DEUTSCHE GESELLSCAFT FUER
TECHNISCHE ZUSAMMERBEIT (GTZ)

PROMOTION OF THE USE OF RENEWABLE ENERGIES (PURE)

FINAL REPORT ON

IDENTIFICATION & ASSESSMENT OF THE APPLICATION POTENTIALOF OF SOLAR PHOTOVOLTAIC WATER PUMPING INITIATIVE (PVP) IN BANGLADESH (STAGE-I A)




20 August 2006

VISIONS

"Plug your Drinking Water Supply to the Sun"
"Green Pumping for a Greener Bangladesh"

Dr.-Ing. Khursheed-Ul-Islam
Energy Project Development & Management Consultant
GTZ-PURE

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1.0 BACKGROUND

Energy, Water and Agriculture, together form a formidable Synergy, which, when managed appropriately and efficiently, can drive a nation way forward to achieve its development goals. Bangladesh has access to all the three important inputs of development. What is primarily required is an efficient and optimum utilization and management of these resources to tap and bring out their potentials to their fullest extent. The poverty, hunger and degradation of humanity that prevail in most of the developing countries of the world, are all results of a miserable failure of these nations to utilize and manage these three basic inputs of development optimally. No matter how many millennium development goals are set (MDG) by the United Nations and sophisticated reports on poverty reduction strategy papers (PRSP) written, in reality the situation in developing countries stand hardly any chance to improve, unless all the three components of this basic synergy are carefully managed, in harmony with each other and in an environment-friendly manner. The later aspect is also important, since excessive greenhouse gas (GHG) emissions from the fossil fuels, presently used (e.g. diesel fuel used to power a few million small irrigation pumps for agriculture) are already creating visible impacts on the climate change, which, in turn, may adversely affect the agricultural outputs and hence the connected global food production.

In fact, long before the advent of the industrial revolution, all human development activities and efforts were centered around utilization and management of the above mentioned three basic inputs, with the difference that only very inefficient traditional means and methods were used, which involved draught animals and human muscle power or other very crude technologies for irrigation and water management. Such methods are still being practiced in many developing countries of the world, in Asia, Africa and Latin America (e.g. muscle-powered hand Tube-wells and 'Doons', used in Bangladesh and camel/bullock-powered water wheels in many undeveloped areas of Pakistan and India). Of course, they are 'environment-friendly', as they do not consume imported petroleum based fossil fuel primary energy, like high speed diesel oil (HSD) or electricity, but they are highly inefficient too, when compared to the requirement and the 'best practices' of modern agriculture, which must follow a 'road map' to attain a sustainable growth, using increasing share of sustainable sources of resources of energy

The world wide developments in modern agricultural practices, like the use of the high-yielding varieties of food grains and other crops have fortunately proved the Malthusian theory to be wrong. The 'doomsday', predicted by him never came, thanks to the tireless efforts of the agricultural scientists and engineers who made and are still continuing to make this possible through their commendable contributions to grow more food by continuously developing high-yielding genes of food grains and other crops and by applying modern best practices and also, if and when found necessary, using 'leap-frogging' through the technology ladder. However, such developments have placed, at the same time, enormous demands and increased stress on the basic inputs such as water, seeds of high-yielding verities of crops and also on increased use of fertilizers, amongst others. The optimal uses of energy and water which, when properly managed, lead to conservation of all other costlier inputs, including the costliest one at their current prices - the chemical fertilizers, to rather enhance the overall agricultural productivity. Even in case of high-yielding varieties of rice, as per field-test based findings of the agricultural scientists and irrigation / water management engineers, huge amounts of irrigation water is being wasted through flooding type irrigation practices, which not only result in losses of fertilizers, but also suffocate the plants by blocking aeration, thus leading to loss of their productivity and may in some cases lead to crop failures. Furthermore, field tests in Bangladesh (Ref: interactions with Bangladesh Agricultural Research Institute (BARI) /Field visit Report - II in Annexure of this Report) have indicated that the yield of most vegetable crops could be increased by a few folds, when water and energy conserving drip irrigation (also termed micro-irrigation) technology was used (e.g. upto 90 MT/ hectare of Tomato yield has been obtained by using a locally developed low-cost drip irrigation (also termed fertigation), compared to the national average of 18 28 MT/hectare (max.).

From considerations of situation analysis in the energy sector, Bangladesh, in spite of being blessed with a reasonable quantity of natural gas and coal as primary energy resources, suffers from an acute crisis of energy and power - both in its urban and rural areas. The demand for energy, especially for electric power is fast outstripping its supply. In rural areas, apart from the crisis of primary fuel and electricity, another area which is tied up with a huge demand in primary (diesel fuel) and also secondary energy (electricity), which is used for providing irrigation. The later is mandatory for protective irrigation as well for attaining the required higher production of food grains and other crops of high the high-yielding varieties, necessary to feed the 140 million mouths of Bangladesh.

Bangladesh's economy is predominantly agrarian, nearly 35% of its GDP being contributed by the agriculture, which employs over 60% of its labour force. However, to support the productive high-yielding varieties of food grains and crops, appropriate use of water as one of the key inputs is absolutely essential through irrigation.

The country annually consumes, on the average, over 3.7 million tons of imported crude and finished petroleum products, out of which about 2 milion tons is high speed diesel oil (HSD). This mid-distillate is a deficit product, over 40% of which is used in the agricultural sector, to operate over 1.5 million tones of HSD based Low Lift Pumps (LLW), Shallow Tube Wells (STW) and Deep Tube-wells (DTWs). The share of electrically-driven irrigation pumps, the current figure of which stands at about 198,000 (as per current connection status of April, 2006 of Rural Electrification Board, REB), is still negligible. The balance 60% of HSD (about 1.2 million tons) is used in the Transport sector, where the demand for HSD is also experiencing a rapid growth, triggered by the development of the country's improved road network and overall transportation infrastructure.

THE POTENTIAL OF SOLAR PV ENERGY IN BANGLADESH – GENERAL OBSERVATIONS

Bangladesh, is blessed, on the other hand with a rich sunshine as a renewable source of energy. On the average, the country receives daily about 4 - 7 kWh/m2/day of Solar energy, with about 300 days of annual sunshine hours. With an area of about 1.49 x 10^{11} sq. m area and a (conservative average) of about 3.5 kWh/m2/day per day (taking into consideration the overcast sky conditions during the monsoons), even if 1% of Bangladesh's land area could be utilized to tap the incident solar energy with an efficiency of about 10% (which is now crossed by most of to-day's polycrystalline based Solar Photovoltaic (PV) Cells and Panels), this would equate to an annual electricity generation of about 5.215 x 10^{9} kWh.

THE ROLE OF 'FLAGSHIP PROJECTS' IN DEVELOPING COUNTRIES TO PROMOTE THE USE OF RENEWABLE ENERGIES (RE)

Following the first 'energy crisis' of 1973, caused by the OPEC oil embargo, which sent a series of 'shock-waves' across the globe and the subsequent price shocks that soon followed, serious efforts were launched world wide to effectively and efficiently harness the gigantic dimensions of incident global solar energy, using both solar thermal as well PV technologies. The tireless R & D team work between engineers, scientists, economists and market specialists, supported by appropriate national policies by a large number of institutions, including those working in the mainstream energy sector, including the multinational oil companies (Shell, BP, TOTAL and others), soon resulted in developing matured renewable energy (RE) technologies and systems, especially in the Solar PV and Wind sectors. Decentralized generation and use of solar photovoltaic energy, especially in the off-grid/remote rural areas of developing countries, including Bangladesh is no longer a 'pipe-dream', but by now a matured technology and its replication is being continued on routine and at a fast pace. However, Bangladesh required an induction through a Pilot Project to gets its first confidence, exposure and experience in use of Solar PV electricity through its first a 62 kWp Solar PV Pilot Project, set up and commissioned at 4 isolated river islands at Narsingdi in 1995/96.

The project was implemented by the Rural Electrification Board (REB) under a French Government Grant. Although designed to operate commercially, on a service charge basis, a number of options, such as stand-alone PV systems (with Solar Panels at the premises of the consumers), central charging station based systems and also mobile solar lanterns etc., were tested for their technical functionability and social acceptability and finally, the most accepted ones - the stand-alone type Solar Home Systems (SHS), with roof-top or stand-based Solar Panels were chosen and later replicated all over Bangladesh - a process, which is still going on at full pace, being financially supported by the World Bank/IDA/GEF, kFW, Germany and other international donors. The other public-sector institutions, like Bangladesh Power Development Board (BPDB), Local Government Engineering Department (LGED), soon followed and expanded their activities in this area, being inspired by the versatility and reliability of the PV systems to serve even the remotest off-grid areas of the country.

To-day, the impressive numbers on the replication of SHS (over 85,000 units of average 50 Wp are reported to have been installed till date) are results of the said large-scale field demonstration or better termed the 'Flagship Project in the PV sector, which gave encouragement and inspirations for further replication of the SHS in this country. In the 'technology-shy' developing countries, like Bangladesh, the practical demonstrations to establish the technical functioning and socially acceptability through 'Flagship' projects at the field-levels are absolutely essential. Typically, "seeing is believing"for the majority of the people in developing countries, so far promotion and dissemination of new technologies are concerned. Presently, the SHS have already reached a "critical mass" from whereon a self-sustaining 'chain reaction' of their routine replications is continuing. The innovative micro-credit based NGOs, tied up incremental income-generating activities, to offset the relatively high capital barriers of PV, have made the success story possible and sustainable, where the Kreditanstalt fuer Wiederaufbau (kfW), Germany and the German Agency for Technical Cooperation (GTZ) through its programme on the Promotion of the Use of Renewable Energy" (PUR), amongst others, have come forward with refinancing and other financial mechanisms and are playing key roles, through Infrastructure Development Company Ltd. (IDCOL) - a government fund management company, Bangladesh.

SOLAR PHOTOVOLTAIC WATER PUMPING (PVP) - THE NEXT LOGICAL CHOICE FOR FURTHER APPLICATION OF SOLAR PV IN BANGLADESH ?

If the question is asked : which other activity, apart from the SHS, in the area of Solar energy in general and Solar PV in particular, should be put on "Bangladesh's Road Map to Renewable Energy", to continue promoting and replicating a sustainable and efficient 'management of the sun' ?, one of the most logical answers could be the **use of solar energy for photovoltaic water pumping for both irrigation and rural drinking water supply.** Energy efficiency and water conservation both go hand in hand in the agricultural sector. As one RE Expert had put a very appropriate logic for potential of solar energy for use in agriculture in a few line :

"…All plants on this beautiful blue planet of ours are already using solar energy every day through their billions of 'solar collectors' - the leaves, to produce food, fruits, fodder,,cellulose, timber and many other essential outputs that greatly contribute to human development, using nature's one of the most well-known 'hi-tech' processes - the photosynthesis, without which the food chain and hence the life on this planet would have perished. What cannot be then more appropriate to the plant kingdom than further use of the sun to make them work more efficiently for us ….? "

The energy professionals have always been keen to improve the **energy efficiency** in areas of industry, domestic and commercial sectors. However, till date, in most of the agro-based developing countries like Bangladesh, the efficient uses of energy and water (two very interrelated issues) in the agricultural sector, remained a neglected issue. This, on the other hand, is the key sector that feeds millions of mouths of the globe and produces a host of other multiple of outputs which contribute to overall human development, growth and poverty reduction through increased generation of income, through their use and trade. Any improvement of the crop productivity, for example, using **resource-conserving irrigation techniques**, including optimal uses of water and energy, could mean so much to the poverty-stricken teeming millions in developing countries, by growing more basic food grains and also high-value horticultural products, leading to increases the (incremental income) on investments to make plants more efficient and hence improve the overall quality of life. **Access to safe (arsenic-free) drinking water in rural areas**, is another issue - rather a fundamental right, no less important than providing access to primary energy and electricity, which the people, living in rural areas are continuously being deprived of over decades in Bangladesh. It is high time to that the nation goes more into specific actions through investments in this direction. The plants are the most wonderful things on earh, and they will pay such investments off.

The above thoughts all inspire one to think of the application of **Solar Photovoltaic Water Pumping (PVP) for irrigation and also water supply in remote/off-grid rural areas as the next logical choice** by making more efficient use of the sun, the fundamental source of all primary energy on earth**,** which is, at the same time, the key energy source for survival of all the flora, as already mentioned above. **The PVP is world wide a quite proven and matured technology**, which has the potential to ideally strengthen the synergy between energy and water to serve the other most important component of the synergetic force - the AGRICULTURE by serving plants with water, required for irrigation, using the sun. No less could be the potential for supplying SAFE (PIPED) DRINKING WATER using PVP to the rural people (from groundwater wells), living in remote off-grid rural areas of the country. The later is also an important aspect in rural, and for that matter, the overall development of the country, where a large number of shallow hand tube-wells have been found to be contaminated with arsenic. Controlled (i.e. analyzed and monitored) piped water supply systems from deeper arsenic-free ground water resources (through planned hydro-geological water mining), using a central overhead storage tanks are already being practiced in the northern regions of Bangladesh, using electric mono-submersible pumps and low-cost DTWs, developed by the Rural Development Academy (RDA), Bogra, who have done very commendable works in the agriculture related water management In fact the RDA models are now being replicated in large numbers (over 210 systems) in the 'Barind' areas of Rajshahi by the Barind Multipurpose Development Authority (BMDA). Presently, it is being done by electric power from the grid. The same integrated concept is technically possible with PVP, which are now manufactured and supplied with dynamic heads of over 100 m (e.g. India) for rural water supply. This could provide ideal solutions for arsenic-free community water supply systems even in off-grid regions of Bangladesh.

The German Technical Cooperation (GTZ) in Bangladesh, through its on-going programme on the **Promotion** of the Use of renewable Energies (PURE), is mandated to explore and promote all potential applications of renewable energy and energy efficient technologies. The GTZ has supported a number of quite comprehensive works on multiple pilot demonstrations on PVP, in a number of developing countries (Section 1.1 for details). There being ample professional logic to believe that a good potential might exist in Bangladesh too, to demonstrate and replicate this well-proven technology, the GTZ-PURE commissioned the Consultant, under Contract No. 83001737, Project No. 022129100100 - Promotion of the Use of Renewable Energies (PURE) to assess and evaluate the potential of PVP, first through an assessment and evaluation task (Stage 1A), with the ultimate objective to plan and implement a 'Flagship Project', which could initiate further replication of the use of PVP in the country, if found techno-economically viable and commercially rewarding. The eventual macro and micro-economic impacts of which could also be substantial (Section 6.0).

This Final Report is presented as the **output of the Stage 1A works**, which included **field visits** for practical situation assessment(Section 2.0 and Annexure), in response to the said contract, the Terms of Reference (TOR) of which stipulated the identification and assessment of the potential of a possible Solar Photovoltaic Pumping (PVP) Initiatives in Bangladesh by GTZ-PURE. The rationale behind the various field visits, the interactions made with the concerned stake-holders/potential partners and the highlights of the findings of the Consultants through such interactions/information/data-collection missions that served as valuable feedback for evaluation, were submitted to GTZ-PURE through **separate Interim Field Reports (I, II & III),** following visits to each relevant area / institution. These Field Reports are enclosed in the Annexure of this Final Report and are further analyzed, consolidated, evaluated and used as valuable feedback for the required identification, assessment, techno-economic analysis and evaluations with recommendations for further specific actions in this direction.

1.1 THE GLOBAL INITIATIVES ON PHOTOVOLTAIC PUMPS (PVP)

The Solar Photovoltaic Pumping (PVP), being technically a very matured technology, has been tested around the world in a number of countries - both developed and developing, including the neighbouring country India. While the experience of India deserves some dedicated observations, where it is being greatly promoted by the Ministry of Non-Conventional Energy Sources (MNES) and Indian Renewable Energy Development Agency (IREDA), the **GTZ works, especially with ten Pilots on PVP in Chile, Ethiopia and Jordan**, **conducted between 1998 -2002** shall first be discussed, as this was one of the largest pilot field demonstrations on PVP from which experiences need to be to be drawn.

First, it deserves to be mentioned here that **over 50,000 PVP are already in operation around the world** and technically speaking, the studies and practical pilot tests have indicated that the PVPs are quite well-suited to work under the harsh field conditions of developing countries, requiring very little attention and almost no operating and maintenance costs, excepting that the PV Panel surfaces need to be kept clean and the pump-motor systems may need to be occasionally serviced (such as changes of brushes, if it is a DC motor system every 3-5 years, depending on the intensivity of use). In arid and semi-arid areas where water is the life-line both for drinking purpose and irrigation, the PVP have been found to provide most viable, reliable and almost uninterrupted services. In this Section, the global experience of GTZ and also that of India will be discussed to obtain feedback from the lessons learnt. The past and on-going activities on PVP done in Bangladesh, although at the very initial stage would naturally constitute and integral part of such discussions/observations.

THE BASIC UNIQUENESS OF SOLAR PHOTOVOLTAIC PUMPING

The Solar Photovoltaic Pumping is unique for their application in lifting water for irrigation purpose, given by its **complementarity between the intensity of solar irradiance and requirement of irrigation water for the crops/plants** irrigated. The more intensively the sun is shining (for example, during the period of no rain or draught seasons), the higher is the power and the connected water output from the PVP, while during the rainy days, it neither possible, nor required, for example, during the monsoons. As per expert opinions, the water demand of the plants at night is also much less than during the day time, as the evapo-transpiration activities of plants increase a few folds more during the day than at night. The second unique aspect of the PVP is that **they do not need Storage Batteries**.

The Motor-pump sets (which may be direct DC or AC type, the latter requiring inverters) may be run directly run by the DC power outputs from the solar PV panels and energy can be stored in the form of potential energy of water lifted to elevated water tanks, which can buffer the night requirements and/or act as reserves for rural drinking water and/or for irrigation. The above-mentioned technical uniqueness of the PVP, when compared to the decentralized stand-alone type off-grid SHS, is a definite technical and cost advantage, as the **storage batteries are the "weakest links" in a whole PV system.** The additional high costs of the special deep-cycle batteries used in SHS, of course add to the capital and also operating costs as also periodic replacements of storage batteries are needed (every 6-7 years). The battery replacements period can even be much shorter, depending on how they are maintained. Furthermore, such storage batteries make the "balance of the system" costs almost double of the PV Panel costs, for example, in case of SHS. The high initial costs, the recurring costs for higher maintenance and periodic replacement costs for the storage batteries all need to be added to the cost stream , while making a life-cycle discounted cash flow (DCF) analysis to work out the financial indices, such as the Net Present Values (NPV) and and Financial Internal Rate of Return (FIRR) . These costs are avoided in case of PVP which is a definite advantage. For the overhead storage tanks, there are various low-cost options, as they are primarily constructed using local material, technology and labout.

REFERENCES OF GTZ PROJECTS ON SOLAR PHOTOVOLTAIC PUMPING (PVP) SYSTEMS

The GTZ implemented quite an impressive PVP Project entitled:**"Resource Conserving Irrigation with Photovoltaic Systems**", involving ten pilots in Chile, Ethiopia and Jordan. It is a very well-known work in the area of PVP. Funded by the German Federal Ministry for Technical Cooperation (BMZ), the project was implemented by the GTZ as a Pilot Programme. It is often referred to as the single largest international demonstration to field test the viability of using PVP for irrigation and rural drinking water supply.

The GTZ project had two basic aims and objectives :

(i) to prove the effectiveness of the PVP to irrigate high-value and high quality crops in a cost-effective and resource conserving manner

(ii) to determine the technical and managerial requirements for operating a PVP Irrigation system

THE PVP INITIATIVE OF GTZ IN CHILE 1998 - 2002

The counterpart in Chile was the University of Tarapaca. The project concluded with a very important observation at a time when the crude price oil price was less than half (in the US$ 25 - 35/bbl.) of its present level (US$ 70-80/bbl.). The project made a very valuable observation with the conclusion :

*"a site specific economic analysis should always be performed prior to any investment decision. Despite their indicated limitations, **solar irrigation are bound to gain importance in the future**…."*

The following were the major **lessons were learnt from the GTZ Pilot Project on PVP (1998 - 2002)**

- The results of PVP Irrigation in Chile indicated a high return on investment, the IRR from crop revenues vis-à-vis the cost of inputs, including irrigation being over 70%

- High-value cash crops like fruits, vegetables and spices were recommended to recoup the relatively higher initial investment costs of the PVP Pumps

- In order to reduce the energy requirements of PVP Irrigation systems, water conserving micro-irrigation (drip irrigation) was suggested.

- Small plot sizes (<4 hectares were recommended under each PV Pump of 1 - 2 kWp, sizes, which are quire cost competitive over the equivalent available smallest diesel pump sizes (e.g. in 4 H.P ranges)

- Since the costs of irrigation water, on a levelized cost basis (Cost per m3 x m height, i.e. Cost per m4) over the life-cycle of the project revealed that PVP in the 1 kWp - 4 kWp range are found to be quite competitive with the equivalent smallest size diesel operated pumps.

- Small areas (about 4 hectares) were recommended as command area of PVP for each PVP of this kW range

- High rates of system utilization were found necessary to achieve the economic viability of the PVP Irrigation systems

Amongst other works on PVP supported by GTZ, the techno-economic analysis of Photovoltaic Pumping Systems by R. Poroski and K. Hars need to be mentioned (Oekonmische Queschnittanalyse von photovoltaischen Pumpensystemse" - 1994, GTZ, Eshborn and "Wirtscahftlichkeit von photovoltaischen Pumpensysteme, GTZ, Eschborn, 1995) need to be mentioned. Both of these studies were related to pure economic analysis of photovoltaic pumps,compared to conventional diesels. The findings also indicated the uses of PVP within the 2 - 4 kWp range under the 1994/95 PV Panel cost situations of PVP.

However, the experience of **Mexico** with over 130 PV Pumping systems, sampled by Sandia National Laboratories (SNL, 1998) have been quite interesting. Of the 130 PV Pumps sampled, the capacities ranged from the smallest DC Motor-driven **106 Wp, upto 2 kWp. The L.C.C, i.e. the life cycle cost analysis** indicated the following :

- Based on hydraulic duty in terms of Cost (in US$) Vs. m4 of Hydraulic duty, the cost of PVP ranged between US$ 1500.- for the smallest to over US$ 18000.- for large PVPs (>2000 Wp), their hydraulic duties ranging between about 3.5 m3/day at 15m head (for **106 Wp**) for the **smallest D.C Motor-based systems** up to large submersible Grundfos type with over 58 m of dynamic head of **2.0 kWp** capacity (at 1998 prices of Panels), the **medium sizes** being in the range of about **800 Wp.**

- Investments, fuel, operation and maintenance costs between gasoline engines and the PVPs showed a very quick pay-back of about 2.5 years for the smallest systems, in which case the comparable gasoline pumps consumed the following **quanitites of fuel** :

  - Small Pumps : 400 litres/Year
  - Medium Scale Pumps : 1500 litres/Year
  - Larger scale pumps : 2,800 litres/Year

The small pump market is quite large in Mexico, as most of its 88000 villages are not connected to the grid. As per the findings of the study, Mexico has a water pump market of the order of US$ 500 million for drinking water and irrigation. When the various discount rates were applied, the real discount rates were found to be 6% in case of small to medium sized PVP. The study, however, was conducted at a time when the oil price was low and the total Pump System Cost was around US$ 10-12/Wp, which is high considering the present day panel prices.

The study concluded that PV Pumps upto 2 kWp could be used for drinking water supply and irrigation systems, the smallest to medium sized PVP (100 - 800 Wp) ranges being quite viable options to gasoline powered systems. Another very interesting and comprehensive work was done by Ing. Buero Mayer on PVPs, Muenchen, Germany, incorporating important analysis on the advantages of PVP when compared with small diesels. The conclusions of the work of Ing. Beuro Mayer goes also in favour of the advantage of PVP in the 1 - 2 kWp ranges. This work was also performed at a time when the crude oil was less than half of its present day base-line level. The viability of PVP is a direct function of the oil price, if government subsidies are not considered. But then why should one consider subsidies on environment-polluting fossil fuels, when one is questions, at the same time, the 'hard commercial viability of the renewable energy systems ? In fact, the World Bank's prescription for pricing of petroleum products, using international price parity (IPP) should be applied as a sentivitity test to the Base Case Returns (NPV, IRR etc.) while evaluating the savings on diesel to test the viability of the PVP, for which the savings on the diesel (or gasoline) fuel are evaluated as the main positive cash flow stream

1.2 THE NEIGHBOURING COUNTRY INTIATIVES ON SOLAR PHOTOVOLTAIC PUMPING

The Indian experience with Solar PVP is quite important in the context of Bangladesh, as over **6800 Solar Photovoltaic Pumps are operating in India** for applications ranging from high flow low head (e.g. 135,000 litres (135 m3 per day for rice irrigation up to low / medium flow and high dynamic head PVP with Q = 25 - 40 m3 at H = 50 - 100m, coupled with mono-submersible pumps, which are highly reliable and have a long life (over 20 years). The Grundfos type brushless A.C. motor-pump systems, of which a DC-AC Inverter constitutes an integral part of the PVP system .The agricultural practices and the rural socio-economic/socio-agricultural practices in India are, in many ways quite identical with Bangladesh.. To boost up the agricultural production through creation of interests amongst farmers to use PVP, which runs with abundantly availailable solar energy, the State Government and the MNES, India, 'buys down about 77% of the capital cost of the PVP. As the following case study, example, based on **"Solar Pumping System for Small Irrigation Projects in Rajasthan"** will show, the balance of the initial high capital cost of PVP are co-finances/refinanced between CBOs/NGOs and the Agricultural Banks :

TYPICAL PVP SYSTEMS USED IN INDIA - CASE STUDY - RAJASTHAN

PV PUMP DETAILS :

Type : Submersible DC water-sealed Centrifugal Pumps for SW sources

[MS-fabricated structure on small rubber tyres with hinged (foldable) PV Array
If a mobile PVP is required which is always convenient]
Solar PV Array : 75Wp x 24 Nos = 1,800 Wp

.

Daily Flow (Capacity, Q) : 135,000 litres/day
Head H) : 5 - 10m
Water Sources : Open Surface Water

THE COST & FINANCING DETAILS

Surface Water PVP irrigation pump cost typically around US$ 6000- per unit
or **IRs 315,000/-** (Exchange Rate assumed : IRs 52 = US$ 1.00……………………(A)

- MNES (Government) assistance is @ IRs 135/Wp-), i.e. IRs 243,000/-…………..(B) which means 77% initial 'buy-down' of the total initial capital cost (the main barrier)
- **Net Price payable by beneficiary Farmer** (B) [23% of PVP Cost] = (A) - (B) = **IRs 72,000/-**
- **Bank Loan** : 90% of the Net payable IRs 72,000/- or Tk. 64,800
- **CBO Refinance : 95% of Bank Loan :** i.e. Tk. 61,800/-

The low head/high flow pumps for example, are used in many places in India, including Rajasthan and are suitable for rice and other food grain irrigation and, of course, can be naturally be used for vegetable and other crops, which demand a water standing height of about **1000 mm (1 m) per m2 of cultivable field divided over the 90 - 100 days** of a typical Rice season season, which equates to about **100 m3/day flow capacity**.

The ‘command area’ of each of the above PVP is about 2 ha.With crops having moderate irrigation requirements, the area is proportionately higher. However, this may have even a larger command area for providing ‘protective irrigation’ or water can be lifted to a tank up to 20 ft high and reserved for slower or continuous use for micro-irrigation through a number of ‘slave tanks’ in the field.

OBSERVATIONS ON MNES POLICY TO POPULARIZE PVPS IN INDIA

As the above Case Study shows, the farmer receives enough incentives from the Government (MNES), which eventually lower the initial capital cost barrier. In the long run the Government will not lose, since an accelerated popularization of the PVP amongst farmers would mean an eventual displacement of about 1000 litres/annum of

HSD. In India the HSD cost at the time of the case study was about IRs. 22/litre. If, for analytical purposes, it is assumed that initially if even if about **0.5% of the LLP market** could be penetrated by PVP as above, it would mean operating about 6000 PVPs in Bangladesh.If and when introduced (say, over a 5-year period), this number of PVPs will save about 7,200,000 litres of HSD (@ avg. 1200 litres per year per PVP x 6000 pumps), which, at the current (subsidized) HSD cost of about Tk. 33.33/litre would mean a saving of about Tk. crores or US$ 3.4 million/year of import based HSD. Although the ‘Flagship Project on PVP’, proposed in this study, rather believes in promoting PVP **through a self-financing** (from net income generated from high-value crops, with some rice irrigation, which are often insisted by the farmers and where also some field-tests are required in Bangladesh with PVP), there is enough financial logic for the Government to ‘buy down’ at least about 30% of the capital cost of equivalent PVP (which at current international market prices would cost about US$ 6,500.- or about Tk. 455,000/-/unit, which would reduce the PVP cost to about Tk. 318,000/-. A model in this direction is discussed under Section 2.0 (Market Aspects of PVP) and also under Financial Analysis (Section 4.0). Such ‘buy-downs’ would pay off within the first 3 years from savings on imported HSD costs, which should be evaluated, in fact, at its real unsubsidized cost of **Tk. 65/litre** (source : Bangladesh Petroleum Corporation, BPC) at real economic costs which the state pays every year on a recurring basis. At this level of real economic cost of diesel oil, the same market penetration would mean a **saving ofUS$ 6. 8 million per year.**

Based on savings on fuel (HSD) and maintenance costs, the **Rs 72000/-,** invested by the farmer, has an IRR of 22% is worked out on farmer’s initial investment. If the total cost the PVP is considered, the IRR, is, off course, less than 7%, based on the Indian HSD cost, which was considered during the case study as IRs. 22/- per litre. In India, many of the ‘green belts’ of Punjab have already switched on routines to small-scale irrigation, based on small surface water PVP as above. The high head PVPs, because of their relatively higher costs, have found more popularity for drinking water supply in rural off-grid (e.g. in desert areas of Rajasthan, where in some cases, water is being lifted from wells with more than 300ft depth, using the very robust mono-submersible PVP (Grindfos type). In Madhaypadesh, Orissa and West Bengal also, the State Governments of India, supported by MNES, is promoting PVP, the reason why India has, by now almost over **12% of the global market share of PVP.** As regards technical experience, India reports that the PVP use, in general, after initial training and briefing to the farmers and most of the contractual maintenance (typically about IRs. 2000/Year) were rather regarded as ‘unnecessary financial burdens’, meaning ‘business for the contractors engaged by MNES. This observation of the farmers only prove how reliable can a good PVP can be, requiring least maintenance.

OBSERVATIONS ON ‘MOBILE’ HIGH FLOW SURFACE WATER AND HIGH HEAD SOLAR PHOTOVOLTAIC PUMPS FOR IRRIGATION & RURAL WATER SUPPLY

The high flow surface water irrigation pumps in India, in many cases, have been made mobile by mounting the PVP (with hinged Panels) on simple structural fames, constructed of mild steel tubular or angular profiles and fitted with small tyres (of the type used for 3-wheelers or left to the option of the farmer, who often uses cost-effective old tyres), so that they can continuously be moved in the field and brought closer to water bodies. This approach also appropriately avoids the requirements investing in long drainage canals of irrigation and increases the command area. They have been found to be quite robust, required minimum attention and maintenance. The DC submersible pumps requires, for example, change of brushes of the motor and cleaning of the panel surfaces. The mono-submersible DTW pumps of the type Grundfos have been found to be associated with least attention and maintenance. As put by MNES in its campaigns for popularizing PVP : *“you can just forget it once you have properly installed it into a groundwater well with strainers and it will continue working for you for decades, like the PV Panel does.”*

EXPERIENCE ON PROTECTIVE IRRIGATION USING PVP TO WIDER COMMAND AREAS

It is a common belief that irrigation of Paddy (rice) and other foodgrain cultivation requires continuous high flow water pumping. This is not true. The water requirements for irrigation is generally worked out and scientifically mentioned in terms of mm of water height per m2 of cultivated area. For Paddy it is common, especially for the high yielding varieties that about 1000 mm of water height per sq. m over is required over the entire seasonal life-cycle of the paddy, which means that to irrigate 1 hectare (10,000 m2), about 10,000 m3 of water is required with intensities over a span of 90-100 days (season). This water volume is required by the rice plant, depending on the soil moisture, water content and the evapo-transpiration (ET) requirements of the plant, which varies at different stages of growth and depends on the ambient conditions of temperature, humidity and also the nature of the plant to be irrigated. The peak requirement for water is during the period of rapid vegetative growth and full reproductive stage. Based on a 100-day seasonal cycle (from sowing to harvesting), on the average, a daily water requirement of 100 m3/day is, therefore required, which should forms the basis for pump-sizing, if a hectare of cultivated land is requires to be irrigated for paddy, i.e. rice cultivation.

The neighbouring country experience with PVP has revealed that rather better results were obtained on paddy yields, using high flow PVP (which have very optimum flow rates, compared to their diesel-operated counterparts, with which the farmers tend to overflow their rice fields constantly with standing irrigation water. It is now an established fact that “over-irrigating” the rice can do more harm than benefit to the plant. Dr. M. A. Sattar, Chief Scientific Officer (CSO) **-** an irrigation and water management expert of Barngladesh Rice Research Institute (BRRI) has endorsed this view, with an interesting observation on scopes to optimize water, even in case of the High Yielding Varieties (HYV) of rice, which is quoted below

“….. in the year when there was a small crisis in diesel, rather bumper yields of rice were obtained. We have every reason to believe that huge irrigationl water and with that energy is being wasted in over-flooding rice fields, which not only wastes water and energy, but rather ‘suffocates’ the rice plants, doing them more harm and useful care. There is scope to further optimize the overall water and hence energy (conservation efficiency) in rice growing to the extent of about 25 - 35%.....” (Ref. : Field visit Report II of the Consulant, enclosed in ANNEXURE).

DRIP OR (MICRO / RESOURCE-CONSERVING) IRRIGATION WITH PVP - EXPERIENCE OF INDIA

India has more real life experience in the drip or micro-irrigation sector (also termed ‘fertigation’) than Bangladesh, as water is scarce in many of its areas of the India, which is also the case in desert areas of the middle-eastern countries, where a world reputed institute located in the United Arab Republic (UAE) is also collaborating with India. They are also associated with BARI, Gazipur, Bangladesh in this respect. Since **micro-irrigation reaches water exactly where it is required by the plants, i.e. to its roots, using ‘emitters’**, through slow but continuous ‘drips’ of water, fed by gravity from overhead tanks, is an ideal application area for the PVP, as the GTZ study, as discussed earlier has also indicated. Increase of yields of Tomato, Pumpkin and many other vegetables have been reported to have multiplied a few folds.

This has also been endorsed by a series of pilot works done at BARI, where up to **Tomato yields** of upto **85 - 90 MT/hectare** has been obtained, using a low-cost drip irrigation technique, using all locally available materials. When compared to the **national average (18 - 28 MT/ha)** this is almost a **5 fold increase** in yield over the conventional irrigation. Control plots were always practically set up, beside the pilots, which used ‘fertigation’ i.e.the drip technique for comparing results under same soil, weather and other conditions. In fact, BARI has already transferred this know how to their extension department for replication by the farmers. The officials of BARI, headed by Dr. Roy and Dr. Serajul Islam (see **photographs in Annexure - Field Report II**) during interactions with the Consultant, has shown keen interest to integrate the application of PVP with their drip-irrigation technique, which requires slow but constant quantities of water over the seasonal cycles of plants.

To summarize the neighbouring country experience on PVP, it may be concluded that that the use of PVP is increasingly becoming popular there and the Government of India’s target has is to save considerable amounts of diesel through its use, which, as typical of any agro-based developing countries, is also a deficit petroleum product in India. One may further observe that within developing countries with similar agricultural and socio-economic situations and practices, India has obtained very appropriate and positive experiences with use of PVP for its use for both for irrigation and drinking water sectors.

2.0 ASSESSMENT OF THE MARKET POTENTIAL OF PVP IN BANGLADESH

It has already been mentioned that the use of PVP in developing counties is gradually becoming more popular and gaining momentum with increase of the global crude oil prices. Although there are 'price spikes' in-between, touching the US$ 80/bbl level, it is highly unlikely that it will drop below **US$ 70/bbl.**, based on opinion of energy economists and petroleum experts. Rather, it is most likely that the crude oil price may soon touch the **US$ 100/bbl.** level when, applying the 'thumb-rule' of engineering economics, the **unsubsidized HSD cost in Bangladesh will be about Tk. 95/litre**. In fact, even now, with the crude oil price at US$ 70/bbl., the Government of Bangladesh (Bangladesh Petroleum Corporartion, BPC/Ministry of Power, Energy & Mineral Resources) is providing over Tk. 4,700 crores on subsidy on HSD Price alone (Re. : BPC officials and the recent public declaration by the ADB Country Representative).

The real (economic) cost of HSD, if the International Price Parity (IPP) formula is used, is more than **Tk. 65/-litre** to the Government of Bangladesh. This means that the Bangladesh Government is providing **Tk. 32/- per litre of subsidy on HSD**, because it is an important primary energy input to agriculture. If the downstream petroleum sector were deregulated to-day, the real market price of HSD would be **Tk. 65/- per litre.**

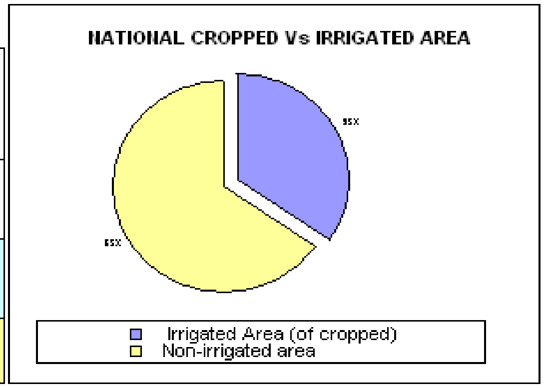
As it has already been indicated under Section 1.0, Bangladesh consumes, on the average, about 2 million tons of HSD annually, all of which is import-based, i.e. a part being the refinery output and most of it imported in the form of finished product. The HSD, as well as Superior Kerosene Oil (SKO) are deficit products of the Refinery and are the most used petroleum products in any developing country, the HSD being used in large quantities for Transport and Agriculture (Irrigation). Of the 2 million tons of HSD, about 40% is consumed for powered (mechanized) irrigation (over 1.15 million Low Lift Pumps termed LLPs and 100,000 Shallow Tube-wells, STW). A smaller quantity of HSD is used for larger 10 H.P. - 30 H.P diesel engines for operating the Deep Tube-wells. In the North Bengal area, especially the 'Barind' areas of Rajshahi, Borga, Rangpur, where rainfall is minimum (see enclosed Field Visit Report I of the Consultant in Annexure), most of the DTWs are operating in the Barind area have been electrified. However, the small to medium low lift pumps (LLPs) and the shallow tube-wells (STW) diesels are used in large numbers (about 1.25 million units) all over Bangladesh.

The enclosed Tables and Charts in the next pages summarize some of the key information on the Irrigation Scenario of Bangladesh (irrigated versus the non-irrigated cropped areas in terms of acreages, number of mechanized pumps by modes of energy used, which are self-explanatory.

TABLE - I HIGHLIGHTS OF NATIONAL IRRIGATION DATA

CHART-I [Irrigated Vs. Non-irrigated cropped areas]

	acres
o Total National cropped Area	35129000
o Total Area irrigated by different Means	acres **12194000**
o Percentage of **Irrigated Area** (of cropped)	**%** **34.71**
Non-irrigated area	65.29



Source : Bangladesh Bureau of Statistics (BBS)

Bulletin : Januray, 2006

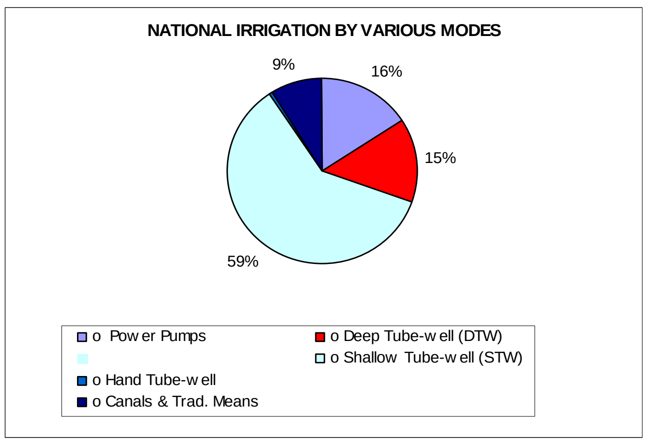


TABLE-II : NATIONAL IRRIGATION BY VARIOUS MEANS

CHART-II

	Figs in acres	%
o 'Power Pumps'	1940000	16
o Deep Tube-well (DTW)	1777000	15
o Shallow Tube-well (STW)	7335000	60
o Hand Tube-well	66000	1
o Canals & Trad. Means	1076000	9
o Total Tube-well	**12194000**	**100**

CHART : III CHART SHOWING NATIONAL SITUATION ANALYSIS OF MECHANIZED IRRIGATION BY FORMS OF ENERGY USED

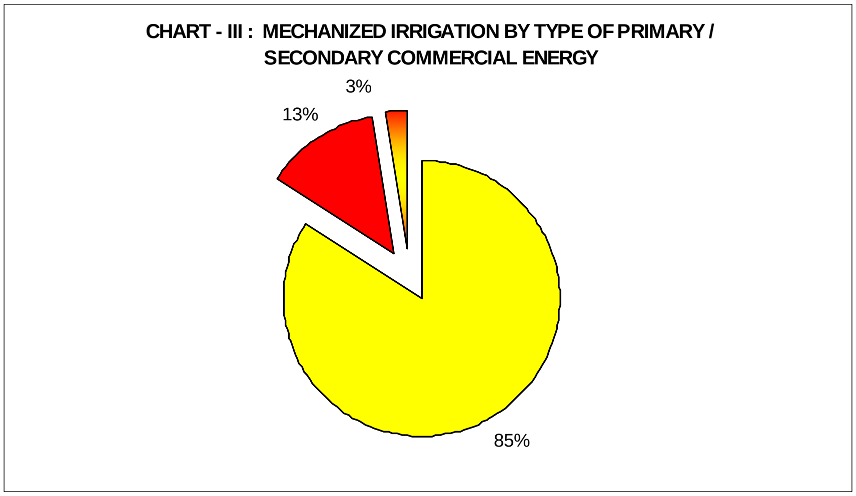


TABLE-III : PRACTICED MECHANIZED IRRIGATION BY TYPE OF ENERGY

		UNITS	% of Total	
o **Diesel Mode**	(yellow)	1250000	84.18	Information Source 1,150,000 Low Lift + 100,000 STW
o **Electricity Mode**	(red)	198,000	13.33	REB MIS Information
o **Both Modes**	(red/yellow)	37000	2.49	Data/Information from BMDA,BRRI
		1485000	**100.00**	

Sources of Information / Data :
1) Bangladesh Statistical Bulletin - January 2006
2) Bangladesh Bureau of Statistics (BBS)
3) Bangladesh Rice Research Institute (BARI), Gazipur
4) RDA, Bogra
5) Barind Development Authority (BMDA), Rajshahi

As evident from the above analysis of trends in the mechanized irrigation sector, it is clear that the use of the smallest diesel low lift pumps (LLPs) + the diesel-driven shallow tube-wells (STW) are the largest consumers of HSD in the irrigation sector and are primarily responsible for consumption about **40% or 800,000 MT of HSD in the agricultural sector** (colour code : yellow). Most of these diesel engines (or “Shallow Machines” as they termed in local rural language of the farmers consume HSD in the range of about 0.75 **-** litre HSD per hour. With about 6 hrs. of daily operation and 210 days/year of operation, this would mean a total annual HSD consumption of about 972,000 MT/Year of HSD consumption. The figure is close to the national consumption of over 800,000 MT of HSD/Year in the agricultural sector, as reported by BPC. In reality, of course, this could very well be around 80,000 MT, since many of the diesels break-down and are not operated for 210 days years, given by the farmers’ practices or financial or availability constraints for diesel.

ELECTRIFICATION TREND OF IRRIGATION PUMPS

Although, following the frequent mechanical break-downs and other problems (injection pump failures), faced with diesel-driven engines by farmers in Bangladesh and also to avoid HSD imports and operate the irrigation sector with the local natural gas cost-effective secondary energy, the Government of Bangladesh started encouraging electrification of the Irrigation sector, it became rather a jump from “fry pan to fire” in many areas.

From engineering and technical logic electric-motors are the best options compared to diesel for irrigation, as motors require much less maintainance/repairs and smooth running. From all technical, financial and also environmental considerations, electrically-driven irrigation pumps are the best options.**But provided that the electricity is available with a reasonable degree of reliability when it is mostly required for Irrigation**, or for that matter, for any other application to which it is put to use !!

11

The fact require hardly to be mentioned here that the Bangladesh suffers from an acute crisis of electric power. Despite various efforts of the government, it is no likely that this situation will miraculously improve in future, the average gap between demand and supply for electric power has already reached about 1000 MW. The problem in Bangladesh is primarily managing the **"peak hours".** The same applies for electric irrigation in **"peak seasons"**. It is the hard experience of Bangladesh farmers that the situation worsens **during the <u>irrigation season,</u> when over 200,000 electric irrigation pumps are switched on.** The already prevailing critical gap between demand versus supply in the **electric power sector worsens when the farmers require its most**. With an average of about **7.5 kW** of load for each pump, the demand for electric power theoretically may shot up to about **1500 MW.** Considering the factor of diversity (say 65%), this means an extra electrical power load of about **1000 MW**.during December **-**February March seasons.

The result ? Grids trips/fails, voltages drop occurs and most of the electrified pumps cannot be operated during the urban demand-caused peak periods. The Government has certainly given a good prescription, which is often announced through public media (newspaper, TV etc.) requesting farmers during season to put their pumps on after the nigh peak flattens, which mean after 11-00 A, M. till morning. During season the 6 hours of day irrigation cannot, in most cases be utilized. The evapo-transpiration of the crops is at maximum during the day period. No body has ever made a calculation in financial and economic terms, when farmers are deprived of about 6 hours of electricity. But a preliminary calculation, based on discussions with Barind Multipurpose Development Authority (BMDA), who have made the best use of electrical Deep Tube-wells in Bangladesh (see Table and Chart), indicates that ideally, if further 6 hours could be utilized, the **crop production could at least be increased by 30 - 40%.**

The Barind area, as evident from the **<u>Field Report - I</u>** of the Consultant has converted an area in Bangladesh from semi-arid desert to an absolute green area, through use of electrified DTW. Thanks to the visionary and dedicated approach of the Executive Director - a national and international expert on Groundwater management as related to agriculture - BMDA, started electric DTW based irrigation to create a green revolution. Soon they started facing the power crisis. To overcome the problem BMDA started building O.H. Tanks with a by-pass line, which can be used both for irrigation and drinking water supply to the rural farmers, with average capacities between 20,000 - 25,000 litres. It is now a model area in Bangladesh where 210 such systems have already been installed and it is planned to replicate the system to all of its over 9000 DTW used for irrigation. It is also the only area in Bangladesh where the **<u>farmers are paying regularly for Irrigation water</u> through a <u>smart (pre-paid) card system</u>**. On the average about **Tk. 85/hour** is charged for irrigation. The farmer/members of a farmers' association gets the smart card charged by paying the amount as per requirement. **When the pre-paid card is inserted into the electric meter installed outside a DTW Pump house, the pump goes into operation and <u>starts discharging water</u>** through the irrigation channel systems to their fields. (see Photo attached with **<u>Field Report - I</u>** of the Consultant, enclosed in Annexure of this report).

Photo shows Flow of Irrigation Water to the Field after SMART CARD inserted by the Farmer /Pump.

Courtesy : BMDA

The drinking water is supplied at the rate of Tk. 1 **-** 1.5 per head per month, through which substantial revenue is coming to BMDA. Typically, about 500 - 100 heads, equivalent to about 200 households per DTW O.H. Tank are taking advantage of quite safe (tested and found free of Arsenic, Microorganisms/Bacteria etc.) As per information of the BMDA, the **annual value of the crop now produced in Barind area is about US$ 219 million.** If there were no frequent power failures and at least **6 more hours** could be utilized for irrigation, a **40% additional crop production** in this highly irrigation dependent area could be produced would mean an additional crop production worth, in macro-economic terms :**US$ 87,000,000.-** As a result the BMDA authorities showed keen interest, whether **large grid-connected PVPs** could be thought of to compensate to make use of the daily 6 hours of sunshine Bangladesh receives, when either they do not get power from the grid, are discouraged to operate their DTWs or their DTWs simply won't run due to voltage drops in the REB / PBS grid from which they draw power. It may be mentioned that BMDA themselves have made huge investments in 33 kV/11 kV Transmission lines for the Electric DTWs

While this issue is handled separately under Sections 6.0 and 7.0 and technical systems have been launched in the USA, where some of the largest grid-connected/backed up PVPS (Ref. : Patent of WorldWater) Irrigation Pumps (range 40 H.P. to over 400 H.P) run and irrigate fields in California.

The electrification efforts of BMDA in converting Diesel based DTW to electrical DTW is best presented through the data/information obtained by the Consultant during the Field Visit.

TABLE IV **DIESEL DTW REPLACEMENT BY ELECTRIC DTW**
(Trend analysis in Barind 'semi-arid' area) 1991/92 - 2003/04

Year	% DTW Diesel	% DTW Electric
1991/92	85	17
1992/93	80	20
1993/94	75	25
1994/95	70	30
1995/96	67	33
1996/97	58	42
1997/98	50	49
1998/99	49	51
1999/00	38	52
2000/01	39	61
2001/02	32	68
2002/03	28	72
2003/04	27	73

COURTESY : BARIND MULTIPURPOSE DEVELOPMENT AUTHORITY (BMDA)

CHART IV

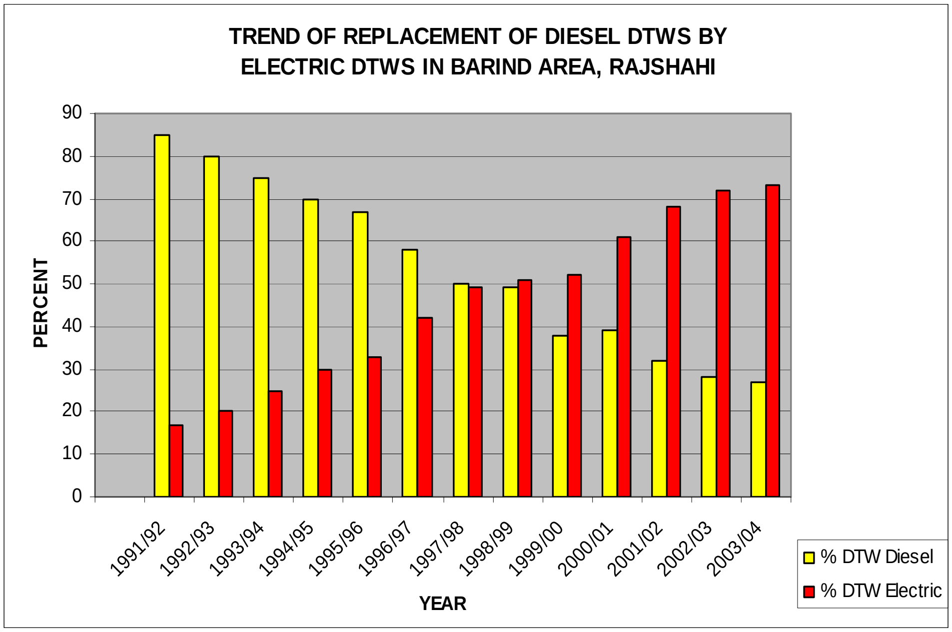
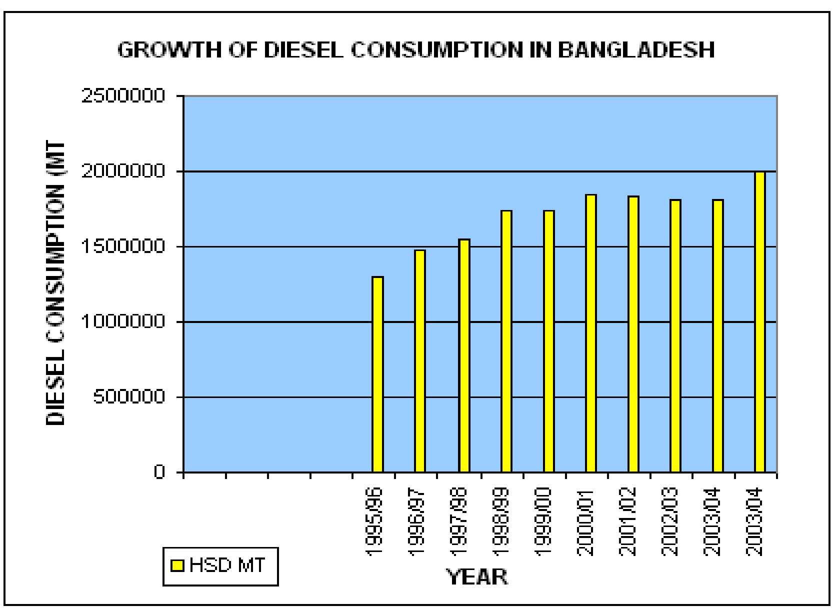


TABLE-V : HISTORICAL GROWTH OF DIESEL CONSUMPTION IN BANGLADESH

CHART-V: Trend Analysis - 10 Year horizon

Year	HSD MT
1995/96	1302787
1996/97	1476198
1997/98	1542004
1998/99	1738933
1999/00	1743251
2000/01	1846239
2001/02	1838266
2002/03	1815159
2003/04	1815159
2003/04	2004402



However, independent of the fact Bangladesh suffers from acute crisis of power, the electrification of irrigation pumps **has contributed positively** towards following developments :

- the farmers have already got access to and experience in electrically-driven pumps. The PVP, either as Stand-alone Irrigation / Water Supply systems in remote/off-grid areas and/or also in grid areas, can, with required modification (e.g. with a variable frequency drive) be conveniently coupled to the existing 7.5 kW to 10 kW DTW systems to increase the efficiency and cost-effectiveness of irrigation energy.

  As US institution has patented this system and is commercially and successfully operating the largest PVPs of the world - from 40 H.P to 400 H.P. in California (see also Section 7.0 - Recommenation / Future Action Plans)

- own resources (natural gas based) is being used which is not import based

- it is leading to clean environment (low GHG emissions, as natural gas, centrally use to generate power is a relatively low carbon fossil fuel than HSD

2.1 1BANGLADESH EXPERIENCE WITH SOLAR PVP

In Bangladesh, till date, the experiences with PVPs at field / commercial levels is very meager and had been limited, till date to a few technical demonstations and tests only. Since 2005, however, the first pilot in this direction has been launched by LGED, under its UNDP-financed Sustainable Rural Energy (SRE) Programme.

THE FIRST 0.1 CUSEC) PVP DEMONSTRATION IN 1982/83 WITH SUPPORT FROM MINISTRY OF SCIENCE & TECHNOLOGY (S & T)

The first work with a small (0.1 cusec) PVP, with a foldable PV Panel, presented by an ex-hydro-geologist, who once worked with the World Bank, to the Ministry of Science and Technology, Government of Bangladesh, in year 1982/83. The Consultant[+)] had the opportunity, being the then Advisor to the Hon'ble State Minister for Science & Technology - Dr. R.A Ghani, to test this PVP at the premises of the Institute for Fuel Research & Development - IFRD, together with Dr. M. Eusuf, the then Head of IFRD (now Head and Senior Fellow, Energy Division, Bangladesh Centre for Advanced Studies, BCAS). Ths PVP was designed and based on the philosophy that the average size of land holdings of farmers in Asia are small, often fraction of a hectare and a water conserving pump, using solar PV could be effectively used for irrigation, saving diesel.. It was a DC submersible motor type pump which when put into shallow wells, pond, diggies, 'khals' (local term for small river-like water bodies) etc. could uninterruptedly pump water at a flow rate of about 60 m3/day at a head of about 5m. The cost of the pump was about Tk 200,000/-. It was imported by the then Minister for Commerce - Mr. Habibullah Khan, who is also an entrepreneur/businessman.

The interactions of the Consultant with Dr. Roy, Chief Scientific Officer, BARI, of the author (see enclosed Field Visit Report II) revealed that, when the PVP was later handed over to BARI, he tested it for growing various crops, including rice. The initial findings were quite encouraging. However, the interest of the Government slowed down with falling oil prices to less than US$ 16-18/bbl. The overall interest in the RE during the Eighties, it needs to be mentioned here, became later a relatively low priority issue. It may be mentioned here that the late President - Major General Ziaur Rahman, took a great interest in this PVP and personally visited the water pumping demonstrated in a small vegetable field in the Bangabhaban (State Chief's Residence/Office), organized by the then State Minister for S & T - Dr. R.A. Ghani, being supported by the Consultant. .

DEMONSTRATION OF A LARGE (1,680 kWp) HIGH HEAD (100 M) PVP AT THE CENTRAL PV CHARGING STATION, OF THE PV PILOT PROJECT AT KARIMPUR, NARSINGDI

The first large DTW type PVP (1.68kWp), which was presented to the **Rural Electrification Board (REB)** by the Government of India in 1998, i.e. about two years after commissioning and successful operation of the Narsingdi Pilot Project of REB, Narsingdi PBS-1 (Section 1.0), at the request of the Consultant +) to then Science & Technology Advisor, India Mr. Agarwaal, who visited the PV Solar Home Pilot Project, for a practical field demonstration at the premises of the Central PV Charging Station at Karimpur.

+) The author had been deeply involved in design and implementation of the 62 kWp First Solar Photovoltaic Pilot Project in Bangladesh, as referred earlier, which inspired the to-days SHS replication in large numbers. The first Solar Flat Plate Water Heater was also fabricated and tested by the author at IFRD as a part of the RE project initiatives of the Ministry of S & T / IFRD during this period.

The PVP tested under field conditions at Karimpur, has the following **Specifications :**
:

▪	**Panel/Array Capacity**	:	**1680 Wp** (35 Wp Panels x 48 Nos)
▪	**Pump type**	:	Variable speed A.C. Motor + Inverter Maintenace-free Capsule Monosubmersible Pump (Make : Grundfos)
▪	**Flow capacity (Q)**	:	**40,000 litres/**on a clear sunny day
▪	**Total Head (H)**	:	100 meter (m)
▪	**Mounting**	:	Central tubular steel stand for the Array

The above type of PVP was installed in a relatively shallow well, dug at the Karimpur Central Charging Station of the 62 kWp PV Pilot Project premises up to a depth of about 100 feet (i.e. 1/3rd of the design head, H was utilized). The same type of PVP deep well is being routinely used in the neighvouring country to supply drinking water from about 250 - 300ft feet deep water wells, which work work with least care and maintenance for years, The simple local method for sinking a 4" dia. well was used, engaging a local Tube well contractor, fitted with PVC strainers, available in the local market. The well and additional local field installations, including a RCC Base for bolting the PV Array, had cost (1997/98 prices) a total of about Tk.30,000/- **The pump ran successfully and almost uninterruptedly** (unless switched off from the Inverter) from the very first day till its dismantling by REB, due to shifting of the Pilot Project site, after the grid reached there. Tests confirmed over over 40,000 litres i.e. 40 m3/day. After dismantling of the Karimpur Central Charging (2001/02) Station this demonstration PVP has been put in the REB store and is lying there..In spite of its very robust and successful operation unfortunately REB did not take further initiatives to replicate this PVP Initiative for its practical application, using an O.H. tank + low cost PVC pipes, which was suggested by the consultant. It may be mentioned in this connection that although REB had been the pioneer in having "led the way to Solar PV" in this country, its interest later dropped down after dismantling of the Pilot Project at Narsingdi. The NGOs rather cropped the benefits of the Pilot SHS demonstration who, having gained confidence through the pilot (demonstration) went ahead with WB/IDA/KfW funds and replicated the SHS to to-day's 85,000 systems.

Unfortunately, this large PVP, whose present market price is about US 10,000.- (H = 100m, Q = 40m3/day) is still lying with REB (in their PV stores) and have not been put to use anywhere for further demonstration to provide encouragements and inspirations for its further replication in the area of rural water supply and small irrigation (with a by-pass). (see also Section 6.0 – Recommendations).

ACADEMIC RESEARCH / TESTS WORKS ON PVP BY BANGLADESH AT THE BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY (BUET)

The Mechanical Engineering Department of Bangladsh University of Engineering & Technology (BUET), led by Dr. Rashid Sarkar and his team at the Energy Research Centre, BUET, conducted a number of testing/evaluation works with a **80 W PVP** (40 Wp x2), which ran a 24 Volt DC Motor, with a capacity of 450 - litres/day. The objective was to test the suitability of this small PVP for use in lifting small quanitites of drinking water at remote off-grid places. The performance of this small PVP was tested under various conditions, i.e. :

- Array Efficiency of the Pump as a function of Irradiance
- Pump Head as a function of.Time
- Efficiency Vs. Solar Irradiance
- Integral water volume pumped throughout the day

The results of the tests of BUET with the small PVP were quite encouraging. The PVP could successfully lift water to an O.H. tank, which was installed on the roof-top of a **6-storied building**. Although, the pump sometimes stopped running during the rainy days with complete overcast skies, which was considered a constraint, in reality it is not so. During monsoons, if rain is a problem, it can also be converted to a resource, by harvesting . The final conclusion of the BUET team was that the PVP can successfully be used for lifting water for small water supply duties or for small (water conserving/protective irrigation in remote/off-grid areas)..

Demonstrations/Experiments are also being conducted at the Renewable Energy Research Centre (RERC), Dhaka University with small pumps, limited to academic works. 'Demos' of small pumps (50Wp - 250 Wp) at PV Exhibitions by a number of institutions, like Local Government Engineering Department (LGED), Bangladesh University of Engineering & Technology (BUET), Renewable Energy Research Centre (RERC), Dhaka University and also by some private sector companies (Energy Systems Limited, Prokaushali Sansad Ltd., Associated Resources Management Company (ARMCO) on various occasions in connection with Solar / RE Exhibitions held at the premises of Dhaka University, Institution of Engineers, BUET etc.

However, all the above works on PVP in Bangladesh have been limited to demonstrations and for academic interests only without real-life/action research/pilot scale operations to establish techno-economic viability at the field-level.

FIRST PILOT PROJECT ON PVP IN BANGLADESH FOR WATER SUPPLY TO 4 'ECO VILLAGES' IN THE BARIND AREA (NOW HANDED OVER TO BMDA, RAHSHAHI

(SEE ALSO MAP PHOTO & **FIELD REPORT - I** IN ANNEXURE

The first large scale Pilot Project on the use of PVP was installed, tested and commissioned at four (4) Eco Villages in the Barind area, near Rajshahi (2004), at the following locations (see annexed Field Report - I, page 5 and photographs, including cover photo of this report) :

▪ Nachole		1.8 kWp Array	50 m Head	26,000 litres/day Flow capacity
▪ Shapahar		1.8 kWp	50m	26,000 " "
▪ Porsha		1.2 kWp	50m	13,000 " "
▪ Patnitala		1.2 kWp	50m	13,000 " "
Total	**:**	**6.0 kWp**		**70,000 " "**

THE 1800 Wp PHOTOVOLTAIC PUMP INSTALLATION AT NACHOLE

The project was launched by LGED under its **Sustainable Rural Energy (SRE) programme**, being funde by the United Nations Development Programme (UNDP) in Bangladesh. After initial testing and commissioning, the installation has been handed over to BMDA (2004/5)\, who are now maintaining and monitoring it.

Each PVP lift water to 10,000 litre capacity overhead (O.H.) water tanks (rectangular RCC construction) for storage and supply of drinking water to about 30 - 40 families and have dynamic heads of about 50m. The beneficiary families are nominally paying for the drinking water, which they are receive through 4 nos. community type Stand-pipe faucets, at Tk. 1/- per head per day. This site was visited by the Consultant during formulation of the Sustainable Energy Formulation Programme of UNDP (2004/'05), being commissioned by the latter as the National Consultant for RE Energy. During that period, however, the PVP were not installed, although the overhead tanks were completed. The total project cost was about Tk. 28 lacs.

The objective of this PVP Pilot Project comes very close to the GTZ-PURE's PVP Initiative and are:

- to provide safe (tested/monitored) drinking water to rural communities
- to test the technical functionability and social acceptability of PVPs by the rural people
- to test the suitability for small scale irrigation and other uses

However, the GTZ-PURE's objective differs in one major aspect - the financial viability of the PVP by off-setting the relatively high capital costs through income-generating applications, which could off-set the still relatively high initial capital costs of PVP. Detailed observations were made on the PVP in the **Field Visit report (I),** which included two major observations :

- the O.H. Storage tank need to be designed with at least 20,000 litres to maintain continuity of supply over two/three consecutive sunless (rainy) days

- to overcome the problem of long rainy days, a simple rainwater harvesting system can be contructed on the top of the tank so that the problem during rainy days are overcome by harvesting the rain, when the sun won't work (!)

While at many places in the Barind, the mono-submersible DTW pumps get water within about 30 meters, the dynamic head of the above 4 pumps were chosen as 50m, as the chosen areas - the Eco-villages had ground water acquifers at deeper levels.

Technically, otherwise, no other problem with the PVP Pilot project has been reported. The people in this Eco-village, it may be mentioned, are at the bottom-line of income-levels. The have also been provided with Solar Home Systems. Each Eco-village has a pond, where aquaculture is being promoted by the BMDA and horticulture (vegetables fruits etc.) can also be grown around to increase their income generation, having the advantage of PVP and making best utilization of water.

For future installations, the O.H. Storage tanks should be constructed with about 25,000 - 30,000 litre capacity, as surplus water pumping was reported during sunny periods, which ca optimally be used for

CONCLUSIONS ON PVP EXPERIENCE IN BANGLADESH

Bangladesh yet has to explore the field-oriented actions in the area of PVP applications, as the country's experience in PV, till date, is yet limited to a 'one-track' direction only, which is the Solar Home Systems. academic works on PVP are no doubt been necessary, looking at the neighbouring country and also other countries of the world, it appears that a lot can be and needs to be done in the practical application and commercialization levels s of PVP, which is the basic objective of this work.

2.1 ASSESSMENT OF POSSIBLE MARKET PENETRATION BY PVP IN BANGLADESH

An assessment and evaluation, targeted eventually to launch a commercially viable operation of the PVP should make also some realistic market assessments, apart from analyzing the technical and financial aspects, being an interrelated issue.

The Field visits by the Consultant, discussions with the potential stakeholders (RDA, Bogra, BMDA, Rajshahi, BARI/BRRI, Gazipur), as well as analysis of the feedback, obtained from the secondary information/data on acreage of irrigation, leads to the following summarized observations, from which a rational market penetration has been worked out :

- **there are about 1.15 million units of small diesel (4 H.P) low lift pumps** in the country. Of these, the northern districts of Barind area, covering Bogra, Rajshahi, Natore, Chapai Nawabganj, Rangpur, Dinajpur, alone have over 80,000 units of diesel pumps for irrigation and are the main consumers of HSD used for irrigation. These low lift pumps are the potential target markets for PVP surface water irrigation. However, given by the relatively high capital costs, project and innovative financial mechanisms are required to penetrate into the small diesel pump market. These are further discussed in this report under Section 4.0 (FINANCIAL ASPECTS). For sake of market analysis, it is assumed at this stage that the Government makes initially a 30% 'buy-down' of a PVP for Irrigation, that costs US$ 6500.-/unit (Tk. 455,000/-), on which the Base Case Financial Analysis has also been made in this study. The MNES, India, as already mentioned is covering close to 80% 'buy-down'. If Bangladesh Government is assumed to make a 30% 'buy-down', it would mean an initial 'seed fund' of US$ 1950.-/unit, the balance being shared between the farmer, Community-based Organizations (CBOs) and Non-Government Organizations (NGOs), such as Grameen Shakti (GS), BRAC, TMSS and others. Commercialization of PVP need to be approached with a better economy of scale, involving aabout 10 Farmers and above and multiple number of PVPs to improve the economy of scale and hence, the returns from the farming, so that the relatively high capital cost is offset from the net returns of the high-value crops

  A financial analysis (see Section 5.0) for this size and type of PVP, which has found a great response in the field irrigation sector in India, indicates that over the life-cycle of the project (25-years, since PV panels last over 30 years and more and the guarantee is provided up to 20 years for good quality polycrystalline Cells and Panels), positive **Net Present Vale (NPV) at 7%** discount rates are obtained from savings of diesel (fuel), operating and maintenance costs of an equivalent smallest and cheapest Chinese diesel pump, whose initial cost is only Tk. 10,000/-. But these diesels hardly last even 5 years. Hence, the reinvestment of Tk. 10,000/- every 5th Year (similar to Battery Replacements in SHS) has been considered in the 25-Year cash flow projection for the equivalent PVP. At the current subsidized diesel oil market price of Tk. 33.33/- per liter, the Financial Internal Rate of Return **(FIRR)** works out to be **7.29 %**. For the PVP No carbon credit has been considered.

- Realistically speaking, it is possible to make the following market penetration targets for PVPs in the small diesel engine market, as mentioned, provided that appropriate promotional and innovative financial approaches are launched. However, as worked out and proposed in this study the same can be achieved by appropriately designing a 'Flagship Project', where the project revenues will off-set the relatively high initial capital cost of the PVP.saved per year, from cumulative number of PVPs : [FIGS. IN US$ / YR.

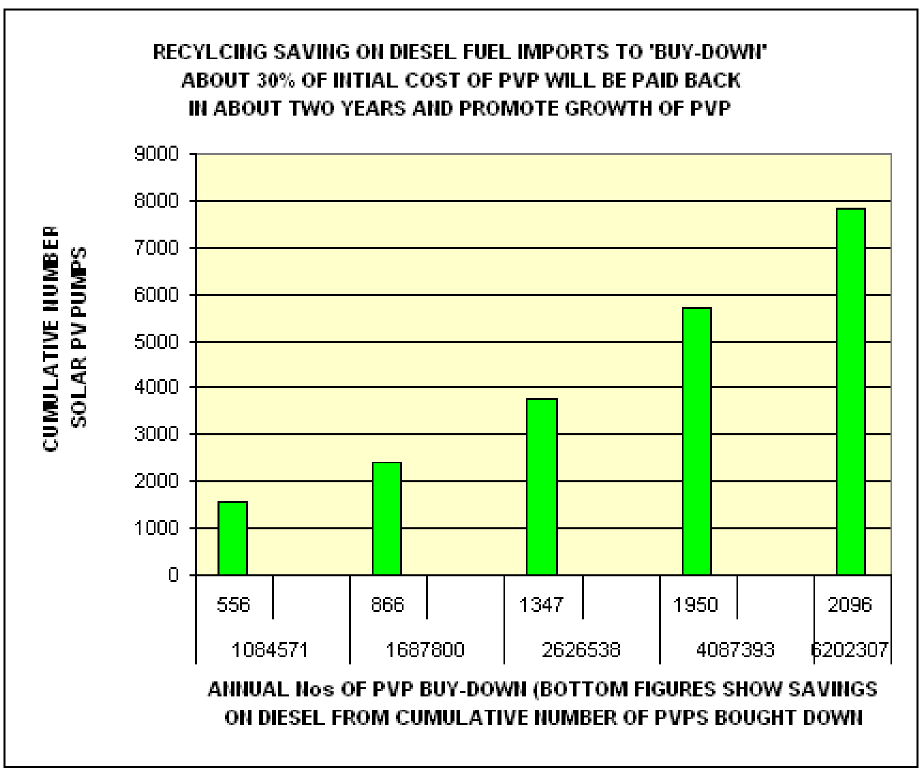
Year	% of Market	Units PVP	GOB BUY-DOWN	DIESEL SAVINGS / YR.
Yr-0 (Investm)	0.087%	1000	US$ 1950/UNIT	RECYCLING
Year-1	0.135%	1556	=US$ 1,950,000	OF SAVINGS
Year-2	0.211%	2422		1,687,800
Year-3	0.329%	3769		2,626,538
Year-4	0.497%	5719	.	4,087,393
Year-5	0.680	7,815		6,202,307

The impact of the first 0.1% penetration of the small diesel engine market by PVP, through a 30% 'buy-down of the **initial capital barrier** would mean that eventually a **recurring HSD saving of about US$ 6 million (by the 5th year)**. As evident from above and from the Table in the following page, in about 2 years time the initial 30% Government 'buy-down' of US$ 1950.- per PVP (each costing US$ 6500/unit) could be recovered. This is better than providing almost 100% subsidy on HSD, the economic (real) cost of which is **Tk 65/litre**. A Financial comparison with small diesel over the life-cycle of a PVP, (Inv. US$ 6,500).- generates an **IRR of 7.29%.** But if the real or unsubsidized cost of HSD is considered, the **IRR improves to 16.8%** [see Section 5.0 Financial Analysis]. Hence, the marketing strategy of the GoB should consider a 'Buy-down' approach (Ref. :MNES]

If the crude oil price hits the **US$ 100/bbl.** mark and free (IPP) deregulated market price of HSD of Tk 92/litre is.considered, the HSD free-market price (without subsidy by Government) would be **the <u>IRR would be : 23.66 %</u>** . In fact, the reason that MNES, India is providing a 77% buy-down on PVP, is based on the concept of gradual permanent relief from huge subsidies that are being paid fast through the savings on HSD, macroeconomically.

TABLE - VI : INITIAL 'BUY-DOWN' AT 30% BY GOB & WILL INITIATE A RAPID GROWTH

PVP Cost : US$ 6500 Buy-down Rate 30% US$ 1950 Per PVP	Buydown Cost **US $**	**HSD Savings** **US$**	Buy-down PVP from Savings **Nos. PVP/Yr**	**Cumulative Numbers** of PVPs	**% of Market 1150000** Small Diesels
Year-0 ('seed fund')	1950000			**1000**	0.087
Year-1		1084571	556	1556	0.135
Year-2	1084571	1687800	866	2422	0.211
Year-3	1687800	2626538	1347	3769	0.328
Year-4	2626538	4087393	1950	5719	0.497
Year-5	3802500	6202307	2096	7815	0.680



3.0 SITUATION ANALYSIS THROUGH PRIMARY INTERACTIONS/DATA/INFO COLLECTION

A situation assessment of the irrigation and water Mmanagement for irrigation and drinking water supply was made through direct Field Visits and Interactions with relevant institutions/experts. These Field Visits and information/data collection formed the basis for evaluation, assessment of the potential of PVP in Bangladesh. Three Field Visit Reports - I, II & III are enclosed in Annexure. A Map of the areas visited with observations by the Consultant is also enclosed, which is self-explanatory);

Detailed Field Reports were prepared, which are annexed and summarized as under :

- **Field Visit Report I** : (i) Covering visit to **Rural Development Academy (RDA), Bogra**
  Field Visit of Rajshahi Barind area and interactions with Barind Multipurpose Development Authority (BMDA), Rajshahi
- Rationale behind Choice of the Area : RDA, Bogra is a highly dedicated institution and conducts the first Action Research in the areas of Water Management, Agro-Energy and related issues. The practical outcomes of RDA's Action Researches are then replicated by BMDA and other agro-development institutions all over Bangladesh

  Barind area is a draught zone with low rainfall, where without irrigation hardly anything grew. The area has the highest number of Deep Tube Wells (DTW) - 9044 units, which provide irrigation to about 337,409 hectares of cultivated land.

- **Major Findings** of Interaction with (i) **RDA, Bogra** is keenly interested to work in PVP sector to develop the first PVP based Pilot Project for eventual replication

  BMDA : (i) The DTW Irrigation is a success story, which produces about 1.86 million tons of Food grain/Yr with a market value of Tk 15.30 billion (equivalent to US$ 219 million/Year)

  1. **Most (about 70%) of DTW** in Barind area have been **electrified**
  2. **Balance 30% are still diesel-driven**
  3. The Farmers are **paying for Irrigation Water at Tk. 85/hr.**
  4. The DTWs are operated on the average, for about **1100 hrs/Yr.**
  5. **Smart (Pre-paid) Card System** has been introduced for Water Payment, for the first time in Bangladesh
  6. The Power **Transmission & Distribution lines** are constructed by BMDA and REB/PBS provide connection and billing services only
  7. On the average there are about 2 DTWs per mile of Transmission Line (Cost : US$ 30,000/mile for 11 kV lines and US$ 12,000 per mile of distribution line, which means, that on the average the Transmission + Distribution Costs per DTW is about US$ 21,000.-
  8. The DTWs in Barind are facing acute problem of power and Requested for possible solution through any kind of grid-connected Solar PV System to make best use of their DTW
  9. The crop losses due to power shortage (over 6 hours of Irrigation time lost due to either tripping or low voltage of the REB/PBS Grid.
  10. The crop losses are of the order of 30 - 50% due to power shortageIdeally, 12 - 16 hrs/day would maximize the production of crops
  11. About 1.1 million Farmer families are benefited by the Irrigation in Barind area. Average Command Area = abt 30 ha/DTW

Field Visit Report II (details in the Field Report in Annexure, submitted to GTZ on 10 August 2006 Enclosed in Annexure of this Final Report)

Area /Institutions visited

A) **Bangladesh Rice Research Institute (BRRI)**

- Team of Experts on Farm & Post-harvest Machinery
- Team of Experts on Irrigation & Water Management Division, BRRI (mostly Rice related R & D)

(B) **Bangladesh Agricultural Research Institute (BARI)** Gazipur, Dhaka (Non-rice, i.e. High-value crop R &D)

- Team of Experts on Agricultural Farm Machinery & Post harvesting
- Team of Experts of Water Management & Irrigation including Drip Irrigation

© **Visit of Test Plots where locally developed <u>Drip Irrigation</u>** is being successfully conducted and now standardized for reolication through the Agri-extension Division

<u>Highlights of Major Findings</u>

BRRI Experts are of opinion that there is scope to conserve at least 25 - 30% of irrigation water for rice cultivation (1000 mm h per sq. m and 100 d season)

Key data/information on Irrigation requirement of obtained from BRRI. Optimized irrigation through PVP possible, as much water (with low irrigation efficiency is wasted with diesel pumps. The flooding water heights rather suffocate plants and do more harm than good to rice plants

BARI Experts on Irrigation expressed their interest to test PVP which could bring in more efficient water and energy management through "Resource Conserving Drip Irrigation"

Almost all Vegetables tested with locally developed Drip Irrigation techniques showed double to five times yield of the national average

Tomato cultivation using low cost drip irrigation resulted in established (standardized) yield in the range of 50 – 85 MT/ha. (compare : national average 18 - max. 28/ha.) with conventional furrow method of cultivation

The Chief Scientific Officer (CSO), Dr. Roy mentioned his involvement in 1982/83 of the first 0.1 cusec Solar PVP (also reported by the Consultant, being involved In the same project

Specific Conclusions on Intearctions with BARI Team

(i) Showed keen interest to integrate PVP capabilities with locally developed Micro-irrigation as first small pilots, if required

(ii) Tomato production <u>using drip</u> is highly recommended as this will quickly offset the higher PVP costs the yields by drip being over 50 MT (upto 85 MT)/ha. compared to the national average of 18 - 28 MT/ha.

<u>Field Visit Report III</u> (details in the Field Report enclosed in Annexure, along with Identifications 2 Sites with Feasibility Report on 10 kW and 20 kW Micro-hydro sites Copy enclosed in Annexure)

Institutions visited :

(A) **<u>Local LGED Office</u>/**Engineer In-Charge at Bandarban

(B) **<u>GRAUS</u> -** a local NGO, who have worked on drinking Water Supply for a Remote off-grid Marma village (local Tribals)

© Visit to a local tribal village at Bandarbans
A gravity-fed Water-supply System (GFS) visited
Water Storage Tank Capacity 5000 litres

<u>Highlights of Major Findings</u> :

(i) **The Prantik Lake** PVP does not exist anymore

(ii) PV Panels also reported to have been stolen (during 2002/03). The whole system was a small (about 5 gpm) PVP set up for the Tourist lodge at Bandarbans

(iii) The local tribals are facing great problems with water during dry season

(iv) **The GFS** comprises of a system, installed by the NGO GRAUS linking an uphill Mountain spring ("Chhara" in local language)

(v) The area is rich in good soil and grows huge quanitites of good vegetables

(vi) But the Mountain spring dries up and the tribal Homestead suffers greatly from crisis of water both for drinking/household and irrigation puposes

(vii) The Marma village visited by the Consultant

a. Feedback obtained from villagers and also a local member on their water problem

b. Elevation being at 1200 ft, there is chance of groundwater (trials to find groundwater were reported to be negative)

c. Two SHS were seen **-** one on the rooftop of a private house and the other on the roof-top of a Buddhist Temple (three lights) – 75 Wp Systems, installed by GS Inquiry by Consultant with the Marma users of both systems on the functionability revealed that there have necer been any problem with the Solar.

d. Villagers are keen to know whether their water problem c n be resolve.

e. Water is surplus during the rainy season but short in supply during winter. There is a river (Sangu) that runs through Bandarbans. Reservoirs and water lifting to an uphill tank might resolve problem.

3.1 PRIMARY & SECONDARY DATA / INFORMATION

Both Primary and Secondary data/information were collected during the Field Vists/ Interactions and also through national secondary data sources. The following data/information were used :

(i) Total National Acreage of cropped land
(ii) Total National Acreage of irrigated land
(iii) Number of Irrigation Pumps by type
(iv) Number of Irrigation Pumps by Modes of Energy
(v) Conversion of Diesel DTW to Electric DTWs
(vi) Growth Trend in the Diesel Consumption
(vii) RDA's Activities/Projects
(viii) RDA's Data on Low Cost DTWs with Costs & Specifications
(ix) Ideal Hours of Operation for DTW vis-à-vis availability of power for irrigation
(x) Total area of Irrigation of BMDA
(xi) Total Crops produced
(xii) Total Value of Crops produced
(xiii) Total Electric Bills paid by BMDA to REB/PBS
(xiv) The Unit Rate (Tk./kWh) and total Electric Bill pais by BMDA to REB
(xv) The per km Cost of Transmission & Distribution Lines, constructed by BMDA
(xvi) Total km of Lines constructed
(xvii) Financial Performance of BMDA
(xviii) Number of Farmer Families benefitted
(xix) National Data on Agricultural Statistics
(xx) Handbook on Agricultural Crops with all data on Yield and Input / Output Info
(xxi) Irrigation Principles & Practices
(xxii) BBS Statistical Handbook (2004)
(xxiii) Annual Report of BARI, containing all necessary information on Drip Irrigation with Yield and Cost figures

While the findings through field visits were reported tn detail through separate field visits, most of the secondary data has been used as feedback of this study, in terms of :

2.1.1 Other Data/Information/Feedback used for Technical & Financial Analysis

- HSD Consumption of of Small Diesel Irrigation Pumps
- Maintenance & Repair Costs of Small Diesel Pumps
- Crop Yield Figures and their Market Prices (Wholesale)
- Cost of all Inputs to produce Vegetable
- Irrigation Water Requirements of various Crops
- Details on Fertigation/Drip Irrigation developed by BARI with Cost (Tk/hectare)

The above semi-processed data/information were then used for project design, project cost estimate revenue and production cost estimates under Financial Section of this Final Report.

4.0 TECHNICAL ASPECTS OF THE PVP

The Solar Photovoltaic Pumps all have the following common technical features :

1) There is a Solar PV Module, arranged in the form of an Array (the Solar Generator)
2) A Motor-Pump System which is connected either directly to the PV Panel (in case of Direct Current (DC) Motor
3) An Inverter, in case of A.C. Motors, including Mono-submersibles
4) Other Accessories, such as the Structure, Cables connecting the Panel with the Pump
5) Hoses for Surface Water type Irrigation Pumps

The PVP used world wide are of 5 basic types :

1) Surface Water DC Submersible type - suitable for low head and high flow
2) Surface Water DC Floating type - also suitable for low head and high flow
3) Surface Water Centrifugal Suction type - same as above, but has disadvantage of a foot valve
4) Deep Tube-well Mono-submersible type -
5) Deep Tube-well Turbine Type with surface Motor

4.1 CHOICE OF PVS FOR FIELD IRRIGATION

Of the above five (5) types the **D.C. Submersible** types have been found to be quite suitable in India and other countries for **irrigation applications** from surface water sources

Floating type DC motor-pump systems also have an uniqueness that the water level need not be always monitored. But based on operating experience, the floating pumps are not so robust and the float may pick up troubles. For the purpose of this Feasibility Study, the best proven submersible type PVP have been analyzed. The Field Irrigation Pumps of this type can be made mobile, by mounting the PV Array on a tubular structure and adding small tyres to it. This is a very simple addition and can be fabricated in Bangladesh.

Foldable PV Arrays have proved to be very useful (which when opened exposes, usually three sets of Panels (see diagramme). .

4.2 CHOICE OF PVS FOR DRINKING WATER SUPPLY

The Mono-submersible PVPs are most suitable for drinking water supply, but can also be used for small irrigation, including drip irrigation through an overhead storage tank, from which the gravity-fed water can be channeled to the farm fields or to sub-tanks at lower heights (if, for example drip irrigation is used).

4.3 DESIGN OF HYDRAULIC POWER & AND PV ARRAY POWR (kWp) OF PVP

In the following page, the details of the Design Philosophy and Design Equation that has been used for sizing two assumed PVP types have been presented, whereby the desired flow (Q) and the hydraulic head (H) are based on the requirement.

The Broad Specifications and typical (budgetary) costs for both Surface Water high flow PVP and Mono-submersible, lower flow, but high head PVP have been presented in this Section.

A ‘Flagship Project’ should include both types, since integrated irrigation and water supply approach was evaluated to be financially most rewarding. Apart from that a Pilot or a Flagship should include possible options, so that the best can be chosen eventually for replication. On the consideration that the major revenues will come from crops, two nos of surface water high flow irrigation pumps, which are also lower in cost, are recommended, For the O.H. Tank based Deep Tube-well PVP, a 50 m3/day PVP with a 30 m head has been chosen as basis of cost and financial analysis.

4.3 DETAILS ON PROJECT DESIGN & BASIS OF FINANCIAL / ECONOMIC ANALYSIS

The Tables 3 A-1 and A-2 have been based on the water requirement for both irrigation and rural drinking water supply for the proposed 'Flagship PVP' Project based a a 10-hectare Pilot Farm, where a commercially viable agro-operation has been designed, based on feedback from the field visits at RDA, BARIND, BARI.

The following steps have been followed for working out the technical design, based on which the Financial Analysis have been made :

Step 1 : Comparison with small diesel pump without any agro-output or water income Revenue basis

A techno-economic analysis (Table 1 A under Section 5.0 Financial Aspects) has shown that on a life-cycle cost analysis basis, a PV Irrigation Pump (Q = 135,000 litres/day H = 5 - 10m (surface water irrigation from pond/khals etc. to replace small 4 H.P Diesel Engines was made. (Tables 1 A, 1 B & 1 C). y)

Step-II : Design of an Integrated Irrigation & Rural Water Supply Project

A 10 hectare of good agricultural farmland, which is quite dependent irrigation, with a good transportation infrastructure (RDA feedback) was chosen and an integrated irrigation-cum-rural water supply project design was made and budgeted.

A crop plan was made and the water requirement for each crop (height of water x m2 of land = water requirement per hectare/season (100days) were worked out and calculated on a m3/day requirement for irrigation.

The water requirement for a 200-household village in the area was taken as basis and based on a per capita water consumption, the daily water requirement was worked out for rural water supply. This worked out to be about 40 m3/day. For water-conserving drip-irrigation on about 4 hectares (out of 10 ha.) of land for growing high-value crop Tomato, which has yielded the best proven results at BARI. This is a low-cost drip irrigation, developed locally and proven at the BARI Pilot Farm at Gazipur.

The total water requirement both for irrigation (including drip) and integrated rural water supply was calculated for the entire 10 hectares for the crops considered for both irrigation and rural water supply and the daily flow **(Q) worked out** (m3/day). The height **H f**or Irrigation was considered a 5 m for the mobile field irrigation pumps and 30 m for Rural Water supply project with overhead tank, which will also be used with a by-pass for additional water that may be required for drip (for example)

The total Q worked out to be = 340 m3 / day, 308 m3/day for Irrigation and 32 m3/day for drinking water supply

Step - III : Based on the **Design Q and Design H,** the PVP Pumps were sized (Table 3A-2). **Broad Specification for the PVPs (Tables 3 A-1, 3 A-2)**

Based on Flow, Irrigation and Water Supply reuirements, the following were recommended :

- **Q =135 m3/day** PVP (design H = 10m) x 2 units
  (field Irrigation) (Table 3 A-2 for details)

  Q = 50 m3/day, (design H = 30m) x 1 unit
  (Table 3 A-2 for details) for Water Supply + small irrigation needs

5.0 FINANCIAL ANALYSES / EVALUATION

Given by the relatively high initial capital barrier, Solar PV Projects are financially evaluated in a number ways to make them techno-economically viable. To-day, if pure cost per kWh were the basis of financial evaluations, there should not have been any Solar Home Systems. Amongst the various modes of design and evaluation of PV projects, the following considerations are usually given :

1. Net Cash flow analysis on pure saving considerations of diesel fuel

2. As high incremental revenue earning projects to off-set the high capital cost barrier and applying discounting to Net Cash flows

In case of the PVP both approaches have been applied and the following results have been obtained :

(A) ON PURE SAVINGS CONSIDERATIONS OVER DIESEL - Table 1 A

The basis of this analysis were the following :

DIESEL CASE

- Investment cost of the smallest Diesel Irrigation Cost was taken : Tk. 10,000/unit (Chinese)
- Max. economic life of the engine for irrigation : 5 years

- Annual operating hours of the diesel : 210 days x 6 hrs/day = 1260 hrs
- Diesel Fuel Consumption : 1137 litres
- Diesel Cost at (subsidized) : Tk. 33.33/lire
- Annual Fuel Cost : Tk. 37,896 / Year
- Lube + 12.5% Maintenance Cost for Engine : Tk. 3,410/Year
- **Total annual operating cost of a LLP : Tk. 41,309/Year**

:

PVP CASE : (1,.8 kWp)

- **Investment cost** of an equivalent Solar PVP : US$ 6,500.**- (Tk. 455,000/-)**
- Economic life (discounting period) : 25 Years (usual for PV)
- **Annual maintenance cost for PVP (avg.) : Tk. 2275/- Year (change and** motor brushes etc. Indian experience)
- Net Cash flow for PVP : Savings on the operating cost of Equivalent diesel engine minus the PVP operating cost

RESULTS OF ANALYSIS : :

- NPV at 6 % discouting : Tk. 66772/-
- NPV at 7% Tk. 23,548/-
- **IRR (Bsase Case) : 7.62%**

Sensitivity Analysis :

- Diesel Fuel subsidy at Tk 32/lite Withdrawn (i.e diesel cost Tk 65/litre) : **IRR = 16..88%**

- Crude Price at US$ 100/bbl. and no Subsidy (diesel price at Tk. 92/litre) : **IRR = 23.65%**

B) PROJECT INCOME BASIS - Table – 2

The second option using the concept of a good cash flow earning project design **(Table 2A),** integrating rural water supply for 200 households (at Tk. 0.70/- per head per day water charge) and growing high-value crops (Tomato, using locally developed high-return drip irrigation on 4 ha. and potato and other crops on the rest) with 2 nos. of PVP field irrigation pumps + 1 No. DTW (50 m3/day), O.H. Water Storage & Supply tank + supply network of low-cost PVC pipe (developed by RDA and replicated aby BMDA, indicated a good commercial viability with an IRR value of 35.93%. The PVP 'Flagship Investment Costs' are presented in **Table 2A-0.**

:

▪ Total Rural Water Supply + Irrigation **Project Investment Cost**	:	**Tk. 3,521,440/-**
▪ PVP Costs only (2 Field + 1 Deep-well)		Tk. 1,624,000/-
▪ Agro-farm to produce high-value Products	:	10 hectares
▪ Revenue from Crops	:	Tk. 2,370,000/Yr
▪ Revenue from Water Supply	:	Tk. 252,000/Yr.
▪ Total Revenue	:	Tk. 2,622,000/Yr.(at 100% oper. level)
▪ Total Operating Costs	:	Tk. 813, 710/Yr. (" ")
▪ Ne Cash flow / Yr.	:	Tk. 1,808,290/Yr (" "
▪ Operating factors	:	Yr-1 - 65%, Yr-2 : 75%, Yr-3 : 85% on above factors

FINANCIAL INDICATORS OF THE PROJECT

NPV at 30% DCF	:	Tk 556,891/-
NPV at 40% DCF	:	Tk (266,405)
IRR	**:**	**35.93%**

The Economic Life of the PVP with robust high quality pumps go over 25 years. The PV Panels last 30 years and more. The discounted cash flow indicated a high IRR value, incorporating Tomato and Banana by locally developed 'drip irrigation' , which has been found to be very efficient, **yielding upto 85 MT/ha.** compared to the national average of 28 MT/ha. For the sake of conservative estimates, about 50 MT/ha. has been considered with an average whole-sale market price of Tk. 7/- per kg or 7,000/MT.

6.0 CONCLUSIONS & RECOMMENDATIONS

The objective of the **Stage 1 A** Study, was to identify and assess the potential of PVP use in Bangladesh and recommend further actions relating to the potential of PVP application of Bangladesh.

The following conclusions are drawn on the Stage 1A of the Study, based on all feedback obtained through primary interactions with concerned stakeholders, as well as desk evaluation, which have been presented through this study report as the Final Output, as per TOR :

1) Bangladesh has already gained intensive exposure to SHS, but a **one-track activity would not do justice to the versatility of Solar Photovoltaic Technology** if also other diversification of PV technology are not field-tested, especially in areas where technology is matured and reasonable financial viabilities are given.

2) Despite relatively higher initial (capital costs), many developing countries of the world are using the Solar Photovoltaic Pumping for applications in Rural Water Supply & Irrigation. The PVP has a good potential in Bangladesh **in irrigation and water management sector**, over the conventional diesel and electrically-driven pumps, based on the following technical and financial logic and findings :

    - **diesel being an import-based fossil fuel** and often poses problem to farmers, the crisis of diesel fuel being a routine issue for most of areas of North Bengal region.

    - Bangladesh also suffers from a **chronic crisis of electric power** in all areas, including the agricultural sector, which is an important sector that feeds the the nation.. BMDA estimates the losses due to power failures and hence non-operation of the DTW irrigation pumps. BMDA estimates their **crop losses due to power crisis to the tune of about 30 - 40%,** which, in financial terms, is of the order of about **US$ 86 million**, which may make even large grid-connected / net metered PV pump operations with much larger PV Array capacities viable (Example : California, USA)

    - having gained **good experience in the application of PV through the SHS**, the experts in all agro-related institutions - RDA, Bogra, BMDA, Rajshahi have expressed their keen interests to work with GTZ-PURE in field-testing the commercial use of PVP

    - **Financial Analysis** has also been made in this study on a **'Flagship Project Concept'**, which showed that PVP investment costs can not only be offset, but the whole project can have a good **commercial return.**

      Operation of PVP requires minimum attention, being a very matured technology and hence it has a good potential for resource-conserving high return irrigation techniques, like drip-irrigation, where, by now experience has been gained by BARI and is awaiting replication.

    - When the Solar Home System first came to Bangladesh, many expressed their cynical opinion that with the high cost it will never make a break-through. But it did, given by the **innovative concepts - both from in terms of designing innovative financial mechanism** and by diversifying its applications in the direction of income generating activites which makes subsidies superfluous.

    - One of the unique advantage of Solar PVP is the **complimentarity between the intensity of the sun and the water requirement of the plants**

- Also, as the project analysis has indicated, the use of PVP for **rural water supply** in off-grid areas is a viable option and the basic works have already been successfully replicated in reasobale numbers this direction by Government institutions like RDA and BMDA

6.1 RECOMMENDED FURTHER ACTIONS

Based on the above conclusions of this Study (Stage 1A), the following action plans are recommended :

- Since a Preliminary Design of a 'PVP Flagship' has already been made as a cost basis, it needs to be further developed for implementation

- Appropriate partners need to be identified and location/site finalized with the potential partners.

Therefore, **Stages 1 B and Stage 2,** as per the TOR deserve now considerations for planning and implemention of a 'PVP Flagship Project'. As regards the **<u>potential partners</u>** a preliminary 'road map' is already visible through interactions made during the study :

- **For 'Flagship'** Projects on PVP : **Rural Development Academy (RDA), Bogra** for developing the first commercial prototype

- **For Replication of the 'Flagship':** **Barind Multipurpose Development Authority** (BMDA), Rajshahi

  BMDA 's problems with of power: with with DTW — The concept of small Solar PVP has now been scaled up and applied to **larger PV intallations**, which are connected both with the grid and large PV Arrays via power transfer controllers and grid-tied inverters. These pumps (40 HP to 400 HP) improve pump and motor operation effieciency with variable speed motor operation and also can make either a change-over from solar to grid or a net metering. They save on electric bill and are able to run large motors **directly from Solar Power.**

- For development works and advise /coorperation in connection with resource conserving and high-yielding 'drip irrigation' : **BARI & BRRI**, Gazipur, Dhaka

- Further appraisal and cooperation for proving solutions to water supply and irrigation problems in the CHT region, including development of two identified Micro/Pico-hydro sites in the Bandarban area **LGED, Bandarban** and local NGO, GRAUS

6.2 BUDGETARY ESTIMATE OF THE PROPOSED PVP 'FLAGSHIP' ANALYZED <u>(TABLE 2 A-0)</u>

Although the design of the 'Flagship' with an appropriate Budget needs to be developed in detail through further works and are not within the TOR of the Stage 1 A works, an indicative budget has already been worked out, as a basis to work out the techno-economic analysis made in this study.

Including PVP (3 Nos. 2 Nos. Surface + 1 Nos Monosubmersible deep-well PVP for rural piped water supply) with all other local cost components the cost of the proposed 'Flagship Project will be about Euro 40,000- of which approximate Euro 18,000.- will be for foreign component for the PVP, including Inverters and other accessories.

ANNEXURE

- Questionnaires /Data-collection Formats
- Executive Summary of three (3) separate Field Visit Repots

Field Visit Report I	: Covering North Bengal areas (Bogra, Rajshai, Barind)
Field Visit Report II	: Covering Interactions with BRRI & BARI, Gazipur
Field Visit Report III	: Covering Bandarban / CHT

EXECUTIVE SUMMARY

Energy, Water and Agriculture together form a formidable Synergy, which when appropriately utilized and managed, can drive any nation way forward - whether developing or developed. In to-days energy-starved world, not only is the efficient use of energy from all sustainable sources is important in the domestic and commercial sectors, but in the area of agriculture and water management, especially in remote rural areas.

The above is most appropriately applicable to Bangladesh - a developing country which suffers from an acute crisis of both primary and secondary energy.. Despite being blessed with natural gas and coal, appropriate management of these energy resources could not yet be done. The demand for electric power is fast outstripping its supply and about 63% of the population does not have access to electricity. The price hikes of crude oil, on the other hand, in the international market, being now at the base-line of US$ 70/bbl., with a the trend projected to touch the US$ 100/bbl., as well as the high greenhouse gas emission, superimposed by thoughts on faster depletion of the conventional sources of enery are driving thoughts and visions of energy specialists, as well as policy-makers to mainstream the all appropriate and more sustainable sources of energy, like solar, biomass, wind, mini/micro-hydro and others, to supplement, the fast increasing demand for all forms of commercial primary energy resources – natural gas, petroleum fuels and Coal.

Despite being blessed with a fertile soil for agriculture, Bangladesh's food and agricultural outputs, given by gaps between the strong demand and supply energy, especially for diesel fuel and electric power for irrigation, suffers drastically, in all areas in general and in the draught areas of the northern districts - the Barind areas of Bogra, Rajshahi, Rangpur, Dinajpur Chapai Nawabganj and other districts of North Bengal.

Bangladesh got its first exposure to use of renewable energy (RE) resources, for supply electricity to its remote rural areas through use of Solar Photovoltaic technology through a French Government-funded (62 kWp) Pilot or 'Flagship' project, implemented by the Rural Electrification Board (REB) in 1995/96. This relatively large-scale demonstration encouraged and inspired the international donors, such as the World Bank, kFW and the reputed local NGOs, such as Grameen Shakti (GS), BRAC, TMSS and others, to replicate the Solar Home Systems (SHS), in relatively large numbers, especially to off-grid areas of the country. While solar PV, from the view-point of 'hard' and conventional approach of Economists, was considered to be a costly and commercially non-viable option, the innovative financial mechanisms, made a wide-scale replication of the SHS possible, over 85,000 SHS having been already been replicated. In this area, Bangladesh has, in fact is often quoted as a model from international considerations. The German Technical Cooperation (GTZ), backed up by the German Federal Ministry for Technical Cooperation (BMZ) and through its programme on the "Promotion of the Use of Renewable Energies (PURE), is already currently deeply involved in the SHS programme, a large scale Bio-gas support programme and is also is playing laudable roles to promote the replication of other appropriate RE technologies, like Bio-Improved Cook stoves, supporting development of Bio-mass conserving technologies etc. all over the country.

Blessed by almost a year-round availability of rich solar radiation of the magnitude of about 5 - 7 kWh/day/m2, Bangladesh should explore also other diversified uses of solar energy in other important areas of applications.

As a natural and logical choice, the use of Solar Photovoltaic Pumping (PVP) appears to be the next important area, the introduction of which through a 'Flagship Project' could trigger off a series of replications, in similar lines as in case of SHS. The PVP is a very matured technology which uses the energy from the sun to run pumps for irrigation and water supply to remote off-grid areas, using the Solar Photovoltaic technology.

World wide, over 50,000 Solar Photovoltaic Pumps are in operation and the neighbouring country India, has already over 6,800 PVP to supply water for irrigation and also to lift safe drinking water from groundwater resources for supply to remote rural off-grid areas. Bangladesh has over 1.25 million units of small diesel operated irrigation pumps, which consume about 40% of import based high speed diesel oil (HSD). In absolute terms, these pumps consum about 800,000 MT/Yr of HSD. The Ministry of Non-conventional Sources (MNES) and its financing subsidiary - Indian Renewable Energy Development Agency (IREDA) 'buys down' about IRs. 135/Wp of Panel Power, up to maximum limited of Rs. 250,000/- which, based on prices of low head surface water PVP equates to Rs. 243,000/- for a PVP used for irrigation, whose cost is Rs. 317,000/- unit to popularize the use of PVP.

The HSD is priced in Bangladesh at Tk. 33.33/litre, but the real (economic) cost to the state is about Tk. 65/- litre, which means Tk. 32/litre, i.e almost a 100% of the of the retail market price is being subsidized by Bangladesh Government, the reason being that HSD is used for irrigation purposes by farmers who produce food for the nation. Any effort in the direction of disseminating the use of surface water PVP (high flow low head) PVP that are being used for irrigating the fields, could take away a part of the huge recurring diesel imports in the country, about 2,000,000 MT of which are annually imported in the form of crude and refined product. The balance 60% of HSD consumption goes to the transport sector.

The GTZ-PURE, supported by the German Federal Ministry for Technical Coopration - BMZ, had supported, during the period 1998/99 - 2002, as 5 year long PVP Programme in Chile, Ethiopia and Jordan, for “Resource Conserving Irrigation, using PVP” It became the single largest demonstration for evaluating the use of PVP. The results were quite encouraging, which concluded about 4 years back, when the crude oil rice was less than half of to-days diesel prices that the PVP is viable option to diesel operation, especially in the range of 1 - 2 kWp of Array capacity. When coupled with high-value crop production, using micro (drip) irrigation techniques, rate of returns of over 70% were obtained. However, the study concluded that there are country specific cost figures and hence for each country evaluations must be made before taking decisions. But a major conclusion of the GTZ study was that “ the Solar Photovoltaic Pumping, despite its limitations, is bound to gain importance in the future…”.

The objective of this study (currently under Stage 1 A) is to look into the techno-economic viability of the the use of PVP for irrigation and also rural drinking water supply. The later is also of great importance, as arsenic contamination of shallow hand tube-wells is a problem in many parts of Bangladesh and the modern PVP can lift water from over 100m depths (over 300 ft.), a prototype of which (1.68 kWp with 40,000 litres/day with H = 100m) was also presented to the Rural Electrification Board (REB) for field demonstration, which also ran successfully for years almost uninterruptedly with no maintenance and with least attendance, until it was dismantled with the PV Station and put in the REB store, when the electricity grid reached the pilot area.

In line with the Terms of Reference (TOR) of the study, field visits were made to relevant Government institutions, NGOs, others stake holders, working in Irrigation, Water Management, including agricultural research stations - Bangladesh Agricultural Research Institute (BARI) and Bangladesh Rice Research Institute (BRRI). The highlights of Interactions and Findings were reported to GTZ-PURE, through three separate Field Reports (I, II & III), covering North Bengal, Central and South Eastern Region (Bandarban in the Chittagong Hill Tracts), the copies of which are also included in this Final Report.

Based on the findings/feedback obtained and also on the desk evaluations, the following conclusions were reached through the Stage 1 A Study, based on its TOR :

- Over 1,150,000 Low Lift (small diesel-operated) Pumps, about 100,000 units of Shallow Turbe-wells (STW) and about 37,000 units of Deep Tube-wells (DTW) and about 198,000 electrically connected (by REB/PBS) are in operation in Bangladesh.

- The PVP, so far small irrigation is concerned, lifts water at a much cheaper levelized cost (on a life-cycle basis), based on a discounted cash flow analysis over the long economic life of the PVP, when compared to the small diesel pumps. The later has a continuous recurring (fuel cost), high operating and maintainence (O & M) costs, although its initial price is low.

- the Net Present Values up to were found to be 7%, the FIRR being 7.29% at the present subsidized cost of diesel at Tk 33.33/- per litre. Sensitivity analysis indicated that based on the real economic cost of Tk. 65/litre, the IRR is 16.88 % and with crude oil reaching US$ 100/bbl., the IRR is 23.65%.

- Based on an Income Generation financial approach, on an Investment of about Tk, 3.5 million for 2 units of high flow low head irrigation PVP (Q = 135,000 litres/day, H = 10m each) and one high head low flow (Q = 50 m3/day, H = 30m), including all import costs for 2 x 1800 Wp PVP for surface water irrigation and 1 x 2000 kWp for rural drinking water supply plus small irrigation and local cost, the IRR of the project from crops such as Tomato, Banana and Potato, after all input and other expenses, works out to be 35.93%,

- A locally developed (by BARI) drip irrigation method was taken as basis, based on feedback from BARI who have obtained yields of Tomato up to 85 MT/hectare. This water conserving method would be very appropriate for operation with an integrated water supply and irrigation project with a by-pass from the overhead tank to low-height sub-tanks (simple barrels) used to feed water slowly, but continuously to where water is most required, i.e. root-zone of the plant.

Based on the above findings and interactions, a preliminary budget has been prepared for a proposed ‘Flagship Project’ for PVP, as the analysis indicated that IRR (based on the total Investment and the Net Cash flow of the Project) much above the commercial interest rates have been obtained, using the discounted cash flow (DCF) method. The Rural Development Academy (RDA), Bogra, Barind Multipurpose Development Authority (BMDA), BARI/BRRI and also the LGED and a local CHT based NGO have shown keen interest to work with GTZ-PURE on their PVP Initiative, if and when required.

Finally, recommendations have been made for further actions, which includes the project design and development of specific activities with the finally selected partner at a specific site, through a second stage study (Stage – 1B).

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ACRONYMS

AC	Alternating Current
BARI	Bangladesh Rice Research Institute
BBL.	Barrel (the small letter version bbl. is used often)
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Centre for Advanced Studies
BMDA	Barind Multipurpose Development Authority
BMZ	German Federal Ministry for Technical Cooperation (Bundesministerium fuer Technische Zusammenarbeit)
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engineering & Technology
CSO	Chief Scientific Officer
DC	Direct Current
DTW	Deep Tube-well
DU	Dhaka University
H.P.	Horse Power
HSD	High Speed Diesel Oil
FIRR	Financial Internal Rate of Return
GDP	Gross Domestic Product
GOB	Government of Bangladesh
GTZ	German Technical Cooperation (Gesellschaft fuer Technische Zusammenarbeit)
IFRD	Institute for Fuel Research & Development
IREDA	Indian Renewable Energy Development Agency
IRR	Internal Rate of Return
KfW	Credit Institution for Reconstruction (Kreditanstalt fuer Wiederaufbau
kW	Kilowatt
kWp	Kilowatt Peak
kWh	Kilowatt hour
LGED	Local Government Engineering Department
LLP	Low Lift Pumps
MDG	Millennium Development Goal
MNES	Ministry of Non-Conventional Energy Sources
MW	Megawatt
NGO	Non-Government Organization
NPV	Net Present Value
O.H. Tank	Overhead Tank
PBS	Palli Bidyut Samity
PURE	Promotion of the Use of Renewable Energies
PV	Photovoltaic
PVP	Photovoltaic Pumping
PRSP	Poverty Reduction Strategy Paper
PVC	Polyvinyl Chloride
RDA	Rural Development Academy
RE	Renewable Energy
REB	Rural Electrification Board
SEDEC	Sustainable Energy Development Centre
SE	Sustainable Energy
SEU	Sustainable Energy Unit
SHS	Solar Home Systems
S& T	Science & Technology
SRE	Sustainable Rural Energy
STW	Shallow Tube-well
TOR	Terms of Reference
UNDP	United Nations Development Programme