IEA PVPS, TASK IX–

CASE STUDY

RESOURCE-CONSERVING IRRIGATION WITH PHOTOVOLTAIC PUMPING SYSTEMS IN CHILE

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Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

1. Introduction

An increasing scarcity of agriculturally utilisable land, coupled with the consequently rising costs of leases and property, often force farmers to move to areas with little infrastructure.

Far from the electric grid, the customary means of pumping irrigation water are diesel or petrol pumps. These have the double drawback of requiring much and expensive maintenance and depending on a regular supply of fuel, so that they cannot be operated unattended. Especially in remote areas of developing countries with inadequate spare parts and maintenance structures, diesel and petrol pumps are often inoperable for several days. The resultant lack of water can seriously damage crops, reducing yields and income. Hence using, conventional pumping systems poses an economic risk to farmers. Moreover, the noise and exhaust from such pumps impact on the environment. The pollution of ground water and soil by diesel fuel and lubricants is no rare occurrence.

Environment-friendly, low-maintenance photovoltaic pumping systems (PVP) provide new possibilities for pumping irrigation water, but still constitute a little-known technical option, especially in the agricultural sector.

2. Aims and objectives

The objectives of the PVP programme were to:

- Prove how photovoltaic pumping systems can be used to irrigate high-quality crops in a cost-effective and resource-conserving manner,
- Determine the managerial and technical requirements for operating a PVP irrigation system.

3. Project background

Supported by the favourable experience gained in a large International Demonstration and Field-testing Programme for PVP, proving the viability of PVP to supply remote villages with drinking water[1], the PVP Irrigation Pilot Project was initiated by the German government.

The pilot project, financed by the German Federal Ministry for Economic Cooperation and Development (BMZ), is being implemented by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, the government's technical cooperation agency. In cooperation with the partner countries Ethiopia, Chile and Jordan, ten pilot installations on private and public sector farms are producing cash crops and undergoing intensive monitoring.

Project implementation started in 1998 and finished in 2002. The counterpart in Chile was the University of Tarapacá.

[1] A case study on this programme is also available.

4. Project description

This case study concentrates on the installations in Chile. Here the project focused on peri-urban small and medium-size farms that use energy and water-conserving forms of irrigation to grow cash crops on up to 3 hectares of land, generating income that could be used to finance a PV-based irrigation system. Four pilot plants (0.3-1.2 kWp) for cash crop production have been installed in the Atacama Desert in northern Chile.

The interdisciplinary character of the PVP Irrigation Pilot Project called for close cooperation with experts from various disciplines. To induce sustainable dissemination processes, suppliers of PVP irrigation systems and their local partners or companies are being involved in the project activities. The project also cooperated closely with national and private sector institutions.

The field-testing of PVP irrigation systems enabled the users and operators of the pilot facilities to assess and evaluate the technology. Therefore the project placed great emphasis on training of project partners and system users.

Key measures implemented have been:

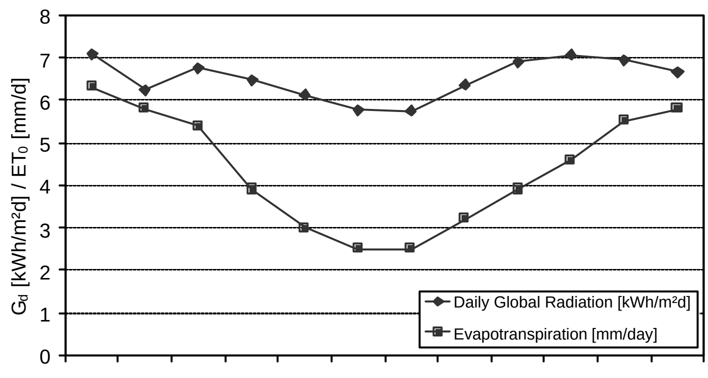
- site selection, ordering and commissioning of PVP systems,
- monitoring the PVP systems and the irrigation system,
- selecting and testing components matching the requirements of PVP irrigation systems
- training of users to manage the PVP irrigation systems
- analysing the cost-effectiveness of PVP irrigations systems
- study on environmental impacts of PVP and diesel pump systems

5. Lessons learned

5.1 Technique

5.1.1 Technical monitoring

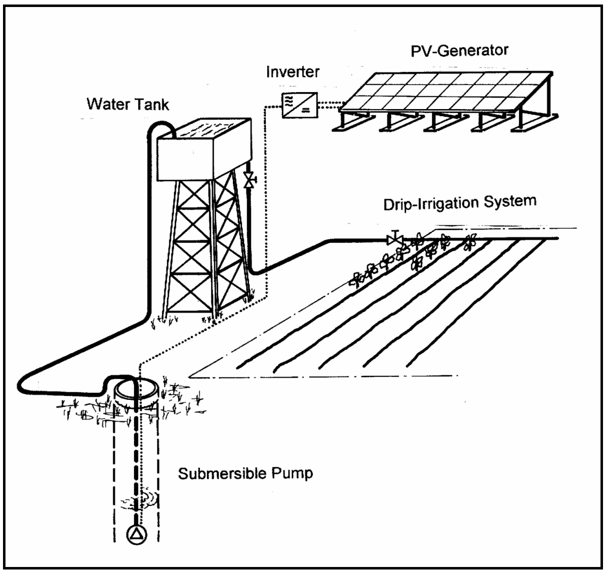
To permit continuous monitoring of crucial operating parameters, all pilot systems have been equipped with automatic data acquisition systems. In addition to the technical evaluation of the performance of the PVP irrigation systems employed, the recorded meteorological parameters facilitated the management of the irrigation systems, and the water consumption data provided information on the degree of system utilisation.



Recorded daily global radiation (G_d) and evapotranspiration (ET_0) at pilot site Chaca, Atacama Desert, Chile

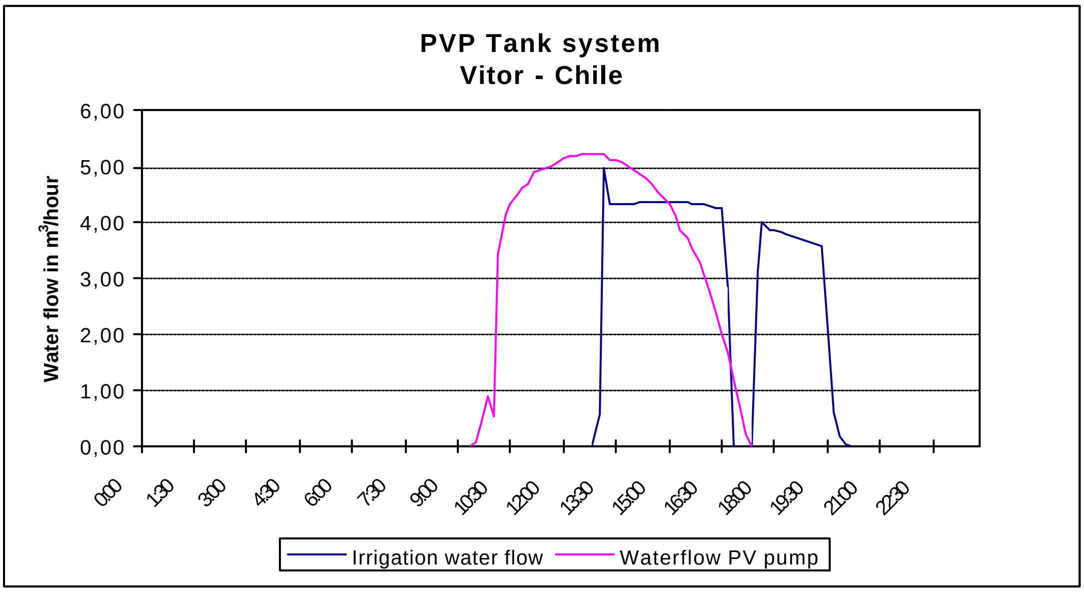
5.1.2 PV-irrigation systems

Two different system configurations have been employed within the scope of the project.



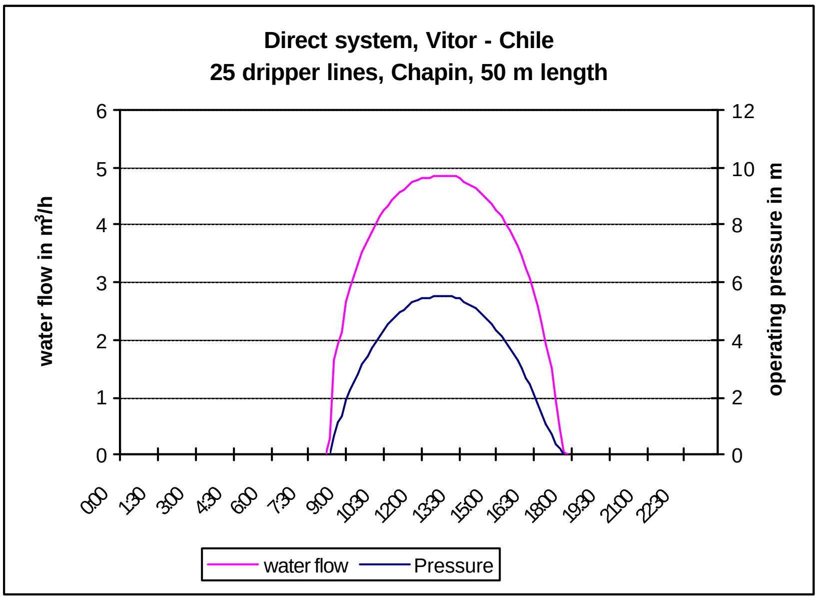
In the first case, a solar generator produces electricity to drive a submersible motor pump, which pumps water into an elevated tank. The tank serves as an energy store and supplies the pressure needed for the irrigation system. The stored water can bridge periods of low insolation and supplies the pressure needed for the irrigation system. Pilot plants equipped with a water tank operate at considerably low system pressures, compared to conventional diesel or petrol pumps. This presumes, of course, that all components of the irrigation system have been designed for such low pressures.

PVP tank irrigation systems operate at constant pressure of approximately 0.2 – 0.5 bar depending on the height of the water tank and with a rather constant water flow. Irrigation is regulated by hand valves



In the second case, the PVP injects the water directly into the irrigation system. As pertinent experience in Chile shows, this can reduce the initial capital outlay by as much as 35%. However, due to daily fluctuations of global radiation, these systems operate at variable system pressures and water flows.

One major advantage of solar pumps is that they do not require batteries, which are expensive and need a lot of maintenance.



The maintenance of a PVP irrigation system is restricted to regular cleaning of the solar modules. Depending on the water quality, the only moving part of the system, the submersible motor pump, has to be checked every 3 to 5 years.

Drip irrigation saves a considerable amount of water compared to other irrigation techniques. Furthermore, it has a rather low operating pressure. Both features reduce the energy demand and make drip irrigation particularly suitable for photovoltaic pumping systems.

Unlike other irrigating processes, drip irrigation is amenable to a continuous supply of water, so the pump can run incessantly through the entire growing season. Since both the crop's water requirement and the output of the pump are functions of the global radiation, the two systems go hand-in-hand up to a certain point. However, the output capacity of the PVP must be designed for the maximum water requirement.

On a yearly average, though, each and every difference between the actual demand and the supply of water detracts from the system's overall degree of utilisation. In that sense, conventional motor-driven pumps are more flexible. The daily output of a motor-driven pump depends not only on its rated power, but also on the easily adaptable time of operation. Therefore diesel pumps can cope with most fluctuations of demand.

The better the crops can assimilate the quantities of water actually supplied, which of course vary according to daily and seasonal fluctuations in insolation levels, the more economical a PVP will be. Since different crops have different water requirements, and since those water requirements fluctuate in the course of the growth cycle, the proper choice of crop successions and combinations is of decisive importance to the degree of utilisation of solar pumping systems. Uninterrupted crop rotation patterns or continuous cropping systems with high value added crops (e.g., cash crops such as fruit, vegetables, herbs and spices) are especially suited to irrigation by a PVP system.

5.1.3 Research and development requirements

While the technical aspects of solar irrigation are generally regarded as adequately developed, a closer look reveals that laboratory and field research is still needed.

- The main field of application for PVP are wells and boreholes with larger pumping heads. But for irrigation purposes mainly surface water pumps are required, which still have to be developed or optimised for PV.

- Up to now conventional drip irrigation systems have been combined with PVP. Contrary to electric or diesel pumps, PVP systems have variable operation characteristics. This requires the development of low-pressure drip irrigation systems suited to operating under such variable conditions, including suitable filters and fertilizer injection devices.
- Drip irrigation systems are not always locally available in developing countries. Research for alternative low-pressure irrigation systems might overcome this constraint.

5.2 Economic aspects

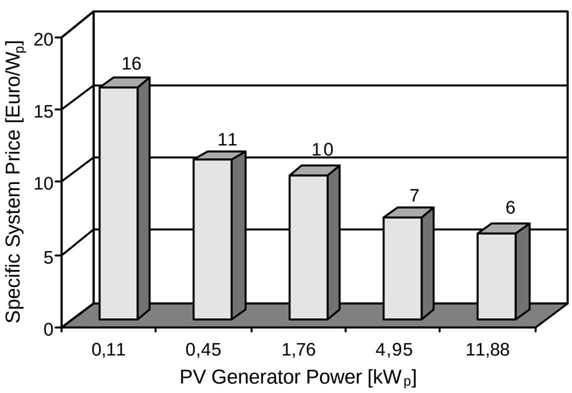
The costs of photovoltaic irrigation are measured against the additional profits gained by the agricultural or horticultural production unit. Consequently, it is not sufficient to simply compare the costs of the competing technologies, i.e. PVP and diesel pumps. Rather, the overall profitability must be investigated, taking agro-economic aspects into account.

The economic analysis is limited to an assessment of the microeconomic advantages of PV-based systems and alternative diesel or petrol pumps. In this case study, no macroeconomic aspects are examined. The acquisition of data and the subsequent economic analysis comprised four steps:

- At first all data of relevance to the economic analysis at the project sites were collected.
- The second step was to calculate, on the basis of a dynamic cost annuity approach, the water pumping costs incurred by the competing technologies. The specific water pumping costs [€/m^4] are used as the criterion to compare both technologies.
- As a third step, the cost analysis was followed by a profitability analysis that allowed agro-economic aspects to be taken into account.
- In the fourth and last step, general conclusions were drawn from the findings of the site-specific economic analysis.

5.2.1 Investment costs

Ready-to-run PVP presently cost approximately three times as much as diesel pumps of comparable performance. In Chile, photovoltaic pumping systems are locally available. Consequently, the corresponding market prices were used for the economic evaluation.



However, national and local constraints can have major impacts on the initial cost of investment. For example, in Ethiopia import duties and other charges increase the basic import price of a photovoltaic system by 47%, while in Chile they are a mere 5–10%.

The high output-specific outlays for PVP are comparatively high financial burdens on farmers who opt for photovoltaic irrigation. Hence, many farmers decide in favour of diesel-driven systems. What they often fail to see, though, is that once a PV-based system is in place, it costs only a fraction of what it costs to operate a diesel pump.

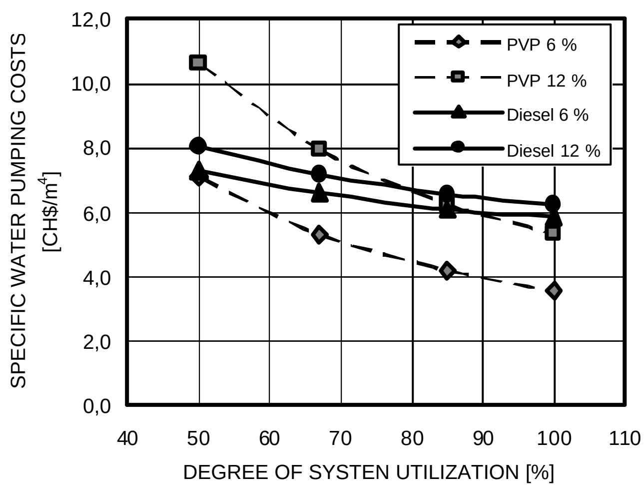
5.2.2 Water pumping costs

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 investment costs as well as running costs into account, to supply one cubic metre per day at a pumping head of one metre. 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.

The specific water pumping costs depend not only on the pumping head but also on a number of other site-specific parameters, which must be accounted for. This makes it difficult to apply the results to other sites and to make generally applicable assertions regarding economic efficiency. The main parameters in question include:

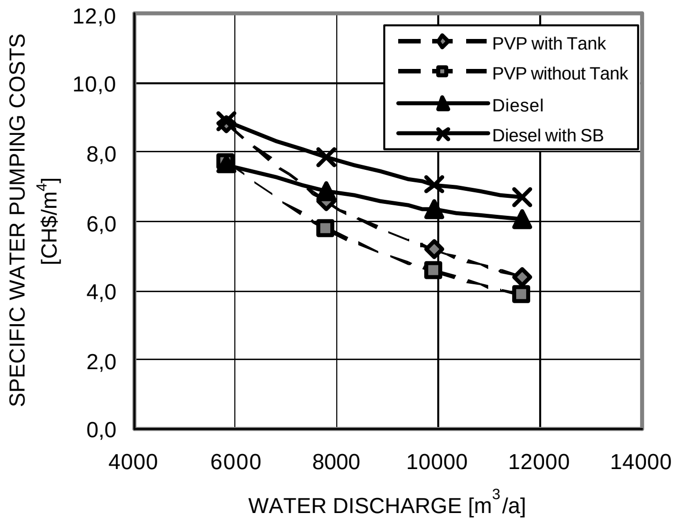
- System output
- Solar irradiance
- System configuration (PVP system with or without storage tank, motor pump or generator with submersible motor pump)
- Operating mode (automatic irrigation or by manual control, motor pump with or without standby generator)
- Discount factor
- Useful life of individual system components
- Degree of system utilisation



The overall costs of a PVP system are much more dependent on the system's rated output compared to diesel pumps. The latter can, for a given rate of consumption, be designed for a higher peak demand without incurring much additional cost. The figure above illustrates the specific water pumping costs [CH\$/m^4] for the project site in Vitor/Chile.The installed PVP system is compared with the smallest available diesel pump as a function of the degree of system utilisation for different interest rates.

High degrees of system utilisation are necessary to make PVP economically viable. Since the diesel system has a lower investment cost, the water pumping costs react less sensitively to interest rate changes. For low interest rates, the PVP option is economically superior, even at a low rate of system utilisation (50%). At the postulated maximum interest rate of 12%, costs equality is achieved for a utilisation rate of approximately 80%.

The next figure illustrates the effects of different operating modes on the specific water pumping costs for variable water discharge rates. High water discharge rates correspond with high degrees of system utilisation for a certain pump. A standby unit (SB) was included with the diesel system in order to compensate for its inferior technical reliability. This increases the specific water discharge costs by 10–18%. A PVP system without a storage tank presents an average cost advantage of 15%.



Generally PVP systems tend to be economically viable with a real discount rate below 12% p.a., a degree of system utilisation above 60% and an irrigation area smaller than 4 ha.

At higher latitudes the field-cropping irrigation season lasts only five months. There PVP will be economically disadvantageous, since a degree of system utilisation in the order of 30% must be anticipated.

5.2.3 Profitability of irrigation

As a rule, irrigation is employed to get additional benefits from agricultural or horticultural production. Therefore, the additional income achieved should outweigh the costs of irrigation and allow for a sufficient profit or amortization of the investment. In the project area, agriculture is not possible without irrigation. Hence the overall costs of agricultural production (including the cost of the water supply) were compared with the sales proceeds achieved for the pilot sites in Chile.

The model calculation of revenues and input costs for various cultures was performed for an average cropland area of 3 hectares using field and statistical data. The results revealed that irrigated farming is highly profitable in northern Chile. The internal rate of return on the capital inputs (soil, wells, irrigation system, etc.) exceeds 70%. The portion of costs of irrigation accounted for a surprisingly low 4–6% for most of the crops analysed. Hence, cost advantages gained via one or the other pumping technology have a small effect on profits.

While the farmer operators of PV-based systems appreciate their superior reliability and the potential for automating their irrigation systems, such advantages are difficult to express in monetary terms. Consequently, most investment decisions tend to favour diesel pumps over PVP systems. That drawback may be compensated, and the farmers' financial risk minimized, by way of appropriate financing and assistance models.

5.3 Management requirements

The production management of a PV-based irrigation system is somewhat more complicated than that of a conventional pumping system due to daily and seasonal fluctuations of the solar insolation.

One of the most important site-specific cost factors is the degree of system utilisation, which is the ratio between the average and the maximum annual water production. This factor will always be below 85 % since fallow periods between the growing periods and the alternating water requirements of the crops at different growth stages don’t permit better system utilisation even under optimised conditions.

Once the system is installed, one of the farmer's main management tasks is to plan the cropping and the irrigation in order to reach a maximum degree of utilisation. As a rule, this entails a change in how the farm is managed. The resultant changes in timing and work routines can be crucial for the acceptance of PVP technology.

Nevertheless, Chilean farmers, who are used to facing daily problems with their diesel pumps, greatly appreciate the high level of reliability and low maintenance requirements of PV irrigation systems. That fact alone contributed much to the acceptance of this new technology.

5.4 Environmental impacts

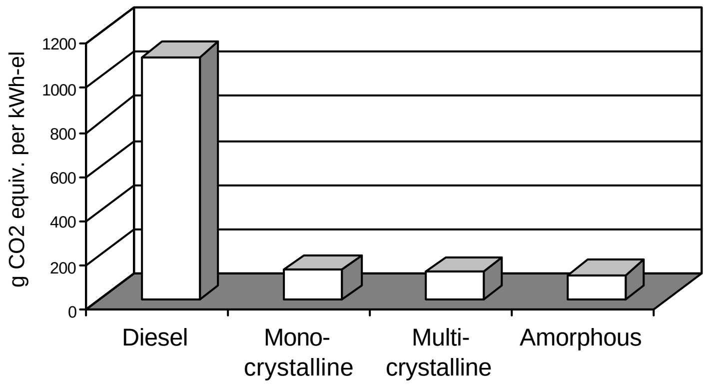
5.4.1 Life cycle analysis of PVP and diesel pumps

A project study conducted in cooperation with the German Institute for Applied Ecology analyzed the environmental impacts of photovoltaic and diesel pump irrigation systems on a life cycle basis.

The study incorporates a calculation of greenhouse gas emissions (as CO_2 equivalents), acid air emissions (as SO_2 equivalents) and cumulated energy requirements (CER). Qualitative environmental impacts, such as the pollution of water and soil by diesel oil, were also analysed. Finally, energy productivity factors and energy payback times of three PV technologies (monocrystalline, multicrystalline and amorphous silicon modules) have been determined.

The life cycle comparison is performed for conditions in sun-rich developing countries (assumed solar irradiation 2000 kWh/m²*a) and analyses the so-called "cradle-to grave pathway" that includes the manufacturing process, transport, operation and partial recycling of system components.

The results of the life cycle comparison show that the greenhouse gas emission balance of PV pumps is approximately 10 times smaller than that of the diesel system. For acid air emissions, diesel and PV systems differ by a factor of at least 50.



5.4.2 Energy productivity factors and payback times

The energy productivity factors and energy payback times are further indicators of the environmental burden resulting from solar modules. The energy productivity factor is defined as the quotient of the total energy supplied by an energy system during its lifetime and the total manufacturing energy input for this system.

The energy payback time is calculated by dividing the energy-specific manufacturing input for an energy system by the amount of energy it supplies annually. It corresponds to the period after which an energy system has "paid back" the energy used for its production through the energy it supplies. Both factors are comparatively favourable for PVP in sun-rich regions.

In summary, PV modules are significantly less of an environmental burden than the diesel reference system, even with conservative assumptions regarding module lifetime, rack and frame construction. In the life cycle comparison with fossil fuel systems, the foreseeable improvements of PV manufacturing technologies will further increase their advantages.

5.5 Perspectives

Although photovoltaics still counts among the most expensive ways to utilise solar energy, it has already found its way into numerous agricultural and horticultural applications, many of which are economically attractive. PVP in particular constitute an alternative worth considering if the object is to pump irrigation water to crops at locations with no access to grid power.

The project experience yields the following conclusions:

- In order to reduce the energy requirements of PVP irrigation systems water-conserving and energy-saving micro-irrigation techniques have to be applied.
- The plot size for PVP irrigation should be below 4 hectares.
- High rates of system utilisation are necessary to achieve economic viability of PVP irrigation systems.
- Therefore PVP systems are limited to irrigate permanent crops and continuous crop rotation in arid climates.
- High value-added cash crops like fruits, vegetables and spices should be given preference to recoup the high initial investment.
- Low-interest loans should be available for the same reason.
- PVP irrigation systems require a careful planning of the crop schedule and are more demanding of user skills.

A site-specific economic efficiency analysis should always be performed prior to any investment decision. Despite their indicated limitations, solar irrigation systems are bound to gain importance in the future, primarily by virtue of their low environmental impact, high reliability and lack of dependence on fossil energy sources.

6. Literature

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