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