TASK 9 – CASE STUDY

Drinking Water Supply with Photovoltaic Water Pumps (PVP)

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Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

1. Introduction

The availability of clean drinking water is a basic human need. Nevertheless, World Bank estimates put the number of people in remote rural areas of developing countries with no access to clean water at roughly one billion.

Dirty and polluted water sources have a strong negative impact on health. Getting water from remote sites is troublesome and time consuming. Poor water supply contributes to the migration of rural people into overcrowded cities.

Consequently, government-sponsored programmes dedicated to the long-term improvement of drinking water supplies in rural areas are being conducted in numerous developing countries. Since most rural areas are not and will not be electrified for decades to come, national water authorities have to rely on diesel pumps in most of those programmes. Due to poor maintenance, breakdowns and lack of fuel, they are often out of service.

Here solar energy opens up new options for pumping water. Photovoltaic pumping systems require little service and no fuel. They can offer a reliable and environmentally-sound alternative. Often, they constitute the only reliable solution to the problem of drinking water supply in remote areas. However, a lack of experience with PVP technology as well as the comparatively high initial costs have precluded its widespread application up to now.

2. Aims and objectives

The objectives of the PVP programme were to:

- Demonstrate the technical maturity of PVP,
- Determine the conditions for a cost-effective utilization of PVP,
- Clarify the ecological benefits and the level of acceptance on the part of users and operators,
- Adapt PVP technology to the users need and to the climate conditions, the aim being to develop a marketable product,
- Clarify the opportunities for future PVP applications as well as their potential for dissemination.

3. Project background

Due to the reliability of photovoltaic pumping systems a huge potential for dissemination in non-electrified, rural areas can be expected. In order to demonstrate the technical maturity of PVP and to clarify the prerequisites of a broad utilization, the German Government funded an “International Field-testing and Demonstration Programme for Photovoltaic Water Pumps

(PVP)". The PVP programme was being conducted by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

The programme started in 1990 and was finished in 1998. It was followed by a second programme investigating the utilization of PVP for irrigation[1].

The GTZ implemented the PVP Programme in cooperation with national energy and water authorities in Argentina, Brazil, Indonesia, Jordan, the Philippines, Tunisia and Zimbabwe. In the course of the PVP Programme, a total of 90 PVP systems have been installed at selected sites in the project countries. Those systems provide potable water to people of the village communities and their livestock.

4. Project description

The PVP Programme analyzed the opportunities for future PVP applications as well as their potential for dissemination. Consequently, the PVP Programme was designed primarily as a demonstration and field-testing programme, with water utilities and PVP suppliers/manufacturers as the main addressees. The results of the PVP projects provided a decision-making basis for:

- ###national or regional water utilities to assess PVP as a viable, least-cost option for rural drinking water supply, and
- ###PVP suppliers / distributors for product adaptation and marketing.

The overall idea was to achieve a major advance toward commercialisation of PVP technology by demonstrating its feasibility at a significant number of sites.

This was done in combination with thorough preparation of counterpart institutions and personnel, intensive interlinking with industry, and an comprehensive performance monitoring programme. The transfer of expertise to counterparts and of experience to the industry was crucial.

Key measures implemented have been:

- ###site selection, ordering and commissioning of PVP systems,
- ###monitoring the technical PVP operation and cost-relevant factors,
- ###measures for community participation and sociological monitoring of the PVP communities,
- ###training of water utilities' technical staff, planners and decision-makers,
- ###adaptation of country-specific planning procedures,
- ###promotion of technology and know-how transfer by involving national companies in the supply and maintenance process,
- ###dissemination of project results and public relations work.

[1] a case study on the follow up programme „Resource-conserving Irrigation with Photovoltaic Pumping Systems" is also available

The conceptual approach behind the PVP Programme did not envisage competition between the PVP systems and hand pumps, wind pumps, grid-fed electric pumps or large diesel pumps. However, it regards PVP as an alternative to small diesel pumps at remote sites for communities with populations of 500 to 2000, since these usually experience:

- ###low reliability of water supply due to irregular fuel supplies and frequent technical breakdowns;
- ###high cost of operation due to operator expenses, high specific fuel consumption and fuel costs, and major expenditures for repair and maintenance.

An attractive power range for PVP application lies between 0.7 and 4 kW_p. Standardized, reliable components have been commercially available; including a suitable range of submersible AC motor pump units and inverters in the power range up to 4 kVA. For medium pumping heads of 50 m and daily insolation levels above 5 kWh/m^2, this power range of PVP can supply drinking water to communities with populations up to about 2000.

The typical PVP standard system consists of a PV generator, an inverter and a submersible motor pump that delivers water to a high-level reservoir (water tank). The water reservoir feeds the water by gravity to public water taps and watering points for cattle.

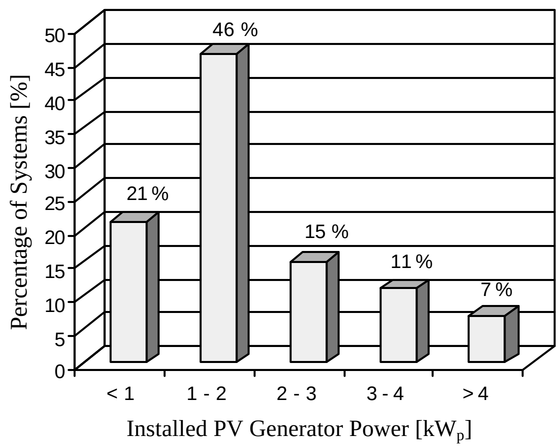
The PVP Programme concept promoted cooperation between the European equipment suppliers and the partner countries' local and national enterprises. As far as locally produced components of adequate quality were available at reasonable cost, they were incorporated into the PVP Programme in order to facilitate maintenance and spare-parts logistics while reducing the foreign currency input.

Community preparation and participation were considered integral parts of the programme, usually extending the institutional practices in the various project countries. Acceptance and social impacts were investigated thoroughly. On the technical side, a comprehensive monitoring programme was designed and carried out to gather all necessary data for evaluating the technical reliability and efficiency. A huge number of financial and economic data were collected and analysed in a couple of studies to judge the economic feasibility.

5. Lessons learned

5.1 Technique

A collective PV generating capacity of 185 kWp has been installed. Approximately 46 % of all systems implemented by the PVP Program operate in the 1-2 kWp power range. The systems' operative range covers daily water discharge rates of 4 to 110 m^3. The pumping heads vary between 10 and 125 m.



In order to keep maintenance and repair as simple and inexpensive as possible, standard-type PVP systems incorporating commercially available components were selected. Besides the PV generator these include a submersible, multistage centrifugal pump equipped with a low-maintenance three-phase induction motor. An inverter converts the direct current (d.c.) provided by the PV generator into the requisite alternating current (a.c.) and serves as a system controller.

To compensate for daily and seasonal fluctuations of solar radiation, a suitable form of power storage must be included in the system. Conventional-type batteries are excluded since they tend to be maintenance-intensive and their service lives are limited to just a few years.

In PVP systems the pumped water is stored in a collecting basin or a high-level reservoir, which feeds the water by gravity to public water taps. The optimal storage capacity is roughly twice the daily water discharge rate.

This standard system has proved very reliable. Despite the usual teething problems associated with the introduction of practically any new technology, an average availability of approximately 99 % has been measured for the 90 PVP systems. The downtime was caused mainly by a total of 22 hardware failures, of which the inverters accounted for 70 %. Obviously, the inverter is still the most sensitive system component.

A rather new innovation are tandem system which consist of two PVP installed at the same well. During periods of high insolation, when good pumping efficiency can be expected, the two plants operate in parallel with mutual independence. During periods of low radiation intensity, however, the two PV generators are coupled together to provide enough power to keep one pump running at a comparatively high efficiency. This concept allows utilizing low and medium solar radiation more efficiently. A one-year data evaluation of a PVP tandem at San Lorenzo, Argentina, proved a higher output of 16% compared to an independent operation mode.

While the high availability underlines the reliability of PVP, the failures that occurred show that PVP are not maintenance-free. The widespread introduction and diffusion of PVP products will require effective 'after-sale services' with local or at least national maintenance structures and readily available spare parts. Long delivery times for spare parts from abroad would cause unacceptable interruptions in the supply of drinking water.

Further optimization of certain system components and establishment of a well-functioning local service structure, including stocks of spare parts, can be expected to further increase the availability of standard-type PVPs. In addition to the use of optimized system components, a crucial prerequisite for the reliability and economic efficiency of PV systems is an appropriate system sizing adapted to local conditions.

5.2 System design and sizing

In order to improve the design process different sizing procedures were compared with the systems' actual field data. Twenty-five different PVP systems were studied, all of which were equipped with automatic data acquisition systems. A pertinent method was developed to account for the daily run of insolation and, accordingly, the hydraulic output of the pumping system.

PVP systems are sized on the basis of the findings from a local data survey. The meteorological and climatic data are usually taken from the closest meteorological station to the site.

Site data to be collected include water quality, water demand, pumping head and special geographical features, e.g. valley locus or shading. The pumping head and the demand are dynamic figures that may vary seasonally or in the long run.

Sociological factors are also a part of the planning process. Users should be involved in data collecting in order to make early allowance for their customs and traditions. For the project's long-term success, it is decisively important to fully inform the users on the targeted goals and any changes and improvements to be expected.

Women in particular must be intensively involved in the planning, because they are the ones who are usually responsible for maintaining hygiene and fetching water. Thus, planning should include both technical and sociological aspects.

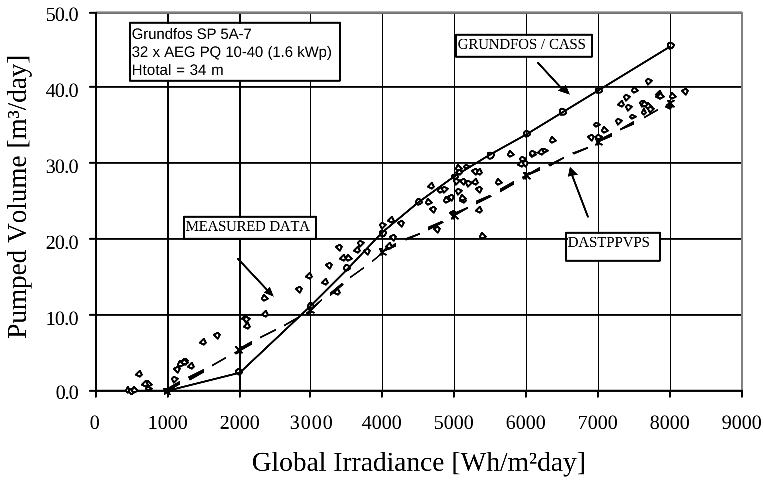
For a quick onsite estimation of the required PVP and the corresponding costs, the following formula has been derived from measured operating data:

$$\boxed{P_{SG} = 11.6 * \frac{H * V_d}{\overline{G_d}}}$$

For instance, according to this formula it takes a 3.5-kWp PV generator [P_{SG}] to deliver water at the rate of 30 m³/d [V_d] at a head of 50 m [H] for a daily total global irradiation of 5 kWh/(m²*d) [G_d].

Several suppliers have developed product-specific system design diagrams in order to simplify the design process. When those graphical designs were compared with the results of the measurement programme, huge deviations have been found. These were in the order of 21 % resp. 27 % for the design diagrams of different suppliers.

Computer sizing programmes can take the daily dynamics of PVP into account and thus overcome some deficiencies of graphical sizing procedures. The available software programmes ranges from simple demonstration programs to highly flexible free-style programs. The results of several programmes were compared with measured size data. A good agreement to the actual measured data was found with the DASTPVPS simulation and design program developed by the German Universität der Bunde-Bundeswehr in Munich. It can serve as a suitable instrument for system design and for checking the performance of PVPs.



Finally the sizing results of the suppliers have been evaluated. Under real operating conditions, most commissioned systems actually delivered considerably less water than expected.

A main reason is the average daily efficiency of about 3.0 % that PVP systems actually achieved. The suppliers were expecting an efficiency of approximately 3.5 %. If the users' consumption patterns are also accounted for in the calculations, the average daily efficiency drops to around 2.0 %. There are many reasons for the apparent loss of performance.

- External causes are inadequate planning data (e.g., pumping head), dirt-plugged pumps, pipes and valves, shading of the PV generator, underestimated temperature effects, premature wear of system components due to corrosive substances in the water and irregular use of water.
- System-specific causes include output limitations imposed by the inverter on an oversized PV generator, inverter and PV-generator mismatch losses, and power reduction caused by defective system components.

External causes are difficult to consider in the absence of appropriate site-specific data. System-specific causes can be avoided by careful sizing. This, however, presumes that the technical planner has access to adequately optimized system components appropriate to the prevailing climate.

5.3 Costs and Economics

Besides technical maturity and appropriate sizing procedures, the economic feasibility is of primary importance for the dissemination of PVP technology. A number of studies were conducted to clarify the conditions for an economic operation of PVP. The studies concentrated mainly on the supply of drinking water to villages without electric power. No consideration was given to sites with livestock water supply only since these are less suitable to PVP due to their strong seasonal demand fluctuations.

As a rule, electric pumps are favourable if electricity is available and hand pumps are the least-cost option for low consumption rates and low pumping heads. However, diesel pumps are used in most villages with populations of 500 or more in unelectrified areas. Hence, diesel pumps are the main competitor of PVP.

The access to clean drinking water is a basic need. Its benefits don't have to be evaluated economically. This is emphasized by the fact that most rural drinking water supply schemes are subsidized. Consequently, the question of profitability can be reduced to the relative cost advantages between different pumping technologies.

5.3.1 Cost survey

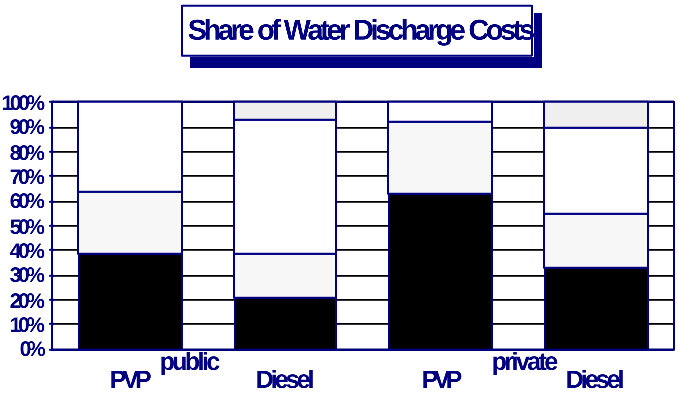
Investment Costs of PVP [in T€]			
	1 kW_p	2 kW_p	4 kW_p
PVP (fob; generator, pump, inverter)	8.3	14.8	27.0
PVP (turnkey, shipment, installat. etc.)	16.9	25.9	43.0

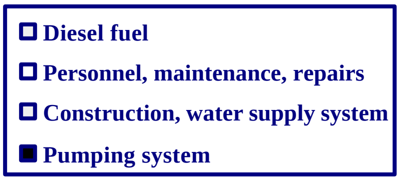
The findings are based on market research and cost surveys conducted in seven project countries between 1993 and 1995. Differentiation was made according to operator (public or private) and plant output. The cost survey covered the pumping systems and the water reservoirs, but not such site-specific components as wells and distribution systems that are identically for both technologies.

Comparing the initial capital outlays, the PVP systems cost between 2 and 3 times as much as the diesel pumps. Day-to-day expenditures of PVP for personnel, maintenance and repair are extremely dependent on the location and particularly on the payments for an operator, but they always remain well below those of diesel pumps.

Running Costs in 7 countries [in €]		
	min	max
PVP (operation, maintenance, repair)	31	3.400
Diesel pump (operation, mainten., rep.)	920	9.800

The running costs makes up for a higher proportion of water pumping costs for diesel pumps vs. PVP and for public vs. private owners. The higher running costs for public owners are caused by higher operators expenses. The impact of fuel costs is comparably low.



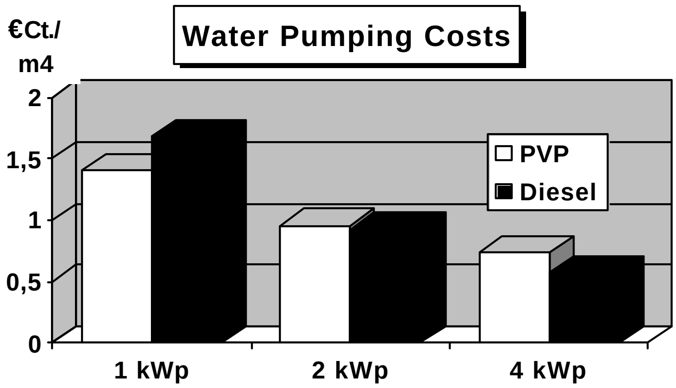


5.3.2 Water pumping costs

The specific **water pumping costs** are the main criterion for an appraisal of different pumping technologies. These are the costs caused by a pumping system, taking into account investment costs as well as operating costs, to supply one m^3 per day at a pumping head of one m. They are expressed in € per m^4.

The costs have been calculated on the basis of annuities, using a country-specific, inflation-adjusted calculatory interest rate, and taking into account the service life of the respective component. Macroeconomic factors have been ignored.

For PVP, the average costs of the 39 cases comes to about 1.5 €cents/m^4 (Example: 1 m^3/day at 20 m pumping head costs 1.5 cents/m^4 * 20 m = 30 cents/m^3). The costs decrease with increasing demand or plant size. Since this effect is stronger for diesel pumps, PVP are more favourable at smaller demands.



While this is true at all sites, the economic viability for a certain demand is strongly influenced by national, regional and sometimes sites aspects such as the interest rate or the expenses for an operator. While in one country all 6 cases investigated proved to be advantageous for PVP, in another one no competitive PVP cases could be found.

In general an economic viability for PVP can be expected if

technically

- ###high year-round utilisation of the pumped water is ensured (constant demand, no seasonal watering of cattle),
- ###well-designed systems with overall efficiencies of 3 % or above and system sizes up to 2 kWp are applied (depends much on country specific conditions)

organisationally

- ###costs for operating staff are low,
- ###installation, maintenance and repair work can be performed by qualified local staff,
- ###additional costs for the water storage capacity can be kept low (community labour support)

financially

- ###low-interest credit lines are available,
- ###import duties or other charges on PV modules, inverters and pumps are moderate or non-existent.

5.3.3 Investment costs vs. water pumping costs

Notwithstanding the economic advantages of PVP technology in many cases, there are still obstacles to be overcome; an important one lies in the practices and established standards of the water supply authorities.

The decision-making process of the water authorities for the purchase of a new pumping system generally takes place on the basis of bids submitted as a result of invitations to tender. The criterion for the decision is, ultimately, the cost of the initial investment. As long as only diesel pumps are included in the comparison, such a procedure may be acceptable. But this practically rules out PVP technology, because the running costs of the diesel pumps are not included in the comparison of technologies.

In many countries, financing of the investment costs lies within the responsibility of the national water authority, while the costs of operation have to be borne by the regional water authorities through provincial government budgets. This mode of cost sharing favours technical solutions with minimal investment costs instead of minimal water pumping costs. The interests of regional water authorities and users to reduce running costs and to ensure a reliable water supply is often disregarded.

5.4 Social aspects and acceptance

A common experience all over the world is that it is easier to install a water supply system than to ensure its sustained operation. Introducing technology into the social reality of rural communities is a task that cannot be addressed solely by technical means. It is a social task and consequently needs social preparations for the project activities. Disregard of this basic experience leads to unresponsiveness to the users' demands and to a high probability of project failure.

The participatory and educational measures of the PVP Programme aimed towards

- ###building up or strengthening sustainable local community structures that can handle their own water management and the self administration of water and hygiene aspects, and
- ###introducing a socially acceptable water tariff that enables the community or the operating agency to cover at least the O&M costs.

The social acceptance of PVP is not a condition for the installation at any particular site, but a result of an education-induced process that is guided by the motivation, participation and self-responsibility of the users and communities. Important indicators identified for the degree of acceptance are:

- ###ownership attitudes of persons or groups toward the installations ('This is our well/PVP'),
- ###regular payment of water charges by the users,
- ###careful handling of technical devices and initiatives for maintenance and repair,
- ###taking over obligations regarding accompanying measures (e.g. gardening, hygiene campaigns, etc.) and task assignments on a community basis.

In those project countries where the regulations and traditional water rights allowed the introduction of water tariffs, an unexpectedly high readiness on the part of the rural water users to pay for their water consumption was encountered. Precondition for the acceptance of the water tariffs by the consumers and their continued readiness to pay are sensible community participation measures and the experienced reliability of the PVP technology.

When the users are charged according to their consumption, the water demand will at least be cut in half as against monthly flat rates. Such causal relations between tariff system and consumption should be taken into consideration by the planner, because proper matching of the PVP to consumption habits affects specific water costs and, in return, the affordability of the water for the users.

5.5 Perspectives

The tremendous unsatisfied need for clean drinking water in rural areas of developing countries will surely continue for many years to come. Since the electrification of remote rural areas will not be affordable in the foreseeable future, the demand for stand-alone pumping systems will endure.

With an availability of 99 % PVP systems have proven their technical maturity and reliability. Tandem plants promise future improvements in energy utilization.

Cost analyses show that PVPs with ratings up to about 4 kWp are cost-competitive vis-à-vis conventional diesel pumps. The smaller the demand and correspondingly the pump, the more attractive the photovoltaic option will be, though prices do vary from region to region. These cost advantages are augmented by such non-monetary aspects as reliability, ecological viability and the ability to pump water at inaccessible locations without need of fuel. On the other hand diesel pumps are more flexible being adapted to changing demand patterns.

Even though the economic feasibility and other advantages of PVP have been demonstrated, the relatively high initial investment costs and foreign-currency outlays often preclude their dissemination. In such cases, development banks should provide compensation in the form of easy-term loans or other financing models.

Suppliers should take advantage of the good preconditions for a wider PVP dissemination. This requires a stronger engagement in developing countries in terms of product representation, consultancy services for water utilities, and building up of a sales and maintenance structure incorporating local partner enterprises. The commercial diffusion of PVP will be contingent upon an in-place maintenance structure and the local availability of spare parts.

Despite all obstacles encountered in the past and the complexity of an intended dissemination process, the accumulated international know-how allows the integration of PVP as a well-defined option for large-scale water supply projects and strategies. The satisfaction of the basic need for drinking water supply will provide a sustainable market for PVP.

6. Literature

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