Analysis of Cost, Energy and CO_2 Emission of Solar Home Systems in Bangladesh

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Abstract- Bangladesh is currently faced with challenges arising from climate change and inadequate energy. The energy situation is in confront since the major power stations are run on natural gas, whose reserves are now on the verge of depletion; if no new mine fields are identified. To reduce the dependence on fossil fuels and increase the energy access in the rual areas of Bangladesh, renewable energy sources, like solar home systems (SHS) could play a vital role. In this paper, the cost, energy and carbon dioxide emission of solar home systems installed in Bangladesh are analyzed. It has been found that around 1.4 million solar home systems are already installed as at the end of January 2013. 40~85 W_p systems are mostly used in the rural areas. The cost of a 40 W_p system was around 24,000 Bangladeshi Taka (BDT), whereas that for a 85 W_p system costs about 45,000 BDT. The average payback period was found to be 4.2 years and varied between 3.1 and 6.5 years. On the other hand, Net Present Values (NPV) varies between 34,500 BDT to 14800 BDT. The total primary energy requirement for a 50Wp in its total life of 20 years is 4593 MJ_{th}. This gives around 253 kg of CO_2 emission. A 50 W_p SHS on the other hand supplies around 11773 MJ_{th} of Energy in 20 years. Energy payback for the same module was found to be 7.80 years and the total CO_2 emission reduction compared to kerosene cosumption of the users' was 11604 kg in 20 years.

Keywords- Solar Home System, Bangladesh, Cost, Energy, Emission.

1. Introduction

Electricity is the most expedient form of energy and a key factor for economic development in any country. It cannot be replaced by other forms of energy. At present, 1.441 billion people or 20% of the world's population does not have access to electricity [1]. Most of these people live in rural areas of Asia and Africa. Currently around 49% of the Bangladesh population is connected to the electricity grid [2]. The electricity supply is not reliable though and peak demand is never met. In the rural areas, where more than 70% of the population live, only about 25% have electricity [2]. At present, the country is facing a severe electricity crisis due to growth of almost each and every sector. According to the Bangladesh Power Development Board, the present peak hour shortage of electricity is around 15-20% of generation [3]. Due to the shortage of fossil fuels, the government has focused on the renewable energy technology - mainly solar energy and biomass. Among all the renewable energy technologies in general, and the solar energy conversion pathways in particular, the solar photovoltaic (PV) conversion pathway is the most attractive and capable to produce electricity in large scale in Bangladesh. It has also gained acceptance among the users due to it's simplicity as well as its ability to produce low carbon electricity. Bangladesh is situated between $20^0\ 34^/–26^0\ 38^/$ degrees north latitude and $88^0\ 01^/–92^0\ 41^/$ degrees east, which is ideal for solar energy utilization. The daily average solar radiation varies between 4 and 6.5 kWh/m^2 [4]. Rural electrification through solar PV technology is popular in Bangladesh. The concept of solar home systems (SHSs) started in 1996-97, but the rate of uptake was very low then because of the high initial cost. This however changed, with significantly increase in uptake recorded from 2004 to 2010 because of the soft credits that inspired uptake, reduction in module prices and the favorable policy by the Bangladesh government [4]. By the end of January 2013, around 1.4 million SHSs had already been installed in the rural areas of Bangladesh [5].

PV systems can potentially lead to enormous changes in the quality of life, generate income through new business developments and reduce health hazards as well as risks of fire by reducing kerosene use. Effective uptake of SHS can contribute towards the poverty alleviation as well [6, 7]. The uptake of solar home systems is also yielding substantial social benefits in Bangladesh. Besides enabling small business owners to stay open longer, thereby substantially increasing their incomes, the artificial light they bring enables students to study in the evening with better quality lighting. It also lifts some of the burden of running a household encountered by Bangladeshi women. On top of all this, installation of the solar home energy systems is quick, safe and relatively simple. PV systems in Bangladesh are also feasible both technically and financially [8, 9]. The purpose of the paper is to analyze the cost of the SHSs installed in Bangladesh and study their energy and emissions.

2. Methodology

This study was carried out using 50 Wp systems, which are mainly used by most of the users in Bangladesh as it allows 04 Flurescent Lamp (FL) for 04 hours. Information on Fivety (50) SHSs from six districts in Bangladesh was collected by field survey between December 2012 and February 2013. Rajshahi, Gazipur, Manikgong, Mymensingh Dinajpur and Sirajgong were the districts from where the data were collected. Systems were chosen randomly, with 20 systems chosen from rural market places while the remaining 20 systems were from household applications. This was aimed at having a variety of uses. The following assumptions were considered during the the study:

- Project life was assumed to be 20 years [9, 10 and 11].
- Solar panel life was considered 20 years (according to panel manufacturers and SHS installers in Bangladesh).
- Two batteries are assumed to be replaced in 20 years. As during data collection it was found that some batteries had already crossed 6 years and were still in running conditions.
- Charge controller: It uses very little amount of electronics, which have lifetime of 10-15 years. On average 10 years is considered for the study.
- Mounting structure: Mounting structures were found to be made by galvanized steel and usually had a long life of about 10 years.

Operational and financial mechanisms, cost, simple payback period, NPV and Internal Rate of Return (IRR) of SHS systems have been analyzed. All the cost and benefit are converted to monetary values. The benefits like environmental impacts in terms of CO_2 emission reduction, benefits relating to children education due to having good quality of light at home has been excluded for financial analysis. To calculate the financial analysis Eq. (1), (2) and (3) were used as follows[10]:

Payback period= Investment/ (Return-Expense)

$$NPV = CO + PV \quad (1)$$

$$\text{Present value} = \Sigma\, Cn/(1+r)^n \quad (2)$$

$$IRR = i1 - NPV1 * ((i2 - i1) / (NPV2 - NPV1)) \quad (3)$$

Where, CO is the initial investment at period 0 which is a negative figure, Cn is the total cash flow, r is the discounte rate, NPV1and NPV2 are two different net present values for the interest rates i1 and i2 where NPV1 is positive and NPV2 is negative.

For the energy and CO_2 emission analysis, the total energy needed for a SHS and the amount of energy that can supply by a SHS in its entire life time were analyzed, including their corresponding emissions. On the other hand, emission reduction by SHS was calculated based on kerosene saving as kerosene was found to be the main fuel for lighting in rural areas. Traditional wick lamps like Kuppi and Hurricane were mostly used by the rural people of Bangladesh. Average value of fuel consumptionm per month before using SHS was calculated based on survey and traditional lamps were tested to get thier fuel consumtion and CO_2 emission per hour as well. Various sources [12,13,14] were consulted as well to get an estimate of the fuel consumtion by traditional wicck lamps and corresponding emission.

3. Solar Home Systems in Bangladesh

Solar photovoltaics appear to be the only appropriate options for renewable electricity generation in Bangladesh. The coastal area of Bangladesh has some potential of wind but its ultimate feasibility is still questionable [8]. The country has a very good monthly average solar radiation all over the country. Table 1 shows the monthly average solar radiation data of the important cites of the country. Radiation is higher during the months of March, April and May and lower in the months of December and January. In Bangladesh, the SHS project has been implemented under Infrastructure Development Company Limited (IDCOL).

Table 1. Solar radiation (kWh/m^2/day) at different locations in Bangladesh [4]

Month	Dhaka	Rajshahi	Sylhet	Bogra
January	4.03	3.96	4.00	4.01
February	4.78	4.47	4.63	4.69
March	5.33	5.88	5.20	5.68
April	5.71	6.24	5.24	5.87
May	5.71	6.17	5.37	6.02
June	4.80	5.25	4.53	5.26
July	4.41	4.79	4.14	4.34
August	4.82	5.16	4.56	4.84
September	4.41	4.96	4.07	4.67
October	4.61	4.88	4.61	4.65
November	4.27	4.42	4.32	4.35
December	3.92	3.83	3.85	3.87
Average	4.73	5.00	4.54	4.85

The operational and financial flow diagram of solar home system in Bangladesh is shown in Figure 1. IDCOL is a financial institution established by the government of Bangladesh. Donors such as World Bank, Global

Environment Facility, GTZ, KFW, IDA & GEF, KfW and IDB provide soft loans and grants to IDCOL to fund projects. Partner Organizations (POs) select the project area, buy the system, install it and provide maintenance support using funds from IDCOL with 6% interest for 12 years. POs sell the solar home system to the user either on credit or cash. Each POs offer different type of installment, terms and conditions and loan repayment year. Table 2 shows the number of solar home system installed by the POs up to January 2013 and table 3 shows the division wise SHSs installation in Bangladesh. Grameen Shakti is one of the major implementer and pioneer of solar system in Bangladesh. BRAC Foundation, RSF and Srizony, Bangladesh are the other key implementer of the solar home system.

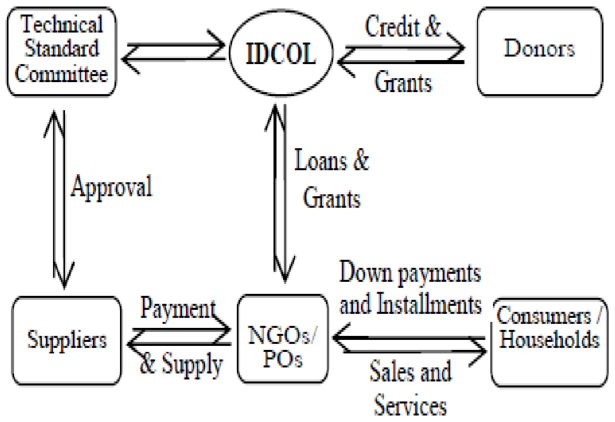

Fig. 1. Operational and financial mechanism of SHS in Bangladesh [15]

The types of financing scheme provide by POs to the users are as follows [16]:

- *Option 1:* 15 % down payment and rest of the 85% payable in 36 monthly installments with flat rate service charges of 8%
- *Option 2:* 25% down payment and rest of the 75% payable in 24 monthly installments with a flat rate of service charges of 6%
- *Option 3:* 35% down payment and rest of the 65% payable in 12 monthly installments with flat rate service charges of 5%.
- *Option 4:* 100% down payment and you will get 4% discount on the package price
- *Option 5:* 25% down payment and rest of the 75% payable in 12 monthly installments without any service charges (only for mosque/temple/church)

4. Cost Analysis

4.1. Cost of SHS Systems

Normally 40~85 W_p systems are mostly used in the rural areas. The cost of a 40 W_p system was 23,600 BDT, whereas for a 85 W_p system, the cost was 44,800 BDT.

Table 2. SHS installation figure in Bangladesh [5]

Partner Organization	Number of SHSs Installed
Grameen Shakti	795,957
RSF	216,434
BRAC	77,019
Srizony Bangladesh	58,927
Hilful Fuzul Samaj Kallyan Sangstha	37,078
UBOMUS	25,234
BRIDGE	20,449
Integrated Development Foundation	14,238
TMSS	13,059
PDBF	10,672
SEF	21,720
AVA	12,817
DESHA	10,931
BGEF	16,995
RDF	20,027
Others	77,883
Total	1,429,440

Table 3. Division wise installation of SHS [5]

Division	Number of SHSs Installed
Barisal	265,320
Chittagong	278,730
Dhaka	374,587
Khulna	158,409
Rajshahi	200,480
Sylhet	151,914
Total	1,429,440

Table 4 represents the cost of SHSs with detail equipments provided by the POs. Battery, PV panel and charge controller are the three main components of the PV system. POs also provide structure for panel and battery, lamps and ballast, switch, switch board and necessary wires during the installation period. But, the owner or user had to buy other equipments if they need, such as, adapter, DC-DC converter for radio, cassette and mobile charger, etc.

The breakdown of total cost of a 50 W_p system is shown in table 5. The Battery and solar panel were found to be the main reasons of the high cost of the PV system. Solar panel contributed to 28%, whereas battery cost was around 30% of the total cost though most of the batteries were produced in Bangladesh. Three years after sale service and installation cost 13.50%, overhead cost 10%, cable, switches and others 7.50% and lamp shade 5% were the significant others costs.

Except these, tube lights and steel structure for panel contributed 2% and 1% of total cost respectively. This break down of cost was also similar for 40 and 60 W_p system as price variation was not much. On the other hand, percentage of battery and panel cost was little bit higher for 80 and 85 W_p system. It was found that for 80 and 85 W_p battery and panel cost were 33% and 30% of the total cost respectively.

Table 4. Current Cost of SHSs system [16]

System W_p	Total cost (BDT)	Equipments
40	23600	One 40 Wp Solar Module , one 55/60 Ah Industrial Battery, 1No. 10 Amps Charge Controller, 1 No. Structure, 3 Nos. 7 Watt Lamp, Switch, Switch Board, Installation & Other Accessories.
50	28500	1 No. 50 Wp Solar Module, 1 No. 80 Ah Industrial Battery (Tabular Plate), 5 or 10 Amps Charge Controller, 1 No. Structure, 4 Nos. 7 Watt Lamp, Switch, Switch Board, Installation & Other Accessories.
60	34400	1 No. 60 Wp Solar Module, 1 No. 80 Ah Industrial Battery (Tabular Plate), 1No. 10 Amps Charge Controller, 1 No. Structure, 5 Nos. 7 Watt Lamp, Switch, Switch Board, Installation & Other Accessories.
65	36000	1 No. 65 Wp Solar Module, 1 No. 100 Ah Industrial Battery (Tabular Plate), 1 No. 10 Amps Charge Controller, 1 No. Structure, 5 Nos. 7 Watt Lamp, Switch, Switch Board, Installation & Other Accessories.
80	42200	1 No. 80 Wp Solar Module, 1 No. 100 Ah Industrial Battery (Tabular Plate), 1 No. 10 Amps Charge Controller, 1 No. Structure, 7 Nos. 7 Watt Lamp, Switch, Switch Board, Installation & Other Accessories.
85	44800	1 No. 85 Wp Solar Module, 1 No. 130 Ah Industrial Battery (Tabular Plate), 1 No. 10 Amps Charge Controller, 1 No. Structure, 8 Nos. 7 Watt Lamp, Switch, Switch Board, Installation & Other Accessories.

Table 5. Break down of cost of PV system in rural Bangladesh

Components	Price (%)
Battery	30%
Solar panel	28%
3 Years after sales service and installment collection	13.50%
Overhead cost	10%
Others (cable, switch etc)	7.50%
Lampshades (4 Nos)	5%
Charge controller	3%
Flurescent lamps (4 Nos)	2%
Structure	1%

4.2. Payback period, NPV and IRR

The total expense (initial, periodic and maintenance cost) of SHS systems in its entire life is calculated in terms of the levilised cost of PV electricity. 02 batteries were assumed to be replaced during the entire 20 years project life. The panel life is assumed to be 20 years. Minimum life and average cost of FL was assumed to be 02 years and 120 BDT. By considering no price escalation and zero salvage value of panel after 20 years, it is found that cost of SHS electricity is around 76 BDT/kWh. Price escalation is assumed to be zero because increasing trend of battery cost can be levilised by decreasing trend of panel and charge controller. Costs are assumed at present market price.

Increase of equipment cost is not considered for this calculation because increasing trend of kerosene can also increase the saving of owner. The cost of SHS in Bangladesh can be reduced by producing all the equipments within the country. During field visit, it was found that there was lack of quality PV accessories in the market. Bangladesh government should help to produce Si and solar panels within the country. Though the panel cost is reducing in the international market, the panel price depends on dollar exchange rate- it is increased to 80 BDT from 70 BDT within the last two years (2009-2011). Simple payback is an indicator that shows the time frame of the return of an investment. Average value of payback period was 4.2 years and varied from 3.1 to 6.5 years (Table 6). On the other hand, NPV is calculated by bringing all the cost and revenue to the year zero with the average lending interest (14.9%) of last five years [17]. IRR is the discount rate that makes present value zero. NPV varies 34,500 BDT to 14800 BDT. For a project, shorter payback period and higher NPV and IRR are desirable to risk free investment.

Table 6. Payback period of NPV and IRR

Parameters	Best case	Worst case	Average
Payback period	3.1 years	6.5 years	4.2 years
NPV	148000 BDT	34500 BDT	53,271 BDT
IRR	200%	56%	95%

For this analysis, extra business activity and amount of profit increase after installing the SHS system are not considered as these variables were very much unstable, difficult to estimate and depend on many factors. Environmental benefit also not considered for this analysis as the owner of the system cannot claim environmental benefit according to the contract.

Results show that SHS The projects will be much more attractive if owners do some extra business activity. During field visit, very few owners were found to do extra business like mobile charging business or mobile phone booth. Financial evaluation of SHS in Bangladesh was done by Mondal 2010. According to his study, payback period varied 2 to 6.34 years and NPV varied from 8422 BDT to 162,181 BDT with a discount rate of 12% [10].

5. Energy and Emission

5.1. Energy Consumption and Corresponding Emission by a SHS

Energy requirement for various components of PV systems found 35 MJ/ W_p for multi crystalline PV module [18]. Total energy requirement by a 50 W_p SHS are presented in Table 7.As the PV systems in the studied case were aluminium framed modules, energy requirement for this has been calculated. According to the estimation of Alsema, 1 m^2 of PV module requires 2.5 kg aluminium frame, which requires 500MJ of thermal energy [18]. The area of 50Wp module is 0.45 m^2 for multi crystalline (BP350). Based on this value, the energy requirement for aluminium frame in the studied area is 225 MJ. Batteries are one of the significant parts of stand-alone PV systems. Alsema suggests that the energy requirement range for lead-acid batteries is 25 to 50 MJ/kg [18]. This value assumes 30 to 50% of lead recycling. The energy density of battery is typically 40Wh/kg, which gives 0.94 MJ/Wh. As the 50Wp PV system uses a 71Ah battery @ 12V (852Wh), the energy requirement becomes 800 MJ per battery.

Table 7. Energy consumption for a SHS in its entire lifetime

Initial Energy Consumption		
Sl No	Item	Required energy
1	PV module	1750MJ
2	Aluminium frame	225 MJ
3	Mounting structure	100 MJ
4	Battery	800 MJ
5	Charge controller	9MJ
Total initial energy requirement		2884 MJ
Energy required for replacement		
Sl No	Item	Required energy
1	Battery	1600 MJ
2	Charge controller	09 MJ
3	Mounting structure	100 MJ
Total Energy required for replacement		1709MJ
Grand Total		4593MJ

Energy requirements for charge controller were very difficult to find. As most of the sources mention about the energy requirement for grid connected PV systems, which do not use any charge controller (rather use inverters), this particular information was not available. Twedell mentions that the energy requirement for a 3 kW inverter is 2,105 MJ[19]. The energy requirement in this calculation was worked out from this figure based on the weight comparison. BP (2003a) gives the weight of a 1 kW inverter is 18.5 kg and Morningstar gives the weight of a 10 ampere charge controller is 0.23 kg [20]. Based on the liner algebra the energy requirement for 10 amps charge controller was calculated to be 9 MJ.

Most of the households in the rural area have tin shed roof. Therefore, to fix the module a very simple and light weight steel frame is used, which is screwed between the module and the roof. The weight of this structure is about 2 kg per system. Wheldon et.al notes the energy requirement for galvanized steel is 50 MJ/kg, which gives 100 MJ per system [21]. Lamps, cables and fixtures, Installation, Transportation are not consider for analysis as energy consumption for these are very low.

Total primary energy requirement for a 50Wp in its total life of 20 years as summarized in table 7 is 4593 MJ.As the all energy used in manufacturing and replacement of PV system is in the form of electricity, the total emission can be obtained very easily. Alsema noted that the emission from electricity generation is 0.055 kg CO_2/MJ [18]. This gives emission over 20 years from a 50Wp 253 kg.

5.2. Energy supplied and emission reduction by SHS

Design of 50 W_p system allows 112 Wh/day (source: field visit) and this gives around 40.88 kWh_e per year that means 163.52 kWh_{th} (11773 MJ_{th}) in 20 years. Energy payback can be calculated by the Eq. (4):

$$\text{Energy Payback time (years)} = \frac{\text{Energy required for PV systems in its lifetime (20 years)}}{\text{Energy output of PV system per year}} = 7.80 \text{ years.} \quad (4)$$

Kerosene is the main fuel for lighting in rural areas, which is used in “Hurricane” or “Kuppi”. Various sources have been consulted to get an estimate of the fuel used per household per month.An early study made by Cabraal shows that kerosene consumption of a household using wick lamps in Sri Lanka was 0.5 to 1 litre per day i.e. 15 to 30 litres per month [14]. Traditional wick lamps (Kuppi and hurricane) used by the rural people of Bangladesh were tested at Bangladesh Council of Scientific and Industrial Research (BCSIR) to get the actual fuel consumption and the result show that the average fuel consumption per lamp was 0.042 lit/hour. Assuming an operating hour of 4 hours, the average kerosene saved by 50Wp systems were around 20.50 liter/month that means 4920 lit in 20 years.

IPCC guide line suggests that CO_2 emission from kerosene is 2.5 kg/liter [12]. According to a study in India, emission from kerosene lamp was 2.45 kg CO_2/lit [13]. But this value can vary with different types of lamps. The traditional lamps used by the rural people were tested at BCSIR. The average CO_2 emission from traditional lamps used by the rural people in Bangladesh was 2.41 kg CO2/liter according to the test.

Therefore, the total CO2 emission reduction will be 11604 kg in 20 years.

6. Conclusion

Analysis of cost, energy and emission has been done for 50 W_p SHSs in Bangladesh and the following conclusions can be drawn from the study**:**

i) Around 1.4 million solar home systems are already installed in Bangladesh. Normally 40~85 W_p systems are mostly used in the rural user level. The cost of a 40 W_p system was around 24,000 BDT, whereas for a 85 W_p system, the cost was 45,000 BDT. Solar panel contributed to 28%, whereas battery cost was around 30% of the total cost

ii) Average value of payback period was 4.2 years and varied from 3.1 to 6.5 years. On the other hand, NPV varies 34,500 BDT to 14800 BDT. It is found that cost of SHS electricity is around 76 BDT/kWh.

iii) Total primary energy requirement for a 50Wp in its total life of 20 years is 4593 MJ. This gives emission 253 kg CO2.

iv) Design of 50 Wp system allows 112 Wh/day and this gives around 40.88 kWhe per year that means 163.52 kWhth (11773 MJth) in 20 years. Energy payback was found to be 7.80 years.

v) The average kerosene saved by 50Wp systems were around 20.50 liter/month that means 4920 lit in 20 years.

vi) The average CO2 emission from traditional lamps used by the rural people in Bangladesh was 2.41 kg CO2/liter according to the test. The total CO2 emission reduction will be 11604 kg in 20 years.

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