

PHOTOVOLTAIC TECHNOLOGIES FOR POVERTY ALLEVIATION IN RURAL BANGLADESH: A SPECIFIC STRATEGY

Wahidul K. Biswas*, Paul Bryce**, and Mark Diesendorf*

**Institute for Sustainable Futures, University of Technology, Sydney, NSW 2007, AUSTRALIA*

***Faculty of Engineering, University of Technology, Sydney, NSW 2007, AUSTRALIA*

ABSTRACT

The paper explores a solar energy business model addressing poverty alleviation in Bangladesh. Under the business model, solar electricity is found viable and competitive with existing technologies (irrigation and domestic lighting systems) up to a maximum investment (ie. Tk. 225,069) available from a micro-credit organization. The electricity price at this situation is Tk. 55 per kWh and all customers benefit relative to the existing kerosene alternative. At a wage rate of Tk. 12.5 per hour, 32% of the people not currently able to support themselves for food would be able to meet their financial deficits through this employment scheme. 22% of the wealthier group would also benefit through supply of electricity from this small enterprise.

KEYWORDS

Photovoltaic technologies; rural electrification; income generation; rural poor

INTRODUCTION

The paper investigates the possibilities of improving the incomes of landless and marginal farmers (LMF) in a Bangladesh village through a solar electricity business model. LMFs live from hand to mouth as income from crop production is not enough to allow them to subsist. This situation is more severe in inundated areas where agricultural land remains under water about one third of the year and multiple cropping is hampered. During the rest of the year LMFs are either engaged in low earning, insecure work or remain unemployed.

Solar electricity could be a promising business and employment opportunity for LMFs, as it is not a seasonal business like agricultural activities. Only 10% of the rural population and 30% of villages can be connected to electricity from the national grid. The electrification of the remaining villages, by grid extension, is beyond Government capital resources (BCAS, 1998). Moreover, 85% of current national electricity generation is sourced from natural gas, and reserves may be exhausted by 2015 with current trends of consumption (Power Cell, 1998). Fuel imports would be required to generate 47% of electricity by 2020. Such import dependency would further reduce Bangladeshi sovereignty over its economic and social policies.

Average national solar radiation ($3.85 \text{ kWh/m}^2/\text{year}$) is quite good for photovoltaics (PV) (Hossain, 1987), but their application is still in an early stage. The Rural Electrification Board installed its first solar power station of 62kW but operation is unsatisfactory due to its improper bill collection and maintenance systems. Instead, the business proposed here employs LMFs in bill collection, customer service and equipment maintenance. Grameen Shakti, is involved in commercialising PVs with loans to solvent rural people with collateral, generally the wealthiest households. In contrast, this paper deals with the problem of capital intensity of PV's by assisting groups of LMFs, to form a business or a cooperative (Biswas, Bryce and Diesendorf, 2001). By selling electricity to wealthier members of the village, the Village Business would repay its loan, thus gaining direct ownership and control over the technology and its applications.

We have studied in detail a village in Gopalganj district, Bangladesh, in order to test this model. LMFs in this village could be involved in electricity business to combat under-employment and their deficit situation. We considered the following criteria: 1) The wage from the business should be competitive with wages from existing activities to meet household deficits. 2) Employment in this business should

with existing services. 4) The business should be protected against bankruptcy resulting from improper bill collection.

THE MODEL

Empowering tool : Deficit driven approach

We defined an '*Empowering tool*' to assess the potential involvement of deficit LMF households in a solar electricity business in order to meet their deficits. Deficit households were classified as households with incomes not able to support food (level 1), incomes not able to support food and clothes (level 2), and incomes not able to support expenditure for all basic items (level 3). The *number of person-days* per deficit household in a business vary with the amount of deficit. This is expressed as,

$$\text{Number of person-days per month} = (\text{Amount of deficit in Tk. per months}) / (\text{hourly wage from the PV business} * 8) \quad (1)$$

The objective was to provide business opportunities during their (otherwise) unemployed person-days. However, the number of person days required by a LMF for this business might exceed the unemployed person-days and overlap with the days allocated for other income generating activities. It should be noted that the wage from this business must be competitive with that¹ from overlapping activities. The less secure jobs although having competitive wage rates would be considered as overlapping days. The annual income of a deficit LMF household involved in this business should be more than the deficit. We express this requirement or *Empowering tool* as:

$$\sum(((\text{person-days for existing activity}_{1j} - \text{days overlapped}_j) * 8 * \text{hourly wage of existing activity}_{1j}) + (\text{person-days for RET business}_j * 8 * \text{hourly wage rate}) - \text{monthly expenditure}) > 0 \quad (2)$$

where, I = 1,2,3n activities performed in a month

J = 1,2,312 months

Sustainability of the business

A positive result was an initial constraint on the model's utility. In addition, the model's viability requires positive assessment from the viewpoint of other stakeholders, notably the lending body and the consumer. *Sustainability of the business depends on the electricity pricing and the benefits obtained from the seller's and consumer's perspectives.*

Solar electricity pricing . The price of the electricity is a function of demand by wealthier households and the wages of LMFs involved in the business. Thus the model varied energy generation and wages to optimize price, within other constraints. Discounted cash flow (DCF) analysis allowed the unit price to be determined, then multiplied by generation supplied to yield total revenue. The unit price can be increased from that determined from DCF analysis so that total revenue is able to cover costs of the loan repayment at 10% interest, plus other associated maintenance and replacement costs including wages of the LMF group over the life of the business.

Seller's perspective. The wage rate should be competitive with wage rates from existing income generating activities. If the wage goes lower, the number of working hours that are required meet the deficit increases. Expansion of generation would therefore be required to increase person-hours. This leads to further constraints to optimization: 1) An increase in the generation of electricity increases the investment, and the latter is constrained by the NGOs/ lender's risk management policies (BRAC 1997). 2) The supply of electricity should not exceed demand from all wealthier households in the village.

¹ 19 LMFs (20% of the LMF population in the village) were interviewed to know what activities they had carried out in each of the last 12 months. Then average wage rates to perform different activities in different working places were calculated.

avoided should be more than the incremental cost of the lighting appliance (ie, replacement of kerosene lamp with lamp and the battery). The net benefit (NB) is expressed as,

$$NB = (PVCK - PVCSE) - \{(PVSFL + PVB) - (PVKL + PVOKL)\} \dots\dots\dots(3)$$

where PVCK and PVCSE are present values of kerosene and solar electricity over the lifetime of the fluorescent lamp. PVSFL and PVB are present values of fluorescent lamp and battery, respectively. PVOKL and PVOKL are present values of hurricane and O&M of hurricane (i.e., wicks, chimney, replacement etc.). The price of electricity should be able to compete with that charged from a local battery charging station for domestic use and diesel driven pump for irrigation.

TECHNO-ECONOMIC CONSIDERATIONS

The viability of solar power can improve with a combination of applications. In this village study, the use of the technology for both irrigation and domestic household use was found advantageous.

Irrigation project

Water and energy demand . The available areas for irrigation among the 22 wealthier households are 0.12Ha, 0.3Ha, 0.4Ha, 0.61Ha and 1.01Ha. Irrigation is continued for 15 weeks from early February to mid May. Water requirement for a hectare of land varies from 196 m³ to 291 m³. The solar pumping required 1316 Wh per day to irrigate 1.01 hectare of land for 2 days a week. There is 12.5% water loss for every 100 m channel through which the water is conveyed is considered (Datta and Mandal. 1985).

Table 1. Weekly irrigation schedule.

Hectares of land irrigated by the interviewed HHs *	Days/ wk	Hr/ day	Day 1	Day 2	Day 3	4 Day	5 day	6 day	7 day
0.40	2	2.5					2.5	2.5	
0.61	2	3.7			3.7	3.7	1.5		
0.30	1	1.9			1.9				
0.12	1	0.7				0.7			
1.01	2	6.2	6.2	6.2					
next arrangement	1.5	0.0				0.5	0.5	0.5	
BASE CASE			6.2	6.2	5.6	4.9	4.5	3.0	0.0
SURPLUS SCENARIO									
next arrangement						0.5	0.5	0.5	0.5
irrigating hour						0.8	1.2	2.7	5.7
irrigating additional ha						0.13	0.19	0.44	0.92
Selling additional water in 15 wks						440	659	1484	3132

*HH stands for household

Irrigation Scheduling. The photovoltaic system was then designed on the basis of water requirement for the largest plot of irrigated land (i.e., 1.01 Ha) in the village. The time required to supply this irrigation to the given area determines motor and panel size, and had been optimised for best utility over several customers (see Table 1).

- Larger units require investments beyond the scope of micro-credit organizations.
- Increased panel and pump sizes reduce portability of the unit, to serve a range of isolated paddies.
- The size of the motor can become so high that a dc motor would be inappropriate. This would in turn require purchase of an inverter to convert dc to ac current.
- Panel size should not get so small so that it would not be able to irrigate other sizes of land.

- The schedule of usage should allow the same pumping system to irrigate different sizes of land.

Technological characteristics. Reciprocating pumps have been found particularly efficient (65%-70%) (Witfield and Burton, 1994). This reduces the capacity of motor and allows the use of DC motor drives which then can avoid the use of an inverter. PV capacity will be insufficient during the irrigation period to supply electricity for both irrigation and domestic purposes. Thus a diesel generator has been included to substitute for these panels for domestic purposes during months of irrigation. With diesel used only marginally, operating hours turn out to be only 140/ annum. Therefore, there will not be significant replacement of the engine over the project lifetime. The cost of a solar tracker has been avoided by involving a worker to rotate the panel 3 times per day.

Direct electricity supply for domestic use

Energy Demand. Electricity supply for TV, cassette player and fans was found to exceed the capital lending capacity of micro-credit organization. The model thus considered initial supply of electricity for lighting only, in 34 households (i.e., 1.75 times the interviewed households) with one fluorescent lamp each.

Technical characteristics of the equipment. The design parameters were similar to those followed by Sandia National Laboratory, USA and Siemens Solar, Germany (SNL, 1991). For designing solar systems for domestic lighting, the days of autonomy², nominal system voltage, depth of discharge of the deep cycle battery, the life time of the battery, the power conversion and battery efficiencies are 3 days, 24 volt, 50%, 10 years, 85% and 80%, respectively (Bhuiyan et al., 1999). Except for PV panel, all components of the systems are manufactured in Bangladesh.

Load management . The design of PV system with a single battery size would not be feasible in this context. The number of batteries may not be same as the number of customers. Charging could be battery from battery with some conversion losses or by a transmission cable to the customers. In order to avoid transmission loss and also the chance of stealing electricity, customers will have their own batteries. The size of the battery will be designed on basis of a household's electricity demand. Different amp-hour batteries of the same voltage from different customers will be connected to the solar system in parallel, with 2 batteries of 12 volts connected in series.

Cost information

Capital cost . PV price is taken as Tk.201/Wp, an average of prices listed by local companies. Insurance and freight is 4.5% of total cost. The sizes of batteries varies among customers because of the variation in their demand. Therefore, the unit battery cost has been taken as Tk.60 per amp-hour. Table 2 gives the breakdown of the costs estimated.

Operation and maintenance cost . For the reciprocator, bearing and pulleys need to be changed every 5 year at a cost of approximately USD200. In case of motor, brush replacement and skimming commutators and replacement of bearing are needed every 2 and 7 years, respectively costing around 5% of the total cost of the motor.

End-use appliances . The cost of fluorescent lamp with built in inverter has been taken as Tk. 500. The costs of kerosene lamps varies among customers. The cost of hurricane lamps purchased by different wealthier group has been gathered from the field survey, and varies from Tk.60 to Tk.110. Kerosene is Tk.15 in the local market.

Person-days required for solar electricity business

Since some machine activities have been transferred to human energy, an increase in the project size (and plant expansion) increases employment (see Table 3).

² The number of days of the week electricity can be stored in the batteries.

Irrigation project			Domestic lighting project			Grand total (Tk)
Components	Number	Cost (Tk.)	Components	Number	Cost (Tk.)	
Panels (80W)	6	100,822	Additional panels	3	50,699	
Motor (0.35kW)	1	27,839	Charge controller	1	12,355	
Reciprocating pump	1	23,513	Cables		1000	
Piping (5 m)	1	1,250				
		153,424			88,076	224,069

Irrigation project . During field work, a person must be with the panel in the field. It would require 1.5 person a day at least for 7 hours as the minimum sunshine hour during the months of irrigation is 62. It has been deduced from the field survey that a person can carry 20 kg straw at a time for a half mile distance to his house. A 1 HP Baldor motor weighs about 10 kg and a 80 W panel weighs 8.5 kg suggesting 2 persons to carry the solar pumping system from field to field. The use of a trolley was found impractical in this geographic context. Charging batteries from an engine would require the extra involvement of a person as other panels are engaged in irrigation.

Domestic electricity project . The distribution of the charged batteries among customers is the most time consuming element in this project. Our study suggests that a given battery needs to be charged every 3 days. The existing trails and paths pass between clusters of villages suggesting that LMF group would carry these batteries by bicycles having two 2 of them on 2 sides of the rear axle. As this foot path go under water during the rainy season, workers may carry the batteries by boat from cluster to cluster.

Table 3. Breakdown of different activities and the man-days required to perform these activities.

Solar irrigation project				
Activity	Unit	Value	Man	Person-hours/month
Field	Hours/day	8	1.5	360
DE operation battery charging	Hours for all Batteries	2.4	2	27
distributing charged batteries	hours/person/week	1		38.5
Bill collection	hours/person/week	0.24	1	21.6
Maintenace	hours/week	6	6	25.8
Admin (book keeping)	hours/week	7	7	30.1
			Person-day/month	61
Solar lighting project				
distributing charged batteries	hours/person/week	1	1	38.5
tracking panels	hours/week	1.75	1	1.75
Bill collection	hours/person/week	0.25	1	9.625
Maintenace	hours/week	6	1	6
Admin (book keeping)	hours/week	7	1	7
			Person-day/month	34

Some LMF members will also be involved in bill collection and the more literate in book keeping.

EMPOWERING RURAL POOR THROUGH PV TECHNOLOGIES

Step 1 : Allocating person-days among the deficits households

households. 47% of the interviewed LMF households have been found to have surplus. 32%, 42% and 52% of the remaining households are found in the deficit levels 1, 2 and 3, respectively. LMF households' wage and deficit level are the variables determining the person-days required meet the basic needs of these households.

For households at deficit level 1 . The wage rate for both irrigation and domestic lighting projects is Tk. 12.5/hour. Table 4a. shows person days required to run the irrigation application are more than required to meet deficits at the given wage rate. During the irrigation application, the deficit households are able to work for more person-days than they require to meet their deficits. However, during the domestic use period, deficit households have insufficient working days to meet deficits. On balance, the households may able to meet their deficits if they take full advantage of the extra work available during the irrigation season. Wages from the RET business are very high compared to wages from existing activities (see Table 4a).

Table 4a. Households having deficit for food.

Households at different levels of deficits	Person-days required to overcome the deficits		Person-days required to run these 2 projects	
	Irrigation project	Domestic lighting project	Irrigation project	Domestic lighting project
-486	5	5	9.2	4.9
-9	1	1	1.9	1.0
-705	7	7	13.3	7.1
-35	1	1	1.9	1.0
-443	4	4	8.3	4.5
-1504	15	15	28.3	15.2

Table 4b . Person days for households at deficit level 2 and 3.

Households having deficit for food and clothes					Households having deficit for all items				
Households at different levels of deficits	Person-days required to overcome the deficits		Person-days required to run these 2 projects		Households at different levels of deficits	Person-days required to overcome the deficits		Person-days required to run these 2 projects	
	Irrigation project	Domestic lighting project	Irrigation project	Domestic lighting project		Irrigation project	Domestic lighting project	Irrigation project	Domestic lighting project
-486	3	3	5	3	-886	6	6	6	3
-285	2	2	3	2	-285	2	2	2	1
-509	4	4	6	3	-1009	7	7	7	4
-1105	8	8	12	7	-1255	9	9	8	4
-300	2	2	3	2	-738	5	5	5	3
-1592	11	11	18	10	-25	1	1	1	1
-443	3	3	5	3	-900	6	6	6	3
-869	6	6	10	5	-1992	14	14	13	7
					-443	3	3	3	2
					-2039	14	14	13	7

For households at deficit level 2 and 3 . The number of person-days required to meet deficits of households at deficit level 1 are more than those required to meet deficit levels 2 and 3. With an increased wage rate, the required number of person-days decreases. In our test analysis, we adjusted wage rates upward while observing that the price of electricity must be competitive with the price from diesel. The wage has been increased from Tk.12.5 to Tk.18/hour and the electricity price has also been increased from Tk.55/kWh to Tk.68/kWh. Table 4b shows the person-days required to run the irrigation project are more than would be required to meet the deficit for levels 2 and 3. However, the number of person days available in the domestic electricity business component is less than required to meet the

three classes of deficit households.

Step 2 : Meeting the deficits

It is assumed that deficit households will do the same activities that they had carried out during the previous year and that they will also be involved in the solar electricity business during the days they were previously unemployed. With person-days of existing activities fixed, person-days for RET business have been allocated during the monthly unemployed period of the deficit earning members of the households. Overlapping times are deducted from jobs such as physical labor and small non-agricultural work. It was found that households at deficit level 1 can totally meet their food deficit if their wage rate is fixed at Tk.12.5 per hour for both irrigation and domestic lighting projects. Table 5 shows there is a monthly average surplus from the solar electricity (SE) scenario, since the wage rate is higher than average wage rates of overlapping activities. A quarter of households at deficit level 2 are found not able to meet their deficit, even when wage rates reach Tk.18 an hour, since person-days are insufficient. Similarly, only 20% of households in deficit level 3 are able to meet the deficits. In short, given the constraints, the business provides viability in terms of food for all, but does not fully provide for other basic needs of LMF households.

Table 5. Meeting deficits through solar energy business.

6 households at deficit level 1		8 households at deficit level 2		10 households at deficit level 3	
Existing scenario	SE Scenario	Existing scenario	SE Scenario	Existing scenario	SE Scenario
-486	673	-486	416	-886	50
-9	992	-285	57	-285	-69
-705	512	-509	761	-1009	339
-35	669	-1105	151	-1255	-372
-443	185	-300	-298	-738	-687
-1504	1841	-1592	464	-25	1027
		-443	-63	-900	-328
		-869	588	-1992	-435
				-443	-222
				-2039	-255

The figures in the table are annual monthly average of deficit (income – expenditure)

SUSTAINABILITY OF THE PROJECT

At a price of Tk.55 per kWh both solar irrigation and domestic lighting (employed in combination) were found competitive with existing lighting and irrigation technologies. Total investment in this business would be Tk.224,069, the BRAC lending capacity under Micro Enterprise Lending Assistance (MILA).

Solar irrigation component. The cost of pumping 1 cubic meter water for irrigation from a head of 4 meter is Tk.0.48 by the solar pump while it is Tk. 3.17 using the existing diesel engine driven irrigation pump to irrigate same amount of land. The existing irrigation situation of the village involves a fixed charge for irrigating a piece of land, at Tk. 1000 to irrigate 1 bigha³ and Tk. 60 an hour for running a diesel engine pump. Here the unit cost of Tk. 1.37 per m³. Some additional non-technical risks can be overcome with use of solar pumps. For example, diesel contractors collect fees in advance of purchasing fuel and often need the money for personal reasons that preclude adequate purchases of diesel. As a result, they cannot irrigate the land completely. This risk can be avoided with a PV irrigation system, where fuel is not an issue.

Domestic electricity component. It was found that the solar electricity market would be competitive with existing kerosene lamp options. The incremental cost of lamps along with batteries has been found less

³ Bigha is the local land unit of the village and is equivalent to 0.2 hectare of land.

with electricity generated by the decentralised diesel plant. With the same supply (ie, 1538 kWh), the unit cost of electricity from diesel is Tk. 67. When the supply is increased from 38 customers to 66 customers, solar electricity is no longer competitive with diesel. Households are found charging batteries for special purposes in local town 3 kilometer away from this village which incur additional cost for transportation. This would not be a viable option if battery is charged frequently (ie, twice a week). Expected revenue may drop because of flooding, a bad agricultural season or customers' tendency to drop out from the list of buyers of the electricity service. Considering these factors, the price can be increased to Tk 59, Tk. 68, Tk. 83 and Tk. 108 for 80%, 60%, 40% and 25% bill collection, respectively in order to pay back the loan in 7 years. Consumers still benefit at a price of Tk. 83/kWh by avoiding hurricane lamps.

Benefits from the national perspectives. If this project is expanded to 90% of the Bangladeshi rural population without electricity access, it would roughly reduce consumption by 23 kTon of kerosene, or 9% of imports in 1997 (BBS, 1998). Since irrigation patterns vary, we cannot estimate the amount of diesel avoided through solar pumping.

CONCLUSIONS

A solar based business based on actual conditions within a Bangladesh village, and directed specifically at poverty alleviation can potentially be viable. It is competitive with existing technologies in the agricultural and domestic sectors at a solar electricity price of Tk.55 per hour. The cost of pumping 1 cubic meter water for irrigation from the head of 4 meter is Tk. 0.5 by the solar pump while it is Tk. 3.17 using the existing diesel irrigation pump to deliver the same quantity of water. Solar pumping is also competitive with the existing price (i.e.,Tk. 1.37/m³) of a unit in the village operating on a larger scale.

Social and economic effects may be significant. This kind of small enterprise may be able to break the circle of households' financial deficits that lead to reduced land and asset holdings, which in turn increase future deficits. The business is viable up to an investment (ie. Tk. 225,069) that a micro-credit organization can provide to a rural enterprise. It could potentially meet the financial deficit of almost all LMF households in deficit level 1 at wage rate Tk.12.5 per hour and about 75% and 25% of the deficits of LMF households in level 2 and 3, respectively at Tk.18/ hour . The business would not be competitive if the wage rate is higher than Tk.18 per hour. Migration of workers from existing poorly paid activities such as weeding to solar electricity business could increase the wage rate for weeding. The analysis suggests that the project would be profitable for both consumer and seller, even at Tk. 83/kWh and 40% bill collection. Duration of supply will be the same as the wealthier groups' lighting hours. Solar electricity can reduce the consumer cost in Tk./lumen/day from 0.60 for kerosene lamp to 0.56, while improving quality of life and effective use of time.

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