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Workshop on "Solar Cells and Water Pumping Systems"

Photoenergy Center, Faculty of Science, Ain Shams University,
Cairo, Egypt 20-22 December *2001*

A I N S H A M S U N I V E R S I T Y

Project No.: TF/GLO/00/105
UNIDO Contract No. 2001/358

[2] Final Report

Professor Dr. M. S. A. Abdel-Mottaleb
Director, Photoenergy Center, Ain Shams University

Book of Abstracts

Cairo, Egypt

hv Center

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

International Center for Science and High Technology

In collaboration with

Ain Shams University

Workshop on

"Solar Cells and Water Pumping Systems"

organized by

Photoenergy Center, Faculty of Science, Ain Shams University,

20-22 December *2001, Cairo, Egypt*

Under the Auspices of

Prof. Dr. M. Shehab
Minister of High Education and Scientific Research

Prof. Dr. M. Tageldin
President of Ain Shams University

Prof. Dr. S. Hashem
V. President of Ain Shams University

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Directed by

M. S. A. Abdel-Mottaleb
Professor of Chemistry, Director
Photoenergy Center

Eng. Umberto Moshella
Consultant, ICS, Trieste, Italy

FORWARD

"Solar Cells and Water Pumping Systems"

Why the Photoenergy Centre?
ICS-UNIDO selected the PHOTOENERGY CENTER as hosting institution for the Workshop on "Solar Cells and Water Pumping Systems", Cairo, Egypt. This is because:

- The Photoenergy Center at the Ain Shams University is a research and development organization that deals with light interactions with matter and the development of new PV products and systems.
- Promising achievements would be expected by using the facilities available at the Photoenergy Center. The Center is also well connected with leading research institutions all over the world. The Center will make use of its scientific connections in realizing and complementing research to be carried out for the development of new low cost and more efficient PV products and systems.
- At a national level, the Center also has very good contacts with local industries that will enable the identification of industrial partners for close collaboration in the project. In this area, the final goal of the Center is in the identification of technologically developed products, which should be correctly integrated and adapted to market conditions.
- Furthermore, we have already collaborated with ICS on numerous occasions. The authorities of ICS and UNIDO described our role as "very professional and active in all aspects. Moreover, the Center is the most suitable focal point as a regional center due to its excellent activities and facilities for the training of PV systems and applications and to its geographic position."

The Problem?

Many regions of the world suffer from severe shortages of rain and surface water, and must depend on underground aquifers for their daily supply. Traditional pumping and irrigation systems, employing diesel engines and electric-grid powered motors, represent a partial solution for some water delivery needs. But the cost of fuel and electricity, spare parts and service —or the equivalent in time and labor of hand pumping systems— make water-pumping technologies prohibitively expensive for many rural towns and villages . . . the populations that need them most.

The Solution is Moving Water with Sunlight!

Clean, silent, maintenance-free solar electric power is a technology made for the water pumping requirements of the developed and developing world.

Studies show that on the village level, photovoltaic systems are less expensive to purchase and operate than similar systems powered by diesel engines. A 480Wp array will provide electricity for a water pumping system that will provide 1,000+ gallons of water per day with a 100' lift.

Nearly 2 billion persons — or 30% of the world's population— lack access to water for drinking, livestock, and irrigation. And for those who have water, many spend inordinate amounts of time collecting and transporting it.
Solar water pumping systems are an efficient, clean and inexpensive way to deliver steady supplies of water for drinking and farming applications during daylight hours.

Who should care and finance PVP systems?
On the international level, ICS-UNIDO, with its access to laboratories, and its international network clearly provides an ideal mechanism for developing relevant skills and diffusing among international industrial communities, interesting research issues and building industrial capacity. ICS through its international connections and activities could promote good projects and find out potential donors for offering funds. This workshop is a good opportunity for ICS to build a database of information on countries needs, promising projects including manufacture of PV modules, system design, application and performance to permit process optimization.

The suggested main objectives of the workshop are:
- To provide an understanding of the necessary prerequisites to establish a sustainable cell manufacturing capacity for PV market developments.
- To develop critical skills in PV conversion and provide to the industry a development forecast for the new technology.
- Update engineers, scientist/technicians in the basic field of planning and designing of efficient cells for more efficient systems.
- Help developing countries to improve their awareness of tools relating to cells research and to the development of new techniques to realize more efficient cells and modules.
- Initiate contacts and promote co-operation between industries, important research institutions and governments.
- To know if it is possible to separate the PV cell production line from the electronic silicon industry.
- To select the best promising cell for the future and to build cell information databases.
- To analyze the specific site working conditions of PV Water Pumping Systems in Africa and Middle East.
- To revue critically the design of a PV Water Pumping System and optimize a standard project that overcome the running problems of installed systems.

The expected outputs are:
- Lecture notes, case studies and basic information on photovoltaic cells.
- Approximately 15 delegates from Europe, Africa and Middle East will meet to discuss PV cell technologies, manufacturing procedure; statistics on working conditions of existing PV Water Pumping Systems in each country, actual running problems and how to cope with.
- Accomplishment of the state of the art in the field of cell efficiency, production and possible cost reduction; state of the art in the field of PV Water Pumping Systems.

Who we are?
The participants of our workshop are a good mix of academicians, expert engineers, laboratory researchers, technicians and high rank (directors) government employees all of whom are involved, in a way or another, in the research and development of PV cells and in the management or responsibility of running a PV Water Pumping System. High-level engineers, scientists and experienced economists and researchers in PV cell development are gathered from different Egyptian institutions. Most of who are specialists in the field of photovoltaic cell research and production and management of PV Water Pumping Systems.

The following topics will be covered and discussed:

- PV market characteristics, and growth scenarios concerning cells availability.
- Cells for a cheaper PV power module and for a more affordable PV Water Pumping Systems.
- Cells production specifications, performance testing, and results.
- Cells quality control techniques and standards.
- Cell factory quality control – Site visit.
- PV cell technology, history, future directions.
- PV cell manufacturing procedures.
- How to better use cells in a module: case study.
- Polycrystalline thin-film silicon solar cells on glass, a pathway towards lowering the cost of solar cells.
- Parallel multijunction thin-film silicon solar cell, aluminium-induced crystallisation (AIC).
- How are running the existing PV Water Pumping Systems in some African countries especially in North Africa and Middle East?
- How can we improve these Systems?
- Identification of the region needs and develop projects.

Acknowledgments
I would like to thank Mr. Kenichi Ushiki and Mr. Umberto Moschella, ICS, AREA Science Park, Padriciano, Trieste, Italy for very collaborative efforts in realizing holding this conference and making it a very successful one. Sincere thanks go to the authorities of Ain Shams University and the colleauges from the Faculty of Science for solid and continuous support. Moreover, I would like to thank the staf members of the photoenergy centre and my research group as well as the Departments of Chemistry and Public relations for the sincere assistance offered during the organization of this fruitful scientific event of applied nature. Last but not least, I thank all lecturers and participants for their scientific and technical contributions that enrich the content of this international event.
I wish you all very sucessful meeting and a nice stay in our sunny country.

M. S. A. Abdel-Mottaleb
Professor of Chemistry,
Director, Photoenergy Center

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

International Center for Science and High Technology

Workshop on

"Solar Cells and Water Pumping Systems"

Photoenergy Center, Faculty of Science, Ain Shams University, Cairo, Egypt 20-22 December *2001*

SUMMARY TIMETABLE

0th Day: WEDNESDAY 19 December 2001

Arrival (meet and assist at the airport)
Transportation to Sonesta hotel
6.00 PM REGISTRATION Ambassador Room
7.30 PM WELCOME RECEPTION/DINNER Coffee Shop [Green House]

1st Day: THURSDAY 20 December 2001

08.30 - 09.30 REGISTRATION Ambassador Room

GENERAL OPENING SESSION

Prince Hall

09.30 - 10.15	O P E N I N G [Abdel-Mottaleb, Moshella, Ushiki] Welcome Address [OFFICIALS, ASU]
10.15 - 10.45	Opening Address [Development of multicrystal silicon PV modules production technology, D. Margadonna, Italy]
10.50 - 11.30	Coffee BREAK
	Chairman: U. Moshella
11.30 - 12.00	Opening Address [PHOTOVOLTAIC APPLICATIONS with Emphasis on PUMPING, A. Sayigh, UK]
12.00 - 12.30	Opening Address [Resource-Conserving Irrigation With Photovoltaic Pumping Systems, A. Hahn, GTZ, Germany]
12.30 - 13.00	Opening Address [Energy Demand and domains of irrigation favourable for P.V. solar energy application, Alfi Malek, France]
13.00 - 13.20	Opening Address [State-of-the-art: PV market and different materials based solar cells, T. Razykov, Uzbekitan]
13.20 - 15.00	Lunch Break [Green House]

EXPERT GROUP SESSIONS FOR ONLY REGISTERED PARTICIPANTS

EXPERT REPRESENTATIONS:

[PV cells/Modules Factory] Feasability study, [Water Pump System] a case study and [Research activity] Research

Chairmen: Sayigh, Moshella, Hahn, Malek

15.00 - 15.15	S. Binqadhi (Yemen)
15.15 - 15.30	Amor OUNALLI (Tunis)
15.30 - 15.45	I. Odeh (Jordan)
15.45 - 16.00	M. Gholami (Iran)

16.00 - 16.30 Coffee BREAK

Chairmen: Sayigh,Moshella, Hahn, Malek

16.30 - 16.45	Abdelfattah Barhdadi (Morocco)
16.45 - 17.00	N. Attili (Palastine)
17.00 - 17.15	M. Dieng (Mauritania)
17.15 - 17.30	A. AbdelMageed (Egypt)
17.30 - 18.00	General Discussion and Conclusion

19.30 - 20.30 Dinner [Green House]

Evening Session

Ambassador Room

20.30 - 22.00 Round Table Discussion [Task Groups [PV cells/Modules Factory] Feasability study, [Water Pump System] a case study and [Research activity] Research] [I. Odeh, P. Parichehreh, N. Raslan]

2nd Day: FRIDAY 21 December 2001

Prince Hall

EXPERT REPRESENTATIONS:

[PV cells/Modules Factory] Feasability study, [Water Pump System] a case study and [Research activity] Research

Chairmen: Margadonna, Hahn, Moshella, Malek

09.00 - 09.15	Ato Gebre (Ethiopia)
09.15 - 09.30	B. Bessais (Tunisia)
09.30 - 09.45	R. Chedid (Lebanon)
09.45 - 10.00	E. Ahmed (Egypt)
10.00 - 10.30	Coffee Break
10.30 - 10.45	Munther Kharraz (Jordan)
10.45 - 11.30	Discussion [chaired by: Margadonna and Moshella]

11.40 - 14.30 BREAK (Friday Parayer followed by Lunch)

Bus will leave from the front door of Sonesta Hotel at 14.30 sharp

14.30 - 22.00	Visit of ASU, Photoenergy Center, EXPERT REPRESENTATIONS:
	Round Table Discussion [Water Pump System] case studies
	City Tour and Nile Cruise/Dinner

3rd Day: SATURSDAY 22 December 2001

Prince Hall

Chairman: Sayigh, Margadonna, Hahn, Moshella, Malek

09.00 - 10.30	I-II-III Combined Sessions [PV cells/Modules Factory] Feasability study, N. Raslan
10.30 - 11.00	Coffee break
11.00 - 13.30	I-II-III Last Combined Sessions [Research activity] Research
13.30 - 14.30	Lunch
14.30 - 18.00	Presentation of Outcomes from Parallel Sessions and Conclusions
19.00 - 22.00	Farewell Dinner [Green House]

4th Day: SUNDAY 23 December 2001

D P A R T U R E

We wish you a safe and nice return flight to your home country

WORKSHOP
"SOLAR CELLS AND WATER PUMPING SYSTEMS"
20 – 22 December, 2001, Cairo, EGYPT

DEVELOPMENTS ON mc-Si PV MODULES PRODUCTION TECHNOLOGIES

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ABSTRACT

In the short-medium time period, the PV market expansion will be mainly based on crystalline silicon PV modules due to the fact that such modules are efficient, reliable, and cost effective. Among crystalline silicon PV technologies, the multicrystalline silicon (mc-Si) is the most promising material to meet the expected requirements for the next decade.
Recent progress in mc-Si technologies are:
-**Material development**: a deeper knowledge of the recombination phenomena occurring in the external skin of a directional solidified silicon ingot made possible to increase the material process yield. Nowadays, crystallisation furnaces have a capacity of approx. 20 kg/hr/furnace, combined with an energy consumption as low as 10 kWh/kg. The capacity of wafering machine has been increased, reaching the a production rate of 10m^2/hr/machine.
- **Solar Cell development**: the introduction of the hydrogen grain boundary passivation in the production practice has significantly improved the mc-Si solar cell performance from the value of 12,5% to > 14%, as average production efficiency. A further improvement is expected from the development of more effective printing pastes able to contact 50 ohm square diffused layers with a printed line width < 100 micron. Efficiency in excess to 16% efficiency was already reached on 225cm^2 wafers [1]
- **Module arraying**: the present arraying and encapsulating technique contribute by a 30% to the total module cost. New and more cost effective techniques have to be developed to use larger and thinner solar cells.
- **Feedstock:** the expected PV expansion could be limited by the lack of silicon feedstock, in large quantities at sustainable price. The commitment of the PV industry in developing suitable Solar Grade Silicon feedstock cannot be delayed further.
In conclusion, the target of $1,5/Wp for mc-Si based PV modules in the year 2010 can be approached by introducing in high throughput production lines technical results already proven at pilot scale level:

- Si Feedstock of constant quality, available in large quantities at prices < $ 15/kg.
- Large area (>225cm2) and reduced thickness (< 250 micron) wafers, having a production cost < $100/m2;
- Upgrading solar cell process line by introducing passivation, and gettering techniques together with more effective printing pastes. A production average efficiency > 16% is expected.
- An effective use of large and thin solar cells will be possible when new arraying techniques will be introduced in mass production.

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[1] S. Arimoto et al., 28th IEEE Photovoltaic Specialist Conference, Anchorage, Sep. 2000

Energy Demand and Domains of Irrigation Favourable for P.V. Solar Energy Application

Alfi Malek and Xavier Goossens

Solar Energy can play its role advantageously in specific irrigation conditions. This paper analyses technical and economical conditions favourable to P.V. application. It is based on the results of energy consumption evaluation for irrigation, made on request of the French "Global Environment Facility"(*). It analyses the main factors having an impact on the energy demand in irrigation projects (water demand, water and energetic pumping efficiency, accessibility of resources, etc). A case feasibility study dealing with a low raise application is presented in terms of dimensioning, cost and Green House Gas Effect, with comparison to conventional systems.

* Xavier Goossens, 2000 – Impact des projets d'irrigation en terme de consommation énergétique et d'émission de gaz à effet de serre, Ecocampus University Bordeaux 1, FFEM (French Global Environment Fund).

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PHOTOVOLTAIC APPLICATIONS With Emphasis On PUMPING

Ali Sayigh

Chairman of World Renewable Energy Congress,
Director General of WREN, Prof at University of Hartfordshire.
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There are more than 300 Photovoltaic (PV) applications which are used in a daily bases. Some of these applications are large in nature but vital so that cost is not a criterion such as in the case of Space Applications. However, there are more than 30 applications, which are cost effective and commonly used around the globe.

One of the important uses of PV now a day in Water Pumping, Oil Pumping and Petrol Filling Stations. Other applications in rural and remote areas such as at homes and in the communities are well described in this paper. Repeater stations and telecommunications are other useful usage of PV. Military, medical and agricultural PV applications are well described and their cost and sizes will be assessed.
PV pumping for desalination, irrigation and other applications will be demonstrated in this paper and their benefits will be stated.

The growing demand on PV around the world, its cost reduction and efficiency improvement will make it one of the best electricity generation options in rural development. The solar cell production is expected to increase from 200 MWp to 940 MWp during the next 10 years. The efficiency will improve (for crystalline silicon) from 15% to 23% during the same period.

RESOURCE-CONSERVING IRRIGATION WITH PHOTOVOLTAIC PUMPING SYSTEMS

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ABSTRACT: In areas of developing countries with no access to grid power, diesel-driven pumps are commonly used for irrigation in farming and forestry. Diesel pumps, however, require regular maintenance and refuelling, and they place a burden on the environment. Wherever the failure of a diesel pump and the expense of its operation constitute an economic risk for the operators of small-scale irrigation systems, photovoltaic pumps (PVP) represent a reliable, alternative means of water delivery.

Keywords: PV Pumping - 1: Irrigation - 2: Developing Countries - 3

1. INTRODUCTION

The use of photovoltaic pumps for irrigation represents a promising option for using solar energy productively and for generating income.

However, the use of photovoltaic pumps for small-scale irrigation is still held back by a lack of information and practical experience [1]. This kind of information is very important for convincing people in the irrigation sector that it is worth considering the option in the first place. To bridge this gap, the pilot project entitled "Resource-conserving Irrigation with Photovoltaic Pumping Systems" was started early in 1998 with a duration of four years.

2. PVP IRRIGATION PILOT PROJECT

2.1 The Role of GTZ and its Partners

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, in cooperation with national project executing organizations in the following countries:

- Ethiopia; Bureau of Agriculture and Natural Resources
- Chile; Centro de Energías Renovables, University of Tarapacá
- Jordan; Ministry of Agriculture (in preparation)

The interdisciplinary character of the pilot project calls for close cooperation with experts from diverse professional areas. With a view to introducing sustainable dissemination processes, the suppliers of PVP irrigation systems with their local structures, together with national and private-sector institutions, are being involved in the project activities.

2.2 Objectives

The project is designed to clarify whether photovoltaic pumping systems can be used to irrigate high-quality crops in a cost-effective and resource-conserving manner, and what management and technical requirements must be met in order to operate a PV-based irrigation system. In the course of the project, 10 pilot systems are being field-tested and intensively monitored at selected locations in Chile, Ethiopia and Jordan.

The field-testing of PV-based irrigation systems is intended to enable the users and operators of the pilot facilities to assess and evaluate the technology. Therefore the project places great emphasis on upgrading of project partners and training of system users.

2.2 Target Group

Due to the comparatively high initial investment cost (see 4.), PV irrigation is <u>not</u> a solution for the individual subsistence farmer.

The project focuses primarily 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, hence generating income that could be used to finance a PV-based irrigation system.

Up to now, four pilot plants (0.3-1.2 kW_p) for cash-crop production have been installed in the Atacama Desert in the northern part of Chile. In order to investigate the application of PV-based irrigation systems in forestry, three pilot plants (0.3-0.4 kW_p) have been installed in Ethiopia to supply tree nurseries with irrigation water. The aforementioned systems have been in operation for about two years. Another three systems for cash-crop production will be installed in Jordan in the year 2000.

3. TECHNICAL ASPECTS

3.1 Operating Principle

The operating principle behind any photovoltaic irrigation system is quite simple. A solar generator provides electricity for driving a submersible motor pump, which in turn pumps water into an elevated water tank (see fig. 1).

The water tank bridges periods of low insolation and supplies the pressure needed for the irrigation system. 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 PV-based 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.

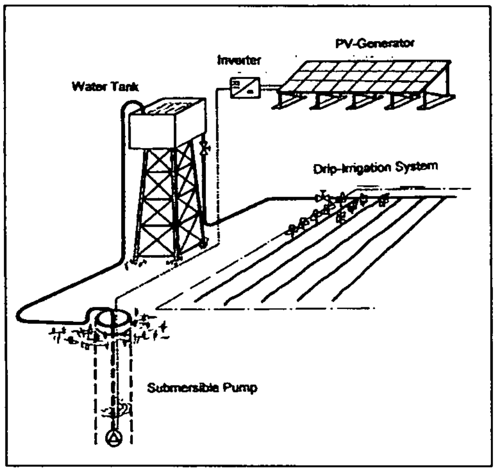

Figure 1: PVP standard system combined with a conventional drip irrigation system

Force of gravity causes the water to flow from the tank to the fields. The PV Irrigation Pilot Project is also testing units that feed directly into the irrigation system and therefore do not require a water tank.

Drip irrigation permits economical use of water, and its relatively low operating pressure makes it particularly well-suited for combination with photovoltaic pumping systems. However, it must be pointed out that such hi-tech irrigation systems are not necessary. Alternative irrigation techniques are possible, as long as they are water- and energy-conserving.

3.2 Technical Monitoring

In order to permit continuous monitoring of crucial operating parameters, all pilot systems are 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 (see fig. 2) facilitate management of the irrigation systems, and the water consumption data provide information on the degree of system utilization.

While the technical aspects of solar irrigation are generally regarded as adequately developed, a closer look reveals that there is still need for research at the laboratory and field-test levels. In that context, the design and testing of special low-pressure irrigation systems, including suitable filters and fertilizer injection devices, must be given special attention.

The Chilean project sites were equipped with locally available, low-pressure drip systems, suitable for operation with PVP equipment [2]. The field data confirmed that the systems are very reliable and operate at low system pressures of the order of 0.2–0.3 bar (tank height), thereby guaranteeing a uniform supply of water to the field (measured uniformity coefficient > 95 %).

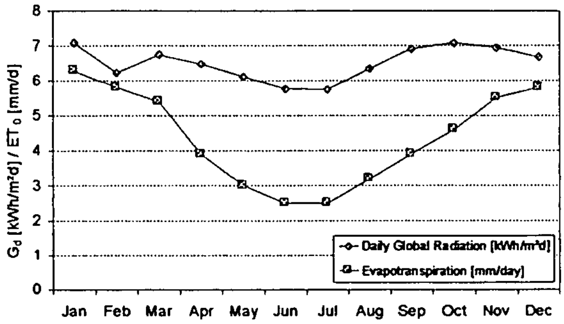

Figure 2: Recorded daily global radiation (G_d) and evapotranspiration (ET_0) at pilot site Chaca, Atacama Desert, Chile

This presumes, of course, that all components of the drip irrigation system have been designed for such a low system pressure. The uniformity of water distribution must also be guaranteed for variable pressure conditions.

In PVP standard systems (see fig. 1) pressure fluctuations are compensated by the water tank. However, building such a tank involves much cost and effort, accounting for a correspondingly large share (35 %) of the capital outlay for a typical PVP system. On economic grounds especially, direct pumping of water to the field is advisable.

4. ECONOMIC CONSIDERATIONS

4.1 Investment Costs

Although the advantages of solar technology are evident, purchase decisions are often taken in favour of the competing diesel-powered systems. The comparatively high investment costs of the solar system are critical here. Figure 3 shows the price of a PVP system related to power generation.

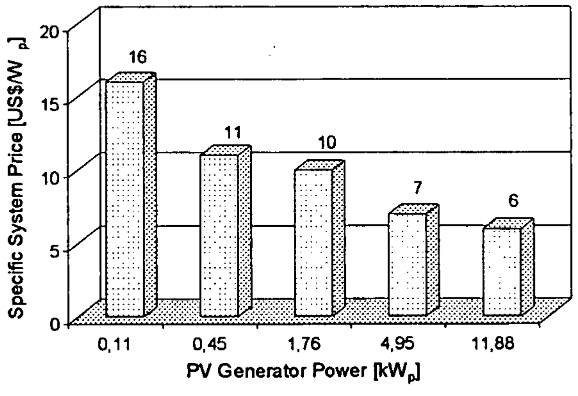

Figure 3: Specific PVP system prices (ex-works) without water tank, fence and surface piping (Source: Siemens Solar)

Today the operator of a ready-to-use solar pump pays about 3 times as much as would be needed for a diesel pump with the same performance [3]. However, it is frequently overlooked that after installation the solar system incurs only a fraction of the operating costs of a diesel pump. Consequently it does not make economic sense to compare different technologies solely on the basis of the investment costs.

4.2 Specific Water Discharge Costs

The specific water discharge costs [Euro/m^4], covering both investment and operating costs, are taken as a basis for comparing the costs of solar and diesel pumps. Furthermore, the specific water discharge costs permit an evaluation of different pumping technologies, even for sites involving different pumping heads and degrees of utilization.

The costs per cubic metre supplied are obtained by multiplying with the pumping head at the relevant location. In the drinking water sector GTZ has demonstrated the cost advantages of solar pumps in the performance range up to 2 kW_p in six out of seven project countries (Asia, Africa, Latin America) [3].

First results of photovoltaic water pumps applied in small-scale irrigation systems are promising, although after two years of operation the present economic data base is still insufficient for a final evaluation. However, it does suffice to identify a basic trend.

To illustrate this point, fig. 4 shows the latest results of an economic study at Vitor, one of the Chilean pilot sites.

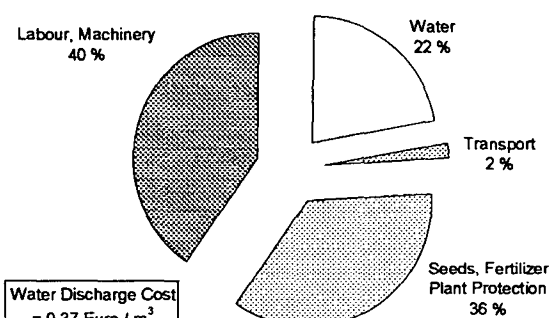

Figure 4: Site-specific distribution of cost for potato production in Chile

It is surprising that the cost for water supply only accounts for 22 % of the total annual production costs. For potato production, the water discharge cost amounts to around 1.57 Euro-Cent/m^4. Compared with a conventional diesel-driven pump, this particular PV-irrigation system is economically viable. However, due to the variability of country and site-specific cost factors, no generally valid conclusion can be drawn with regard to the overall viability of photovoltaic pumps.

4.3 Range of Application for PV Irrigation

Generally, it can be stated that as long as the following site-specific conditions apply, economic advantages of photovoltaic pumps over competing diesel pumps can be expected:

- arid/semi-arid climate
- no access to the public power grid
- problems with the maintenance of diesel pumps and the supply of fuel for their operation
- pumping head up to roughly 30 metres
- max. field size of 3 hectares
- cultivation of high-quality crops for secure markets
- use of water-conserving and energy-saving methods of irrigation (e.g. drip irrigation)
- high degree of system utilization through adoption of permacultures or systematic crop rotation

However, a site-specific analysis of the economic viability should always be carried out before a decision on investment is taken.

5. MANAGEMENT REQUIREMENTS

Compared with a conventional pumping system, the production management of a PV-based irrigation system is somewhat more complicated, due to daily and seasonal fluctuations in the amount of energy provided by the sun.

One of the most important site-specific cost factors is the degree of system utilization, which is the ratio between the average and the maximum yearly water production. Due to fallow periods between the growing periods as well as the alternating water requirements of the crops at different growth stages, a utilization degree of ≈ 85 % is the maximum achievable [4].

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 utilization. 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.

One advantage of diesel-driven pumps is the direct availability of water after pump start-up. Some farm-workers seemed to have far more difficulties in getting used to handling a PVP-system than their employers. Accustomed to the "instant-power effect" and high pressure of diesel pumps, some farm-workers complained that the PVP system delivers too little water. In spite of initial doubts, the farmers and workers are now showing a high degree of acceptance.

The high level of reliability and low maintenance requirements of PV irrigation systems are the features most appreciated by Chilean farmers, who are used to facing daily problems with their diesel-driven pumps. That fact alone has contributed much to the acceptance of this new technology.

6. ENVIRONMENTAL IMPACTS

6.1 Life-Cycle Analysis of PVP and Diesel Pumps

Within the scope of the pilot project, the environmental impacts of photovoltaic and diesel-driven irrigation systems were investigated. Together with the *Institute for Applied Ecology*, GTZ has carried out a life-cycle analysis, comparing the two different technologies [5].

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), as well as qualitative environmental impacts, such as the pollution of water and soil by diesel oil. In addition, 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", including 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 (see fig. 5). For acid-air emissions, diesel and PV systems differ by a factor of at least 50.

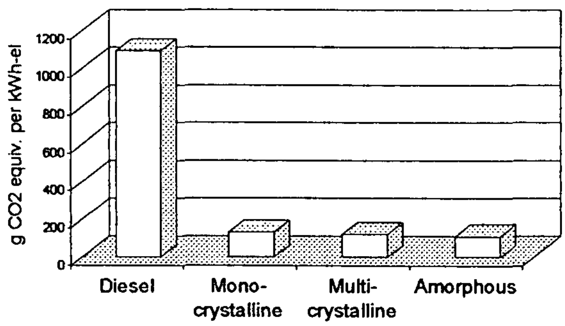

Figure 5: Life-cycle comparison of greenhouse-gas emissions

6.2 Energy Productivity Factors and Payback Times

The energy productivity factors and energy payback times are considered to be further indicators for the indirect 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 input for this system. It thus describes the energy productivity of the system.

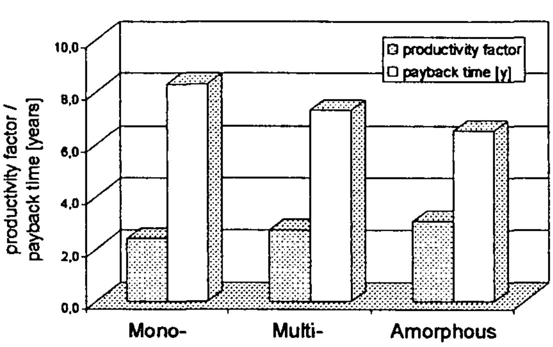

Figure 6: Energy productivity factors and energy payback times of PV modules

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. This thus corresponds to the period in years after which an energy system has "paid back" the cost of its production through the energy it supplies.

As fig. 6 shows, both the energy productivity factors and energy payback times of PV modules are comparatively favourable in sun-rich regions.

In summary, PV modules are significantly less of an environmental burden than the diesel reference system, even for conservative assumptions regarding module lifetime, rack and frame construction. In the life-cycle comparison with fossil-fuel systems, the foreseeable developments of PV manufacturing technologies will further increase their advantages. Other aspects, such as contamination of soil and ground-water resources can be completely avoided when deciding in favour of the PVP option.

7. CONCLUSION

In conclusion, one can state that in principle, PV irrigation systems are suitable for small-scale irrigation purposes in farming and forestry. Photovoltaic pumps require little maintenance and no fuel and therefore often constitute the only reliable solution to the problem of irrigation water supply in remote areas. The adaptation of a conventional irrigation system to the photovoltaic pump still leaves scope for component improvement.

First results concerning economic efficiency confirm that PV-pumps are able to yield cost advantages over diesel-driven pumps, as long as certain site-specific conditions apply. However, the high initial investment costs are still the main obstacle to distribution of PV pumps. Therefore it is necessary to compensate for the high investment costs by providing loans on favourable terms via development banks or through other suitable financing models.

Besides the purely financial evaluation, additional criteria are needed for an overall evaluation of PVP-technology. Fuel and lubricants for diesel pumps often pollute wells, soil and groundwater. By contrast, photovoltaic pumps are an environmentally sound and resource-conserving technology. This fact, together with the high level of technical reliability, has contributed much to the farmers' acceptance, in spite of initial doubts.

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IRRIGATING WITH THE SUN – GENERATING INCOME WITH PHOTOVOLTAIC WATER PUMPS

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ABSTRACT: In horticulture and agriculture, many crops require regular watering to achieve good yields and high quality. Photovoltaic water pumps (PVP) are always an alternative worth considering when the object is to pump irrigation water to crops at locations with no access to grid power. In the course of multi-year field tests performed by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, PV-based irrigation systems were able to demonstrate both their technical reliability and their economic competitiveness.

Keywords: PV Pumping - 1: Irrigation - 2: Developing Countries - 3

1. INTRODUCTION

Within the scope of the pilot project entitled *Resource-conserving Irrigation with Photovoltaic Pumping Systems*, which is being financed by the Federal German Ministry for Economic Cooperation and Development (BMZ), GTZ has since 1998 been investigating the application potentials of photovoltaic water pumps in small-scale irrigation systems [1]. In cooperation with the partner countries Ethiopia, Chile and Jordan, a total of ten pilot installations on private- and public-sector farms are serving in the production of cash crops and undergoing intensive monitoring.

With regard to technical reliability and social acceptance, the pilot installations studied have met all expectations, hence mirroring the results of prior evaluations stemming from the drinking water sector [2]. Due to a lack of field experience, it has not yet been possible to fully answer the question of whether photovoltaic pumps are able to supply irrigation water at lower cost than comparable conventional systems. The aforementioned pilot project includes site-specific case studies enabling delimitation of the economically viable range of application for PV-based irrigation.

2. OFF-GRID IRRIGATION

2.1 Diesel/Petrol Pumps

An increasing scarcity of agriculturally utilizable land, coupled with the consequently rising cost of leases and property, often induces farmers to move to areas with little infrastructure. The customary means of pumping irrigation water in areas devoid of grid power are diesel- or petrol-driven pumps [Fig. 1]. Such conventional pumps, however, have the double drawback of requiring much and expensive maintenance and depending on a regular supply of fuel, so that unattended operation of such equipment is not possible. Often, especially in remote areas of developing countries with inadequate spare parts and maintenance structures, diesel- and petrol-driven pumps can repeatedly suffer outages of several days' duration. The resultant lack of water can cause such serious damage to crops that yields drop noticeably.

For the farmer, the use of conventional pumping systems therefore amounts to an economic risk. In addition, the noise and exhaust from such pumps impact upon the environment, and the pollution of ground water and soil by diesel fuel and lubricants is no rare occurrence.

Figure 1: Conventional diesel-driven pumps require regular maintenance and refueling and they place a burden on the environment

2.2 Photovoltaic Water Pumps

Environment-friendly, low-maintenance PVP provide new possibilities for pumping irrigation water, but they still constitute a little-known technical option. The operating principle behind any photovoltaic irrigation system is quite simple. Within the scope of the pilot project, two different system configurations are employed.

In the first case, a solar generator provides electricity for driving a submersible motor pump, which in turn pumps water into an elevated water tank [Fig. 2]. The water tank serves as an energy store and supplies the pressure needed for the irrigation system. Pilot plants equipped with a water tank operate at considerably lower system pressures (0.2-0.5 bar), as compared to conventional diesel- or petrol-driven pumps. This presumes, of course, that all components of the irrigation system have been designed for such a low pressure.

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 systems pressures and water flow.

Drip irrigation permits economic use of water, and its relatively low operating pressure makes it particularly well-suited for combination with PVP. Unlike other irrigating processes, drip irrigation is amenable to a continuous supply of water, so the pump can run all day over the entire growing season. Since both the crop's water requirement and the output of the pump are functions of global radiation, the two systems go hand-in-hand up to a certain point. However, the capacity of the PVP must be designed for the maximum water requirement.

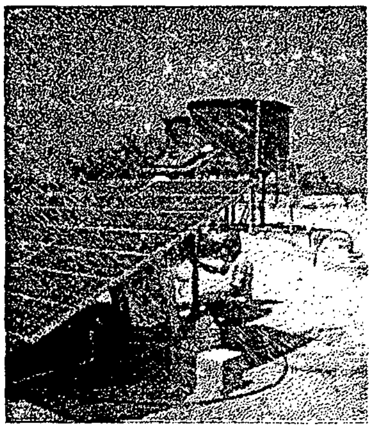

Figure 2: Photovoltaic irrigation system for cash-crop production in Chile (1150 W_p)

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 utilization. In that sense, conventional motor-driven pumps are more flexible. The maximum daily output of a motor-driven pump depends not only on its technical specifications, but also on the (freely selectable) daily operating time. This gives it a comparatively high level of adaptability to fluctuation in demand.

The better the crops are able to assimilate the actually supplied quantities of water, 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 utilization of solar pumping systems. Uninterrupted crop rotation patterns or continuous cropping systems with high value added (e.g., such cash crops as fruit, vegetables, herbs and spices) are especially suited to irrigation by a PV-based system.

3. ECONOMIC ANALYSIS

The economic efficiency of photovoltaic irrigation is measured against the profits made by the agricultural or horticultural production unit. Consequently, it does not suffice to simply compare the cost of a PVP with that of a competing diesel-powered system. Instead, the overall profitability must be investigated with allowance for agro-economic aspects. The following chapters summarize the results of economic monitoring at the pilot installations in Chile and Ethiopia. Initial results from Jordan are anticipated in early 2002.

3.1 Methodology

The economic analysis is limited to an assessment of the microeconomic advantages of PV-based systems and alternative diesel- or petrol-driven pumps. No macroeconomic aspects are examined. The acquisition of data and the subsequent economic analysis comprised the following four steps:

- The first step was to gather all data of relevance to the economic analysis at the project sites.
- The second step was to calculate, on the basis of a dynamic cost annuity approach, the water discharge costs incurred by the competing technologies. The specific water discharge costs [costs/m^4] serve here as a basis of comparison.
- In the third step, the cost comparisons were followed by site-specific profitability analyses that allowed for agro-economic aspects.
- The fourth and last step was to investigate, based on the results of site-specific analysis, the extent to which general conclusions can be drawn from the findings.

3.2 Investment Costs

Ready-to-run PVP presently cost approximately three times as much as diesel pumps of comparable performance. Figure 3 illustrates the investment costs of PV-based pumping systems with different outputs.

In the partner countries of the pilot project, photovoltaic pumping systems are locally available. Consequently, the corresponding market prices were taken as the basis of economic evaluation. However, national and local situational constraints can have such major impacts on the initial cost of investment as to often impede the dissemination process.

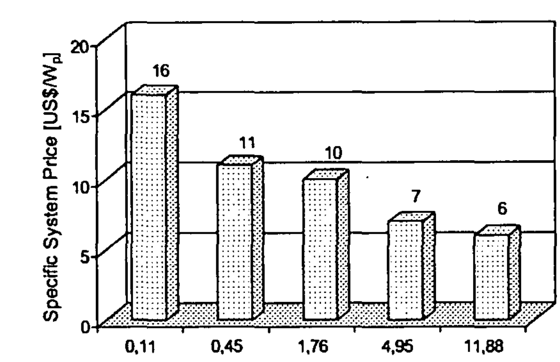

Figure 3: Specific PVP system prices (ex-works) without water tank, fence and surface piping (Source: Siemens Solar)

For example, import duties and other charges increase the basic import price of a photovoltaic system in Ethiopia by 47%. By contrast, the import duty on diesel engines is a mere 5–10%. That is one of the main reasons why Ethiopia's overall installed photovoltaic output of 420 kW_p is one of the lowest installation rates in Africa.

The high output-specific outlays for PVP impose comparatively high financial burdens on farmers who opt for photovoltaic irrigation. Hence, many farmers instead 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 as much to operate as a diesel pump. Consequently, it makes little sense from the standpoint of economics to compare different technologies solely on the basis of their investment costs, and to do so would be tantamount to ruling out the PVP option.

3.3 Cost Comparison – PVP vs. Diesel

The specific water discharge costs [costs/m^4], covering both the cost of investment and the operating costs, are taken as the basis for comparing the costs of solar and diesel pumps. Sites with different pumping heads can also be compared on the basis of specific water discharge costs by plotting the costs per cubic metre and per metre of pumping head [costs/m^4].

The specific water discharge costs depend not only on the pumping head but also on a number of other site-specific parameters, which must be accounted for and appropriately varied in the cost-comparison calculations. This makes it difficult to transfer the results to other sites and to formulate 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 utilization

In principle, the overall cost of a PVP system is much more dependent on the system's rated output than in the case of a diesel-driven pump. The latter can, for a given rate of consumption, be designed for a higher peak demand without incurring much additional cost. Figure 4 illustrates this by way of an example for the *Vitor* site in Chile, where the specific water discharge costs [CH\$/m^4][1] of the installed PV-based pumping system are compared with those of the smallest available diesel generator as functions of the degree of system utilization, with allowance for various interest rates.

Since the diesel system has a relatively low investment cost, its curve reacts less sensitively to interest-rate changes, but for low interest rates, the PVP option emerges as the more cost-effective system, even for a low system utilization rate (50%). At the postulated maximum interest rate of 12%, cost equality is achieved for a utilization rate of approximately 80%.

Figure 5 shows the effects of different operating modes on the specific water discharge costs. A standby unit (SB) was included here for the diesel system in order to compensate for its inferior technical reliability in comparison with that of a PVP system. This increases the specific water discharge costs by 10–18% (though any higher degree of system utilization would reduce the cost disadvantage).

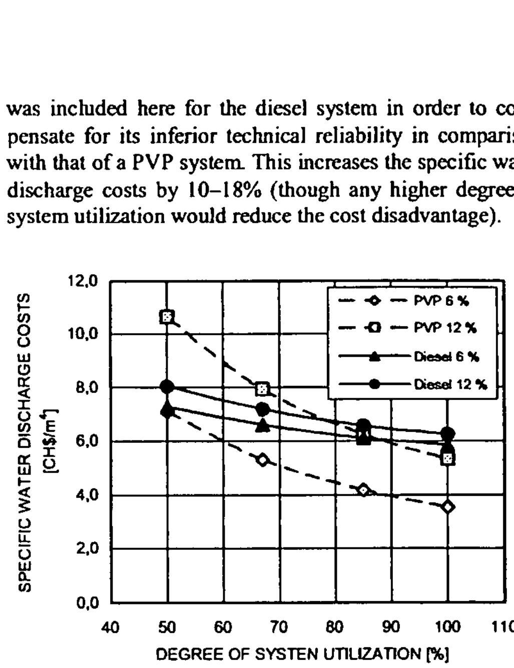

Figure 4: Site-specific water discharge costs of PVP and diesel pump as function of the degree of system utilization, with allowance for various interst rates

The PVP system was assumed to have no storage tank, hence securing an average cost advantage of 15% in comparison with a tank-equipped system. The PV-based system is seen to offer significant cost advantages at the assumed interest rate of 9 %.

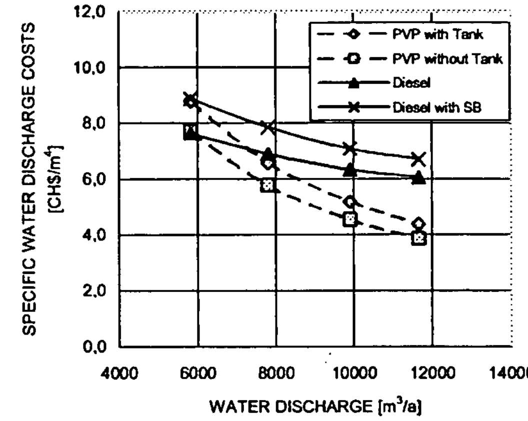

Figure 5: Effects of different operating modes on the specific water discharge costs

As evidenced by the results of economic evaluation in Chile, PV-based systems of needs-oriented design can, under certain circumstances, be more economical than conventional systems of comparable output. For cultivated areas in excess of five hectares, however, diesel systems become the more economical variant due to their degressive initial cost per unit of output (price/kW). For PV-based systems to enjoy cost advantages over conventional systems, the real discount rate should not go far beyond 12% p.a., and the average annual utilization rate of the PVP-provided supply of water should not drop below 60–70 %.

[1] 0.511 Euro = 265 CH\$

Since, however, the field-cropping irrigation season in middle latitudes does not last more than five months, degrees of system utilization in the order of 30% must be anticipated, and the water discharge costs are accordingly high in comparison with conventional pumping technologies. In such a situation, photovoltaic pumping systems cannot be expected to offer any net economic advantages. On the other hand, if the farm's entire production costs are considered, the water discharge costs remain a relatively minor factor (see below).

3.4 Profitability of Irrigation

As a rule, irrigation is employed as a means of making agricultural or horticultural production more profitable. That being so, the achieved additional benefits should outweigh the attendant costs. Thus, the overall costs of agricultural production (including the cost of the water supply) were compared with the achieved sales proceeds for the pilot sites in Ethiopia and Chile.

3.4.1 Chile

The model calculation of revenues and input costs for various cultures performed for an average cropland area of 3 hectares using project data and statistical data supplied by INDAP (Instituto Nacional de Desarollo Agropecuario) shows that irrigated farming is highly profitable in northern Chile. The internal interest on the capital inputs (soil, wells, irrigation system) came to over 70%, and for most of the crops examined the cost of irrigation accounted for a surprisingly low 4–6%. Hence, cost advantages gained via one or the other pumping technology have little effect on profits. While the operators of PV-based systems, i.e., the farmers, do take a positive view of the superior reliability of PV-based systems and of 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, especially in the absence of favourable-term loans and when other, alternative investment options are available. That drawback could be compensated, and the farmers' financial risk minimized, by way of appropriate financing and assistance models.

3.4.2 Ethiopia

Ethiopia presents a completely different situation. The Ethiopian tree nurseries that have received PVP in connection with the pilot project remain unprofitable no matter what kind of pumping technology they employ, because the saplings they grow can only be sold at a loss. This is a result of the special function of government-operated tree nurseries in Ethiopia, which are subsidized to produce indigenous species of trees with which to augment the country's reafforesting efforts. In ecologically degraded regions, where the share of forested area has gradually declined over the past century to a present 1% of the land area, Ethiopian policy attaches priority to reforesting the land – not to the break-even operation of tree nurseries. Hence, the government-operated tree nurseries value the photovoltaic pumping system's superior technical reliability (in comparison with that of diesel pumps) more highly than any attainable economic advantages. Indeed, the positive experience that the Ethiopian project partners have had with the project has induced them to declare the dissemination of photovoltaic irrigation systems, both for supplying water to tree nurseries and for expansion into the agricultural sector, as a priority goal. However, the question of financing still arises in this case, too.

4.0 RANGE OF APPLICATION FOR PV-BASED IRRIGATION

As elucidated in the preceding chapters, the use of photovoltaic pumps for irrigation purposes can be assumed to offer economic advantages over competing technologies, as long as the following site-specific conditions apply:

- no access to the public power grid
- problems with the maintenance of diesel pumps and the supply of fuel for their operation
- pumping heads of up to approximately 30 m
- maximum field size of 4 hectares
- cultivation of crops with high value-added
- use of water-conserving and energy-saving methods of irrigation (e.g., drip irrigation)
- high degree of system utilization (> 70%) through uninterrupted crop rotation or continuous cropping systems
- availability of favourable-term loans
- little or no import duties on photovoltaic systems.

The above selection criteria enable comparatively close delimitation of the economically judicious range of application for PV-based irrigation as a function of site- and country-specific framework conditions.

5.0 CONCLUSION

Despite the fact that photovoltaics still counts among the most expensive ways to utilize solar energy, it has already found its way into numerous horticultural and agricultural areas of application, many of which are economically attractive. PVP in particular constitute an alternative worth considering when the object is to pump irrigation water to crops at locations with no access to grid power. In combination with water-conserving and energy-saving micro-irrigation techniques, PVP are particularly well suited for small-scale irrigation purposes in arid climates on small plots of land (up to 4 hectares). Cost advantages in relation to conventional water-handling techniques can be expected if a high degree of system utilization can be achieved and low-interest loans secured. Prior to any investment decision, however, a site-specific economic efficiency analysis should be performed. 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.

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An Outline on the Feasibility Study Of ICS-Proposed Project : "PV Cells/Modules Factory for Water Pumping and Desalination Applications"

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1- INTRODUCTION :

A workshop on "Project Development for PV technologies" was held in Trieste, 26-30 June 2001. During Triesta workshop, it was proposed that ICS-in cooperation with representatives of countries from North Africa and Middle East region-will prepare a feasibility study for establishing : a PV cells/ Modules Factory for satisfying the high priority needs of the region as regarding water pumping and desalination applications.

The motives encouraging to do this project study are the following :

- Being a regional project : it ensures good marketing.
- The expected local demand of the PV-energy in the region is more than 8 MWp/Year (app. 1; ICS Expert Group Meeting on : "Networking of Photovoltaic Systems and Applications", 26-28 April 2000, Cairo, Eguypt).
- The distortions in prices of PV cells in the world market, and the expected shortage in their supply. The PV world market in 2001 is about 275 MWp and it is expected to be about 550 MWp by 2005.

2- ORGANIZATIONAL ASPECTS :

2.1 Three Expert Working Groups (EWG'S) were formed :

Expert Working Group A :

Mission is to prepare the final project feasibility study (PFS) and propose funding mechanism.

Expert Working Group B :

Mission is to evaluate the PV local market demand in participating countries, especially for water pumping and desalination applications.

Expert Working Group C :

Mission is to survey the existing applied R & D related to the project. Also, it can search for funding support from international organisations.

The Three Expert Working Groups work under the coordination of ICS. ICS ensures coordination and international promotion also.

2.2 Official letters were sent - by ICS - to concerned organizations of participating countries, including summary of Trieste-June Workshop.

ICS is waiting for official confirmation showing the interest of every country, so that the Expert Working Group's can start the feasibility study.

2.3 ICS has issued an "Offer for National Consultant in PV Water Pumping Systmes" in North Africa and Middle East region. The job is to collect methodically the information necessary to evaluate the status of Water Pumping Systems existing in the region. This will help to design properly the water pumping system required for the proposed project, based on field practical data.

If necessary, to satisfy complete evaluation process, some pumping systems with different types, sizes and manufacturers could be installed in different countries.

3- BASIC ASPECTS OF THE FEASIBILITY STUDY :

The feasibility study should handle the following :

- Technical Aspects.
- Financial Aspects.
- Marketing.

3.1 Technical Aspects :

The production of PV modules involves fabrication of wafers, cells, and modules. The complete factory will consist of three lines :

- Silicon crystal growth & Wafer line : this production line will convert raw silicon to wafers ready for the cell line.
- Solar cell line : this production line will process the P-type silicon wafer into a cell ready with necessary contacts.
- Module line : this production line will assemble groups of solar cells into a complete module.

A survey of best available proved technologies will help to choose suitable equipment for the factory (specifications and prices).

3.2 Financial Aspects :

A proposal for financing mechanism from :

- Interested countries (partners).
- Grants and/or soft loans from international funding organizations (World Bank, EC, GEF, ...).

Also, trying to find a J.V. foreign partner will help in marketing and assured know-how transfer.

3.3 Marketing :

Marketing will be confirmed by results from the Expert Working Group-B, based on evaluation of PV market local demand in different countries.

3.4 The feasibility study should take into consideration the following points :

- Reduction of module cost : since module cost represents about 50% or more of the overall cost, we should use techniques and technologies helping to reduce module cost, such as : increasing cell efficiency, decreasing of wafer thickness, using larger cells and modules, using better antireflection coating, ... etc.

- Adapting available technology to the real operating conditions. (e.g., taylor pump system to local conditions, design BOS components according to local specs., ...).
- Supply and demand in world market determines the selling price of 1 Wp.
- Good feasibility study makes easy financing mechanism.
- Applied R & D should be one of milestones of the project to guarantee good quality of cells.

4- CONCLUSION :

A proposed Project Feasibility Study Implementation Mechanism is shown in appendix 2.

It is expected to finish the PFS during the period of 6-8 motnhs.

Appendix 1

Existing and Expected Demands of PV-Energy In Arab Region

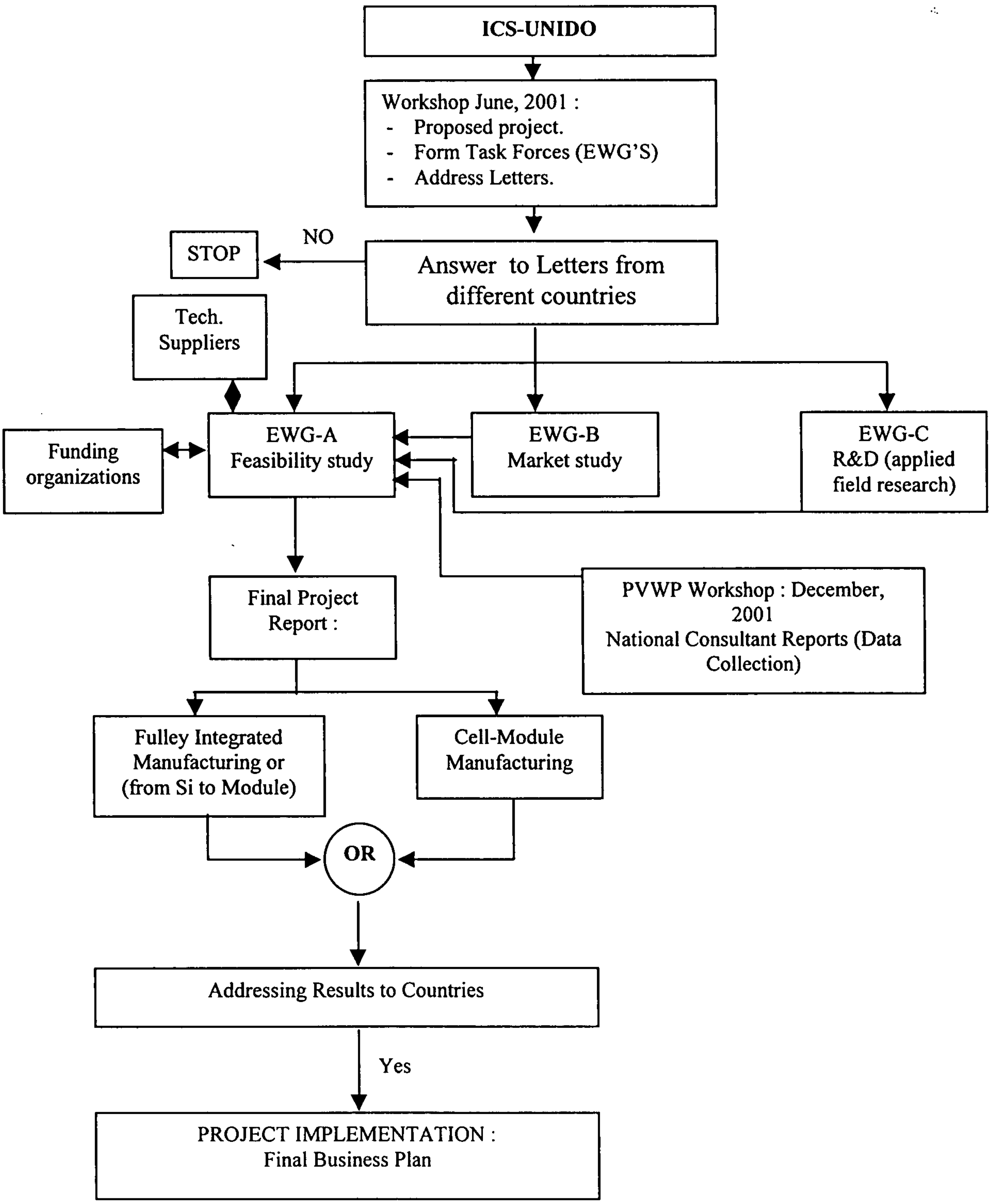
Ser.	Country	Total Installed (MWp)	Expected Demand/year (MW)	Industry	Applications
1	Egypt	2.	2	Encapsulation and Module Assembly	Telecom. Rural Electrification Water Pumping
2	Morocco	5.	1.	-	Rural Electrification Telecom.
3	Algeria	1.	2.	-	Rural Electrification Telecom. Water Pumping
4	Tunisia	0.700	1	-	Rural Electrification Telecom. Water Pumping
5	Saudi Arabia	0.350	-	-	Hydrogen production Water desalination Highway Lighting
6	Jordan	0.164	-	-	Water Pumping
7	Syria	0.050	-	-	Rural Electrification Water Pumping
8	Yemen	0.053	1	-	Rural Electrification Water Pumping Telecom.
9	Palestine	0.035	1.2	-	Rural Electrification
	Total	~10.MWp	~8. MWp/year		

Reference : The ICS Expert Group Meeting on (Networking of Photovolatic Systems and Applications), 26-28 April, 2000, Cairo, Egypt.

Appendix 2

Project Feasibility Study (PFS)

Implementation Mechanism



UTILIZATION OF PHOTOVOLTAIC TECHNOLOGY FOR WATER PUMPING IN EGYPT

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Photovoltaics (PV) is fully established as a reliable, economic source of electricity for off-grid applications worldwide where utility power is not available. This market is fully applicable in Egypt without major changes in policy, prices or attitude. Virtually all off-grid applications are sold in Egypt. However, it is recommended that a serious exchange of system requirements and design be arranged. Also, in-country cell and module manufacturing, would greatly reduce the cost of the deployment of most of the PV power stations needed for the desert development projects taking place in Egypt.

The most common source of energy for water pumping in areas far from the grid is diesel generators. The use of diesel power has serious environmental consequences and requires costly service and fuel. PV, on the other hand, provides an excellent alternative from both the economic and environmental points of view. MCEET and MERI carried out a study to determine the economic and technical viability of the utilization of PV electricity for large-scale water pumping. The prototype PV system is designed to supply water and electric energy in Toshka using PV cell technology. The project covers the first phase of what is hoped to be a much larger project (10,000 Feddan). The building unit of this project is a 33kW PV-water pumping system capable of providing all the needed water for irrigation of 100 feddan using a single well. This phase includes installation of three unites on three wells. An array of 26.7 kW output capacity can be added to the water pumping array to power the research facility next to one of the well pump sites. On the hand, smaller distributed PV systems can be designed and supplied to provide electricity to individual farms or homes. In this project, water and power will be provided to the end-user under a Water and Power Purchase Agreement (WPPA) authorized and guaranteed by the Ministry of Water Resources and Irrigation. There are a number of unique and beneficial features of the proposal:

First, the Government of Egypt does not need to provide any investment capital for financing the project

Second, the contracts for the project are focused on the provision of water and electric power, not the purchase of equipment. Unless Egypt decides to buy out the project at some point, there is no need for the Government of Egypt to maintain or own equipment.

Third, the supplier assumes all risk associated with the technical performance of the project. In other words, if the systems do not work, the supplier will not get paid.

Fourth, A key advantage of using solar energy for water pumping is that there is more solar energy available during the summer period, when irrigation requirements are the highest due to increased evaporation and evapotranspiration.

Fifth, the project uses innovative technological features that will improve the water and power output of the systems, including:

PHOTOVOLTAIC TECHNOLOGY: THE EGYPTIAN OPPORTUNITY

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Arab Academy For Science And Technology And Maritime Transport

Photovoltaics (PV) has been recognized now as an effective criteria in the electrical-generation technology which is a primary organizing force of all aspects of today's social and economic development. In recent years many opportunities have been identified for applying cost-effective PV systems to loads usually served by utilities. The common features of these loads are their remote locations, relatively small power requirements and high cost of service if conventional technologies are used. Therefore, it is anticipated that PV will provide a less expensive solution for this particular load requirement when compared to the cost of extending the utility line to the site or the cost of operating an on-site diesel generator.

There are presently five commercial processes for producing PV modules (to be discussed briefly) dominating the current world shipments. These are the single-crystal and polycrystalline Si technologies, accounting for more than 75% of the total shipment. Amorphous Si has contributed about 20% of the total shipments, but the majority of these have been consumer products (watches, calculators, etc.) rather than terrestrial power generating resources. Other technologies, especially the very promising thin-film CdTe and CuInSe2 approaches, are still developing in the industry sector, and must start to penetrate the markets in the near future to ensure their viability.

In-country cell and module manufacturing, and volume purchases (including reductions due to experience) would greatly reduce the cost of the massive deployment of PV power stations needed for the desert development projects taking place in Egypt. Once a cell and module manufacturing plants are established, the Egyptian market will immediately benefit from in-house manufacturing. The present module manufacturers in Egypt that purchase cells and make modules can not compete with imported modules owing to duties, shipping, and profit for distribution. The policy issues on duties, taxes, subsidy of conventional fuels and electricity must be examined in the light of the impact of renewable technologies on the environment, desert development, trade, balance of payments.

This presentation will provide a review and update of the development directions and projections of the PV technologies. The manufacturing details, device structure, and performance characteristics of these cell types are presented. Priority areas for PV applications in EGYPT with examples of cost effective applications and programs directed to make this energy resource a viable electricity choice will be identified and discussed.

Project Proposal

Submitted to ICS-UNIDO within the framework of Cairo Workshop on

Solar Cells and Water Pumping Systems,

Photoenergy Center, Cairo, Egypt, December 20 – 22, 2001

PV – Pumping of Groundwater for Desalination: A Study Case in Some Desert Areas of Egypt

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Definition of the Problem

Desert regions in Egypt constitute more than 96% of the total area of the country. The other 4% of the area includes mainly the cultivated lands in Nile valley and Delta. On the other hand, the majority of Egyptian population is concentrated within the area of the Nile valley and Delta whereas less than 5% of the population are scattered in all desert areas. Such situation resulted in serious economic, social and environmental problems.

The increasing population in Egypt and the limitation of the surface water resources (mainly Nile water) and, accordingly, the limitation of the cultivable lands in The Nile Valley and Delta urged the successive governments to draw various programs for land reclamation in desert areas. Such programs, mostly, depend totally or partially on exploitation of local groundwater resources in desert areas.

The exploitation and utilization of groundwater in most desert areas of Egypt are confronted by either one or both of the two following problems:

First: **Bad quality of groundwater in some desert areas, especially those areas extending near to the Mediterranean Sea or Red Sea where groundwater quality mostly ranges between brackish and saline. The use of such water resources for water supply, animal husbandry or irrigation depends on the possibility of its desalinization economically.**

Second: **Availability and high cost of energy required for groundwater pumping, especially, in very remote desert areas such as East of Oweinat and Darb El-Arbaein in the Western Desert of Egypt.**

To overcome the above-mentioned problems a research project is proposed for utilization of photoenery for production of energy power needed in some desert areas for pumping and desalination of brackish and saline groundwater. Different PVP systems will be tested. Reverse Osmosis Technique using reverse osmosis membranes, prepared by different methods will be applied.

Duration and Partners

The proposed research project is supposed to cover three years and to be executed by a team of research groups from Desert Research Center, Photoenergy Center – Ain Shams University, and other potential partner(s) from agriculture community and other relevant research institutions (to be identified).

Targets of the project

The main targets and expected outputs of the present proposed research project may be summarized in the following:

1- To produce economically feasible electric energy in two representative desert areas making use of the available solar radiation.
2- To use the produced energy for economic lifting of groundwater in the representative desert areas.
3- To use the produced energy for desalination of brackish and saline groundwater. The reverse osmosis technique is selected for application due to its possible commercial feasibility in desalination of brackish and saline water.
4- The project includes model design and construction of PVP - Desalination Unit (on a semi-industrial scale) in order to verify the performance efficiencies of the system and its components; for example, solar panels, pumps (DC versus AC/Converters) and the in-home prepared membranes, through the determination of the factors which affect their water flux , salt rejection and stability in terms of operating life compared with other commercially available membranes.
5- Estimation of the behavior of elements that constitute the groundwater through the desalination process by chemical analysis of water samples.
6- Evaluating the cost of energy used for groundwater pumping using solar energy compared with the other energy sources.

The estimated cost requested is about $290,000 US. This applied research project lies within the interest of task III of working group PVP identified during the expert group meeting that was held in Trieste, on June 2001.

General Authority for Rehabilitation Projects

& Agricultural Development

GARPAD

Water Pumping In East of Oweinat region using PV systems

(from the economical point of view)

Engineer

A.Rahman A.Mageed Aly

Deputy Chairman

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2001

Water pumping in East of Oweinat using the PV systems (Italian – Egyptian Renewable Energy Settlement) IERES

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The Egyptian western desert enjoy a rich aquifer offering the possibility of suitable development.

The main issue is the water pumping. Since the solar radiation is very rich in East of Oweinat area, beside a promising wind potential, Italy and Egypt begin to install a complex of renewable energy model in the second half of 1980"s decade, funded by an Italian donation,under the name "Italian-Egyptian Renewable Energy Settlement (IERES).

The main working component was a system of PV of 125 KW for water pumping to irrigate a farm of 100 hectar.

The conclusion reached after 15 years of application is that PV water pumping is not feesible for irrigation, although it is completely feesible for potable water.

1. Historical background :-

East oweinat area remained as one of the unknown remote areas in the Egyptian desert . There was a lack of informaton about the natural resources of the area before the General petroleum company (G.P.C) started its activities in the area in the late seventies. In 1978, an area of 60,000 km_2 (about 14 million feddans) was selected in the area to carry out a preliminary study soil and groundwater resources evaluation. Selection of this area was based on the preliminaty interpretation of the landsat maps provided by continental oil company (CONOCO) which showed an extensive area of good soil. Since 1978, an integrated program to study the basic resources in the area was initiated by (G.P.C) . A regional soil survey for 7 million feddans was done in 1982-1983 under the supervision of Desert Research Center (DRC).

The (G.P.C) has made several activities during the period from 1978 to 1988, out of these activities was the conductance of a comprehensive geological, geophysical, hydrogeological and test drilling program, beside, establishing of a meteorological station for collecting climatic data, conducted agricultural trials to test the cultivation of some field crops, vegetables and fruit trees. Also, during this period, the Egyptian Government received a grant from the Italian Government which was implemented in the construction of the so called Italian Egyptian Renewable Energy Settlement (IERES).

2. <u>The solar village (IERES)</u>

This project aimed to initiate a pilot farm of 200 feddan using renewable energy for irrigation.

<u>The components</u>:

a. <u>Water facilities</u>

Two wells with pumping rate of 150 m^3/hour

Ground reservoir of capacity of 40.000m^3

b. <u>Energy facilities</u>

- 120 KW of PV system
- 4 wind turbines each of 12 KW and one turbine of 125 KW
- Biogas unit of 15 KW
- 2 deisel engines each of 75 KW
- Elctronic control center for the total system.

During the last 15 years the PV system was the only working component, and it covered all the irrigation needs of the farm both for water pumping from the two wells to the ground reservoir and for water pressure in the drip and sprinklers systems .

3. <u>The economical studies</u>

This pilot project for renewable energy use in water pumping for irrigation purposes can give us now a clear conclusion about both of the technical and economical results .

In the following we will discuss the expenses of the energy needs for irrigation of one feddan per year using the PV system or a deisel engine . We will calculate also the expenses of energy needs to pump the potable water needed per capita per year .

<u>Calculations of energy expenses for irrigation</u>

a-<u>Using PV systems</u>

125kW array with cost (A) = 1,25 x 10^6 USD

<u>Cost for 25 years</u>

Cells = 0.5A (Life time = 25 years)

Battaries = 0.25Ax4 = A (Replacement every 5years)

Others = 0.25Ax2 = 0.5A(Replacement every 10years)

Total expenses through 25 years

= 0.5A + A + 0.5A

= 2A = 2.5x10^6 USD

$= 2.5x10^6 x4.25=10.625x10^6$ LE

<u>Expenses of energy needed to irrigate 1 fed per year</u>

$$= \frac{10.625x10^6}{200 \text{ fd x } 25 \text{ years}}$$

$= 2.1x10^3$ LE

= 2100 LE

b. <u>Using deisel engines</u>

Price of deisel engine 125KW = $7x10^4$ LE

With life time of 8 years

Price of the engine through 1 year

$= \frac{7}{8} x10^4$ LE = 8750 LE = $8.75x10^3$ LE

Expenses of one hour of operation of the deisel engine

(fuil,oil,operator,maintenonce.... etc)

= 25 LE

Expenses of operation for one year

= 25 LEx12 h x300 days

$= 9x10^4$ LE

Total expenses per year = $9x10^4 + 8.75x10^3$ LE

$= 9.875 x10^4$ LE

Expenses of energy needed to irrigate one fd.per year

$= \frac{9.875x10^4}{200}$ = 494 LE = 500 LE

C. <u>Expense for potable water pumping using PV</u>

Expenses of energy needed to irrigate 1 fd = 2100 LE

This is for pumping 6000 m^3/year

The potable water rate of use

= 100 Litres / day

= 0.1 m^3/day

= 40 m^3/year

This means that pumping of 6ooo m^3/year

is sufficient for 150 persons

- Expenses of energy needed to pump potable water/Capita

$$= \frac{2100}{150} \text{ LE}$$

= 14 LE/Capita / year

Conclusion

As we see according to the calculations that using PV systems as a source of energy for pumping for irrigation is too expensive compared with using deisel engines (4.2 : 1).

Beside the fact that the investment is very high at the beging for PV systems compared with deisels.

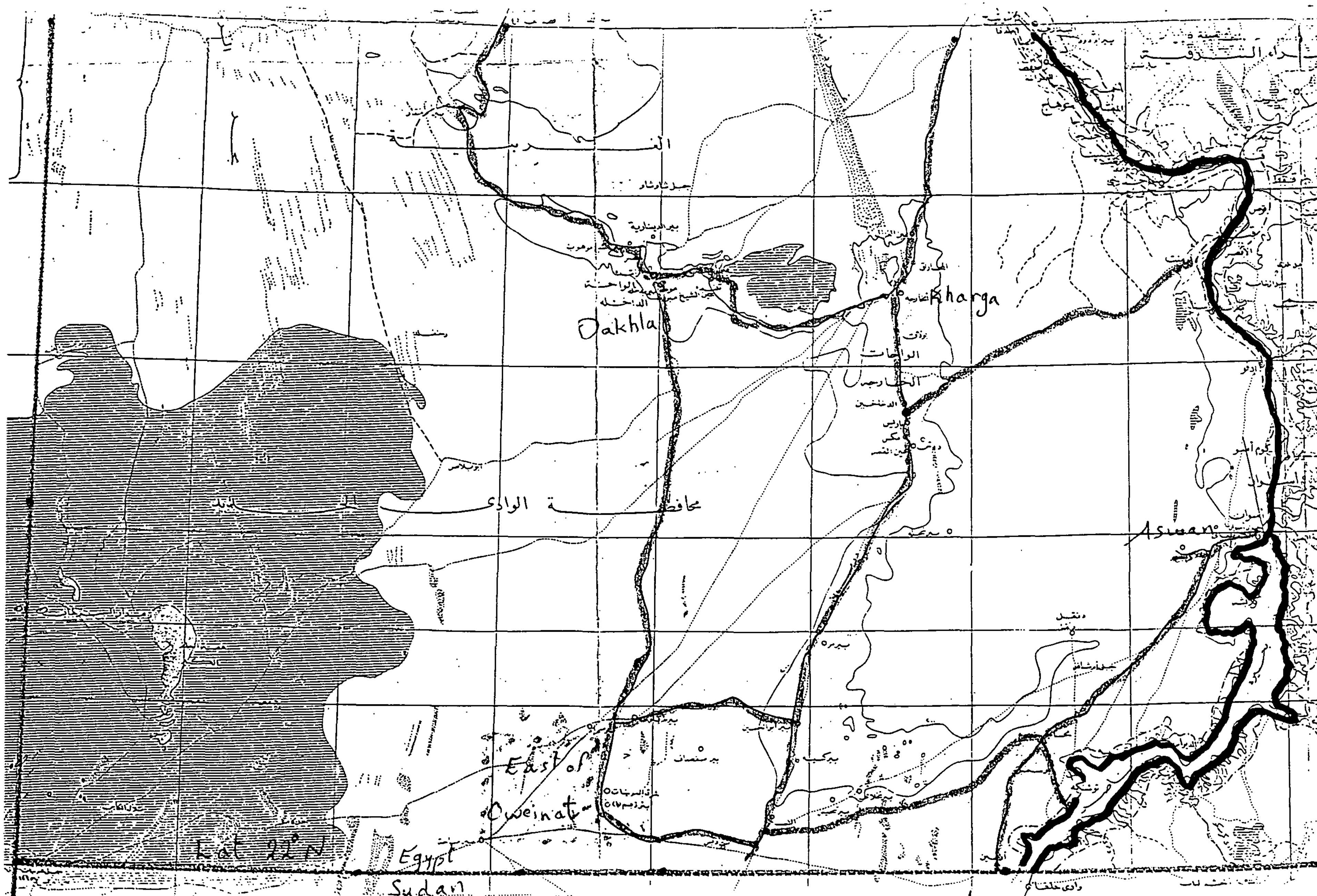
$(1.25 \times 10^6 \times 4.25$ LE : 70.000 LE)

5.3×10^6 : 7×10^4

530 : 7

75 : 1

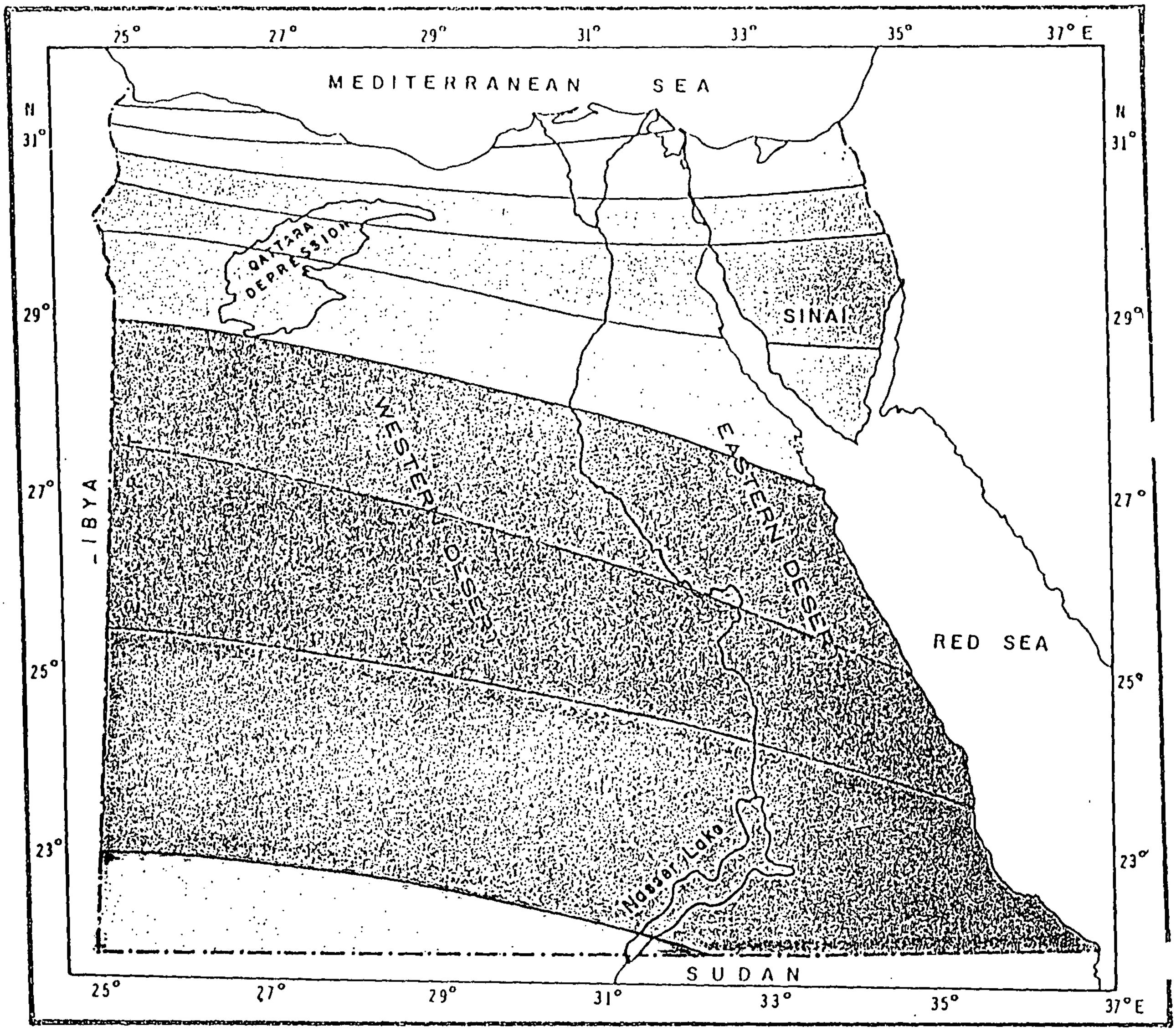
At the same time using PV systems as a source of energy for pumping potable water is reasonable.



Location of E. Oweinat

Egypt Annual Average Of

Solar Energy on Full Tracking System



< 7.5 kWh/m²/day	9.0 - 9.5 kWh/m²/day
7.5 - 8.0 kWh/m²/day	9.5 - 10.0 kWh/m²/day
8.0 - 8.5 kWh/m²/day	10.0-10.3 kWh/m²/day
8.5 - 8.9 kWh/m²/day	10.3-10.5 kWh/m²/day
8.9 - 9.0 kWh/m²/day	> 10.5 kWh/m²/day

Map (105) The annual average of the solar energy density on full tracking system over Egypt in $kWh/m^2/day$.

Ministry Of Agriculture. & land Reclamation
General Authority For Rehabilitation Projects
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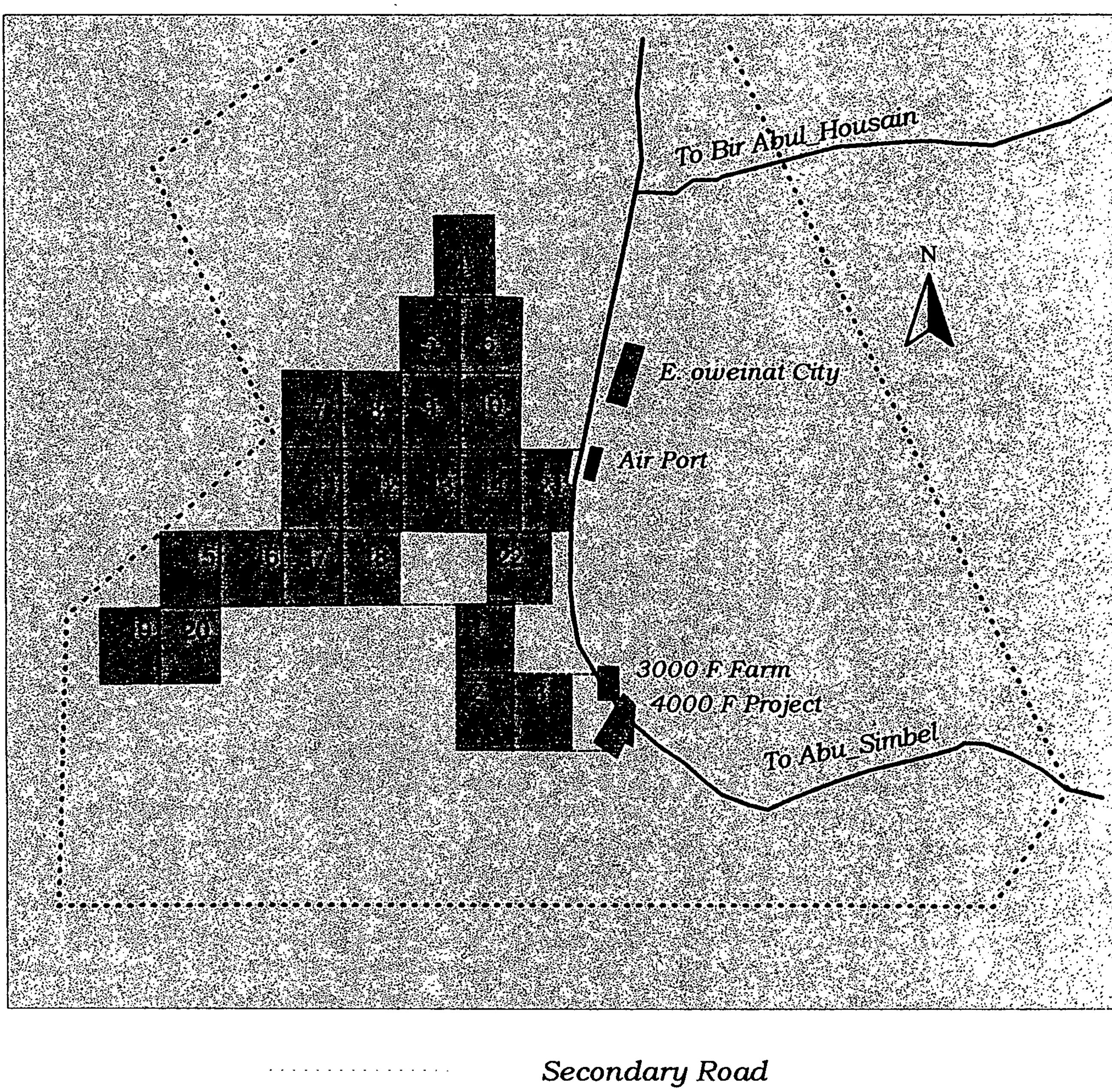
Investment Areas in East Of Oweinat



Secondary Road
Main Road
Regional Road

The Use Of Photovoltaic Water Pumping Systems In Northern Ethiopia

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Diesel driven pumps are the conventional means of conveying water for irrigation in areas that do not have other cheaper means of lifting water. The problem with diesel pumps is that they require regular maintenance and refueling. The unexpected failure of pumps together with shortage of skilled technicians imposes some risk on crop especially in remote areas. To minimize the risk environmentally sound and resource conserving photovoltaic pumping systems can be considered as an alternative means of delivering water particularly for small-scale irrigation systems. However, the use of photovoltaic pumps for small-scale irrigation is still held back by a lack of information and practical experience.

Ethiopia, being in the tropics receives an average insulation of 5.4 Kwh/m^2/day. As a result, it can be said that this source of light energy is a promising and a potentially capable so as to contribute in our endeavor attaining food security. In Tigray region, northern Ethiopia, there are around fourteen photovoltaic water-pumping systems of which three have been installed in pilot tree nursery stations, which used to get water by means of diesel driven pumps. The stations are provided with a mobile data acquisition system [MODAS]. So far, most of the pumps are operating reliably. Nevertheless, there are problems that are associated with optimization and installation. The operational experience in the region generally reinforces ones confidence in the technology.

BRIEF REPORT ON

FIELD AND LAB RESULTS FROM EXPERIENCE IN PV-WATER PUMPING SYSTEMS

BY

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FOR PRESENTATION IN

THE WORKSHOP

SOLAR CELLS AND WATER PUMPING SYSTEMS

20-22 DECEMBER 2001
Cairo, Egypt

ICS – UNIDO and PHOTOENERGY CENTER,
AIN SHAMS UNIVERSITY

APPENDIX

1- Brief Background Of PV Water Pumping Systems, Requirements, Applications, Common Types And Main Competitors

1.1- Technical Description Of A Standard PVP-System

Pumping Water in remote areas using Photovoltaic technology has proven a high technical reliability and economic feasibility over other traditional systems like diesel. Technically, these systems utilize the free solar energy to pump water from a well, a spring or any other source to an elevated reservoir from where the water is to be distributed to the consumers.

Electric power is produced by a solar generator that converts solar energy into electrical energy. PV cells are arranged in specific order (series and parallel) so as to provide the required values of (DC) current and voltage. The output power of this generator can directly drive a DC-Motor-pump set, or it can also be converted into an AC power by means of a DC/AC Inverter in order to drive a common AC-Motor-pump. This inverter can be equipped with a maximum power point tracker in which operating current and voltage is selected to achieve maximum operational power.

The motor – pump set is the third part of this system, which mostly installed inside the water. A 3 Phase AC Motor is nowadays the most common reliable type that can be operated without any maintenance requirements. In general it drives a submersible deep well pump, preferably made of non-corrosive stainless steel material.

In general, the standard PVP System consists of the following main components (figure (1.1)):

- Photovoltaic Solar Generator
- DC/AC Inverter
- Submersible Motor-pump set
- Complementary components like storage tanks, pipes...etc.

The system does not include any batteries; instead the water tank is used for bridging the demand during nighttime hours and cloudy days.

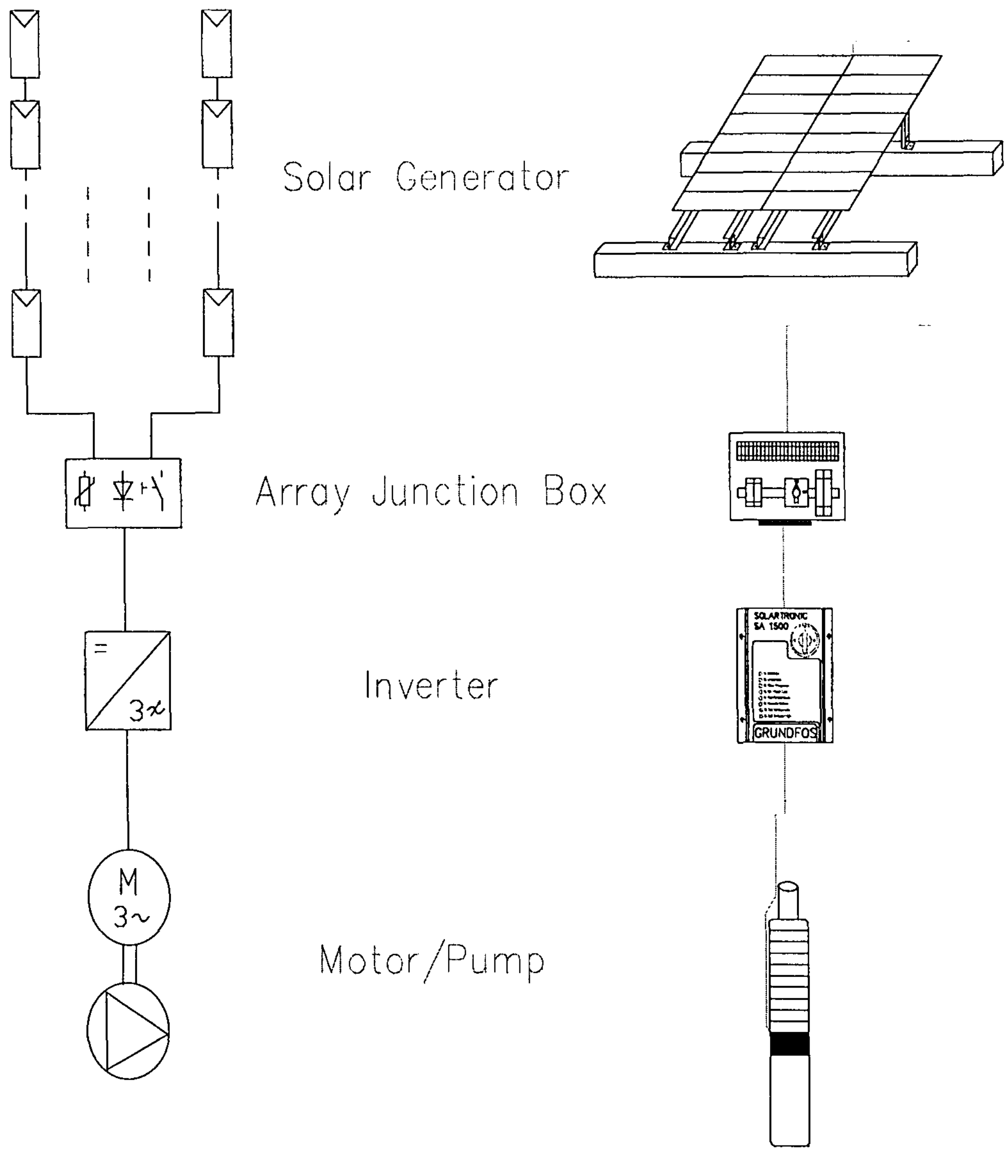


Figure (1.1):Photovoltaic Pumping System, Block/Schematic Diagram [1]

1.2- Common Types Of Pumps And Main System Characteristics

In the last few years, different types of pumps have been tested and utilized for photovoltaic pumping applications. Many research projects have been sponsored to conclude the most efficient types of pumps. In this chapter, main features of different systems are briefly described [1]

1.2.1- 3-Ph Centrifugal Submersible Motor- Pump Set

Nowadays, this system is the most popular type for PV pumping applications; it uses a multistage pump and a sine-wave inverter. The main advantages of this configuration are:

- Wide range of pumps are available for any well characteristics
- Good adaptation of pump performance to solar radiation by means of high efficient DC/AC-inverter
- Acceptable lifetime and high reliability of motor and pump
- Very little wear and tear of moving parts
- Standard components, same as used for grid-connected deep well-pumps known by users and service companies
- Different manufacturers with different manufacturing materials are available
- Good availability of spare parts

1.2.2- DC-Centrifugal Submersible Motor-Pump Set

The main advantage of this system over the previous AC system is that it does not need a DC/AC inverter, but unfortunately common DC-Motors are equipped with carbon brushes for commutation of the Direct Current. Even with newly developed, long lasting brush-materials, it is still the main disadvantage of DC-Motors, that the pump should be taken out from the well between time to time in order to change the brushes. Most motors are completely sealed and instead of changing the brushes, the entire motor has to be changed. This means additional maintenance cost.

As an alternative to DC-motors with carbon brushes the so-called "brush-less" DC-Motors are used, where commutation is achieved electronically by an electronic commutator embedded in the motor itself. The main disadvantages of these types of motors are the high cost and the scarcity of the suppliers. For future applications, these kinds of DC motor- pump set might be a serious alternative to the aforementioned AC types

1.2.3- AC Rotating Positive Displacement Pump "MONO-Pump".

The main advantage of this pump is the high levels of efficiencies that can be reached.

Generally, the water is pumped by the rotation of an eccentric steel rotor inside a rubber stator. Special care should be considered in the design process of the rotor and stator since the gap in between plays a major role in system efficiency and starting up requirements. Special type of parameterized inverter should be used for supplying the necessary starting torque at low solar radiation values.

1.2.4- Rotating Positive Displacement Pump with Surface-Mounted DC-Motor and Long Shaft

In this system, DC-motor is installed at the ground not inside the well the fact that reduces service cost. Maintenance work can be done easier without needs for taking the motor out from the well. Technically, the pump is driven by a long shaft connected from the motor at the ground to the pump inside the well. This causes additional losses and additional system cost.

1.2.5- Positive Displacement Membrane Pump With Submersible DC-Motor

Generally, these types of pumps are used for domestic application with small water output requirements. The main disadvantage of it is that it needs a continuous maintenance work for replacing the membrane of the pump and the brushes of the DC motor. However the application of these pumps for public water supplies is not recommended unless spare parts and maintenance requirements are ensured at low cost.

1.2.6- Reciprocating Positive Displacement Pump

Namely known as the "Jack-Pump" or "Nodding Donkey", it is suitable for very high pumping heads and low flowrates applications. These pumps create a cyclic load on the motor, which needs to be balanced for efficient operation. As a solution a large (1.5 m) flywheel can be equipped to the system.

1.2.7- DC Floating motor-Pump set

Mainly, these types of pumps are used to pump water from an open reservoir (surface water) to a low head consumption place. Therefore, they are generally designed as a single stage centrifugal pump for low pumping heads and high flowrates applications. The DC-motor is installed at the surface, so maintenance requirements are easier. Even though, Brushless types are used. The main disadvantage of these types of pumps is the plastic material that is manufactured from. This material is not suitable for severe use conditions like what is expected for the places where these pumps are to be installed

1.2.8- Suction Pump

Surface suction pumps are used to take out water from a place of maximum 8 m below the level of the pump to a certain place above the pump level. To be equipped with a PV system and achieving an automatic operation mode, it needs a priming chamber or non-return valve. Unfortunately, these additional components mean additional cost, additional maintenance requirements and additional losses.

1.2.9- Tandem system

This arrangement consists of two pumps with two inverters connected to solar generator arrays. When solar radiation is low, the total generator is connected to one pump so as to utilize the small intensity of threshold radiation to pump water. After increasing irradiance to a specific amount, the PV generator is divided into two parts feeding both pumps. In Jordan, this system was tested where considerable percentage of additional output water was achieved.

To avoid the additional cost of the additional components, another less efficient option is considered. The idea is to use a two parameterized inverters in which the first inverter starts earlier than the other one by certain programmed time, the fact that permits enough time for increasing radiation in the morning time to be adequate for driving both pumps.

Another advantage of this system configuration is noticed in case one component fails; the second system will still be able to operate on its own, until the faulty component is repaired.

1.3- Competing Water Lifting Devices

When planning to install any system to provide a service, all possibilities shall be considered. A comparison study shall be conducted and the most techno-economic system should be selected. In this regard, it is important to have an idea about the main characteristics of these systems considering the capacity in terms of daily hydraulic energy needed. Table (1.1) shows these characteristics.

Note: The daily hydraulic energy equivalent (DHE) is calculated as follows:

*DHE = Water discharge (Q) * Pumping head (H)*
*= Q [m^3/day] * H (m)*
*= Q * H [m^4 / day]*
Conversion factor: 1 kW =~ 367 m^4/h

Hand pump Characteristics	Diesel Characteristics	PVP - Characteristics
-Max. pumping head ~ 45m - Max. DHE (8 h operation) 200 m^4/day - Efficiency 40 % - 80 % - No need for storage tank	-Limited minimum size -Field efficiency 4% - 15 % - Operation time responded to the demand (flexible) -Low investment cost - Intensive service and maintenance -Pollution by fuel, lubricant, exhaust-gases and noise	- Daily overall efficiency 2.7 % - 7 % -Operation time responds to weather conditions: (need for storage tank) -Low operating cost -High investment cost -Low specific water cost if: *Constant daily demand *High irradiance without seasonal variance -Reduce service and maintenance -Pollution free -No noise

Table (1.1): Main characteristics of competing water lifting devices

1.4- Site Criteria For PVP-Systems

One of the most important factors for PVP application is the site criteria. The site should be suitable for applying this technology from all aspects. It directly affects the initial cost of the system required which is considered as the key element that affects the progress of this technology. As a first approach to PVP system selection the following factors shall be evaluated:

- Water source with acceptable quality must be available, and it should be not possible to provide this water for consumption without using energy
- Techno-economic study should prove the advantages of this technology over other traditional alternatives like diesel system
- Electric grid should be far away from the site and it shall be clear that it is not economic to extend it to the site
- Pumping head (H) and flowrate (Q) should be within limited values (i.e. Q*H<certain economic value of (m^4/day).
- This technology should be accepted by users

Depending on the location and the economic situation of the site specially price level like fuel cost, the site criteria may have a positive or negative effect on the PVP-systems. These criteria should be taken into consideration for the site selection so as to make these systems technically, economically and socially successful. Table (1.2) shows these criteria.

Site Criteria for PVP-Systems	
Positive site criteria	Negative site criteria
-Other solutions are unavailable. -Power demand is too high for hand pump (DHE > 200 m^4). -High costs or unreliable supply for diesel fuel (sites with little and dispersed population). - High solar irradiance without much seasonal variance. - Steady water consumption over the year (irradiance matches water demand)	- Financial availability doubtful. - Extension to electric grid feasible. - Low fuel cost on site. - Fluctuating water consumption (Cattle, irrigation). - Low irradiance and high seasonal variance. - High power requirement (DHE is too high). - Drawdown of well is significant - Acceptance doubtful. -Population is used to diesel pumps. - Storage tank capacity is too small. - Community has no experience in water management.

Table (1.2): Site criteria for the PVP-systems

1.5- Site data for PVP System Design

Before making any serious decision for installing PVP system on a specific site, the exact site data should be prepared by technical staff or a consultant specialized in PVP-Systems. Based on these data, the supplier or the designer can calculate the exact system requirements on which the system components are purchased and installed. After that, an acceptance test should be executed to ensure that the delivered components are matching the requirements or not. For that, the technical site data are very important in this regard.

The design procedure of the PV- pumping system depends on the data of the sites where theses pumping systems are to be installed. These data should be collected carefully to make a correct design and implementation of the system. The main advantage of a precise and complete data-basis is the better comparability of the received quotations, because the technical specifications clearly define the limits of the offered equipment

These data are briefed in the following:

1.5.1 Characteristics Of Water Source

The following information specify the required data of the water
-Maximum sustainable yield (m^3/day).
-Static water level (m).
-Drawdown (m) at ... m^3/h.

These characteristics can be determined by pumping tests.

- Quality of water (through water analysis).

The maximum discharge rate of the PVP-Systems shall not exceed 75% of the maximum sustainable yield of the well.

1.5.2- Water requirement (Consumption / Demand)

- Sources of information on water consumption

  * Records from water meters.
  * Records on operating hours of diesel pumps
  * Interviews with diesel pump operators.

- demand estimations:

* Site conditions
* Variable demand patterns.
* Growth of demand.

The basic of water demand is estimated as follows:

-Human water demand

*WHO guidelines 5 to 30 L/day * capita.
* National standards vary considerably.
* Actual consumption.

-Animal livestock water demand (RSS criteria]:

Cattle	20 ~ 40 L/day * head
Camels	15 L/day * head
Horses / mules	20-40 L/day* head
Goats / sheep	5 L/day * head
Chicken	0.5 L/day * head

The parameters of the variation in consumption are as follows:

- Seasonally changes
  * Hot season: higher consumption
  * Rainy season: surface water for animals

- Annual / long terms changes

  * Growth of population
  * Migration of population
  * Increased per capita consumption (improved distribution)

1.5.3- Meteorological data

The meteorological data needed for sizing the PVP-systems are as follows:
- Annual patterns of mean daily irradiation
- Diffuse fraction of global irradiation
- Statistics on consecutive overcast days (if available)
- Monthly means (min., max.) ambient air temperature
- Monthly means of wind speeds (if available)

1.5.4- Outcomes and recommendations

Finally, after accumulating all necessary data, the supplier can now calculate and design the PVP-System, according to the data submitted by the customer. As more detailed the data submitted by the customer are, as less assumption have to be made by the supplier, and as more precisely the offered system will fit to the real circumstances on site. Even if the supplier shall not deliver certain components (e.g. pipeline, cable, watermeter, wellhead etc.), he/she might give some recommendations for minimum requirements like cross-section, cable dimensioning, etc.

1.6- Applications

PVP-systems have proved a high reliability in different fields of applications where electricity network is not available. There are several successful possibilities of application especially in remote areas.

***- Village Drinking Water Supply**

The problem of ensuring a steady supply of drinkable water remains unsolved in many countries. Pumping systems can be used to obtain pure ground water from deep wells instead of surface water that is frequently impure and biologically contaminated.

***- Drinking Water Supply for Livestock**

Pure well water is also a basic need for animal herds. A reliable and continuous supply of drinking water can make the raising of livestock possible and noticeably increase the size of existing herds.

***- Small-scale Irrigation**

As population grows in the countries, the carefully directed irrigation measures can serve to intensify food production.

2- Technical Comparison Between Main PV Water Pumping Systems- Lab Results

Many tests on PV pumping systems have been conducted in a high tech specialized Lab. The aim of these tests was to conclude the performance characteristics of different kinds of pumps and to identify areas in which further R&D is required. Designed test procedures in addition to other general tests were used so as to conclude the necessary results. To give an idea about the performance of some of these systems, general results are demonstrated below [2].

2.1- Single Phase Centrifugal Pumping System:

A conventional multistage centrifugal pump driven by a submersible single-phase AC motor was used. The inverter can be set to a specific voltage according to the PV generator used and operates as a constant voltage tracker. The components used have the following specifications:

Pump:	Grundfos SP2A-4
Motor:	Grundfos MS402 90V
Inverter:	Grundfos SA400 V10 inverter

- Main results:

As a standard first-generation PV pumping system, it behaved as expected. Efficiencies were lower than second-generation systems with larger head dependencies. In general, these types of pumps are mass-produced and larger pumps have better efficiencies than small pumps.

Figures (2.1) & (2.2) & (2.3) show the main results:

2.2- Shurflo Pumping System

This system uses a second-generation positive displacement pump driven by a permanent magnet DC motor. Generally, the system has the following specifications:

Pump:	Type Shurflo 9325, three-chamber diaphram
Motor:	Permanent magnet, thermally protected, 24V
Controller:	DC/DC converter type LCB-G

- Main results:

This pumping system has shown relatively higher efficiency than the centrifugal pumping system. Concerning reliability, it is expected to be necessary to change the diaphragm every few years

Figures (2.4), & (2.5), & (2.6) describe the main interested results:

2.3- Solarjack Pumping System

This positive displacement pumping system uses a submersible diaphragm pump powered by a low voltage DC motor with operating voltage range of 12 to 30 V.
It has the following main characteristics:

Motor-Pump set:	Solarjack SDS-Q-128, input voltage=12 to 30V
Controller:	load-matching device, voltage regulator at MPP type PC10-28H

-Main results:

Generally, the performance of this pump is comparable to that of the Shurflo pump. It is expected that the diaphragm needs to be replaced every year or two.

Figures (2.7) & (2.8) & (2.9) show the main characteristics of this system:

2.4- Suntron Pumping System

This pumping system uses a Suntron, helical rotor, and positive displacement pump driven by 800 W brushless DC motor. This system has the following main features:

Motor-pump set:	Suntron SM041, SM042
Controller:	800W, current booster, variable operating point in accordance to temperature

- Main results:

Two Suntron pumps with different head capacities were tested. In general, these types of pumps have shown a very high efficiency compared to all other pumps.

Figures (2.10) & (2.11) & (2.12) & (2.13) & (2.14) & (2.15) describe the behavior of both pumps:

2.5- NQ14 Screw Pumping System

In this system a screw pump was equipped with a 3 Ph motor. In general the system has the following specifications:

Pump: Netztch NQ14 Screw type
Motor: Franklin 3 Ph, 220 v, 2.2 kW
Inverter: Siemens Solarverter3, 3 kW

- Main Results:

Head-flowrate characteristics at variable frequency settings are depicted in Figure (2.16).

2.6- 3 Phase Centrifugal Pumping System

A 3 Ph centrifugal pumping system has been used for a special test to describe the performance of the PV pumping system at variable frequency settings. The system has the following specifications:

Pump Type	: UPA100 4/15
Inverter	: ASE Solarverter 3 kva
MOTOR	: Franklin 127 V 3 PHASE 1.1 kW, PF = .79

- Main Results

Power factor increases with frequency increase. This means that the pump will show better performance at higher frequency. This is also clear when looking to the active, reactive power curves. It should be realized that frequency increases with increase of solar radiation values.

Figure (2.17) describes the main interested results:

Figure (2.1): Behavior of centrifugal pump(sp2a-4) at different head settings

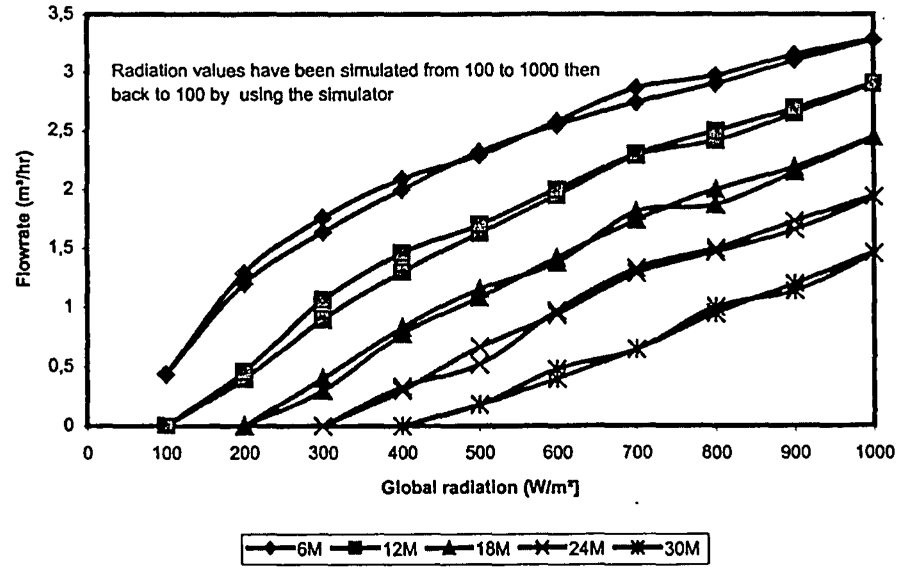
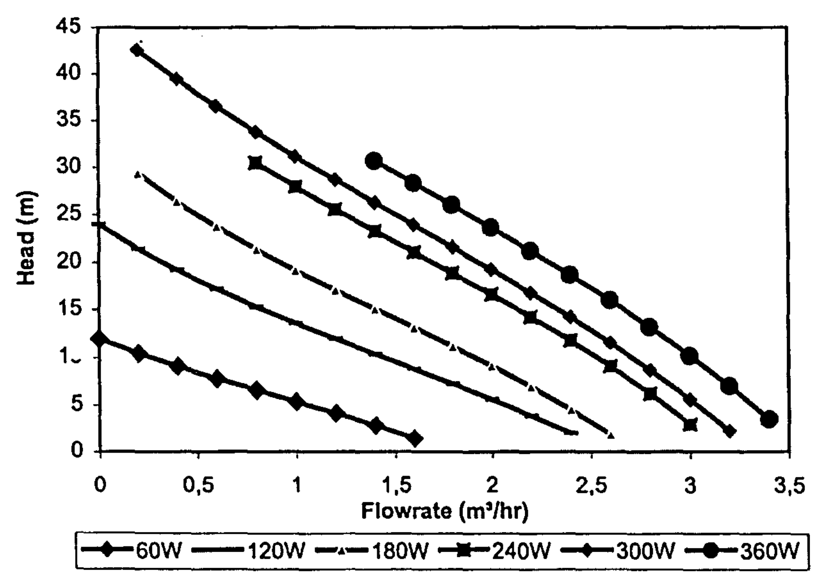


Figure (2.2):Head-flowrate curves at different input power settings (Centrifugal sp2a-4 pump)



Figure(2.3): Subsytem efficiency vs head at different input power settings(sp2a-4 centrifugal pump)

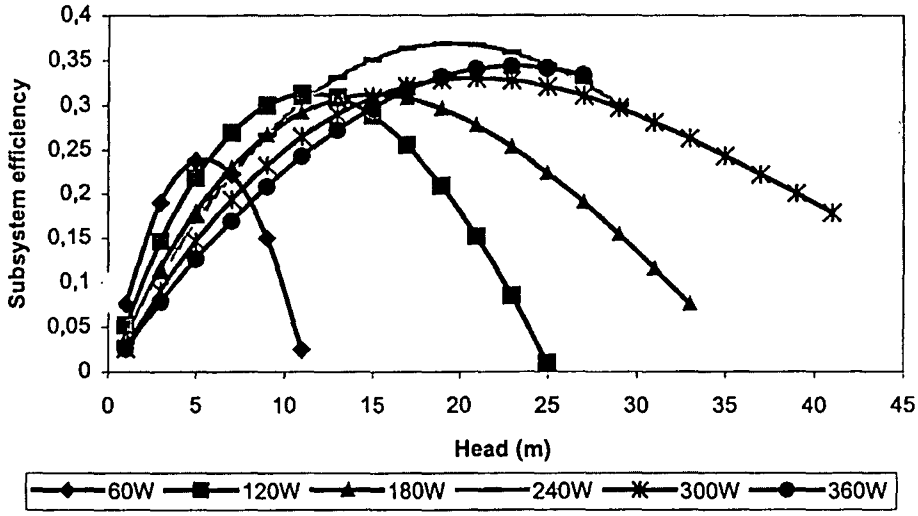
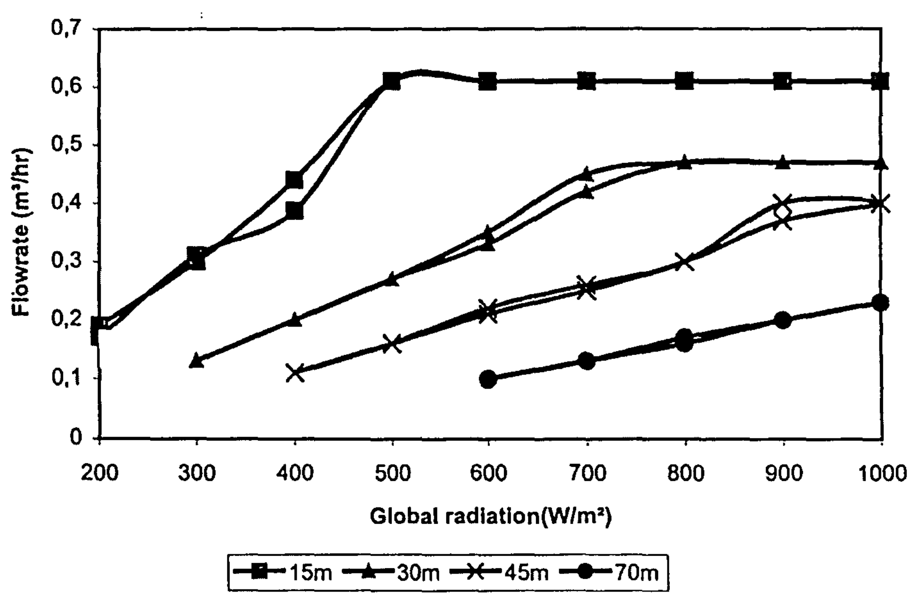
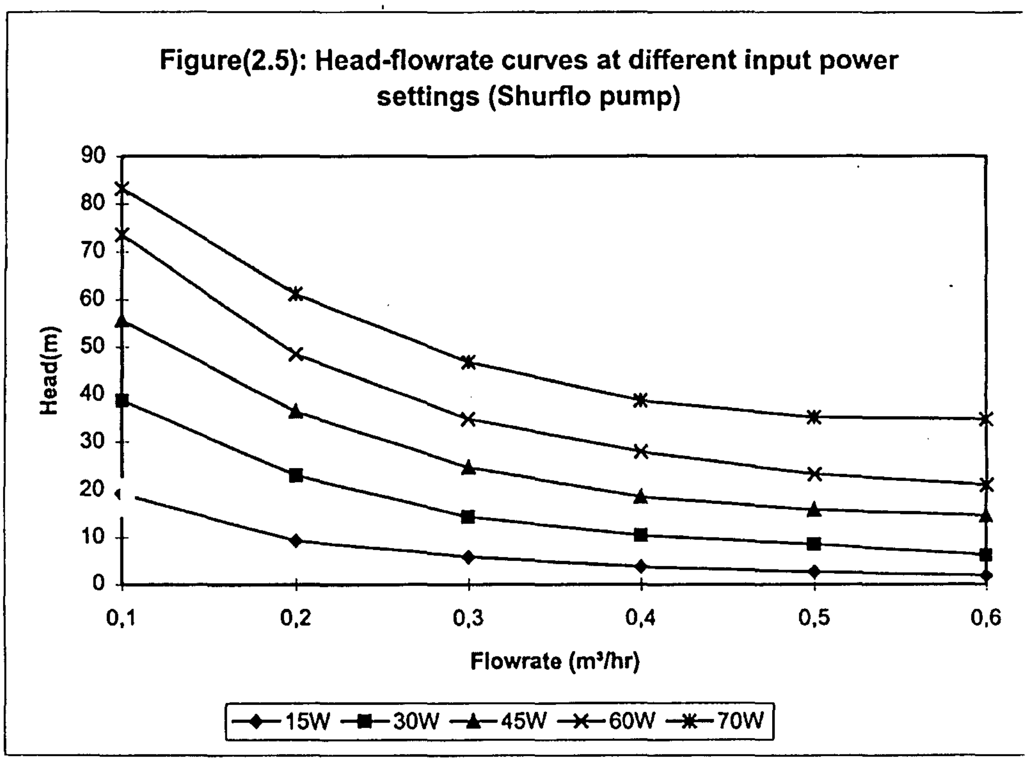


Figure (2.4): Behaviour of Shurflo pump at different head settings




Figure(2.5): Head-flowrate curves at different input power settings (Shurflo pump)
Head(m)
90
80
70
60
50
40
30
20
10
0
0,1
0,2
0,3
0,4
0,5
0,6
Flowrate (m³/hr)
15W
30W
45W
60W
70W

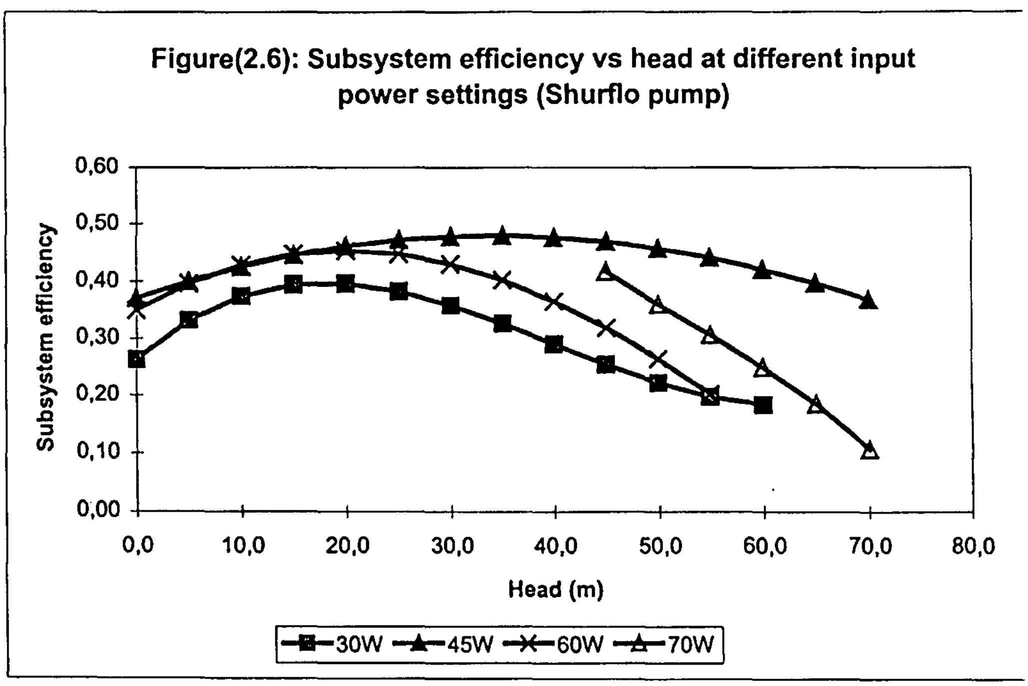
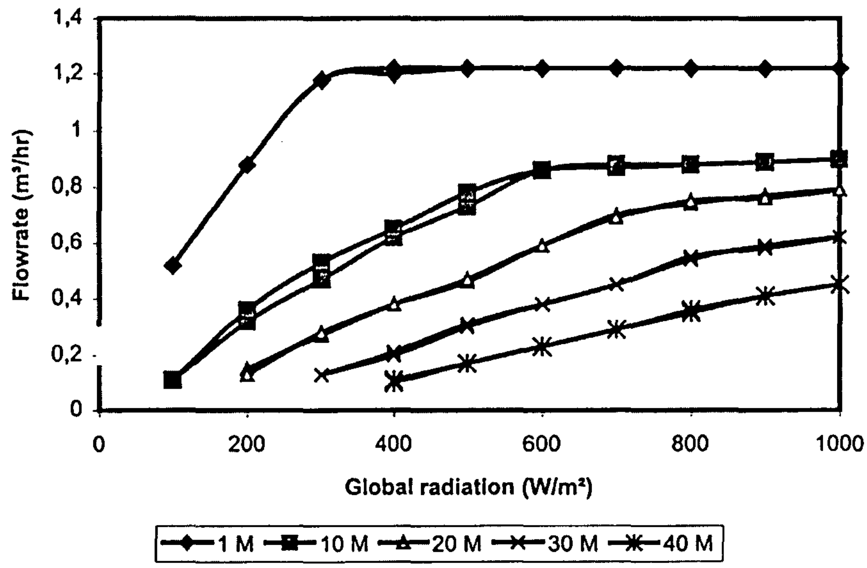
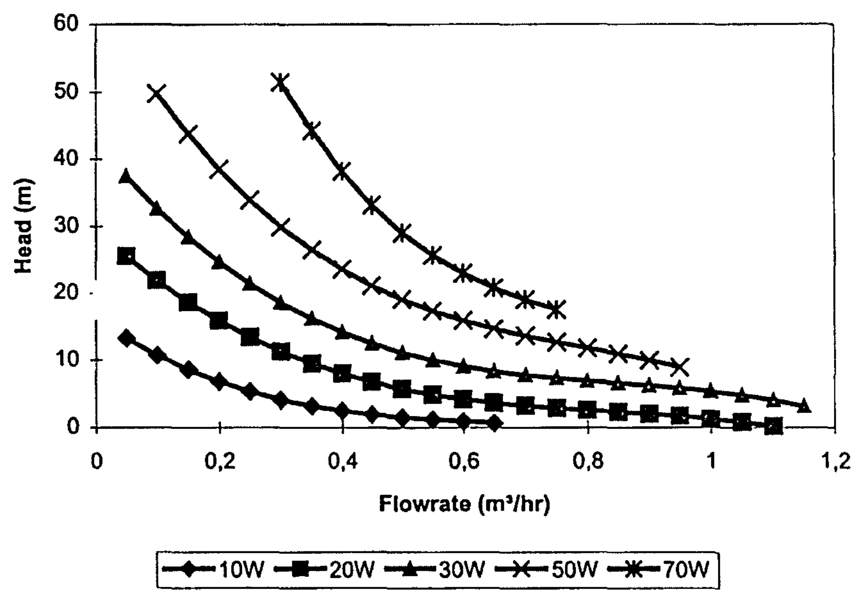

Figure(2.6): Subsystem efficiency vs head at different input power settings (Shurflo pump)
Subsystem efficiency
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0,0
10,0
20,0
30,0
40,0
50,0
60,0
70,0
80,0
Head (m)
30W
45W
60W
70W

Figure (2.7): Behaviour of Solarjack pump at different head settings



Figure(2.8): Head-flowrate curves at different input power settings (Solarjack pump)



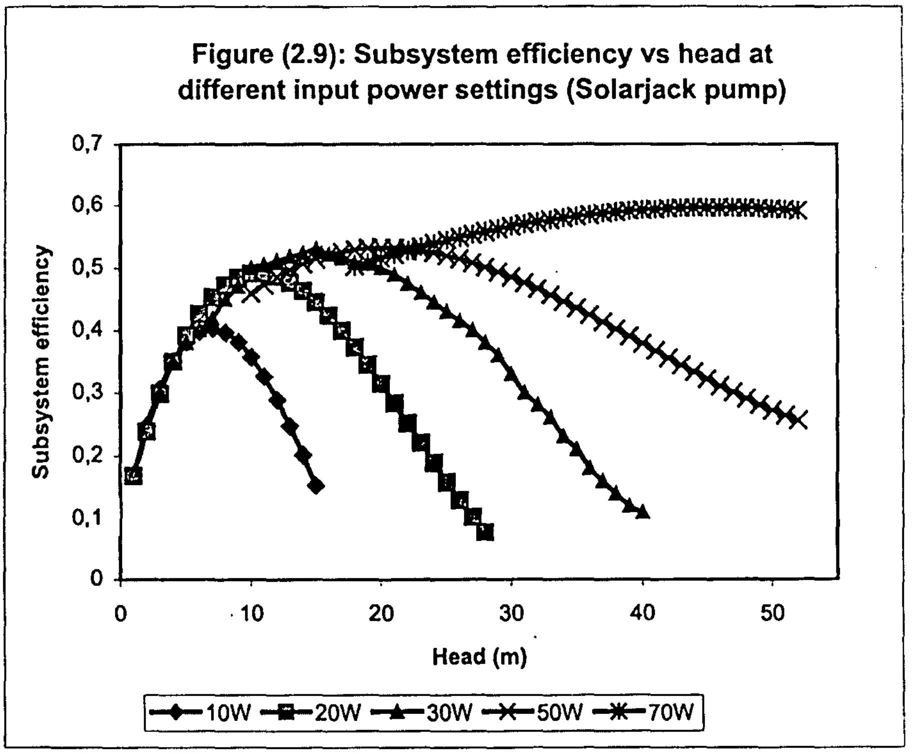
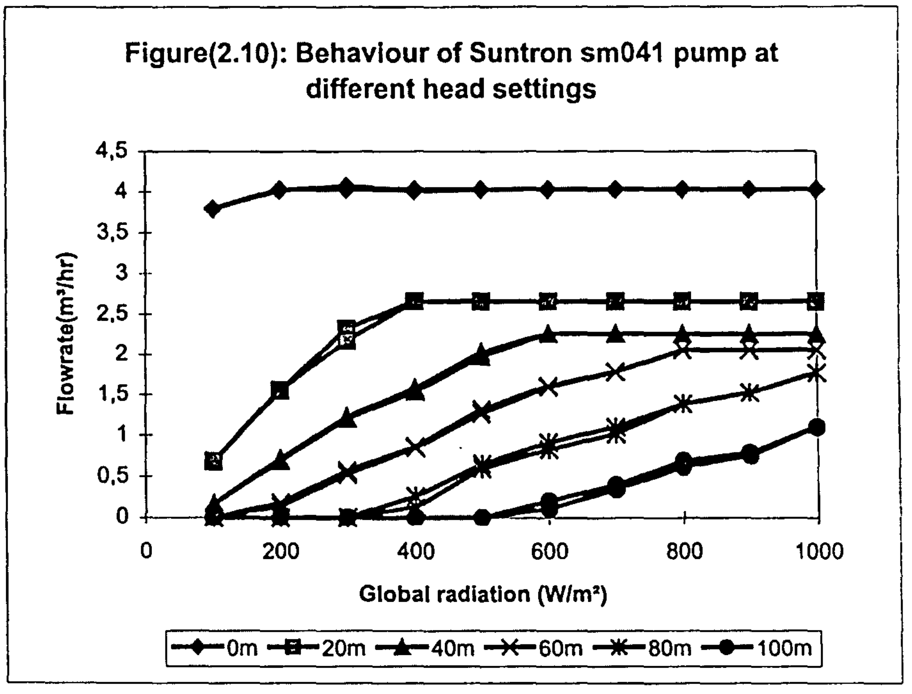
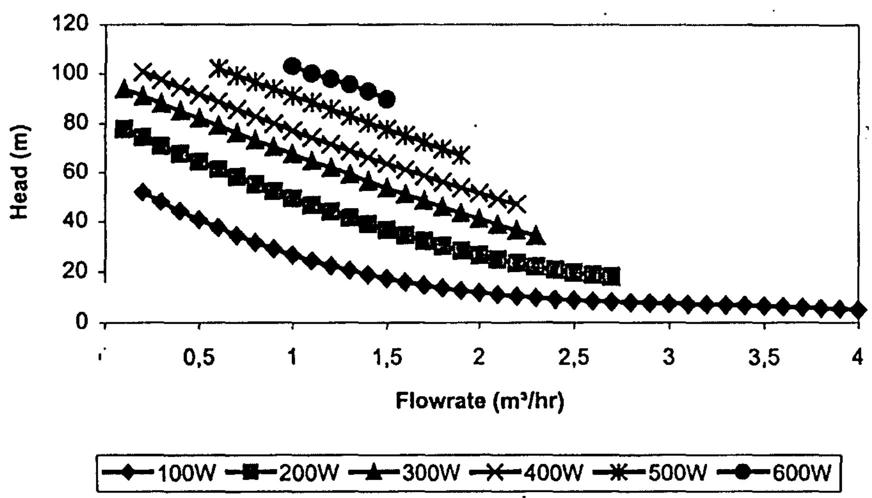


Figure (2.9): Subsystem efficiency vs head at different input power settings (Solarjack pump)
Subsystem efficiency
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
10
20
30
40
50
Head (m)
10W
20W
30W
50W
70W


Figure(2.10): Behaviour of Suntron sm041 pump at different head settings
Flowrate(m³/hr)
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
0
200
400
600
800
1000
Global radiation (W/m²)
0m
20m
40m
60m
80m
100m

Figure(2.11): Head-flowrate curves at different input power settings (Suntron sm041 pump)



Figure(2.12):Subsystem efficiency vs head at different input power settings(Suntron sm041 pump)

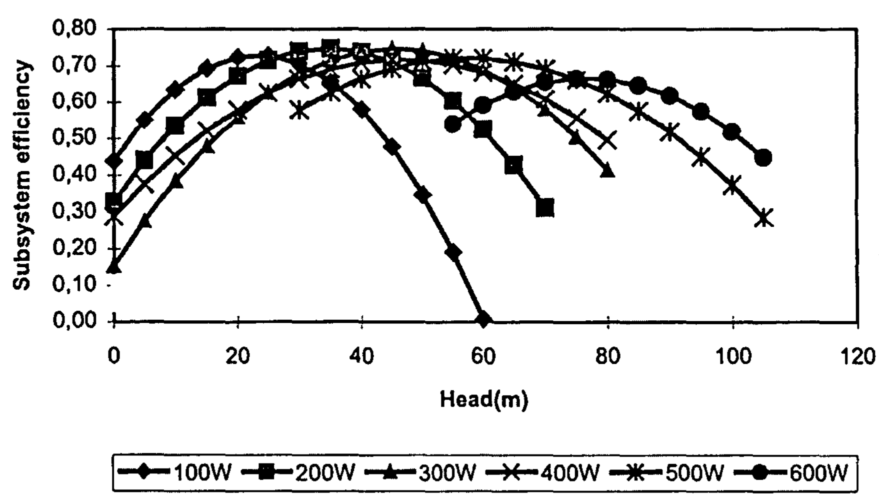
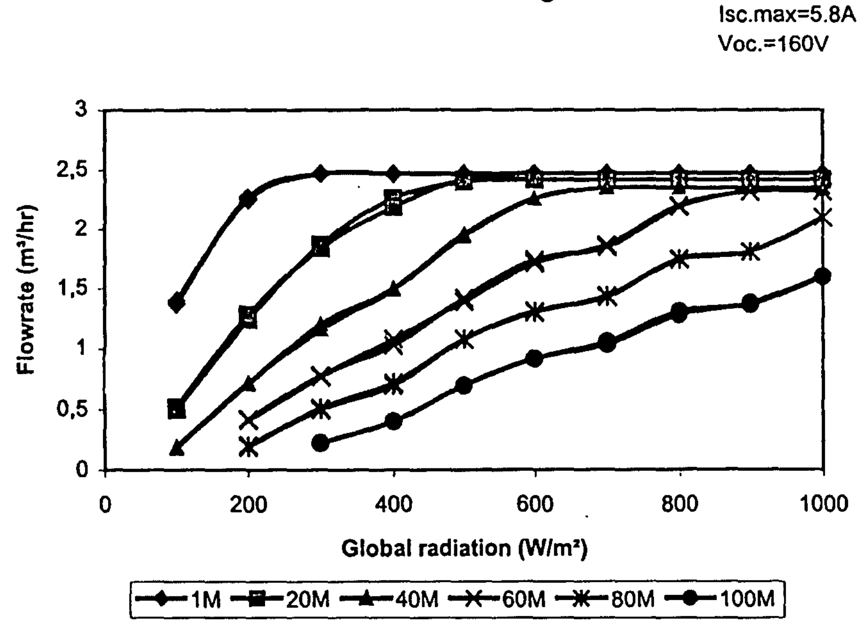
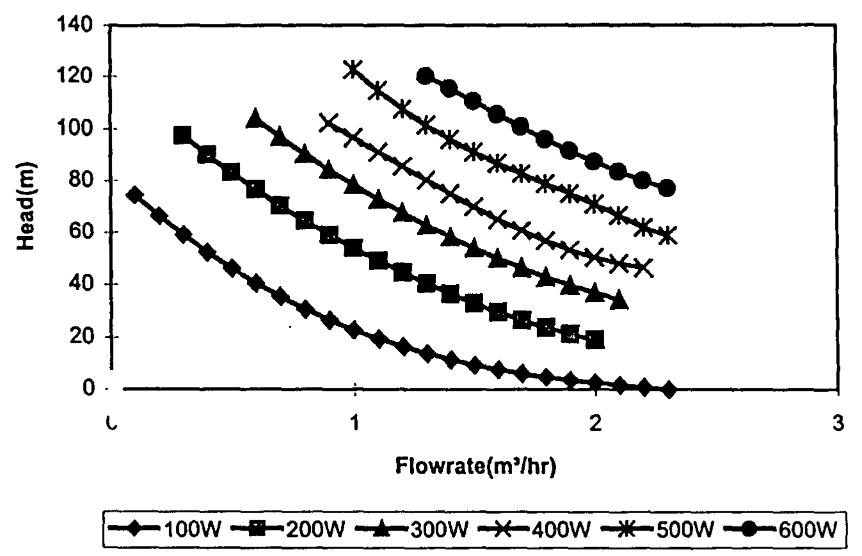


Figure 2.13): Behaviour of Suntro sm042 pump at different head settings



Figure(2.14): Head-flowrate curves at different input power settings (Suntron sm042)



Figure(2.15): Subsystem efficiency vs head at different input power settings (Suntron sm042 pump)

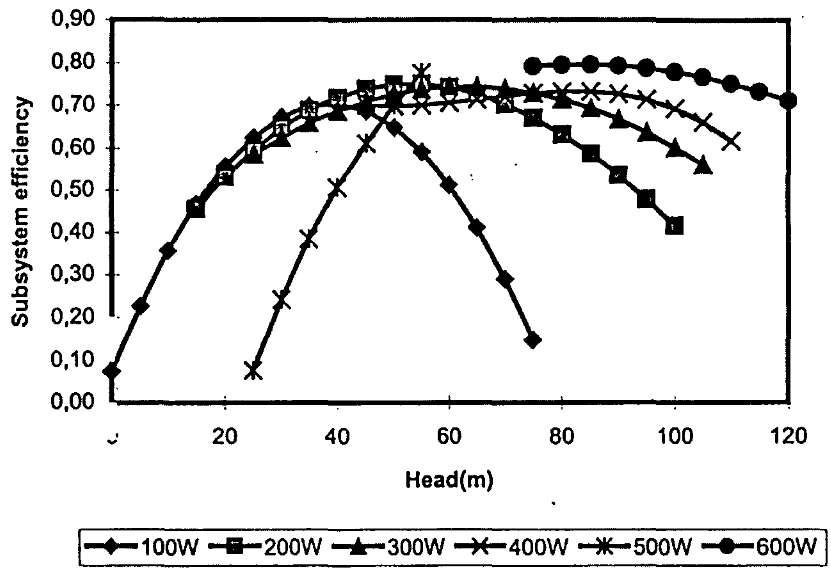


Figure (2.16):Head flowrate characteristics of SCREW PUMP (NQ14) at different frequency settings

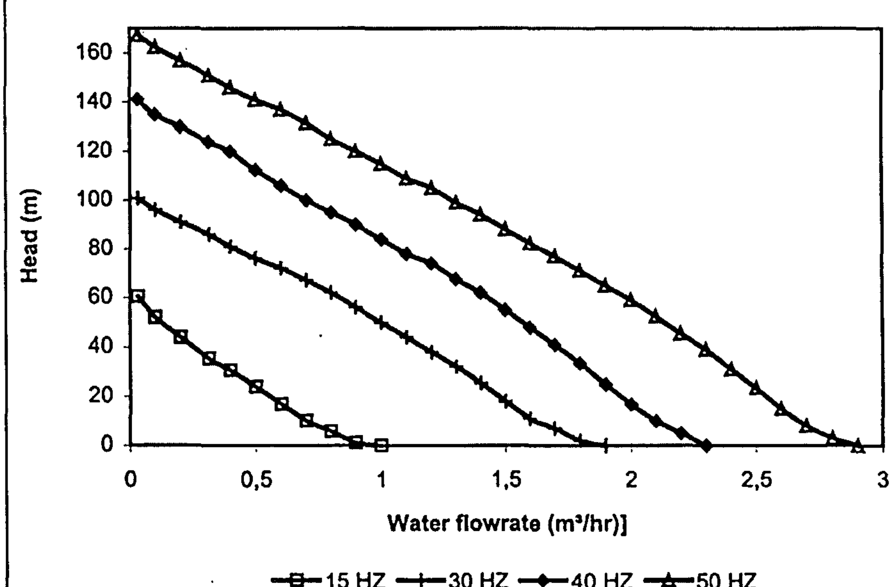
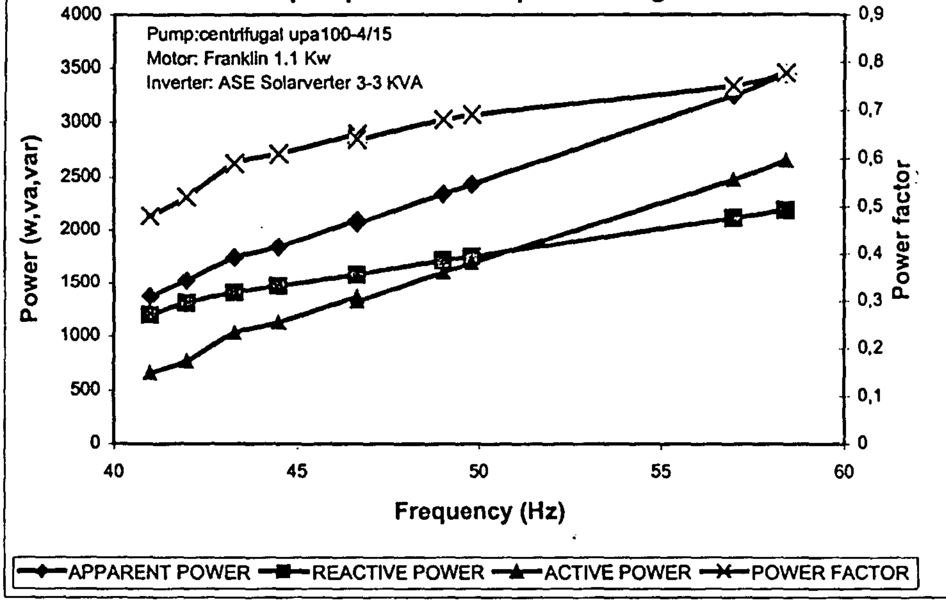


Figure (2.17): General characteristics of a 3 ph centrifugal pump at different speed settings



3- Economic Feasibility Of PV Technology- Case Study For PV Water Pumping Systems In Comparison To Diesel Systems

For any proposed project the importance of the economic feasibility is considered as one of the main factors that affect the project at all. It plays a key role for the decision of investors, financing institutions, and so technical planners.

It's worthy to mention here that there is a difference between financial analysis and economical analysis. The financial analysis takes the perspective of private investors (utility), bank, financing institution, and donor (loan). Where as economical analysis takes the perspective of government and society, public sector and donor (grant). In addition the economic study should consider the effects of foreign exchange costs, real interest rates, taxes and subsides, employment and social effects. So, the financial analysis is a basic tool for investment decisions or technology selection. Further important rational decision factors are the economical and technical assessment.

In this study, a detailed analysis and evaluation will be executed for three cases of PV water pumping systems of different sizes. In addition, other comparable cases for diesel pumping systems will be investigated so as to compare the economical feasibility of PV-Pumping systems in comparison to diesel pumping systems.

3.1- Main Parameters Affecting The Economics Of The PV Project

For executing accurate economical analysis, many parameters that affect the results directly or indirectly have to be considered. Here are the main important direct parameters. Other indirect parameters like social and environmental aspects are not considered here because it is mainly dependent on the place, situation,...etc.

* Field of application (electrification, pumping, ...etc.).
* Alternatives (Diesel, Batteries,...etc.).
* Location (effect of distances).
* Geographical location (effect of meteorological parameters).
* Electric load.
* Interest rate.
* Inflation rate.
* Intensity of solar irradiance.

* Fuel price.
* Installation costs.
* Lifetime of components.
* Component costs.
* Maintenance costs.

3.2- Key Factors Of Economical Results

The following 3 factors are the main indicators of the economic evaluation results:

* Net present value (N. P. V).
* Annuity (A).
* Cost annuity per production unit.

3.3- Methodology

Aiming at presenting a realistic economical study, actual technical data has been considered from 3 PV-Pumping systems. Technical and actual output data for these 3 stations (Station 1, Station 2, Station 3) are briefed in table (3.1). The costs of components are taken from actual competitive prices 2001.

Interest rate of 8%, inflation rate of 5 % are considered. The whole system life was assumed to be 20 years with no salvage value for any components.

Table(3.1): Financial data for PVP-systems

Specification, items	*Unit*	Station 1	Station 2	Sharq El-Hasa	Life time
-Output equivalent hydraulic energy	m^4 / year	579000	846000	1472000	
-Installed PV power	kWp	2.8	4.5	6.3	
-Specific module price	US$/Wp	4.7	4.7	4.7	20
-Specific price for structures	US$/Wp	0.4	0.4	0.4	20
-Total PV generator/structure	$	14280	22950	32130	
-Inverter cost	$	4200	5800	7000	10
-Cost of submersible pump	$	450	600	900	10
-Cables and wires cost	$	50	100	150	10
-Pipes cost	$	200	300	500	10
-Cost of installation	$	500	800	1200	
-Storage tank cost	$	3000	3000	3000	20
1.Total initial investment costs	$	22680	33550	44880	
-Operator (if needed)	$/year	/	/	/	
-Maintenance (yearly)	$/year	400	600	900	
2. Total operating costs	$/year	400	600	900	

For diesel pumping systems, 3 comparable cases are considered. Technical data are taken from manufacturer specifications and expertise. Table (3.2) shows the details.

Table (3.2): Technical and financial data for proposed diesel pumping systems

Specification, items	Unit	Station 1	Station 2	Station 3	Life time
-Output equivalent hydraulic energy	m^4 / year	579000	846000	1472000	
-Nominal power of diesel generator	KVA	3.5	5	7	
-Efficiency of diesel engine	%	25	28	32	
-Efficiency of generator	%	75	78	82	
-Efficiency of the pump-motor set	%	40	43	46	
-Overall efficiency	%	7.5	9.4	12	
-Specific hydraulic equiv. per lit. fuel	m4/l	275	345	440	
-Specific fuel consumption	L/1000 m4	3.6	2.9	2.3	
-Flow rate	m^3/hr	10	8	7	
-Total pumping head	m	24	50	85	
-Hydraulic energy discharge	m4/h	240	400	595	
-Diesel consumption	L/h	0.87	1.16	1.35	
-Yearly diesel consumption	L/year	2084	2453	3386	
-Diesel generator set price	$	1500	2500	3500	5
-Submersible pump cost	$	450	600	900	10
-Cables & wires cost	$	40	50	100	10
-Pipes cost	$	200	300	500	10
-Price for installation	$	400	400	400	
-Storage tank cost	$	1500	1500	1500	20
1. Total investment costs	$	4090	5350	6900	
-Fuel price + transportation cost	$/L	0.2	0.2	0.2	
-Fuel + transportation cost	$/year	417	490	677	
-Lubricant (0.01 liter/ hour)	$/year	50	60	80	
-Operator (if needed)	$/year	2000	2000	2000	
-Maintenance	$/year	200	300	400	
2. Total operating costs	$/year	2667	2850	3157	

Note: These information were taken mainly for Jordan market. To apply this for other markets, see item "Sensitivity analysis" in which the costs are tolerated for ± 50% of this cost and data results are calculated on this basis

3.4- Results And Conclusions

After collecting all necessary data for the economical study it has been entered to computer software specialized for economical analysis (EPRO-ITW). The results are briefed in table (3.3) and table (3.4)

Table (3.3) : Dynamic indicators for PV - Pumping systems

	Unit	Station 1	Station 2	Station 3
Initial Investment	$	22680	33550	44880
Net present value	$	- 32407	- 47726	- 64899
Cost annuity	$	2150	3166	4305
Cost annuity per Production unit	$/1000 m^4	3.71	3.74	* 2.92

* Good design (Tandem system)

Table (3.4) : Dynamic indicators for diesel Pumping systems

	Unit	Station 1	Station 2	Station 3
Initial Investment	$	4090	5350	6900
Net present value	$	- 48236	- 54729	- 63570
Cost annuity	$	3200	3630	4217
Cost annuity per Production unit	$/1000 m^4	5.53	4.29	2.86

The cost annuities per production unit in the last two tables are depicted in figure (3.1). It is clear from this figure that PV pumping systems are competitive to diesel pumping systems in the range lower than 1.4 * 10^6m4/year or 3800 m^4/day.

On power basis, PV systems of output peak power equal or less than 6 kW are competitive to diesel pumping systems in regions where yearly average tilted solar radiation is in the range of (6 kWh/m^2.day).

3.4.1- Variation Of Unit Cost With Pumping Head

The equivalent hydraulic energy (m^4) which is the multiplication of water output volume (V) in cubic meter by the pumping head (h) in meter is the basic output unit. These results are applicable for any well by substituting the head and thus concluding the cost of 1 m^3 water.

To demonstrate the effect of the well depth on the cubic meter cost, figure (3.2) has been depicted depending on the following criteria:

1 m^3 cost ($/$m^3$) = cost of 1 m^4 ($/m^4)* head (m)

Considering the equivalent hydraulic energy cost equals to 3.7 \$/1000 m^4 (i.e 0.0037 \$/m^4). the equation becomes: 1 m3 cost (\$/m^3) = 0.0037 * h

3.4.2- Effect Of Production Units On The Cost Annuity Per Production Unit

To demonstrate the effect of changing the yearly output quantities of equivalent hydraulic energy units (m^4), an increase of 50% and decrease of 50% of the actual output units have been considered in figure (3.3) for station 1 and PV case.

In this figure, it is concluded that decreasing output by 50% will increase the unit cost (\$/1000m^4) from 3.71 to 7.5 (100%) while increasing output by 50% will decrease the unit cost (\$/1000 m4) from 3.71 to 2.5 (33%).

The importance of the results of this figure are briefed in the following:

- Demonstrating the effect of yearly average solar radiation and its changes from year to year or from place to another onto the cost of the output water units. A decrease of solar radiation from 6 kWh/m^2.d to 5 kWh/m^2.d will increase unit cost (m^4) by 20%.

- Visualizing the differences of the unit cost between month to month in the same year, according to changes in solar radiation intensity.

- Estimating the increase of unit cost in case of system failures. For example, in year x if the system has failed for 36 days (10% of the year), the unit cost will increase from 3.71 to 4.15 (12% increase).

- Demonstrating the effect of generator power output with time. A degradation of 1% per year will decrease water output with about the same percentage. This will cause an accumulative additional cost of water output units.

3.4.3- Sensitivity Analysis

In figure (3.4) , increase and decrease of 50% on the cost of the major components and on the running cost is considered. This gives a general impression of the following:

- effect of price oscillation for any component on the unit cost.

- demonstrating the effect of the input parameters values on the unit cost, for example the interest rate value has a major effect on the unit cost while the operating cost has a minor effect. In figures, increasing the interest rate value from 8% to 10% (25%) will increase the unit cost from 3.71 to 4.2 (13%) while increasing the PV-generator cost of the same value (25%) will increase unit cost of about 11%.

3.4.4- Effect Of Water Tariff And Pumping Head On The Cost Annuity Per Production Unit, Net Present Value, Internal Rate Of Return, And Pay- Back Period

Based on the results of figure (3.2), it becomes clear for investors to determine the price of water which is to be supplied to the consumer to achieve the required profit. As a demonstrative example, Station 1 PV-system is considered with 3 different water tariffs (0.2, 0.45, 0.7) $/ m3 and 10 different values for well depth (10, 25, 40, 55, 70, 85, 100, 115, 130, 145) m.

The results are briefed in table (3.5) and figures (3.5), (3.6), (3.7), (3.8)

Depending on the above mentioned figures, the following are concluded:

- The cost annuity per production unit ($/m³) is proportionally increased with increasing pumping head.

- To achieve a minimum internal rate of return = 20% at water tariffs = 0.2, 0.45, 0.7 $/m³ the following pumping head should not be exceeded (30, 65,100) m respectively.

- For the three different water tariffs (0.2, 0.45, 0.7) $/m³, the system will be critically balanced (net present value =0) at the following pumping head 54, 120, more than 150 m respectively.

Table (3.5) : Net present value, unit cost, internal rate of return, and pay - back period at different water tariffs and pumping head

Water tariff $/m³	Head m	Yearly water output m³	Net present value ($)	Cost annuity per unit $/m³	Internal rate of return (%)	Pay-back period (Year)	Revenue $ / Year
0.2	10	57900	142171	0.04	56.5	2.1	11580
	25	23160	37424	0.09	23	5.9	4632
	40	14475	11237	0.15	13.1	12.8	2895
	55	10527	-673	0.2	7.7	-	2105
	70	8271	-7472	0.26	3.9	-	1654
	85	6812	-11874	0.32	0.9	-	1362
	100	5790	-14949	0.37	-	-	1158
	115	5035	-17226	0.43	-	-	1007
	130	4454	-18975	0.48	-	-	891
	145	3993	-20362	0.54	-	-	799
0.45	10	57900	360395	0.04	123	0.9	26055
	25	23160	124714	0.09	51.1	2.4	10422
	40	14475	65797	0.15	32.5	4	6514
	55	10527	39007	0.2	23.5	5.7	4737
	70	8271	23705	0.26	18	7.7	3722
	85	6812	13800	0.32	14.2	11.8	3065
	100	5790	6880	0.37	11.2	14.8	2606
	115	5035	1755	0.43	8.9	18.4	2266
	130	4454	-2195	0.48	6.9	-	2004
	145	3993	-5316	0.54	5.2	-	1797
0.7	10	57900	578618	0.04	190.8	0.6	40530
	25	23160	212003	0.09	78.1	1.5	16212
	40	14475	120357	0.15	49.7	2.4	10133
	55	10527	78687	0.2	36.6	3.5	7369
	70	8271	54882	0.26	28.9	4.6	5790
	85	6812	39474	0.32	23.7	5.7	4768
	100	5790	28695	0.37	19.9	6.9	4053
	115	5035	20735	0.43	16.9	8.3	3525
	130	4454	14599	0.48	14.5	11.5	3118
	145	3993	9730	0.54	12.5	13.4	2795

Figure (3.1) Effect of system size on unit cost

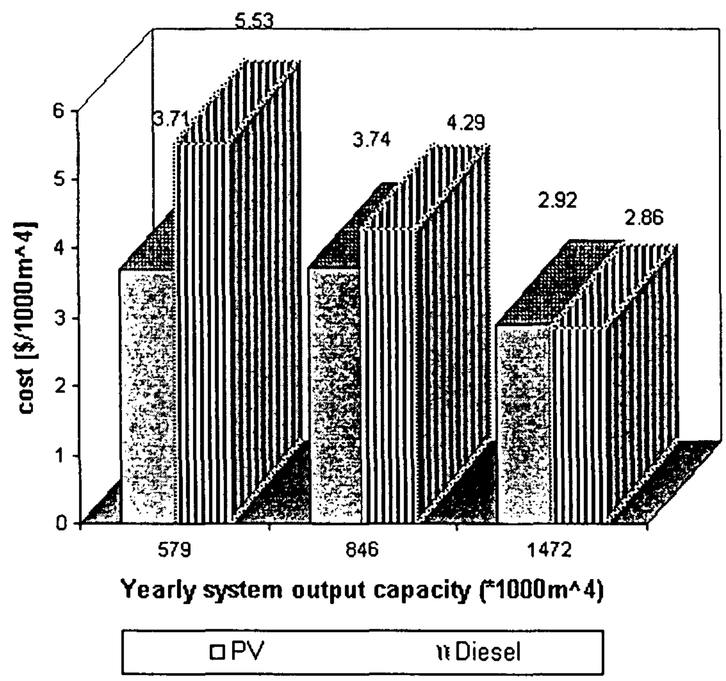
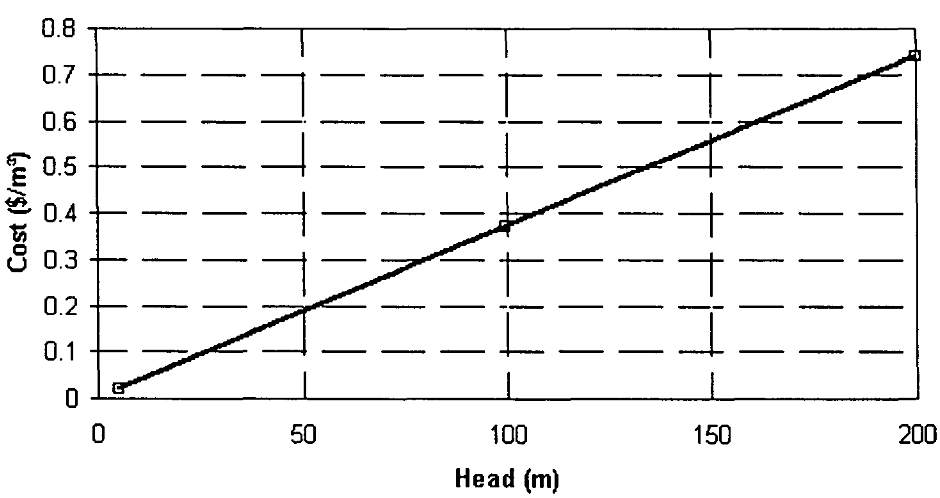
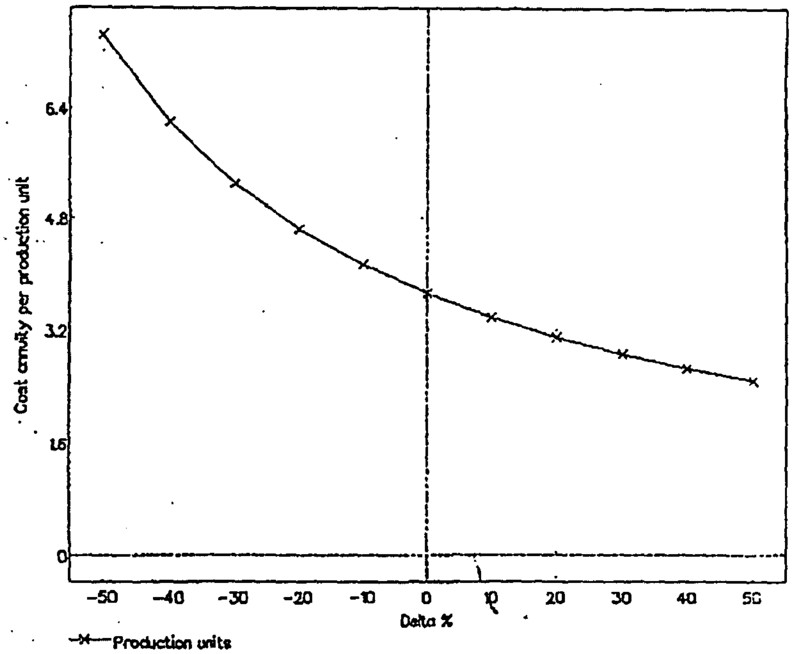


Figure (3.2): Effect of pumping head on the unit cost



Figure(5.3): Effect of produced unit quantities on the unit cost



Figure(5.4): Effect of major parameters on the unit cost

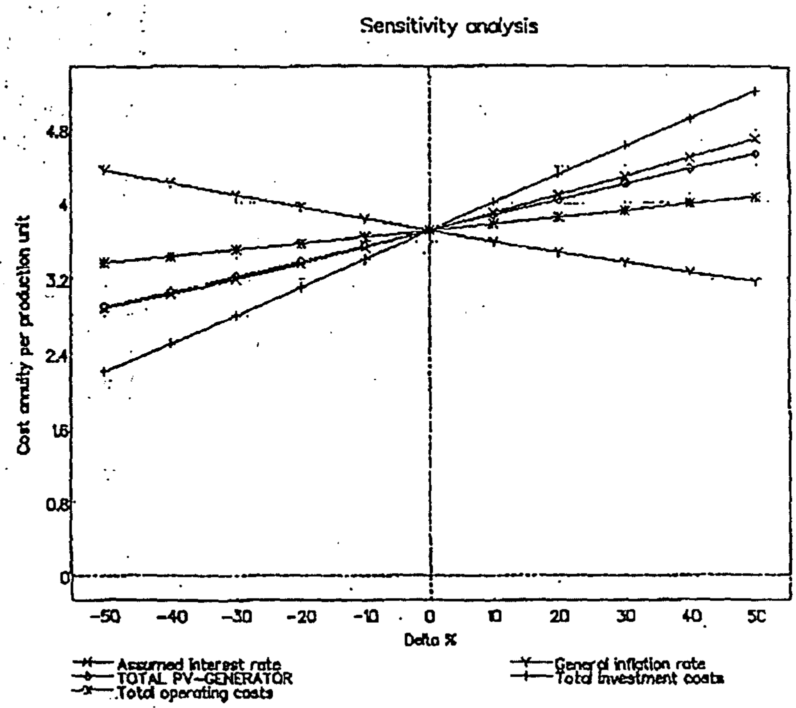


Figure (3.5): Net present value for pvp system at different water tariffs

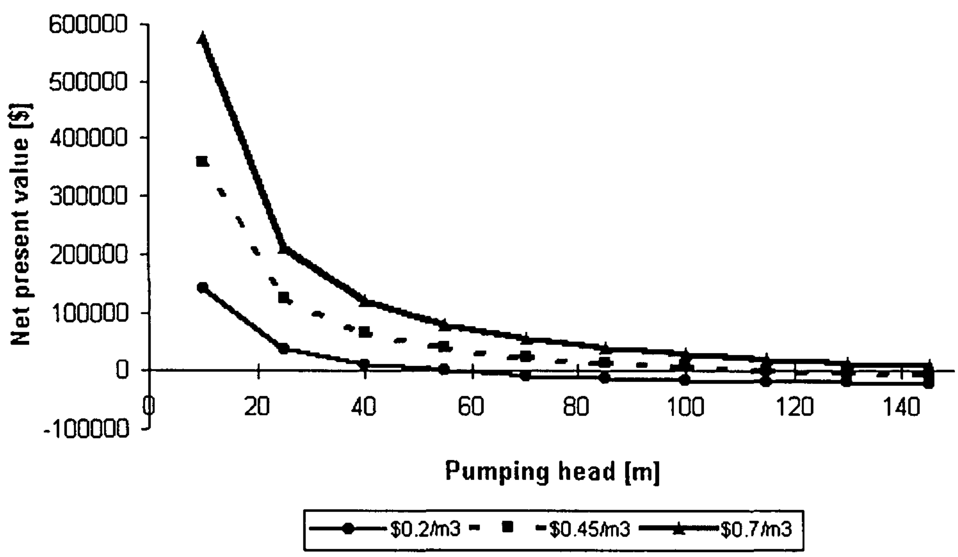
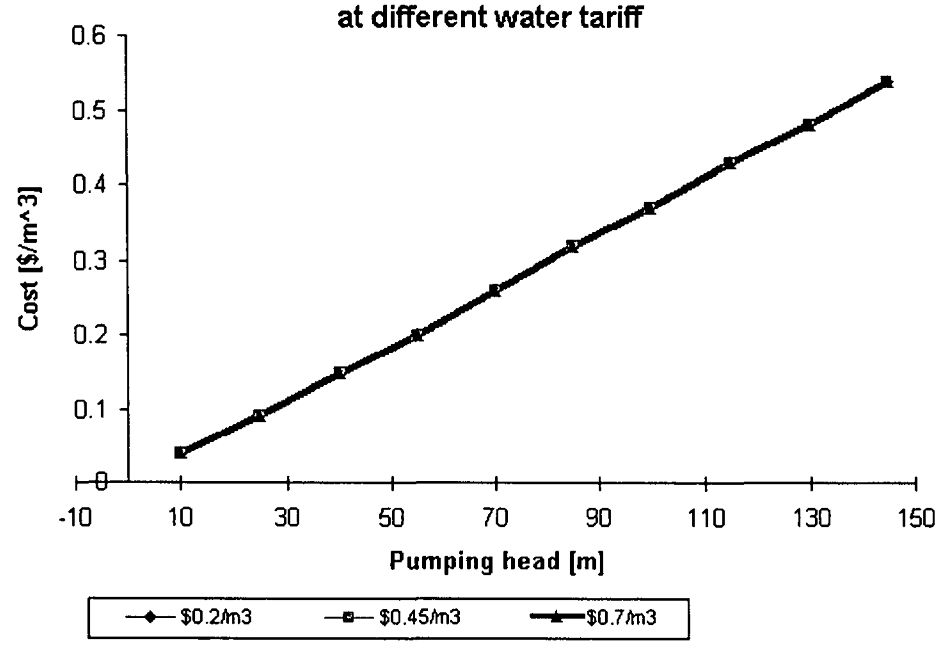


Figure (3.6): Cost annuity per prod. unit for pvp system at different water tariff



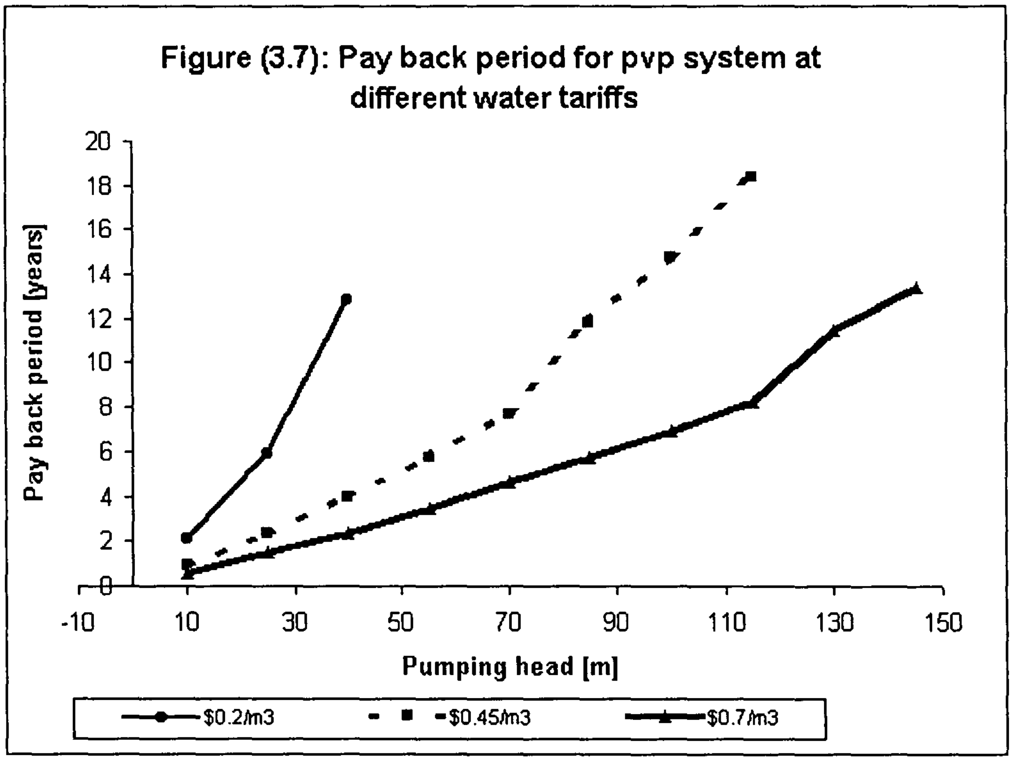


Figure (3.7): Pay back period for pvp system at different water tariffs
Pay back period [years]
20
18
16
14
12
10
8
6
4
2
0
-10
10
30
50
70
90
110
130
150
Pumping head [m]
$0.2/m3
$0.45/m3
$0.7/m3

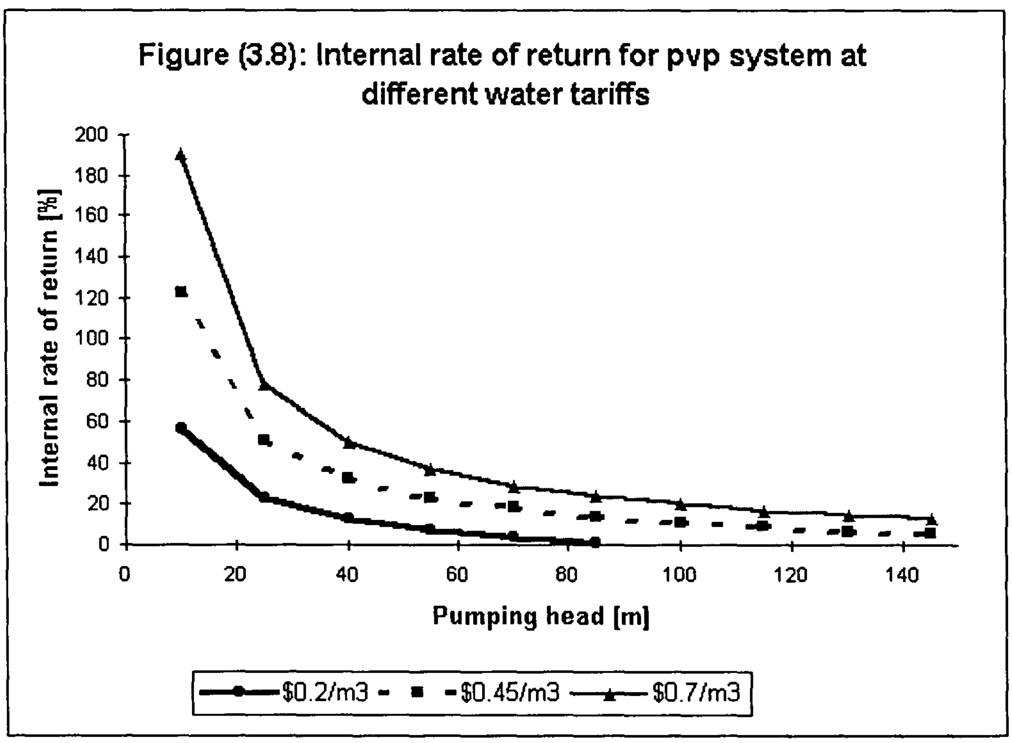


Figure (3.8): Internal rate of return for pvp system at different water tariffs
Internal rate of return [%]
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Pumping head [m]
$0.2/m3
$0.45/m3
$0.7/m3

4- Conclusions And Recommendations Based on Field Experience

It is worth mentioning to make it clear here that the below mentioned results, conclusions, and recommendation are based on personal experience in PV water pumping systems in Jordan through executing many international research and application projects in cooperation with many technical and financial institutions in Germany and others. To the best of my knowledge, I tried to conclude the major important information that are necessary to technicians and decision maker peoples who are planning to implement this technology for PV projects:

- For a research work, the measuring stage is considered as the corner stone in achieving the required results. The measuring process, measuring system, and the related sensors should be carefully selected after determining the necessary variables needed to conclude the target results. Calibration of sensors shall be regularly done and when deviation is noticed. The evaluation process shall be started directly through the measuring process and not later. The collected data shall be checked and evaluated directly so as to discover any anomalies in the system.

- The monitoring process during measurement should be carefully planned and adopted. Visual checks for system components shall be executed regularly.

- Basic manual measurements are sometimes needed in the field for check or repair objectives.

- Lab tests for system components are sometimes needed specially when notifying any anomalies.

- A person with field experience shall check the system between time to time. This will include manual measurements, computer data, visual check, voice check (pump operation)...etc.

- The tilt angle of the PV generator shall be carefully selected. The latitude, solar radiation distribution through the year and the demand pattern are the main factors that determining the tilt angle. Mostly in remote areas the demand for water is increasing in summer and decreasing in winter. This means that the tilt angle shall be selected to gain more radiation in summer. In this case, water output at the lowest radiation month shall be carefully considered. As a result, optimization process would be the most feasible solution.

Another point which should be considered here is the design factors of the system components specially the size of the generator and the pump and the radiation value at which the system reaches its maximum output. For example if the system reaches its maximum output at 600 W/m^2, it is unfavorable to have very small tilt angle. On the other hand if the system reaches its maximum output at say 900 W/m², it could be feasible to have small tilt angle so as to gain as much as possible in summer time specially if the water demand in winter is very limited.

Moreover, the type of the pump has a role in selecting the tilt angle. As it will be stated later, some pumps are performing better than others are, when operated at part load. So again, optimization process is a favorable option here

- Two angle-setting possibilities are recommended depending on the demand pattern. One to be set in wintertime and the other for summertime (September/March – settings).

- In case of installing more than one row of modules, the shadowing effect shall be considered. The distance between rows should be carefully calculated.

- Solar radiation measurements for a reasonable period are necessary for the design process. Minimum and maximum monthly data based on hourly values is highly recommended.

- Demand pattern information through the year should be available. This will minimize the possibility of over-sizing the system or under-sizing it. Moreover, it is necessary -as mentioned above- for the tilt angle setting.

- Depending on the place of installation, it is generally recommended to have a fence around the system. This fence shall be designed according to the place and the nature behavior of the people around. For example, sometimes it is necessary to have a tool to minimize the danger of throwing stones on the PV generator. This fence should be selected and installed in such a way to not make shadowing on the generator.

- It is very important to avoid the existence of a guard on the system in order to minimize the system operating cost. This factor is a major one for the attractiveness of PV systems over diesel systems which are in need for an operator

- During the installation process of the system in the field, the following main points should be considered:
  - Safety conditions when working with electricity and when installing the pump in the field
  - For deep wells it is necessary to have a steel wire connected to the pump and tightened above at the casing head.
  - Cables and wire diameter shall be suitably selected to avoid voltage drop.
  - Components shall be installed close to each other to avoid wiring losses
  - The length of the pump cable shall be checked before installing the pump. The cable shall be tightened to the water pipes by using special connectors.
  - The pump shall be tested in a barrel before installation
  - The wellhead shall be covered after installation.

- The well casing diameter shall be suitable for the pump size
- The dynamic head of the well has to be already known so as to determine the total depth at which the pump to be installed.
- Pipe diameter and length have to be carefully designed and selected to avoid head losses
- Joints, fittings, bends and valves in the pipe lines have to be carefully selected from types of minimum friction losses
- For long pipe distances on the delivery side, valves have to be carefully selected to avoid water hammer phenomena.
- The phase sequence of the pump has to be matched with that of the inverter to avoid reverse direction operation.
- The foundation of the generator shall be strong enough to avoid any expected wind conditions in the region
- Earthing system has to be well done.
- Manual measurements have to be done before operating the system especially in the generator side.
- Submerged electric water connectors for cables shall be carefully worked out by experienced person

- Considering the fact that solar radiation increases in summer and decreases in winter and having in mind that mostly water demand increases and decreases in the same pattern, this makes water pumping systems an attractive application for solar energy

- Water is stored in storage tanks without need for batteries. This means lower initial and operating costs.

- Tilting the PV generator at an angle 30 degrees (in Jordan) which is close to the latitude has gained 11% of solar irradiance over horizontal surface settings. Even though, there were some periods in winter of loosing solar energy due to tilting the generator.

- An optimization process should be adopted together with the design process. This is needed for the following aspects:
  - The point at which the system starts pumping water and the point at which the system reaches its maximum output have to be carefully selected considering also the economic aspects. Unfortunately, they are contradicting each other. The bigger the generator is, the higher the cost, the earlier system operation, the earlier system reaching maximum output, the higher amount of flowrate output, the higher period at which the system can not benefit from high values of solar radiation. So, all these facts together with the economical factors should be considered and simulated.
  - The pattern of the demand and the pattern of solar radiation distribution through the year will determine the system sizing, tilt angle and the needed storage tank capacity.

- The type of the monocrystalline silicon cells use in the field has showed a maximum cell efficiency of 12%

- Centrifugal motor pump set of PVC impeller material has showed a maximum efficiency of 40%

- Generator and total system efficiencies are decrease during the noon time due to the effect of increasing ambient temperature and also due to the fact that the system has reached its maximum output capacity where further radiation is not interpreted to benefit output.

- System voltage is decreasing with ambient temperature increase. For a multicrystalline generator of three years old (50 W_p, it was found that the degradation in voltage for each module per unit ambient temperature is 0.089 V/module. °C.

- Lifetime of modules has showed some effects on the system behaviour. Some modules were highly affected while others not. In general, for some tested modules, it was found that the output power and the fill factor are the major affected parameters. In this regard, it should be emphasised that field basic tests of short circuit current and open circuit voltage are not enough. An I-V curve tracer is needed to draw the I-V curve.

- Tandem system has showed a big advantage over normal system. In Jordan, this system has been tested where it showed 19% of additional water output quantities over the normal system.

- DC systems are still facing a serious problem in the motor brushes, which has to be changed between time to time. The advantage of this system is its higher efficiency.

- One of the most promised system is the DC systems with brushless motor. The main handicap in this regard is the scarcity of manufacturers.

- Nowadays, centrifugal pumping systems are the most popular systems available in the market. Its main advantage is the availability of pumps and spare parts.

- Lab tests have showed the following maximum subsystem efficiency for different systems:

* Single phase centrifugal pumping system:	37%
* Shurflo pumping system-DC:	50%
* Solarjack pumping system-DC:	58%
* Suntron SM041 (screw) pumping system-DC:	75%
* Suntron SM042 (screw) pumping system-DC:	80%

- In terms of efficiency, screw pumps have shown a clear advantage over all other pumps in this field of applications.

- Even with its high efficiency, screw pumps are still facing a starting problem. Development processes has shown no advantage of reducing the rotor diameter.

The best way was to provide a parameterized inverter where some parameters can be set according to the type of the pump used. Moreover, matching processes has shown the need for big motor to be connected with the pump to help in the starting process.

- Screw pumping system has shown a big advantage at part load operation. This fits with the fact of the daily solar radiation pattern. Field results have indicated a best operational region of 22 to 42 Hz with maximum instantaneous total system efficiency of about 5.5 %

- The output water of centrifugal pump is highly affected by increasing pumping head while slight effect on screw pumping system is occurred. Thus, in deep wells, the use of screw pumps is highly recommended.

- Screw pumps are also still having some technical problems represented in failures of some parts. Efforts are now faced toward improving the material of the connected rod and the coupling system.

- Field testing results of 3 phase screw and centrifugal pumping systems installed in the same well and operated under the same conditions have shown the following main results:

	Screw pumping system	Centrifugal pumping system
Cell efficiency	12%	12%
Radiation needed for start pumping	150 W/m²	240 W/m²
Radiation needed to rotate the pump	120 W/m²	< 50 W/m²
Frequency needed to start pumping	7 Hz	40 Hz
Best hourly subsystem efficiency	40 %	33%
Best hourly total efficiency	4.8%	4%

- On the long run operation screw pumps have shown better performance than centrifugal. It pumps 17% more water than centrifugal. In cloudy weather conditions, screw pumps have big advantage over centrifugal. For sample cloudy days, screw pump has delivered 61 % more water than centrifugal pump.

- In general, screw pumps have better performance at part load operational periods the fact that fit with the nature of solar radiation pattern. When solar radiation decreases, output frequency and thus output flowrate decreases and this is the meaning of part load operation in this case.

- At full load operation (normally 50 Hz), screw and centrifugal pumping system have shown the same performance.

- PV systems in general have better performance in the period morning to noon than the period noon to evening. This is due to the increase of ambient temperature and thus cell temperature in evening time.

- During the noon time, PV cell and system efficiencies are decreased due to two reasons: the first one is temperature increase and the second one is the load limitation where the load is reaching its maximum before the solar radiation reaches its maximum values. So, further increases in solar radiation is not interpreted into more output.

- Concerning the reliability of the system components, the following are 3 years monitoring results:

  - Damage of modules by throwing stones from children
  - String fuses are sometimes failed and this means a separation of the complete string from the field.
  - Browning has been occurred in some modules.
  - Dust is accumulated on the surface of the generator in the dusty regions.
  - Inverters have encountered some problems represented in damage of electronic boards or need for parameterization.
  - For pumps, the plastic non-return valve was the most frequent problem. Other problems in the plastic impellers have been encountered.
  - Motors were the most reliable component in the system. No failure was noticed.
  - Other problems in cabling and wiring have been registered.

- Economic studies have shown the following results:
  - The initial investment in PV systems is relatively high, but the net present value has shown competitive figures to Diesel system up to certain limit. It was found that for the situation of Jordan, PV systems are more economic than Diesel for system capacity of up to 3800m^4/day.
  - Interest rate has a major effect on the cost annuity per production unit. For example, increase of interest rate from 8% to 10% will increase unit cost by 13%
  - Operational cost has a minor effect on the unit cost
  - Unit price is proportionally increased with increasing pumping head. For example, the unit cost for a well of 60 m pumping head is double the unit cost of a 30 m pumping head.
  - Decreasing the output cubic meters of waters have a major effect on the unit cost. For example, decreasing output by 50% will increase unit cost by 100%. On the other hand, increasing output by 50% will decrease unit cost by 33.3%

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The Status of Renewable Energy Development in the Arab Countries

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Workshop on
Solar Cells and Water Pumping Systems

Photoenergy Center

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TABLE OF CONTENTS

I. INTRODUCTION

This report details the status of renewable energy (RE) in the Arab countries with the purpose of evaluating available resources, justifying the need for harnessing these resources, describing activities in the RE fields and identifying the institutions responsible for RE development. The report follows the following structure:

a. An introduction providing general information on Arab countries related to population, rural development and water supply problems.
b. Energy resources in Arab countries: conventional and renewable energy resources, energy consumption.
c. Institutions responsible for RE development
d. RE activities
e. Coordination and cooperation programmes

A. Population

The Arab countries are spread over a vast land extending from west Asia through North Africa. The total population of the Arab countries was around 270 million in 1999, 60% of which belong to the Mashreq countries known as ESCWA* countries, and 40% belong to the Maghreb countries.

B. Economic indicators

The Arab countries can be classified into two main groups according to their economic activities. These are the major oil producing countries of the Gulf Cooperation Council (GCC), and the countries with more diversified economies. The latter also differ greatly among themselves in terms of their economic development and living standards because some of them have reasonable oil resources, others have flourishing sectors such as tourism, trade, banking etc., while some others experience poor living standards Table 1 shows the GDP per capita in the Arab countries in 1999.

Table 1: Gross Domestic Product per Capita in 1999

GDP per Capita [USD]			
Country	GDP/Capita	Country	GDP/Capita
Algeria	1499	Oman	6724
Bahrain	10183	Palestine	-
Egypt	1435	Qatar	20601
Iraq	3674	Saudi Arabia	6525
Djibouti	842	Sudan	307
Jordan	1539	Sumal	200
Kuwait	12504	Syrian Arab Republic	1096
Lebanon	4676	Tunisia	2226
Libya	5858	United Arab Emirates	10573
Mauritania	365	Yemen	383
Morocco	1271		

* ESCWA is made up of 13 Arab countries, namely: Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates and Yemen.

C. *Rural development*

Many Arab countries still have substantial proportion of their population live in rural and remote areas. In the ESCWA region, for instance, the high-income countries are highly urbanized (except for Oman), with a large percentage of the population living in cities and towns. These countries are already above 80% urban and will reach 90% urbanization by the year 2020. Meanwhile, the rate of urbanization in the middle-income countries varies from 50% at present to 65% in the year 2020. Low income countries experience a high rate of urbanization from 40% to 60% in the year 2002. Table 2 shows the degree of urbanization in the ESCWA region.

Almost 43 percent of the ESCWA region's population live in remote and rural areas. Similarly, a higher percentage is believed to live in rural areas in the Arab Maghreb countries. The common feature of the Arab rural areas is the limited access to: (1) appropriate electric supplies, (2) safe drinking water and sanitation (See Table 2), (3) education and basic health conditions, and (4) the harsh working conditions for women. One of the factors that affect rural development in Arab countries is the restricted and expensive energy suppply, especially that very few countries were able to extend their local electric grids to rural areas because of the huge budget involved which is, in many cases, beyond governments reach. This fact puts emphasis on the importance of renewable energy development as an essential option for sustainable development in the region.

Table 2. Degree of Urbanization and Access to Sanitation and Safe Drinking Water in the ESCWA Region as Compared with Selected Developed Countries.

Country/Area	Urban Percentage			Access to safe drinking water (percentage) 1995		Access to Sanitation services (percentage) 1995	
	1980	2000	2020	Urban	Rural	Urban	Rural
Egypt	44	46	56	82	50	23	6
Jordan	60	74	81	91.8	82.8	41.1	1.7
Kuwait	90	98	98	100	..	100	..
Lebanon	74	90	93	99	99	89	89.5
Oman	32	84	93	97	50	97	68
Saudi Arabia	89	91	93	..	..	..	..
Syrian Arab Republique	66	86	90	100	74	100	30
United Arab Emirates	47	54	65	92	78	100	100
West bank and Ghaza Strip	71	86	90	700	100	100	77
Yemen	20	38	52	..	..	..	..
France	73	76	81	100	100	100	100
Japan	76	79	83	100	85	..	..
United Kingdom	89	89	91	100	100	100	100
United States	74	77	82	..	..	..	..

Source: World Resource Institute, UNEP, UNDP and the World Bank, World Resources 1998 –99: Environmental Change and Human Health (New York and Oxford, Oxford University Press, 1998).
Note: Two dotes indicate that the data is not available.

D. *Problems of water supply.*

Population growth and rapid development are constantly placing increasing demands on the limited water resources in the Arab countries. The viability of the region's land resources, urban and rural productive activities , human health, tourism, etc., all depend to a large extent on sustaining the available water resource base. For example, few countries in the ESCWA region, such as Egypt, Iraq, Syria, and Lenbanon have seasonal rainfall-run-off occurrence both inside and outside their territories, in amounts sufficient to generate perennial river flow. The water resources in the remaining countries in the ESCWA region originate from two basic sources: groundwater drawn and aquifers; and desalinated water from the Persian Gulf and to a less extent from the Red Sea. In these countries, the demand for both ground water and surface water is high and generally exceeds overall available supplies. It is estimated that the need for water supply in the ESCWA region will increase from 170 billion m^3 in 2000 to further 228 billion m^3 in 2025. Table 3 shows renewable freshwater resources and withdrawal in the ESCWA region.

Table 3. Renewable Freshwater resources and withdrawal in the ESCWA Region (Million Cubic Meters)

	Conventional Water Resources[a,b]			Non-conventional water resources		
Country/Area	Surface Water	Ground Water Recharge	Groundwater Use	Desalination	Wastewater and drainage reuse	Water Consumption
Bahrain	0.2	100.0	218.0	75.0	17.5 3)[b]	310
Egypt	55500.0	4100.0	4560.0	31.7	4790.0 (3800)[b]	63100.0
Iraq	60850.0	2000.0	513.0	7.4	1500.0	49100.0
Jordan	475.0	275.0	509.0	2.5	59.0	882.0
Kuwait	0.1	160.0	405.0	388.0	30.0	701.0
Lebanon	2500.0	600.0	240.0	1.7	2.0	1225.0
Oman	9128.0	550.0	645.0	47.3	21.5	1235.0
Quatar	1.4	50.0	190.0	98.6	25.0	298.0
Saudi Arabia	2230.0	3850.0	14430.0	795.0	131.0 (24)[b]	16300.0
Syrian Arab Republique	16375.0	5100.0	3500.0	2.0	1447.0 (1270.0)[b]	9810.0
United Arab Emirates	185.0	130.0	900.0	405.0	108.0	1223.0
West bank and Ghaza Strip	30.0	185.0	200.0	0.5	2.0	440.0
Republic of Yemen	3500.0	1400.0	2200.0	9.0	52.0	2715.0
Total	142565	18500	28310	1863.7	8183.0	147330.0

Source: ESCWA, Survey of Economic and Social Developments in the ESCWA Region 1997-1998(E/ESCWA/ED/1998/5).

a The flow of the Tigris and Euphrates rivers can be reduced by upstream abstraction in Turkey

b Drainage water reuse

As a result, it is expected that the issue of water supply will be more problematic in the future, a matter that calls on joining efforts for exploring and identifying ground water resources, and intensifying desalination activities. All of these efforts must go in parallel with strict policies on rational and efficient use of water resources.

The success in water supply efforts and policies would lead to further increase in energy requirements; a matter that can not be satisfied without the exploitation of all available energy resources, particularly the renewable ones.

II. Conventional Energy Resources and Production

A. Conventional Energy resources

The Arab countries enjoy tremendous energy resources both fossil "Oil and Gas" and non-depletable renewables. However, the primary energy production in the region is still dominated by oil and gas with limited contributions from renewable resources.

Basically, the Arab world depends on conventional systems for power generation, mainly fossil fuel power plants. The oil and natural gas play a decisive role in boosting the development programs in these countries. They also have a major impact on balance of trade and greatly affect government budgets.

A.1 Oil Production and Reserves. The oil industry in Arab countries plays a decisive role in boosting the development programmes, where, the oil revenues have a major impact on the balance of trade and greatly affect the government budgets. For example, Oil revenues still account for around 85% of the exports of Gulf countries and over 80% of their budget revenues.

Oil will continue to play an important role in the economies of Arab countries for many years to come. In 1999, the region proven oil reserves were estimated at 646.5 billion barrels, while the region produced an average of 19.9 million barrels per day in 1999. It is estimated that the ESCWA region can sustain its 1998 production level almost for another 87.9 years.

Table 4 summarizes the oil reserves and production in 1999.

Table 4: Oil Production and Reserves in 1999

OIL PRODUCTION AND RESERVES					
Country	Reserves [Billion Barrels]	Production [Million Barrels / day]	Country	Reserves [Billion Barrels]	Production [Million Barrels / day]
Algeria	10	0.76	Qatar	4.5	0.63
Bahrain	0.2	0.17	Saudi Arabia	263.5	7.7
Egypt	3.7	0.80	Sudan	-	57
Iraq	112.5	2.65	Sumal	-	-
Kuwait	96.5	1.88	Syrian Arab Republic	2.5	0.54
Libya	45	1.33	Tunisia	0.3	0.083
Morocco	-	5	United Arab Emirates	98.1	2.06
Oman	5.4	0.89	Yemen	4	0.40
			Other Arab Countries	9.7	1.36

A2. Natural gas production and reserves. The natural gas production in the region, although still lower than oil production, has increased during the last 25 years more rapidly than oil. In 1999, the gas production in the Arab region was 374.5 MCM. In the ESCWA region alone, gas production registered an annual growth rate of 4.53 percent compared to only 0.6 percent growth in oil production. The production of natural gas in the Maghreb countries was equivalent to 158 Barrels/day in 1998, whereas in the Mashreq countries it was around 129 Barrels/day.

The natural gas reserves in the Arab countries totaled 33736 billion cubic meters in 1999. Table 5 summarizes natural gas reserves and production in 1999.

Table 5. Natural Gas Production and Reserves in 1999

Natural Gas Production and Reserves					
Country	Reserves [Billion cubic meter]	Production [Billion cubic meter / day]	Country	Reserves [Billion cubic meter]	Production [Billion cubic meter / day]
Algeria	4522	153	Qatar	8500	26.2
Bahrain	110	11.1	Saudi Arabia	5777	49.8
Egypt	1223	18.5	Sudan	85	-
Iraq	3110	-	Syrian Arab Republic	241	7.7
Jordan	7	0.3	Tunisia	78	2.4
Kuwait	1480	10.9	United Arab Emirates	6003	49
Libya	1313	15.3	Yemen	479	15.3
Morocco	3	-	Other Arab countries	1379	26.1
Oman	805	10.5			

B. Renewable Energy Resources

The Arab countries enjoy a very high availability of indigenous, clean and non-depletable renewable energy (RE) resources, specifically hydro, solar, wind, and biomass. Such RE resources can be technically and economically utilized for several energy services in the region based on currently mature or maturing technologies, and the accumulated experience for their development in the region.

B.1 Solar Resources: The Arab region enjoys excellent solar resources with an annual average of global and direct normal solar radiation varying from 4 to 8 $kWh/m^2/day$. Table 6 shows solar energy resource data for Arab countries.

Table 6. Solar Energy Resources

Solar Energy Resources [$kWh/m^2/day$]			
Country	Solar Energy	Country	Solar Energy
Algeria	5-7	Oman	5-6
Bahrain	5-8	Palestine	4-6
Egypt	5-9	Qatar	5-6
Iraq	5-6	Saudi Arabia	6-8
Jiputi	4-6	Sudan	5-8
Jordan	5-7	Sumal	6-9
Kuwait	5-8	Syrian Arab Republic	5-6
Lebanon	4-6	Tunisia	5-7
Libya	5-7	United Arab Emirates	5-6
Mauritania	6	Yemen	4-6
Morocco	5-7		

B.2 Wind Resources: The wind resource in the Arab countries varies between 2.8 to 7m/s with exceptions in some countries like Egypt and Syria where the wind speed can reach 10m/s in certain locations. Table 7 shows wind energy resource data for Arab countries

Table 7. Wind Energy Resources

Wind Energy Resources: Speed [m/s]			
Country	Wind Speed	Country	Wind Speed
Algeria	2.8-4.1	Oman	4-6
Bahrain	5-6	Palestine	3-5
Egypt	4-10	Qatar	5-7
Iraq	-	Saudi Arabia	4.5-6.5
Jiputi	4-5	Sudan	5-6.5
Jordan	5.5-7.5	Sumal	5-7
Kuwait	5-6.5	Syrian Arab Republic	4.5-11
Lebanon	3-5	Tunisia	5-6
Libya	3-6	United Arab Emirates	3.5-4.5
Mauritania	6-7	Yemen	4-6.6
Morocco	5-8		

B.3 Biomass Resources: The biomass resources are those related to wood and agriculture residues, and animal wastes. The biomass contribution to the energy sector in the Arab world is limited and confined to 5-6% (~17mtoe) of the total energy demand. Table 8 shows the biomass potential in the Arab countries.

Table 8: Biomass Energy Resources

Biomass & Fuel-wood Energy Resources: [m.t.o.e/year]			
Country	Potential	Country	Potential
Algeria	1.66	Oman	0.47
Bahrain	0.14	Palestine	0.015
Egypt	3.9	Qatar	0.07
Iraq	6.3	Saudi Arabia	3.0
Jiputi	-	Sudan	3.9
Jordan	0.74	Sumal	0.35
Kuwait	0.37	Syrian Arab Republic	1.24
Lebanon	0.59	Tunisia	0.18
Libya	0.127	United Arab Emirates	0.33
Mauritania	0.107	Yemen	3.5
Morocco	4.8		

B.4 Hydro Power Resources: Many Arab countries are facing water shortages and using underground water which is rapidly being depleted. Few countries in the region, particularly Egypt, Iraq and Syria have effectively utilized their hydro resources for electricity generation. However, limited non-recovered small hydro resources are still available in the region, and may be recognized as a potential RE source. Table 9 provides information on the installed hydropower stations in the ESCWA region and the potential for future exploration.

Table 9. Installed and potential hydropower in selected countries

COUNTRY	INSTALLED HYDROPOWER, MW	POTENTIAL HYDROPOWER, MW
Egypt	2805	8520
Iraq	2620	-
Jordan	7	50
Lebanon	283.1	533
Syrian Arab Republic	1505	1236

C. *Energy Consumption*

C.1 The per capita energy consumption

The energy consumption in the Arab countries is mainly in the form of commercial energy, particularly crude oil and natural gas. In the ESCWA countries, it has increased rapidly to an average energy intensity of 0.549 kg.o.e/dollar of GNP in 1996 against 0.31 kg.o.e/dollar of GNP world average. The average energy consumption per capita in the Arab countries was estimated at 1167 kg.o.e in 1999 but varies greatly among countries. Table 10 shows the Per capita energy consumption and emissions of air pollutants in the ESCWA region and selected development countries.

Table 10 Per capita energy consumption and emissions of air pollutants in the ESCWA region and selected development countries.

Country/Area	Per capita emission of CO_2 in tons/year (1991)[a]	Per capita emission of CFCs in Kg/year (1990)[a]	Per capita emission of SO_2 in Kg/year (1990)[a]	Per capita emission of NO_2 in Kg/year (1990)[a]	Per capita energy consumption[b]	
					Gigajoules 1993	Percentage change since 1973
Bahrain	6.93	0.28	..	..	..	..
Egypt	0.42	0.16	..	..	28	149
Iraq	0.75	0.10	..	..	48	142
Jordan	0.69	0.18	..	..	30	104
Kuwait	3.54	0.56	222.5	96.6[c]	265	71
Lebanon	0.93	..	..	..	43	29
Oman	2.24	..	..	..	81	1324
West bank and Ghaza Strip	2.08	1.16	58.6	31.8	96	54
Qatar	10.47	..	430.8	138.2	..	..
Saudi Arabia	3.64	0.43	99.2	66.8	171	718
Syrian Arab Republique	0.66	0.13	..	..	41	266
United Arab Emirates	9.05	1.18	..	..	572	313
Yemen	0.75	..	..	..	..	..
France	1.74	1.12	21.5	31	170	..
Japan	2.34	0.97	9.2	15.7	141	24
Sweden	1.6	0.16	24.5	23.2	191	12
United Kingdom	2.65	1.27	66.3	47.3	164	7
United States	5.26	0.88	84.7	79.8	317	(-7)

Note: Two dote indicate that data were not available; (-) indicates lower consumption.

a UNEP, Environmental Data Report 1993-94 (Oxford, Blackwell Publishers, 1993)

b World Resources Institute, UNEP, UNDP and World Bank, World Resources 1996-97 (New York and Oxford University Press, 1996).

c Calculated from Kuwait EPC 1992 National Report.

C2. The energy consumption by sector.

The residential, industrial and transport sectors were the highest end-use energy consumers in the Arab region. However, the residential sector comes first in GCC countries, while industry is the main consumer in mixed economy countries. Studies showed that the transport sector is the highest consuming sector of petroleum products (sharing in the ESCWA region 38.4 percent of total energy consumption in that region).

C.3 Electricity production and consumption

The electric power sector in the Arab countries has developed tremendously during the last two decades. Such a development in the electricity sector has brought increased pressure on the region's environment mainly through emissions resulting from combustion of fossil fuels in thermal power plants which contribute to 91 per cent of electricity generated in the ESCWA region (See Table 10).

The total installed capacity in the Arab countries reached 95551 MW in 1999, out of which ESCWA countries had a share of 77328 MW. The installed thermal generation capacity was 86455 MW (ESCWA 70115 MW) accounting for 90.5 per cent of the total installed capacity. The generation capacity of hydro power station came to 9043 MW (ESCWA 7213 MW) or about 9.46 per cent of the total installed capacity. Thermal generation capacity included 41718 MW and 37091 MW of steam and gas power plants respectively as well as 5528 MW of combined cycle power plants and 2118 MW from Diesel technologies. The total installed capacities in the ESCWA region alone is expected to grow at a rate of 4.5 percent up to year 2010 to reach 127 121 MW, whereas the energy demand would reach 555 729 GWh in the same year. Figures 1 and 2 show the evolution of electric energy demand in the last decade and the per capita electric energy demand in the region respectively.

The sectoral energy consumption in the Arab world varies from country to country, but in general the residential sector consumes more than 40 percent of the total electric energy consumption, the industrial sector consumed 30 percent, the commercial sector consumed 10 percent and the agricultural sector and others consumed 20 percent.

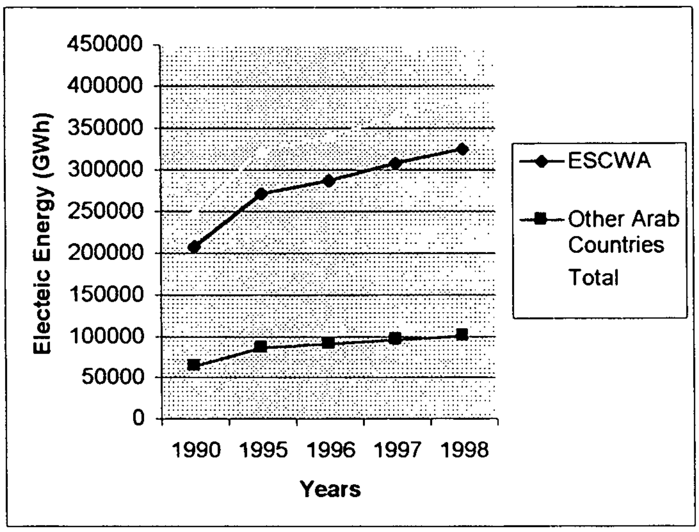

Figure 1. Evolution of electric energy demand in the last decade

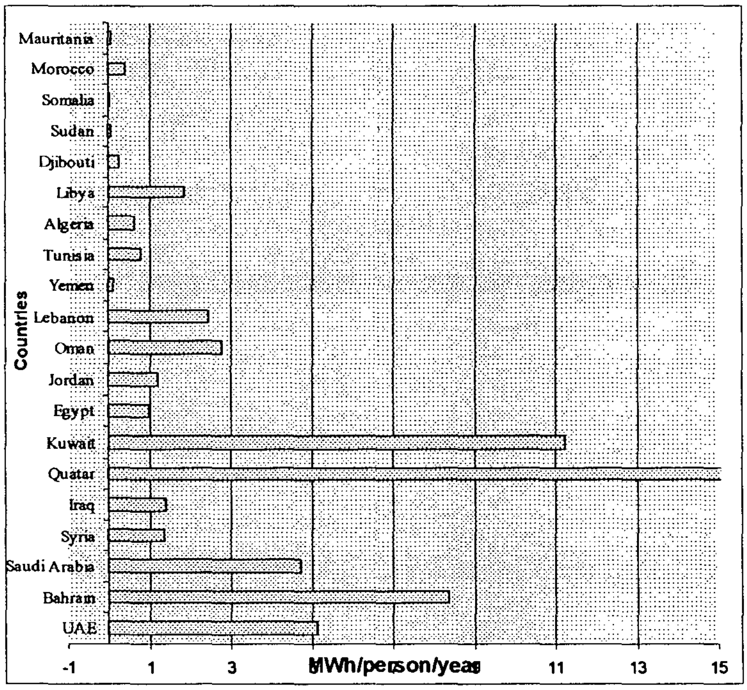

Figure 2. The per capita electric energy demand in the region .

III. INSTITUTIONS RESPONSIBLE FOR RE DEVELOPMENT

Renewable energy (RE) has never been a priority to Arab governments despite the fact that all Arab countries enjoy a very high availability of one or more of non-depletable RE sources. A minor contribution in the energy sector comes from hydropower applications, solar-thermal panels for water heating and wind turbines for water pumping. The available RE resources may be harnessed more effectively especially in remote areas where the grid connection does not reach, but of course this requires further attention from governments and other institutions.

The effective institutional framework for RE development is either not existing or still not sufficiently developed in most of the Arab countries. During the past two decades, most of the RE activities in the Arab region were mainly linked to the R&D activities of the academic community in the countries, and were not considered as an integral element of the national energy plans. In addition, limited strategies and policy issues were adopted to facilitate the dissemination of RE applications. Few countries like Egypt, Jordan, Morocco and Syria have taken steps towards formulation of policies and plans for RE development.

For example, the government in Egypt formulated in the early 1980's a national strategy for the development of RE applications and energy conservation measures as an integral element of its national energy planning. The strategy has been periodically reviewed, and currently the targets are:
(1) to save 10 percent of the projected primary energy consumption by the year 2007 through energy conservation measures and efficiency improvement of existing facilities; and (2) to develop

RE technologies to supply 3 to 5 percent of national primary energy needs by the year 2007 mainly from wind, solar and biomass.

Similarly, the national strategy targets in Jordan are: (1) to develop local energy resources and technologies to supply 28% of national primary energy needs by the year 2010, and (2) to improve energy efficiency and encourage energy conservation.

Along the same line, the national strategy in Syria is to save 5% of the country's total energy consumption around 2010 from solar and wind resources.

Almost in all Arab countries, renewable energy development is being taken care of by universities, research centers and by departments within relevant ministries such as ministries of energy, electricity, water and environment. Table 11 gives a summary on national institutions following up on renewable energy development in selected Arab countries.

Table 11 National institutions following up on renewable energy development in selected Arab countries.

Country	Organization	Activities									
		1	2	3	4	5	6	7	8	9	10
Bahrain	University of Bahrain	+									
Egypt	NREA		+					+			
	Ministry of Energy & Mineral Resources										
	General Organization for Industrialization			+	+						
	The Egyptian Standardization Authority					+					
	Industries				+						
	Academic institutions	+					+		+	+	+
	National Research Center	+					+		+	+	
Jordan	National Energy Research Center	+	+					+			
	Renewable Energy Research Center	+			+				+	+	
	Industries				+						
Lebanon	National Renewable Energy Center/Universities	+					+			+	+
	Ministry of Energy & Water		+								
	Industries				+						
Saudi Arabia	Universities	+							+		
	Ministry of Industry & Electricity							+	+		
Syria	Renewable Energy Office		+								
	Scientific Studies and Research Center	+				+					
	Ministry of Industry/Private industries				+						
	Syrian Organization for Standardization and Measurements					+					
UAE	Trade & Industry Department		+				+				
	Universities	+					+				

1. R&D
2. Planning/feasibility studies
3. Technology transfer
4. Manufacturing
5. Development of Standards and codes
6. Resource Assessent
7. Implementation
8. Demonstration
9. Testing
10. Training

IV. RENEWABLE ENERGY ACTIVITIES

A. Resource Assessment "RA"

Solar, wind and biomass resource assessments have been undertaken by most of the Arab countries. However, the depth of the collected data, its analysis and usage differ from country to country.

Some countries like Egypt, Jordan and Saudi Arabia have devoted serious efforts for RE resource assessment and have developed appropriate databases for it, while the remaining countries still have limited activities in this regard.

B. Research and Development (R&D)

Since the late 1970's, several universities and research institutions in the region have directed efforts towards investigating PV technologies and applications. The research work covered both theoretical and experimental investigations on components and systems. However, the majority of research were linked to the performance evaluation of the demonstrated systems. In Egypt, Jordan and Syria, the PV potential applications and markets were the subject of several planning studies, particularly in connection with rural electrification programmes. Most of the studies proved that PV for rural electrification have high potential in most Arab countries.

Several universities and research institutions in the region are carrying out R&D activities on the different aspects of wind energy systems. Considerable experience, in countries like Egypt, has been gained in the operation, analysis and development of wind energy systems. Table 12 provides information on R&D activities in selected Arab countries .

Table 12. R&D activities in selected Arab countries

RESEARCH AND DEVELOPMENT									
	DSWH	SIPH	Solar Thermal	Passive solar designs	Desalination	Hydrogen Production	Academic Research	Wind electricity /grid applications	Small Scale wind electric systems
Bahrain							X		
Egypt	X	X	X				X	X	X
Iraq									
Jordan	X		X	X					X
Kuwait				X			X		
Lebanon	X						X		
Oman					X		X		
Palestine	X						X		
Qatar					X				
Saudi Arabia					X	X	X		
Syria	X						X		X

C. RE Technology Demonstration

Through the bilateral and multilateral cooperation programmes, several RE technologies were demonstrated for different applications in the Arab countries. Some of the demonstrated projects were effectively evaluated and programmes for the development of the relevant technologies were implemented or being planned. Examples include DSWH, Solar Industrial Process Heat (SIPH) systems, PV rural systems and wind turbines.

C.1 Domestic Solar Water Heaters (DSWH): DSWH were demonstrated in many Arab countries with different penetration levels, types, capacities and fields of applications. For example, in Egypt 200 000 units are in operation, saving annually around 80 000TOE. Also, in Syria and Jordan, the installed DSWH are estimated to be around 15000-20000, and 200 000 units respectively. Several designs were developed and manufactured in Saudi Arabia. Some systems were installed and tested in the solar experimental station of the solar village in Riyadh, and in commercial buildings.

C.2 Solar thermal electricity generation: The only advanced solar thermal power plant in the region is in Egypt. In 1995, NREA in Egypt initiated a programme for large scale power generation focusing mainly on wind and solar thermal technologies. A large scale 150 MW integrated solar combined cycle system, using parabolic trough solar technology with a conventional gas turbine combined cycle, is currently under implementation by NREA with financial support from GEF. The plant capacity will be around 130 MW with solar contribution around 10%. Operation is expected in early 2003.

C.3 Photovoltaic: PV technologies are not widely spread in the Arab countries due to many reasons including their high capital costs and the low level of awareness about their values. As such, they are used in small applications, mainly in rural and remote areas. Examples of such applications include water pumping, battery chargers, small electrification system, hybrid PV-diesel system for ice making and rural electrification. Below is a description of PV activities in selected Arab countries.

The PV based demonstration projects in Egypt have a total capacity of 400 kWp including: (1) more than 10 water pumping projects with capacities varying between 2 kWp and 10 kWp; (2) several clinical refrigerators in the rural areas; (3) microphone, battery charger, TV and telephone repeater stations; (4) a 200 kWp central electrification system for a land reclamation farm at Owinat; (5) a hybrid PV-diesel system for ice making; and (6) remote village electrification project with a total capacity of 28 kWp serving 20 households street lighting and water pumping.

In Syria, the total capacity of demonstrated PV systems is around 80 kWp used for water pumping and in some pilot scientific cooperation projects for water pumping and desalination as well as for supplying electricity to houses in certain villages.

PV were also demonstrated in Jordan for a total capacity of more than 100 kWp. Demonstrated applications include emergency telephones, rail radio communication systems, relay stations for radio telephone communication, provision of minimal basic energy needs for remote communities, and water pumping in remote areas.

Finally, the application of PV technologies in Saudi Arabia is the mostly advanced among all Arab countries. The creation of the "Solar Village" in the seventies led to major research and development of PV-based systems including PV pumping, electricity generation, desalination, telecommunication, over-speed detection on high ways, hydrogen production and others.

C. 4 Wind energy systems

Wind energy in some Arab countries has gone from the research and development phases to field applications where real contributions to national energy needs have already been made. Examples of serious developments can be found in Egypt, Jordan, Morocco, and Syria.

In Egypt, wind energy is used for water pumping, electricity generation, and other applications as indicated below:

- Wind electricity: Ras Ghareb grid connected wind farm of 400 kW capacity was connected to the 11kV grid in 1988. A 4.8 MW wind farm at Hurghada has been successfully operating since 1996 using locally produced blades and towers. Large-scale wind farms have started based on these demonstrations.
- Wind Water pumping: Five wind/diesel systems were installed in Matrouh Governorate. Each system consists of 6 wind turbines of 25 kW and two diesel units each of 100 kW.
- Hybrid wind/diesel ice making system: was installed at Abou Ghusson on the Red Sea Coast. The system consists of a 55kW stand-alone wind turbine and a 32 kW diesel generator.

On a lower scale, in Jordan, more than 12 demonstration projects totaling 1620 kW of wind turbines were implemented, tested and evaluated for the following applications:

- Wind water pumping: (mechanical wind pumps- pumping more than 40,000 m^3 of water per annum, electrical wind pumps- pumping more than 80,000 m^3 of water per annum).
- Wind electricity: A Danish 320 kW grid connected wind energy demonstration plant was installed in Jordan in 1988 with annual energy production reached 0.75 million kWh. Another example is the 1996 Hofa wind farm, which consisted of five 225kW turbines producing an average annual energy about 2.5 million kWh.

Table 13 shows RE demonstration activities in selected Arab countries.

Table 13 RE demonstration activities in selected Arab countries.

RE DEMONSTRATION ACTIVITIES												
	DSWH	SIPH	Solar Thermal	Solar Active cooling	Passive solar designs	PV Desalination	Hydrogen Production	PV pumping	PV electricity	Wind electricity	Wind pumping	Wind/diesel
Egypt	X	X	X			X		X	X	X	X	X
Iraq												
Jordan	X			X	X	X		X	X	X	X	
Saudi Arabia	X			X		X	X		X			
Syria	X				X	X		X	X	X	X	
Algeria	X							X		X	X	X
Morocco	X							X	X	X	X	

V. COORDINATION AND COOPERATION PROGRAMS

B. Bilateral, regional and International Cooperation Programs

Most of the RE development activities in the Arab countries are characterized by being implemented through bilateral and multilateral cooperation with foreign countries, agencies and companies. The bilateral activities were mainly with developed countries like USA, Denmark, France, Germany, Italy and Japan. On the other hand, the main regional and international organizations that have been active in promoting and developing RE in the region are USAID, European Union, UNDP, UNEP, Arab League and ESCWA. Table 14 shows examples of RE coordination and cooperation programmes in Selected Arab countries

B. Cooperation Among Arab Countries

Despite tha fact that certain countries in the region have acquired intensive experience in various RE fields, and have been recognized by their active participation to RE technological development, and by their capable national institutions, cooperation among Arab countries has so far been very limited.

To boost cooperation among Arab countries in the field of RE, some regional and international organizations are spending serious efforts to achieve this goal and as a consequence to accelerate RE development. Among these organizations is the ESCWA who initiated the Renewable Energy Promotional Mechanism in which 12 ESCWA countries are coordinating their RE activities for the mutual benefits of all of them. The concerned departments in the Arab Leagues are also trying to promote Regional cooperation in the field of RE.

Table 14. RE coordination and cooperation programmes in Selected Arab countries

ESCWA MC's	Cooperating and Funding Agencies															
	Bilateral								Regional			International				
	Denmark	France	Germany	Italy	Japan	Netherlands	Spain	USA	Arab League	ESCWA	European Union	FAO	UNDP	UNEP	UNESCO	GEF
Bahrain										X						
Egypt	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Iraq										X						
Jordan			X						X	X		X	X	X	X	X
Kuwait			X							X						
Lebanon								X		X	X		X			X
Morocco							X	X					X			
Oman										X						
Palestine										X						
Qatar										X						
Saudi Arabia								X		X						
Syria				X	X					X			X			
UAE										X						
Yemen						X				X						

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The Palestinian Energy and Environment Research Center
(PEC)

WORKSHOP
on

"Solar Cells and Water Pumping Systems"

Cairo - Egypt

20-22 December 2001

Nabil Attili
Head of Projects Dept.
PEC / Palestine

INTRODUCTION

Palestine is suffering hardly from shortage of water for domestic use. Water demand per capita in rural areas of Palestine is about 12 m^3 per year which is very low in comparison with other countries in the region (the demand in Israel per capita is 516 m^3 per year). The main reason for this phenomenon is absence of water pipelines services particularly in rural areas as a result of financial obstacle and Israeli occupation restrictions.

PEC executed a study focused on the investigation of water resources, water supply, water cost, etc., in rural areas of Palestine, aiming in the provision of solutions for the water scarcity problems, water pumping or water desalination, with the most reasonable way, photovoltaic or conventional energy sources.

In order to select the data, a survey in seven selected villages was accomplished. The main criteria for the villages selection were the water scarcity, partially or non-electrification and the availability of at least one water resource. A general description of the water resources and solar potential in Palestine is presented in this report.

OVERALL GOAL

The utilization of photovoltaic systems for water pumping instead of diesel driven pumps, to provide the residents of remote isolated areas in Palestine and their cattle with fresh drinking water from springs and wells.

WATER RESOURCES AND SOLAR POTENTIAL IN PALESTINE

In the Palestinian territories, water is the most precious natural resource and its relative scarcity is a major constraint to economic development.

Water from wells and springs is the main water resource in the area. The groundwater from the wells is extracted mainly by diesel pumps for agricultural purposes and manually for village water supply, in remote areas, where there is lack of grid electricity.

- Most of the wells and the springs provide fresh water in the range of 250 to 700 ppm TDS.
- The wells have a depth of 12 to 40 m, with water flow rates in the range of 0.3 up to 125 m^3/h.
- Additional water sources are rainwater collection in small reservoirs in each house as well as water transportation by tankers. Lack of water distribution network characterizes most remote villages, only large communities have a water supply network.
- The water consumption in remote villages, ranged from 7lit/inh/day to 67lit/inh/day, depending on the site, the availability of the water resource and the unit water cost. A representative example is Ammorya village in Nablus, where water is transferred by tankers from neighbouring villages at a high price ($5/$m^3$), and the consumption is of 7 lit / inh /day (5 lt/day is required for a person to survive in tropical areas). Further, in many areas especially in Bedouins areas, the estimation of the water consumption is difficult due to the emigration.
- Concerning the atmospheric conditions, West Bank as well as Gaza Strip characterized as tropical regions with a relatively hot summer and mild winter. Temperatures during winter range from 10 to 18 °C while in summer from 20 to 30 °C.
- Rainfall is of around 600 mm/year with small differences between northern and southern areas.
- West Bank has a relatively high solar insulation. A daily average of the solar insulation on a horizontal surface is of the order of 222 W/m^2. This varies during the day and through out the year. For the three regions, Jenin, Nablus and Hebron an annual average global solar radiation of 5.7 kWh/m2.day is considered.

EXPECTED RESULTS

1. Clarifying the possibilities of utilizing photovoltaic systems for water pumping from springs and wells in Palestine.
2. Identifying different types of water pumping systems to select the most efficient and appropriate one for pumping by PV.
3. Determination of health, social, economical and environmental influences on the residents of rural area as a result of utilizing PV water pumping systems instead of diesel powered pumping systems.
4. Improving the conditions of breeding cattle and pasturing lands.
5. Spreading out rational use of water sources.
6. Reducing air and water pollution by substituting diesel pumps by PV pumping systems.
7. Reducing the fuel consumption which is very expensive as it's imported from outside Palestine.

The residents of rural areas in Palestine obtain their needs of domestic water by one the following means:

- By water tankers of different capacities which transport water from artisan wells to the villages. Water in this case is relatively expensive (one cubic meter of water costs about 3$).
- Collection of rain water in wells. The capacity of these wells ranges from 20-30 m3. This amount is not enough to meet the needs of the residents all over the year, especially in the summer season.
- Utilization of spring's water. Water is transported by animals, trucks or manually by children and women. In most cases, animals are used for transporting water bottles.

Artesian wells are also used in some villages to provide residents with domestic water. Diesel pumps are the mainly used on these wells. Using PV systems will give clean, quiet, cost-efficient alternatives to conventional diesel-powered systems. It will also simplify maintenance processes and lowering its costs. Meanwhile repair and maintenance of diesel pumping systems are very complicated and expensive. Applying PV pumping systems for springs and establishing storage tanks and distribution nets in that areas will improve the living conditions of the residents mainly in the social and health sectors.
The total annual discharge of springs in West Bank is estimated to 50 million m3 per year. Very limited percent of this quantity (not more than 3%) is recently used for domestic proposes.

SOCIOECONOMIC CHARACTERISTICS OF THE SURVEYED VILLAGES

The survey shows that local people have a low income and their main economic activity is agriculture. Diesel generators electrify most of the remote villages.

Diesel-pumping systems are preferred for water pumping for irrigation purposes. In small remote villages the water is pumped manually. The inhabitants of all the surveyed villages mentioned the need for the supply of sufficient good quality water.

People even at the most remote villages aware the use of photovoltaic modules. On the *question "what is your opinion concerning the installation of a PV pumping system*?", the inhabitants answered that they are much interested, though they cannot afford the installation cost of such systems.
However, they are willing to be trained to operate and maintain, as well as to pay the running costs of a PV pumping system. Additionally, local authorities are able to support them with trained technicians.

In cases where diesel generators are used, several maintenance problems as well as complains concerning the high cost of the fuel are reported. As it is mentioned, due to the lack of machine shops in the villages or at the area around, the maintenance of the diesel generators is difficult and costly.

Finally, it should be mentioned that the introduction of the PV water related technologies into the social reality of rural communities is a task that can not be addressed solely by technical means. It is a social task and consequently needs social preparation and introducing an acceptable water tariff.

EXECUTED PV PROJECTS IN PALESTINE

In cooperation with local and international organizations, PEC installed many systems through two main projects:

ELDORADO regional project:

- Twelve (12) rural clinics: Installed capacity 7.370KWp
- Twenty (20) schools: Installed capacity 13.000KWp
- 24 Bedouin tents: Installed capacity 5.00KWp
- The governor office in Nablus city
- Two mosques
- Security check point at the village of Rameen

Total installed capacity 32KWp

Baden-Wuttemberg Progect:

PEC find good partners (local banks) for constructing a joint project with a third partner – government of Baden-Wurttemberg- who funded this project with a revolving fund with loan duration of 3-5 years, to promote the use of photovoltaic systems in Palestine. PEC role was the technical part and the bank role was the financial part. Some of the executed systems are listed below:

Agricultural farms

Private sector:

- 24 systems in different areas were installed for houses in rural areas with a capacity of 8.0 KWp
- Vocational school in Nablus
- Animal zoo in Qalqiliah city
- Bldg. Of planning committee in Yata-Hebron
- Project car, equipped with a movable demonstration system
- Cows farm

This project is continuous and two systems were installed during the last two months in spite of the difficult situation in Palestine.

Total installed capacity 13kWp

FUTURE ACTIVITIES

The gathered data showed that the following PV applications seem to be feasible in future

a. Rural clinics and schools:	
▪ Non-electrified clinics	67
▪ Non-electrified schools	134
▪ Schools (1st phase	30
▪ Clinics (1st Phase)	10
▪ The expected capacity will be around	30 kWp
b. Street lighting in rural roads:	
▪ (200) sites, with a capacity of	22 kWp
c. Telecommunications:	
▪ (2) Transmission and re-transmission stations	1KWp
▪ (8) Offices, with a capacity of	20 kWp
d. Water pumping:	
▪ About **60%** of the power consumed for pumping water comes from standby diesel generators, amounting to an average power of **4.2MW**.	
▪ (22) sites can be supplied by PV systems in 1st phase, with a capacity of	12kWp
e. Botanic garden in Jericho:	
The estimated load of the garden lighting and water pumping will be around	5 kWp.
f. (20) Bedouin sites, estimated capacity	10kWp
g. 60 private houses, estimated capacity	30kWp
h. Some proposals for water desalination by PV systems were prepared. Overall goal was the provision of potable water through exploiting available brackish water resources.	
Total expected capacity to be installed until the end of the year 2003: 130KWp	

PEC CURRENT PV & ENERGY CONSERVATION PROJECTS:

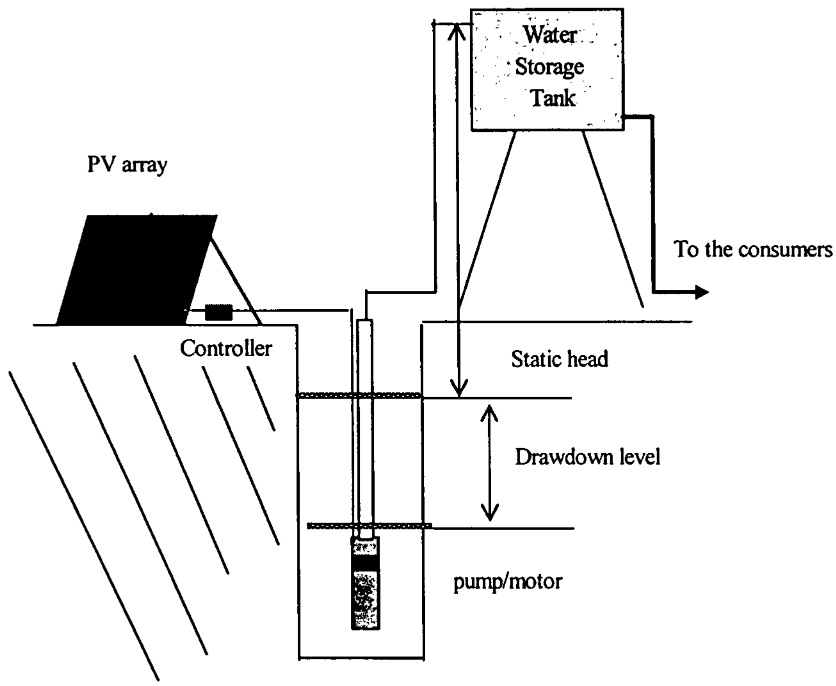
1- Electrification of Al-Aqaba village through PV systems:
This project will be a joint project between PEC, Irrigation & Environment Department in PARC (Palestinian Agricultural Relief Committees), funded by Small Grant Program / Global Environmental Facility SGP/GEF/UNDP.
The proposed PV system will be a centralized system, able to electrify the 10 houses in the village (including lighting, fans, TVs, small water pumps, small washing machines) and three refrigerators. In the future, the system will be enlarged to operate 10 sewing machines in the village.
The total capacity will be about 5KWp.

2- The dissemination of energy efficient appliances in the Palestinian villages. The Agence Francaise de Development (AFD) has awarded a grant of 1.8 million EURO drawn from the French Fund for Global Environment (FFEM) to the Palestinian Authority. PEC and ADEME will implement the project. Over 3 years, 20000 high-performance appliances (energy type class A or class B) will be disseminated.
This project will be a continuation to similar projects implemented in some Palestinian villages like Sikka (Hebron) and Taibah (Jenin) dealing with energy conservation matters.

A photovoltaic water pumping system consists of four main components. Some of these components could be added or changed depending on the well, spring and site characteristics and on the kind of water end use. The main system components are:

1- PV Panels
2- Inverter
3- motor pump
4- Storage tank

The specification of these components will be exactly determined according to the properties of spring and well site and the quantity of water required for the resident's consumption in the respective site.



Typical diagram of the PVP system

ASSESMENT ON THE POTENTIAL OF PV-WATER RELATED TECHNOLOGIES

Although West Bank is a rich area of the solar potential prospect, the PV systems are not well developed nor widely utilized. This use is limited for lighting of some remote areas. The climate and topography of the West Bank is ideally suited to power generation from PVs for a wide range of applications.

West Bank offers a great potential for PV water pumping for village water supply according to the following:

- Most of the water resources provide fresh water.
- The available water resources characterized by low heads.
- Small amounts of water required for village water supply.
- High tariffs of water per cub meter ($0.25-0.75/m^3 from large diesel pumping systems, $1.88-5/m^3 by water transportation or tankers)

The suitability of PV pumping for irrigation is uncertain because large amounts of water are required and the demand may vary greatly with seasons. PV pumping systems may be able and cost effective to provide small-scale irrigation for instance small farms for vegetable cultivation.

Based on the above conclusions, small PV pumping systems (less than 2 kW), are recommended for village water supply at the remote villages of West Bank (see Table 1).

In order to decide for the installation of a PV water pumping system, the following parameters should be obtained:

- Small scale systems should be studied due to:
  - High capital cost of PVs,
  - The rather dispersed population- villages consist of small groups,
  - The lack of distribution system
- Fundamental features for the system should be:
  - Simple operation and maintenance,
  - Low energy requirements,
  - high reliability
- The case of a diesel pumping system should be examined as the main source in comparison with PVs

PV water desalination potential for the area of West Bank seems to be relative small. Only few water resources provide brackish water. This is the case of Al Maleh spring in Nablus. Even if the installation of a PV desalination system would be reasonable (see Table 1), the fact that most of the inhabitants are Bedouins and the lack of essential education makes the installation and operation of a PV desalination system not suitable.

Concerning the maintenance of such systems, specific procedures (membrane cleaning, filters cleaning or replacement, battery maintenance, etc) should be followed, thus at least one employee is required.

Besides, from experience drawn from applications all over the world it is easier to install a system than to ensure its sustained operation.

In conclusion, solar energy to drive water pumping systems seems to be an economic and reliable alternative for the water scarcity of remote areas of the West Bank characterized by partially or none electrified.

Table 1 Proposed PV pumping desalination systems for the areas under study

Location	Population	Water Source	Water Source Name	Water Source Characteristics	Water type	Suggested System	Number of proposed units	Approx. Size of the unit
Jenin								
Tannek	817	spring	-	Flow rate: 0.83 m3/h	fresh	PVP	1	4 m3/d, 170 Wp (1)
Hashmieh	705	spring	-	Flow rate: 0.4 m3/h	fresh	PVP	1	2 m3/d, 70 Wp (1)
Kufr Quod	1000	spring	-	Flow rate: 1.4 m3/h Depth: 12 m	fresh	PVP	1	7 m3/d, 270 Wp
Al Shuhada	1297	spring	-	Flow rate: 0.5 m3/h	fresh	PVP	1	2.5 m3/d, 90 Wp (1)
		well	Yousef Arabi Nazzal	Depth: 35 m Flow rate: 18-26 m3/h	fresh	-	-	-
		well	Shabaneh	Depth: 40 m Flow rate: 30 m3/h	fresh	-	-	-
Nablus								
Al Fara	1713	spring	Al Fara spring	Flow rate: 187.5 m3/h	fresh	-	-	-
		spring	Duleep spring	Almost dry	fresh	-	-	-
Ammorya	234	spring	-	Flow rate: 0.83 m3/h	fresh	PVP	1	4 m3/d, 170 Wp (1)
Tal Street	550	spring	Ein El Fawar spring	Flow rate: 1.5 m3/h	fresh	PVP	1	7.5 m3/d, 250 Wp(1)
Jalood	330	spring	-	Flow rate: 1.87 m3/h	fresh	PVP	1	9.5 m3/d, 320 Wp (2)
Yanoon	115	spring	-	Flow rate: 0.4 m3/h Depth: 7m	fresh	PVP	1	1.8 m3/d, 100 Wp
		spring	-	Flow rate: 0.3 m3/h	fresh	PVP	1	1.5 m3/d, 80 Wp
Joreish	990	spring	-	Flow rate: 1.87 m3/h	fresh	PVP	1	9.5 m3/d, 320 Wp (1)
Zawata	1420	spring	Zawata spring	Flow rate: 52.5 m3/h	fresh	PVP	1	56 m3/d, 1600 Wp (1)
Toubas	151	spring	Al Maleh spring	Flow rate: 93.5 m3/h	brackish	PVRO	1	6 m3/d, 4000 Wp
Al Jeftlik	3178	well	Waheed Al Masri	Depth: 23.35 m Flow rate: 70 m3/h	Slightly brackish	-	-	-
		well	Inad Al Masri	Depth: 31.7 m Flow rate: 125 m3/h	Slightly brackish	-	-	-
		well	Abdel GhaniAbuSamrah	Depth: 21.4 m Flow rate: 50 m3/h	Slightly brackish	-	-	-

Location	Population	Water Source	Water Source Name	Water Source Characteristics	Water type	Suggested System	Number of proposed units	Approx. Size of the Unit
Hebron								
Arab Kaabneh	2200	spring		Flow rate: 7.5 m3/h	[illegible]	PVP	1	37.5 m3/d, 600 Wp (1)
Sair	9672	spring	Sair spring	Flow rate: 9.1 m3/h	fresh	PVP	1	45 m3/d, 750 Wp (1)

PVP: photovoltaic pumping system

(1) due to the lack of information a head of 10m is assumed
(2) lift of the water at a height of around 10m to a storage tank close to the village

CONCLUSIONS

The areas under study offer a great potential for the application of water pumping systems driven by PVs. The use of PVs mainly for electrification is already known in the rural villages of Palestine. People are well informed on the usage of such systems and are very susceptible on their use.

Pumping water by the use of PVs is today the most appropriate and successful application in the solar energy field, especially in remote and isolated areas.

Additionally, diesel generators, which are the most widely used power systems for water pumping in the villages under study, have reduced their reliability due to frequent problems related high cost of fuel, the maintenance and the provision of spare parts.

The utilization of PV pumping systems is gaining a significant importance and is proven to be the most ideal application for the provision of fresh water.

Concluded, according to the case study, PV water pumping appears as an economic alternative for the provision of fresh water to the small remote villages of Palestine. Relatively small-scale units are able to provide fresh water at an attractive cost and in certain cases less than other water supply sources.

(ICS-UNIDO, Trieste, Italy and Photoenergy Center, Ain Shams University)
Workshop on Solar Cells and Water Pumping Systems
20-22 December 2001, Cairo, EGYPT

Research and Development in the Photovoltaic Pilot Plant of INRST (Tunisia)

Brahim BESSAÏS

1. Installation of PV systems in Tunisia

Last years many noticeable efforts have been done to connect remote rural zones to the national electrical grid network. While 100% of urban zones have been electrified at the end of the 8^{th} national plan (1992-1996), only 73% of rural zones have been grid-connected. At the end of the 9^{th} national plan (the end of 2001), it is foreseen that this rate attains 90%. In Tunisia, PV systems remain interesting to supply energy for remote and dispersed rural zones that cannot be grid-connected nor at medium terms neither at long terms. Tunisia have approximately 300,000 surface wells, this should encourage the development of PV pumping systems, which should constitute a rather important market.
The ANER (National Agency for Renewable Energies, formerly AME), which is the governmental institution in charge of installing PV systems cooperates with research Institutes and High Engineer Schools to promote PV Technologies. More than 5000 houses and 200 schools have been electrified. This important step enables to manufacture special batteries and regulators, for the first time in Tunisia. The strategic studies of the 10^{th} National plan related to renewable energies foresee to diffuse PV systems for the electrification of about 70, 000 remote rural houses that cannot be linked to the grid (foreseen investment 140 Millions $ from 26-26 presidential project). All PV installations are experienced by the ANER. Remote area, pumping need, comfort and social development should push PV technologies to open an important market.

2. Research and Development in the PV Pilot Plant (PVPP) of INRST

2-1. Background

At the end of the 1980's and in the framework of a national project promoting renewable energies, a PV Pilot Plant (PVPP) was installed (1985) at INRST (National Institute for Research Science and Technology) by local competences. Since 1986, the role assigned to the PVPP is to apply renewable energy - based national programmes, particularly related to Research and Development (R &D) of PV materials and technologies. Our main first objective was the development of a local PV technology that may produce monocrystalline Silicon solar cells and modules with efficiencies approaching international ones. At the beginning of the 1990's, the efficiency of the best-achieved cells was about 14.3% (silicon wafers of 4 " diameter, solar grade quality) and an average of 12.8% was achieved at a small scale production.

2-2. Achievement of low cost crystalline Silicon Solar Cells

At the start of the PVPP, beside our daily effort to try producing silicon solar cells, our research was essentially focused on how can we improve the Quality/Price factor of PV cells by introducing alternative materials (i.e., thin film solar cells etc.) or new efficient low cost processes (i.e., Screen

Printing, Spin-On etc.). Many specific projects in these fields have been or are being executed. New low cost technologies reducing cost materials, handling and processing steps were applied:

- Development of low cost processes for surface treatments: texturisation and Antireflection Coatings (ARC) may be replaced in one step by forming Porous Silicon (PS).
- Low cost treatments, suitable for cheap polycrystalline silicon solar cells, may be used for the passivation and gettering of polycrystalline silicon. Porous Silicon could act as a passivating layer and a getter for polycrystalline silicon solar cells.
- New silicon solar cells design could also be done using Porous Silicon and silicon etching properties. Buried contacts suitable for high efficiency silicon solar cells could be used by grooving silicon via Porous Silicon.
- Development of epitaxial silicon thin films using low cost substrates (i.e., Porous Silicon etc.).
- Development of new processes and techniques for the application of Porous Silicon in large area silicon solar cells

The use of a superficial porous silicon layer at the front side of polycrystalline silicon solar cells can enhance their opto-electronic parameters by acting as an anti-reflection coating (ARC) or as a passivating agent. The surface reflectivity decreases from 15% for untreated cells to about 6% for PS-treated cells. The introduction of a thin PS layer onto the top surface of the cells combined with the gettering effect should enhance considerably the opto-electronic parameters of the polysilicon material and then the quality of the cells. When a PS layer is applied onto the top surface of monocrystalline silicon solar cells a surface reflectivity of 4% is attained. PS treated monocrystalline silicon solar cells exhibit a dramatic improvement, with respect to untreated ones. This improvement was attributed to deep light absorption owing to the antireflection and light diffusing character of PS and to its surface passivating role. Etching silicon with appropriate acid solutions enables to realise controlled low cost grooves suitable to be used for buried metallic contacts in silicon solar cells.

2-3. Research on PV systems

Beside semiconductor science and technology activities, and despite investigations on monocrystalline, polycrystalline and Porous Silicon at both fundamental and technological levels, electrical engineering applied to PV systems emerged. PV system Sizing and modelling for water pumping using a simulation - Bond Graph technique were developed. This enables to modelise the dynamic behaviour of several PV systems. Sizing and connection of PV generator to a water desalination system is also being studied.

Water pumping

Actually, in some arid countries great interests are focused on PV systems for water pumping. This may supply water for drinking and irrigation. The relatively high cost of the PV generator compared with its moderate efficiency remains the major inconvenient of these systems.

To solve these problems, two ways could be followed:

- increasing the efficiency of the PV generator
- maximizing the PV generator power

The last way constitute a research subject in the PVPP. During PV system sizing, we often try to obtain the maximum of energy to satisfy the diverse energy needs. A PV generator may work in a large range of voltage and current, however it delivers a maximum power only for a couple of voltage and current. The solar illumination and the temperature may affect the I-V characteristic of the PV panel. These climatic variations lead to a fluctuation of the maximum power point. Due to these fluctuations, we insert several static converters between the PV generator and the receptor, which always enable to track the maximum power point. These converters, called MPPT (Maximum Power Point Tracker) ensure the coupling between the receptor and the PV generator by forcing the latter to deliver its maximum power.

In this field, one study consists to point out the transient phenomena induced by the command and the PV generator-receptor system. The study of the stability of the system enables to define the tolerable field of the command and the ideal dynamic behavior. A classic modelisation by intern representation of the PV systems has been often used in diverse works.
PV systems are hybrid types so that they make complex the classic modelisation. Hence, a new unified approach based on the Bond Graph technique has been used. This technique is completely systematic and presents a certain flexibility regarding the introduction of different components in the system. The effectiveness of this modelisation method has been shown in many conception and simulation problems and for the calculation of command laws. Madansure et al. have presented the first application of the bond graph formalism to study PV systems in 1995. The second application of the bond graph formalism was done in the PVPP by Andoulsi et al. (in 1999), in order to couple DC or AC motors to PV generators throughout DC/DC or DC/AC converters. The bond graph formalism was used for the structural modelisation and analysis of the PV systems. The control of each PV system is actually assured by the robust command techniques in sliding mode (or in non linear). This work is made in the framework of collaboration between our group and the LAIIL (Laboratoire d'Automatique et d'Informatique Industrielle de Lille).

V.N. Madansure, S. Banergjee, A. Mukherjee, P.K. Chattopadhyay, Modelling and simulation of PV powered intermittent load systems by bond graph technique. Solar Energy , Vol 55, N° 5, pp 367-375.
R.Andoulsi, A. Mami, G. Dauphin-Tanguy, M. Annabi, Bond graph modelling of a photovoltaic generator coupled to a dc motor. Proceeding of ICBGM'99, pp 371-378.

Application of PV systems to desalination by reverse osmosis

The variable structure command (VSC) is a robust command technique that has shown its proofs in many fields where the command is essentially of commutation type. Its main advantage is its robustness against extern perturbations and a relative simplicity of implantation. Theoretical of the variable structure command has been developed during the 1950's in URSS in the continuing range. The use of microprocessors incited researchers to investigate some studies on discrete VSC. We begin applying discrete VSC for the command of a reverse osmosis desalination unit in order to improve its efficiency and to ensure its optimum functioning. This unit will be coupled to a brackish water pumping system. All of the system is supplied by PV energy to enable its running in remote sites.

3. PV projects and possible links with industry

Several attempts have been done to promote and transfer the technological know how acquired in the PVPP by inviting industrials both at national or international levels. All of them recognize the capability and the level attained by our group, which as far as we know, is the first Arabic and African research team who master and develop silicon solar cells processing and PV modules.
Last year we realized an important project for the ALECSO consisting of producing 25 PV bags (distributed in the Arabic countries) for the education of technicians and engineers working in the field of renewable energy. Each bag contains a PV module having a power of 20 – 30 Watts, and encloses different applications (lighting, pumping, etc.). This bag may resume all what can be done in the PVPP. A valorisation project preparing the industrialisation of these PV bags is being emerged in collaboration with local industries. The latter could be implanted in the future Area Science Park of Borj-Cédria, which is planned to be developed around the INRST. The Area Science Park is designed to promote some activities of formation and research of high level in relation with industry, and new and high technologies. This may offer a setting to the enterprises in order to develop some new technologies (i.e., PV technology). This Science Park may also receipt enterprises that may produce entire PV modules. The PVPP of INRST should assist it.

UTILISATION DE l'ENERGIE SOLAIRE PHOTOVOLTAIQUE POUR LE POMPAGE DE L'EAU EN MILIEU RURAL.

CAS DE LA MAURITANIE

I GEOGRAPHIE ET POPULATION

1.1 *Géographie et Climat*

Située dans la partie occidentale du désert, entre les 15 et 17 ^{èmes} degré de latitude nord, les 5 et 7 ^{èmes} degrés de longitude ouest, limitée à l'ouest par l'Océan Atlantique, au Sud par le Sénégal, à l'Est et au Sud-Est par le Mali, au Nord par l'Algérie et au Nord-Ouest par le Sahara occidental, la Mauritanie, pays le plus aride du Sahel couvre une superficie de 1.030.700 km² dont plus de 75% en zone désertique.

Elle connaît deux (2) saisons :

Une saison pluvieuse variant entre trois et cinq mois de pluviosité irrégulière et mal répartie.
Une saison froide très courte (novembre, décembre, janvier, février).

1.2 La Mauritanie : La Situation Socio- Economique.

La Mauritanie appartient au groupe de pays les moins avancés (PMA) en raison de son PNB par habitant estimé à 410$ US en 1998. Le désert du Sahara occupe plus des deux tiers du territoire (1,025 millions de km2) et gagne une dizaine de kilomètres par an sur l'étendue de la bande sahélienne. La croissance moyenne de la population observée est de 2,69% par an , avec une progression spectaculaire du taux de population urbaine, lequel passerait de 41% en 1988 à 66% en 2013.
La richesse du pays est constituée essentiellement de l'agriculture, l'élevage, l'exploitation minière et de la pêche. Le PIB est caractérisé par un poids très élevé du secteur rural dans sa composition. Le secteur rural emploie près 64% de la main d'œuvre et contribue pour environ 23% à la formation du PIB.

1.3 ressources en eau en énergies solaires et éoliennes

1.3.1 Eau

Les ressources en eau en Mauritanie sont suffisantes pour assurer un développement harmonieux des différentes composantes de sa population. Elles sont cependant essentiellement de constituées d'eau souterraine. Les réserves des systèmes aquifères sont estimées à 8480 $*10^6$ m^9.

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1.3.2 Le potentiel Solaire

L'examen des donnés acquises en ce qui concerne le rayonnement solaire à l'aide de statistiques significatives montre un nombre élevé d'heures d'ensoleillement (moyenne à Nouakchott et à Nouadhibou, soit environ 3.200 heures/an.

En Mauritanie, la bonne régularité saisonnière de l'ensoleillement (moins de 30 % d'écart entre la période la plus ensoleillée aux mois de Mai et de Juin, et la période la moins favorable, soit Novembre et Décembre, rend la ressource solaire convenable pour plusieurs applications.

Globalement on peut estimer que l'énergie solaire qui frappe une superficie plane et normale aux rayons est au environ de 5 KWh/m2 par jour. Le rayonnement global reçu par le sol représente dans presque tous les cas plus de 50 % du rayonnement extraterrestre.

En conclusion, les résultats obtenus montrent l'importance du potentiel solaire et la possibilité d'utilisations significatives de cette source énergétique.

1.3.3 Le Potentiel éolien

De nombreuses tentatives ont été effectuées par plusieurs auteurs en vue d'estimer directement ou indirectement la ressource éolienne en Mauritanie. De leurs évaluations, il résulte que la principale ressource existante est localisée sur la côte, avec des vitesses moyennes annuelles d'environ 8m/s. A l'intérieur du pays, les vitesses moyennes seraient d'environ 5m/s. Alors qu'elles diminueraient à 4m/s. voire à des valeurs plus basses, dans l'extrême méridionale.

D'une façon générale, le potentiel éolien est très important non seulement par la force ses vents, mais aussi par leur régularité tout au long de l'année.

II ALIMENTATION EN EAU POTABLE

Le secteur de l'alimentation en eau Potable est aujourd'hui au seuil d'importantes réformes. La situation actuelle peut être résumée comme suit : **i)** la Société Nationale d'Eau et d'Electricité (SONELEC) est responsable de l'alimentation en eau urbaine, **ii)** la Direction de l'Hydraulique du Ministère de l'Hydraulique et de l'Énergie est responsable de l'étude, de la gestion et de la programmation des ressources en eau ainsi que de l'étude et de l'exécution des systèmes d'alimentation en eau rurale. On note également plusieurs ONGs nationales et internationales ainsi que des entrepreneurs et bureaux d'études agissent dans le secteur.

La majorité de la population s'approvisionne aux bornes-fontaines ou auprès de vendeurs d'eau. Leur consommation est estimée à environ 20 l/hab/j.

Les moyens d'exhaure équipant ces ouvrages sont de cinq types selon la source d'énergie de pompage. L'énergie peut être fournie par un groupe électrogène utilisant un combustible fossile (gasoil, le plus souvent) ; elle peut aussi être renouvelable tel le solaire et l'éolien, ou humaine dans le cas du puisage manuel (puits de grand diamètre) et à l'aide de pompes à motricité humaine.

Les différents types d'équipement et leurs plages de production

Type	m3/j
Pompe à Motricité Humaine	5
Éolienne mécanique	5 –10
Pompage motorisée sans réseau de distribution	10 – 30
Adduction d'eau avec pompage par énergie solaire	20 – 60
Adduction d'eau avec pompage par énergie thermique	20 – 200

2.1 ALIMENTATION EN EAU PAR LE SYSTEME SOLAIRE.

2.1.1 Généralités

La Direction de l'Hydraulique dispose d'un parc théorique d'environ 2.500 ouvrages dont la capacité annuelle serait de 13,3 millions de m^3 pour une population de 1.460.000 habitants, soit environ 25 l/j/hab. Sur le terrain, seuls 1300 Ouvrages sont fonctionnels. En utilisant la base de 3 millions de m^3 pour les ouvrages opérationnels, le taux de desserte ainsi déterminé, serait de l'ordre de 11 l/j/hab.

2.1.2 Le Pompage de l'eau par Systèmes photovoltaïques.

le Programme Régional Solaire (PRS) ,qui est un programme du CILSS vise deux objectifs majeurs :

- à court termes : amélioration des conditions de vie et de la sécurité alimentaire en milieu rural ;
- à long termes : promotion de nouveaux systèmes de production de plus en plus en rapport avec les exigences de préservation de l'environnement et renforcement de la capacité des populations rurales à s'organiser pour surmonter les contraintes du milieu.

Pour ce faire, le programme tentera de valoriser 30à 40% des forages existants ayant des débits supérieurs à 5m 3/H

En Mauritanie, le Programme Régional Solaire (PRS) a démarré depuis 1983. Dans ce cadre, le projet PRS a permis d'installer 63 systèmes de pompage de type P3 à P6 qui assurent la fourniture d'eau à 60 localités rurales. La puissance totale des installations est de 132, 8 kwc. Le détails des systèmes installés est indiqué dans les tableaux ci-dessous.

Tableau 1 : Caractéristiques type des systèmes solaires

Synthèses	P3-1	P3-2	P4-2	P4-3
Puissance (Wc)	700	800	1400	1400
Energie hydraulique journalière en m^4/j	345	360	700	855

Synthèses	P5-2	P5- 3	P6-1	P6-2	P6-3
Puissance (Wc)	2 700	2700	3800	3 800	3800
Energie hydraulique journalière en m^4/j	1340	1340	2175	2175	2175

Tableau 2 : Réalisation de système de pompage par type.

Gamme-Synthèse	P3	P4	P5	P6	Cumul
Quantité (nbre)	8	29	15	11	63
Puissance Totale en Wc	6100	44400	40500	41800	132800

Les équipements fournis comprennent des pompes de surfaces(types P1 et P2) et les pompes pour installation sur forage(P3, P4,P5,P6) . Le système fournis fonctionnement au fil du soleil, sans accumulateurs. Le systèmes sont dimensionnés pour un climat sahélien et pour un ensoleillement de 6kwh/m2/jour avec une distribution correspondant à profil de journée. Ils se composent comme suit :

P1 pompe de surface 300 à 350 Wc	P1-A1	P1-B1	P2-B2 performance moy: 180m^4 /jour	2m	5m	7m
P2 pompe de surface 600 à 650 Wc	P2-A12	P3-B1	P2-B2 performance moy: 340m^4 /jour	5m		
P3 pompe immergée 600 à 650 Wc	P3-1	P3-2	performance moy: 340m^4 /jour	20m	30m	
P4 pompe immergée 1350 à 1450 Wc	P4-1	P4-2	P4-3 performance moy: 820m^4 /jour	20m	30m	45m
P3 pompe immergée 2300 à 2500 Wc	P5-1	P5-2	P5-3 performance moy: 1340m^4 /jour	20m	30m	45m
P3 pompe immergée 3700 à 3900 Wc	P6-1	P6-2	P6-3 performance moy: 2050 m^4 /jour	20m	45m	75

2.1.3 l'impact du PRS

Les installations du PRS représentent près de 25% des stations de pompages en services. Elles desservent globalement 15200 personnes soient plus de 30 % de la population rurale bénéficiant d'une adduction d'eau potable. 2500 ménages sont desservis par une installation d'un branchement particulier

Le PV de pompage offre des avantages certains. (i) Fiabilité intersèque de la technologie du PV (ii)Qualité professionnelles des prestations d'installation (iii)Une durée de vie longue et peu de maintenance mais, le coût de l'installation très élevé (coût du WC rendu 14 EURO et 20 EURO pour l'installé) et le mauvais état des ouvrages hydrauliques de distribution constituent une barrière de taille pour son développement

Le PRS a permis la banalisation du PV. Il a apporté une contribution décisive dans la validation de la technologie PV aussi bien pour le grand public que pour les pouvoirs publics.

Les systèmes ruraux sont gérés par des régies communales, des comités villageois ou des concessionnaires. Ces derniers prennent de plus en plus en charge la gestion des systèmes ruraux parce l'entretien communal n'est pas suffisamment efficace. La maintenance des équipements solaires est généralement assurée par la société BTI, celle des équipements éoliens par la société DEYLOUL

2.1.4 Perspective pour le pompage d'eau par système photovoltaïque en Mauritanie.
Le gouvernement Mauritanie a lancé deux nouveaux projets de pompage d'eau en milieu rural par système PV. (1) L'eau de la route de l'Espoir et (2) Programme régional solaire Phase II Dans ce cadre on prévoit que le taux de pénétration devrait dépasser les 70%.

Workshop on "Solar Cells and Water Pumping Systems"
Cairo, Egypt, from 20 to 22 december 2001
Rapport presented by Amor OUNALLI, ANER, Tunisia

1 Introduction :

In order to achieve the economic growth of Tunisia, taking into account the environment protection for a sustainable development, up grading the energy sector represents one the great challenges that Tunisia will have to face in the future. Indeed, demand in energy is estimated at 11Mt (Millions of tons) in 2 010 and at 22 Mt in 2 025. At the same time, the national primary energy production of is estimated at 3 Mt in 2 010 and at 2 Mt in 2 025. This would imply a shortage of 8 Mt in 2 010 and 20 Mt in 2 025. The balance would be imported and paid by hard currencies. In the face of these estimates, it has become imperative to give a priority to exploit all the opportunities in the area of energy conservation and renewable energy utilization in order to decrease the dependence on foreign sources of energy.

Consequently, future actions in areas of energy saving and renewable energy promotion need to be strenghened. These actions are being conducted by the National Agency for Energy Conservation.

2 The National Agency of Renewble Energy:

2.1 ANER's Mission :

Created in 1985, the National Agency of Renewable Energy (ANER), is a public , non administrative entity working under the aegis of the Ministry of Environment and land use Planning.

ANER's mission is to enact the State's energy control policy, particulary through the conception and launching of efficient long term strategies based on the promotion and conservation of existing ressources.

2.2 Objectives :

They consisit mainly on :

- Developping non energy-intensive and non-polluting activities to ensure energy saving both at the entreprise level and at the national level;

- Promoting renewable energies and energy subsitution while tring to a balance betwen economic interests, the quality of the life and environmental protection.

2.3 ANER's Programmes in the field of Renewable Energies :

The main components of these programmes are :

- Spreading the use of photovoltaic solar systems for rural electrification projects on a large scale;
- Promoting the use of photovoltaïc pumping;
- Encouraging the use of solar energy for water heating and pumping;
- Optimizing the use of biomass;

- Promoting the use of wind energy;
- Developping geothermics;
- Promoting Research and development activities in the field of renewable energy. .

3 Photovoltaic activities :

3.1 Rural electrification :

The depth of State commitment to providing at least a minimum level of infrastructure services for even the most remote rural households in Tunisia is illustrated by the national photovoltaic program. This is designed to meet the electricity needs of isolated rural sites which otherwise would not meet rural electrification criteria. At present, more than 8 500 households have been electrified with photovoltaics, about 1 per cent of total electrified rural households, in addition to 200 school, and a few clinics and forest/border posts.

The grid and PV programmes are seen as complementary, and PV has become an interesting alternative as costs of PV electrification per household, compare favorably with the present ceiling costs for grid connection .

The objective of the PV program is to contribute to the national goal of 100% electrification by 2010, of which 97% of households will be electrified by the grid and 3% by PV systems. Nonetheless, it should be noted that only about 71,500 rural households remain to be electrified in the entire country, while in the last five year plan alone, 200,000 households - three times those remaining - were connected to the grid.

The factors contributing to the success of the national photovoltaic program to date include:

- the complementarity of the PV and grid systems and institutions;
- demonstration and pilot dissemination projects to test feasibility and adapt components;
- finance through State and international subsidies as a minimum public service;
- attention to users' needs and training; and
- an emphasis on maintenance and after-sales support.

Demonstration And Pilot Dissemination Projects To Test Social Feasibility And Technical Performance And Adapt Technology To Tunisian Conditions

Interest in photovoltaics developed at the beginning of the 1980s, on environmental and social grounds. Several demonstration projects were followed by pilot dissemination projects that showed that the technology could contribute to meet the basic electricity needs (lighting, audiovisual) of isolated rural households, and that individual PV system were better adapted to isolated households than centralized systems, biogas or eventual grid extension. A German cooperation project for electrification of 1000 households in Kef, and a rural schools program financed by the State, were prominent projects.

An important facet of the pilot projects was to evaluate the technical performance of PV systems. Some of the results of this field experience included:

- the adoption of 100 W systems, since with 50 W systems, outages were frequently experienced in the winter months;

- the confirmation of the good performance of silicium monocrystalline and polycrystalline modules, with only some manufacturing defects that were returned under the 10+ year guarantees;

- the extension of storage battery lifetime from an initially low 12-24 months, through studies and trials in cooperation with local manufacturers and the Mechanical & Electrical Industry Technical Center (CETIME), resulting in a decision to use more expensive tubular plate batteries that tolerate the charge/discharge cycle better;

- the testing of technical performance of various brands of other components such as regulators, bulbs, voltage adaptors for radios, cables and installation accessories, where manufacture quality and international standards have improved over the years;

- the need, still, for improvement in the quality of installation (connections, equipment placement, wiring), despite ANER training sessions.

These findings have been implemented in the National Rural Electrification Program (as the PV rural electrification program is known). The installed systems used in this program have the following minimum specifications :

- Crystalline photovoltaic panels with a minimum power of 100 Wp (Watt peak),
- Tubular plate batteries with a minimum capacity of 200 Ah (Ampere hour),
- 12V/15A charge/discharge regulator,
- 3 lighting fluorescent bulbs 12/18 W,
- Radio voltage transformer 12 V/9; 7.5 and 6 V,
- 12 V electrical outlet for TV.

The technical and social feasibility of PV electrification in Tunisia has hence been well-tested and is well-established.

Attention To User Needs And Training

The national photovoltaic rural electrification program has sought to meet user needs in several ways. First, systems have been increased in size, from 50 W_p to 70 W_p and at present the standard is 100W_p, in recognition of the higher power needs and lower insolation in winter. This equipment feeds a continuous 12 volt current: 3 light bulbs, a black and white TV, and a radio-cassette player.

Second, because of the lack of familiarity with PV systems, ANER organizes training workshops for regional administrators and beneficiaries to explain the working of the systems. But even with the ANER training, many households appear not to have a full understanding of the limitations of their systems.

Third, ANER has tried to meet the increasing demand for refrigeration. Refrigeration cannot be accommodated under present PV systems without costly supplementary equipment. But users have been reluctant to participate even partially in these costs

Emphasis On Maintenance And After-Sales Service

Maintenance and after-sales service has been a continuing emphasis of ANER. Originally it was hoped that the beneficiary contribution would serve as both motivation and evidence of financial interest in continued maintenance. Two problems have emerged though.

First, users have felt that the responsibility for maintenance lies with the State. Second, the few Tunisian suppliers (2-5 maximum) are not able to profitably offer a national maintenance network, due to the small number of dispersed installations, so spare parts are not easily available, in spite of the two year guarantee.

ANER has dealt with this problem in several ways:

- rehabilitation of schemes where, due to lack of replacement of spare parts, systems have deteriorated;

- subsidy of spare parts, up to 65%, outside of the guarantee;

- training sessions for local technicians in installation and after sales service (so far 200 technicians have been trained in this program).

3.2 Photovoltaïc Water pumping (PVP) :

Untel now 35 PVP pumps have been instaled in Tunisia :

- 14 PVP have been installed by the German cooperation and by the ANER;
- 1 PVP pumps has been installed by the Spanich cooperation and ANER
- 20 PVP pumps have been installed by the CRDAs (Regional Development Agriculture Authority)

Wihin the framework of the German -Tunisian cooperation, 14 photovoltaic pumping systems have been intalled in order to demonstrate the reliability of this technology and to evaluate the conditions for economic competetion with diesel and electric pumps (through the grid). This would contribute to the improvement of the water supply in rural regions of Tunisia.

The sites have been selected according to social and technical aspects. The village selection criteria for the installation of a PVP system are the following:

- the daily demand of water for human and animals;
- The sufficient productiveness of the well;
- The distance to the national grid;
- The readiness of local administrative unions, so-called *Association d'intérets collectifs*, (AIC), is appreciated.

The PVP systems comprise the following main components : the PVP generator, the inverter, the submersible pump with a.c. motor and the monotoring equipement.

The power range for PVP application lies between 1,2 and 3,5 kW_p.

Raisons of the succes of the project :

The site selection is one of the most important step for the successful realisation of the project. It's normally combined with the priority expressed by the regional water authorities, in order to satisfy the demand of potable water in rural areas.

The performance of the photovoltaic pumps: the real pumping rates are somewhat below the rated values measured under laboratory conditions. Nevertheless, these values are acceptable.

The reliability of the PV systems during the first few years is excellent. This remark is true for all components of the system, also for the modules; but after few years, the modules showed brown discoloration (browning). This effect was attributed to material problems related to the manufacturer's production batches. Most of the modules in question have been exchanged within the scoope of supplier warranty services.

The two type of inverters installed have given the excellent reliability proof. No technical breakdown has been signalled until now.

The Motor-pumps have equally shown an excellent degree of reliability.However rare breakdowns have been observed on some installations in the region of the Center. These breakdowns have been associated with the reliability of the equipment and with quality of the well and of the water.

Design of the selected plants.

Difficulties met:

Among the problems met, we can note those linked to the social acceptability, to technical performances and to maintenance.

- Social acceptability :

Indeed, when system PVP replace others pumping equipment, such as diesel motor-pumps, that disturbs established habits, namely the tranquillity to have the water in abundance by pushing just on a starting button, or again of the stop of a relative lucrative activity to supplying gasoline that is generally held by the president of the AIC (Common Interest Association)

- Technical performances:

The major technical problems are linked to the quality of modules of which the power falls and as a result their performances decrease (described before)

- Maintenance :

Similarly maintenance policies practiced by CRDA were efficient, although the approches adopted to achieve maintenance were different from one Institution to another. As exemples of these approches we can mention the following:

- There is a CRDA that has concluded contract maintenance with an enterprise specialized in the area of solar electricity and in contact with the local representative of the supplier of the project.

- CRDA that establishes, occasionnaly, a market with the local representative of the supplier of the project., to face the curative maintenance as well as preventive.

- An other CRDA estimated that they have sufficiently technicity. They insure the maintenance by themselves while purschasing the spare parts to the local representative of the supplier.

- Monitoring:

CRDAs have solid technicity concerning water management in rural aereas and essentially with traditional pumping equipments such as diesel pumps and electric pumps. Nevertheless, the photovoltaic pump management needs other knowledge in the area of solar energy and in the " computerized " monitoring of the installations. CRDAs have been probably inadequately trained in this field. As consequence, they do not succed until now to achieve a correct monitoring of PVP stations using measurement equipment available with them.

Conclusions :

Solar electricity has been widely used in Tunisia for rural electrification by photovoltaic systems, for dispersed housholds wich are distant from electrical grid. This utilization will be again maintained to equip rural housholds that will not be connected to the national electrical grid for several years. The corresponding potential reaches some thousands of housholds. For the future, one has to consider this potential as well as the opportunity for using solar electricity for applications such as water pumping or water desalination of the brakish water and the seawater. This is all the more true that demonstration projects on photovoltaic pumping have shown that the used technology is mature, reliable and efficient when it is used in arid regions. The main problem is the cost of the first investment. Solutions could be found to through research and developpement programmes as well as within a wider vision of the market.

STATUS OF PHOTOVOLTAIC SOLAR ENERGY WATER PUMPING IN YEMEN

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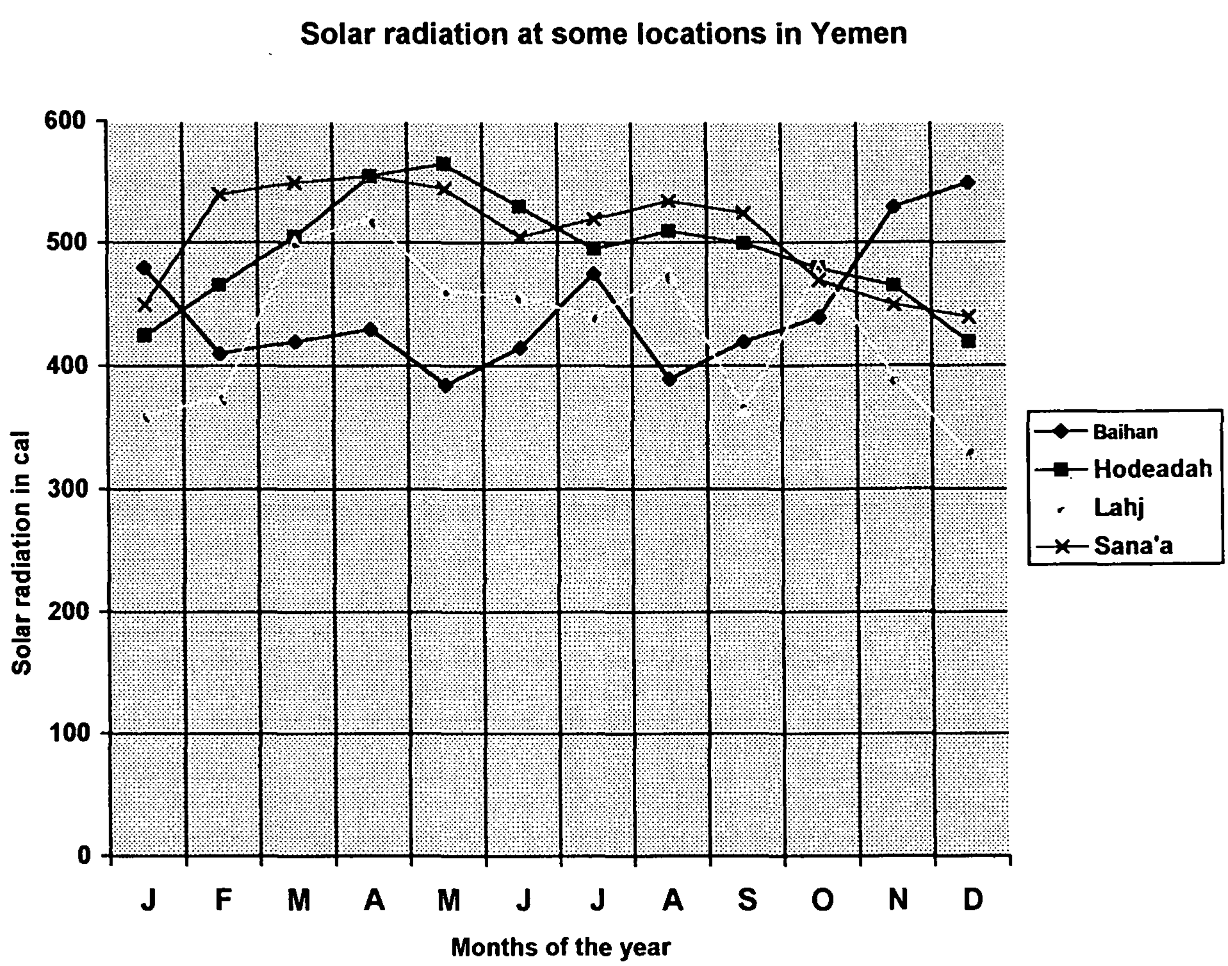
1.Background

Yemen is located in the southern part of the Arabian peninsula, The total area is 555,000 sq.km and the population is 17 millions. Yemen enjoys very diverse natural physical structure mountainous, coastal, plateaus, deserts regions and islands and consequently a very diverse climate that degrades from hot-wet orbital climate to cold climate. Yemen has a very coastal strip of more than 2600 km, 30 –60 km wide along red sea, gulf of Aden and Arabian sea.
There is a great potential for PV Solar energy conversion and renewable energy applications on the coastal strips, offshore area, mountains and islands.
The average solar radiation in Yemen is 18-26 MJ/sq.m/day with average od daily sunshine hours is between 7.3 –9.1 hours/day. Hybrid system (Solar/Wind) also can be used and makes the energy utilization at these location very feasible.
The following figure shows the solar radiation at some locations in Yemen.



2. CURRENT PHOTOVOLTAIC SITUATION IN YEMEN

In recent years attempts have been made to utilize PV systems to provide power in many applications. These include telecommunications, radio and TV transponder system, water pumping, health centers and lighting systems. It must be remembered that Yemen has no infrastructure for PV Technology yet. What has been achieved in the past mainly due to recommendation from specialist to solve specific energy needs. At present, realization of using PV systems by the government and citizens for different applications to solve their electrical needs has become certain. Tables 1& 2 explain this fact.

2.1 Telecommunications

One the major user of PV is the telecommunication sector for microwave and radio transmission and repeaters. The use of PV in telecommunication is increasing more compare to the other applications. The recent figure of about more than 250 kW_p PV systems are used in this sector

2.2 Television and Radio Transponders

PV systems are widely used in radio and television transponder applications due to mountainous terrain of the country. PV/Wind and PV/diesel generator hybrid system are used.

2.3 .Water Pumping

There is a number of PV powered pumps being operated and being successful in supplying water over a period of more than 10 years. At present PV water pumping application has shown a noticeable increasing.

2.4 Health Centers and Vaccine Refrigerators

There some PV systems were installed to supply power as a replacement of diesel generator. Similarly, vaccine refrigerators were also used.

2.4 Electrical Lighting

At present, the most PV system market is for households lighting of rural areas. This shows those PV systems for rural electrification application is among the most potential PV system market.

It can be concluded that due to electrical power shortage in Yemen, presently, there is a lot of work and interest in the application of PV system in different areas.

The following are four main PV Solar distributors:

- Technical Supplies Center(TSC)
- Tihamah Company
- Solar Energy Center-University of Science and Technology
- Mareb Establishment
- In addition to the above some General Electrical Appliances stores..

The main distributors are Tihamh and TSC. The following data are the recent obtained from TSC:

Table 1:Sector wise PV Systems in W_p Installed in Yemen by TSC, Sana'a For Years 1995 -2000

Sector/ Year	1995	1996	1997	1998	1999	2000	Totals
Telecom	19800	7680	0	78720	0	86400	**192600**
Medical	0	0	0	2880	17280	0	**20160**
Remote Houses	0	0	0	6000	7200	9300	**22500**
Instrumentation	0	0	0	0	720	0	**720**
Water Pumping	0	0	1920	0	1800	5580	**9300**
Totals	19800	7680	1920	87600	27000	101280	**245280**

3. WATER PUMPING IN YEMEN

The national economy is based on oil, fisheries and agriculture. As many countries of the world, Yemen faces the problem of shortage of water resources especially in the main cities and rural areas. This problem is increasing due to limited water resources and the growth of population, which is estimated as about 17 million at present. At population growth of 3.6% the population will be about 36 million by the year 2020.

Water pumping technology for drinking water and irrigation using electrically or diesel driven pumps efficient with the availability of electricity or diesel generator with reasonable cost , which is the case in many parts of Yemen. Water for irrigation for some parts of Yemen depends on monsoon rains, while other parts depend on ground water. Water for drinking is taken from ground water.

PV Water pumping has started gaining more importance, especially for rural drinking water.

According to the information available with the author the following PV water pumping systems are available in Yemen.. Table 2 summarizes these systems with their location and capacity.

Table 2: PV Solar Water pumping Systems for Drinking in Yemen(According to author's knowledge)

Name of Project	Location	Capacity	Remarks
UNDP DrinkingWater Project	Lahj -	12 kW_p	No more information
Local Authority Water Pumping for desert people	Thamood – Hadramout	-----	Since 1985(approx. No information
Pilot project by FOA	Taiz	___	Dismantled
Pilot project by Finland	Jarahi village – Taiz	9 m^3/day and 12 kW_p	Since 1998
5 PV Water pumps	Hodeidah	15 m^3/day, and 1 kW_p(Each)	Working well
3 CIDA / UNCIF/NGO Projects	Lahj	11 m^3/day and 0.84 kW_p(Each)	Working well one is visited by author on Nov.2001
9 Projects by local authority	Lahj	11 m^3/day and 0.84 kW_p (Each)	In progress

From contacts made by the author with Lahj Governorate Local Authority, there is a near future program to incorporate 35 PV water-pumping units at different location of Lahj Governorate.

Approximate estimates of PV water pumping application, is found 30 kW only. Expected expansion in water pumping is so large in the coming period..

3.1 Scope for Large Scale PV Water Pumping System In Yemen:

The potential for water pumping for drinking water is explained from the Tables. While the potentiality is expected increasing as predicted later by the concerned people.

The followings areas are seen the feasible for application of solar pumping systems:

1. **Water pumping for fishermen communities**:

Since Yemen has coast extending 2600 km and about 5 million people live in this coastal area at present with huge fish wealth, there is great need for fresh water for fishermen communities for their use and for fish catching and processing industry. Therefore, large scale water pumping and desalination is a potential application for this areas. Combined water pumping and water desalination projects will have impact on the people's life and economic aspects of fish wealth in Yemen.

2. Water pumping for rural areas:

Most of the country regions is rural. Majority of rural people works in agriculture or fish catching. They use to have their drinking water from wells by using the manual lifting, using water pumps driven by diesel engines or electrical motors, if electricity from generator or from the grid line is available.

Grid extension to rural areas becomes costly and, if available, the cost per kWh for commercial applications is high (0.1 US$). Using diesel engines has the problem of high diesel cost (0.1 US$/lit), in addition to the problems of maintenance and environmental pollution.
Due to all the above limitations, PV technology is becoming the viable option for water pumping if the problem of high initial cost is solved.

In Yemen, realization of energy problem solution is towards using PV technology for water pumping, water desalination, remote areas electrification etc is becoming the issue of governmental decision-makers, NGOs and International Agencies.

4. CONCLUSIONS

In Yemen there is high potential for PV application in the following fields:

- Water pumping and water desalination especially at rural coastal and agricultural regions
- Telecommunications
- Rural electrification

Awareness of using PV Technology is increasing during last few years after realization its importance in solving energy needs for some applications. This is seen from the contacts made by the author with different concerned bodies and from the noticeable increase in marketing PV systems as shown in Table 1,
The most good steps taken by the Yemeni Government towards giving more importance to the renewable energy sources are:

- There is a proposal for forming a National Committee for the Renewable Energy to be submitted to the Prime Ministers Council for approval.
- World Bank has nominated a consulting company to prepare studies for Rural Electrification with considering the Renewable Energy Resources.
- The declaration of Socotra Island as an Environmentally Protected Island.

In conclusion, to enhance the idea of implementing PV Technology, there is need for more cooperation and mechanism to enabling the necessary coordination of all national and international efforts.

Active Steps Taken by the Author After 26-30 June Trieste Meeting and Workshop on Project Development for PV Technology

- Following a suggestion to hold a Solar Energy National Workshop and Renewable Energy Systems Exhibition after 3 months at University of Aden aimed to focus the government and decision makers, researchers to the benefit of solar energy especially for water pumping systems. Similarly, efforts are going in the same directions by Ministry of Electricity and Water, University of Science and Technology and University of Hadhramout.
- Guiding a group of final year Mechanical Engineering students for a problem of solar water pumping system in Yemen.
- Visited a project of solar water pumping project at Lahj governorate.
- Surveying a potential site farm for using PV solar water pumping system for irrigation at Al-Qatin- Hadhramout, University of Hadhramout farm.
- Communicating with Solar System distributor (TSC), Local authority of Lahj governorate.
- Series of scientific discussion with a specialized researchers in renewable energy in Yemen.

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- University of Aden- Aden
- University of Hadhramout-Hadhramout
- University of Science and Technology-Sana'a
- Local Authority- Lahj Governorate.

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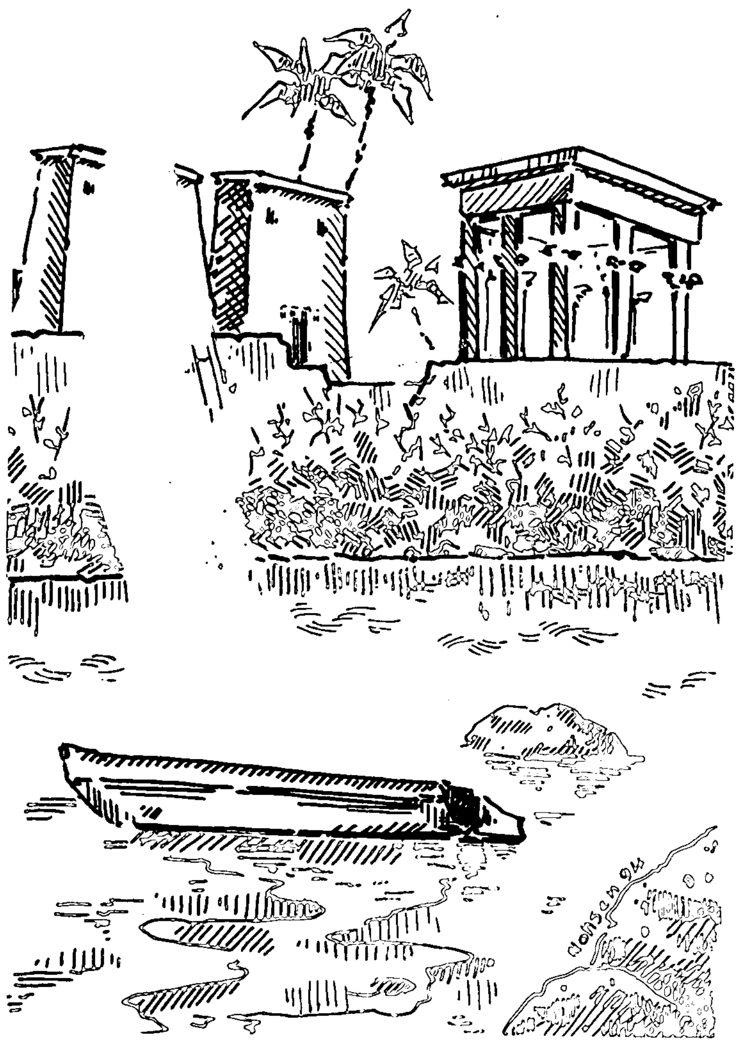

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