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ASSESSMENT OF SOLAR APPLICATIONS FOR TRANSFER OF TECHNOLOGY:

A Case of Solar Pump

Jyoti K. Parikh

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PREFACE

IIASA's Energy Systems Program examines various energy options, including soft options. It has been felt by many that, due to their decentralized nature, solar applications would be relevant for the rural environment and especially in the developing countries, where electricity is often not available. Therefore, a close examination of specific solar applications is carried out to see if they could meet the requirements of the user under field conditions.

A particularly interesting question is the use of solar power in agricultural production. This paper compares solar water pumping and diesel pumps chosen as reference technology in present day operation. The findings point to the importance of carefully adapting soft solar technologies to local conditions. It also exemplifies the significant differences in the development potential of given technological concepts with respect to varying conditions of use.

The article points out the challenges that lie ahead in the development of these applications and stresses that these developments should account for the requirements of the field conditions for a successful transfer of technology from laboratory to field.

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ASSESSMENT OF SOLAR APPLICATIONS FOR TRANSFER OF TECHNOLOGY
A CASE OF SOLAR PUMP†‡

JYOTI K. PARIKH
International Institute for Applied Systems Analysis, Laxenburg, Austria

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Abstract—For the large and increasing rural population in the developming countries, decentralized solar applications could be relevant. However, new solar technologies being developed in the laboratories presently have to ultimately be acceptable in the field conditions. The conditions which have to be satisfied before the solar applications could be acceptable are discussed. The solar pump is examined in detail in particular due to the interest expressed by many developing countries in this specific application. A comparative techno-economic analysis is carried out for solar pumps and diesel pumps which considered escalation of the diesel price and factors related to climate, geography, locale, social and institutional environment for two types of uses namely for drinking water and for irrigation. It seems unlikely that a solar pump could compete with the diesel engine before the costs are brought down by a factor of 20–50 for irrigation purposes. However, for obtaining the drinking water the cost reduction required is by a factor less than 10 than currently charged for the prototypes. Although specific example of India is taken the matters are relevant to most developing countries. The issues discussed for the case of a solar pump are also relevant to other solar applications used only for seasonal purposes since the capital costs are high and operating diesel pumps during the season would be cheaper for several decades.

1. INTRODUCTION

The intensity of solar radiation is low and therefore a considerable amount of land is required for utilizing solar energy. Solar applications therefore would be more suitable for the rural environment where the land is available easily rather than for the urban areas. Conventional centralized energy systems have not yet reached the large rural population in many developing countries. Solar applications which contribute a decentralized energy system could provide a significant improvement in economic productivity in the rural areas.

According to an estimate of the United Nations[1], in 1970 the rural population of the world was 2.26 billion out of which 1.89 billion were in the developing countries. The percentage of persons living in the rural areas of the developing countries is expected to decrease from 75 per cent in 1970 to 59.2 per cent by 2000 A.D. However, their absolute number will still be 2.92 billion, a substantial increase over the present number. Figure 1 shows the region-wise rural population, as projected in Ref. [1].

The energy requirements of rural people, although extremely low, are largely met at present by locally available non-commercial resources such as firewood, agricultural waste and dung. Yet, energy planners in the governments of most of the developing countries are concerned primarily with the development of large energy systems, appropriate for urban and industrial purposes. Although efforts are being made in most of the developing countries to expand rural electrification its progress is slow because it is capital intensive, especially when it involves connecting remote villages to the network. Thus, there is a need for developing decentralized energy systems for the rural areas.

Scientists and technologists do come up occasionally with solutions for decentralized energy systems. When these are not adopted they generally complain about the difficulties of technology transfer, resistance from established interests, etc. Though these obstacles are not to be underestimated, their claims about the relevance of their research and development are many times not found to be valid for actual adaptations in the field when all the facts are put together. Therefore, a careful appraisal of the difficulties of the transfer of technology is essential.

In this paper we consider first the issues that are important in assessing technology. Then some of the solar technologies are evaluated keeping these issues in mind. Since photovoltaic cells are very expensive at present, we have considered for this analysis only decentralized low thermal devices. In particular solar pumping is evaluated in detail as a case study.

Algebraic expressions can be used for application to any country, although numerical results for the specific case of India are given.

2. ISSUES CONCERNING THE TRANSFER OF TECHNOLOGY

Here "Technology transfer" would mean the transfer of invention from a laboratory to the field. It has to be recognized that the users cannot run an experimental energy system. Due weight has to be given to the perfection of the invention and the development of institutions which are required, such as establishments which look after the user's problem. The user's viewpoint could be classified into two categories; techno-economic and social or relating to the operating en-

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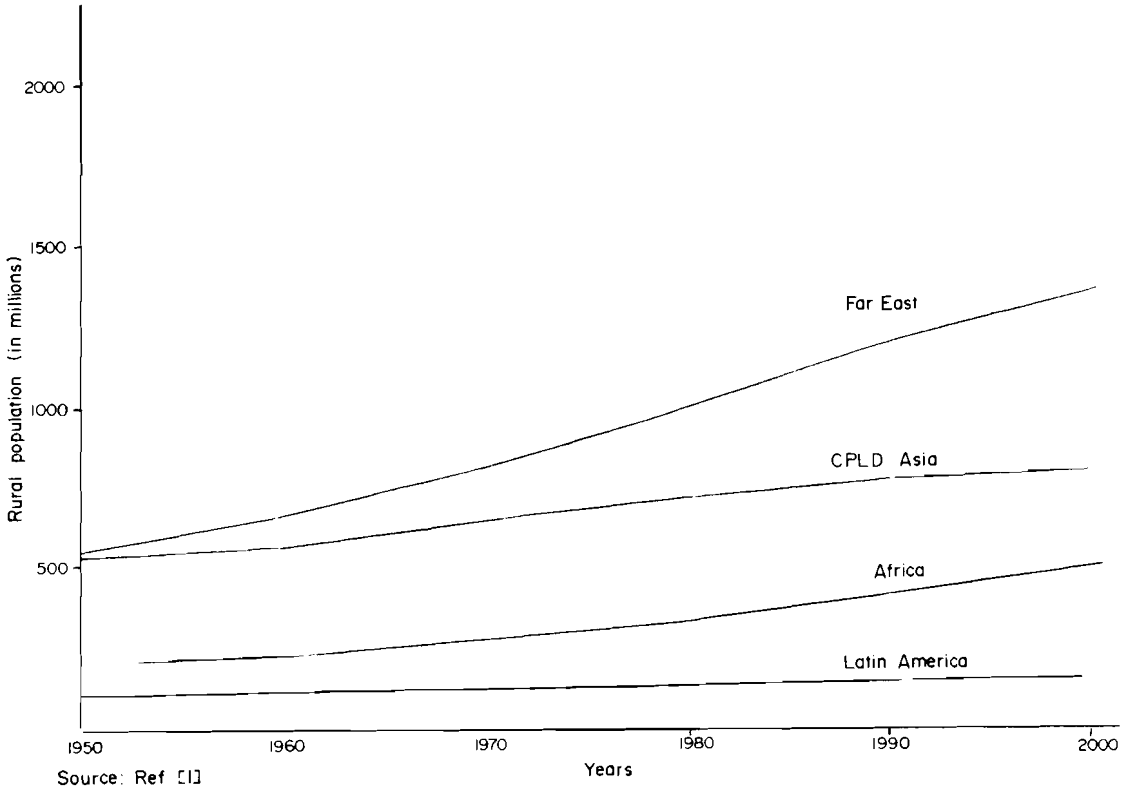


Fig. 1. Past and projected rural population of developing regions.

vironment in which the technology has to be used. In general, the following points need to be considered.

Private and social benefits

The benefits, savings, etc. are often calculated on national, state or village levels and not for the consumer who is going to use it. Though benefits at the national level, such as saving of foreign exchange, curbing environmental degradation overall health effects etc. are important, they are meaningful only if the new technology is acceptable to the user. If the user does not benefit, yet an invention needs to be promoted for national or social benefits, the individual user has to be compensated if he is to be induced to use it. This requires a national policy action where subsidy, financing facilities, tax rates, etc. have to be introduced to promote better technology.

Thus, the cost-benefit analysis should be done also from the user's point of view along with the analysis from the social viewpoint. One then identifies the loss, if any, that the user has to incur and to what extent the government might subsidize him judging from the indirect costs the society has to bear if the new technology is not promoted.

Comparison with other alternatives

The economic benefits to the user should be calculated keeping in mind the best possible alternatives that a user has. For example, if the advantages of bio-gas plants are calculated by taking kerosene or even coal as the alternative, they would look substantial. But actually the comparison has to be made with the cheapest possible alternative, i.e. burning dung and purchasing fertilizer, if at all he needs it. Of course, the fringe benefits and conveniences and nuisances of both the alternatives should be weighed appropriately. Only then one understands why certain innovations are not catching on. In addition, possible future developments in the existing alternatives should also be considered.

Scale of technology

Some technologies may turn out to be inappropriate—economically or managementwise—if the proper scale is not chosen. For example, in some situations many small solar pumps may be more expensive than a large pumping station. Yet the small pumps may be preferable when the management problems associated with the different scales are considered. Again, giving an example of bio-gas technology, our earlier analysis[2] shows that a community bio-gas plant may be more economical and socially desirable than family bio-gas plants.

Introduction of technology

The manner in which a technology is introduced determines its success. For example, adversely affected or less beneficiary groups may offer resistance. Besides, at the planning state itself, problems of cooperation, maintenance and repair would have to be foreseen.

Compatibility with the environment

If an invention requires a change in lifestyle or is in conflict with the surroundings, it will face difficulties in its adoption. In such a case, the strength of the existing establishment of older technology should be carefully assessed and whether or not the society is ready for the change should be considered.

Acceptance of technology

An invention has to be appropriate for the kind of use for which it is meant. For example, as will be demonstrated later in this paper, there is a need to consider the manner in which a pump is presently utilized while designing a solar pump for agricultural purposes.

It is therefore necessary that a government with limited resources should evaluate new technologies carefully so that only appropriate ideas are encouraged. The development of inappropriate inventions may waste precious scientific manpower and limited research funds and also cause a loss in the credibility of new technologies in general. Although these may appear to be a matter of common sense, there have been many failures of new technologies due to neglect of simple practical considerations in the past. Therefore we attempt to analyze the difficulties of transfer of technology for one of the applications of solar energy, within the context of the above mentioned criteria. Although the general framework of the analysis is applicable to any country, a case study for India is carried out.

3. SOLAR PUMP

Since many developing countries have shown interest in solar pumps there is a need for a detailed analysis of this application. For example, in countries like India, Pakistan etc. development efforts are underway whereas countries like Mali, Senegal, Niger, Mexico, etc. have already installed solar pumps at very high cost.

Solar pump for irrigational purposes would be a significant application of solar energy for the developing countries where 40–50 per cent of GNP originates from the agricultural sector for which water is an essential input. Table 1 provides some relevant data for energized pump-sets and their electricity consumption in India. About 9 per cent of the total electricity consumption in India is accounted for by energized pump-sets alone[3] inspite of the fact that hardly 20 per cent of the villages were electrified in 1967 as shown in Table 2. The number of pumps required[4] in the next 2–3 decades can be more than 10 million. Table 2 also shows[5] that the rate of electrification for small villages of 500 persons is much slower than the large towns. In view of the slow

Table 1. Pumpsets and electrical energy consumption in India†

Year	No. of sets in operation	Energy consumption (10^9 kWh)	Total electricity consumption 10^9 kWh	Consumption per pump set (kWh)	Consumption in kWh per kW of connected load
(1)	(2)	(3)	(4)	(5)	(6)
1966–67	649182	2.107	33.26	3245	842
1967–68	847357	2.585	36.76	3050	814
1968–69	1088774	3.466	41.46	31.83	834
1969–70	1342006	3.770	45.02	2809	738
1970–71	1642006	4.110	48.65	2503	657
On 31.3.74	2444596				
On 31.3.79 (Target)	4022790				
1983	6.5 million				
1990	12.0 million.‡				
2000	20.0 billion				

†Ref. [3].
‡Ref. [4] p. 55. This projection takes into account the growth of population and the need for additional food production and is compatible with the ground water potential of the country.

Table 2. Villages electrified in India

Population Range (1961 census)	Total	Number electrified as on				
		31-3-61	31-3-66	31-3-71	31-3-72	31-3-73
Up to 499	351,653	3,986	10,265	31,518	39,730	46,665
500 to 999	119,086	4,306	9,787	26,436	32,602	37,880
1000 to 1999	65,377	5,918	11,567	25,715	27,971	31,586
2000 to 4999	26,565	5,458	9,441	17,036	18,326	19,922
5000 to 9999	3,421	1,319	1,963	2,674	2,753	2,913
10000 to above	776	560	647	702	712	729
Total	566,878	21,547	43,679	104,091	122,094	139,695

Source: Ref. [5]

electrification of the rural areas, the importance of the agriculture sector and the necessity of energy for pumping, solar pumps could be an extremely relevant application.

3.1 *Techno-economic considerations*

The conditions for solar pumps to be acceptable would be that they provide adequate pumped water, are cheaper than the existing alternatives, or alternatively, are more convenient so that farmers would be willing to pay a higher price.

We shall develop a general framework for such a techno-economic comparison between any two alternatives. The symbols being used in the calculations are explained in Table 3.

Table 3. Symbol definitions for techno-economic evaluation

	Solar	Electric	Diesel
Capital costs	K_s	K_e	K_d
Life time of the pump	l_s	l_e	l_d
Number of pumps required for a period T of service	n_s	n_e	n_d
Price of fuel per unit of fuel as a function of distance and time	—	P_e (kWh)	P_d (l.)
Quantity of fuel required per year	Sx365	q_e	q_d
Maintence costs	m_s	m_e	m_d
Operation costs	O_s	O_e	O_d
Annual work done	W_s	W_e	W_d

In general $O = m + p \cdot q$ for a given option. The annual discount rate d for all options. The subscripts are dropped during general discussion of any engine.

In the presence of electricity, the solar pump would have to compete with electrical pumps and with the diesel pumps in the absence of electricity.

As a pump in the range of 1/2 kW or kW could easily be replaced by animals or human power, a higher range of 4 kW and above is considered.

3.2 *Average annual costs per installed kW*

We assume that the annual cost of the loans made to finance the installation would be equal to half the rate of interest (discount) plust the operation costs. Neglecting inflation but considering depreciation, we get the following equation

$$K_s\left(\frac{d}{2}+\frac{1}{ls}\right)+m_s = K_d\left(\frac{d}{2}+\frac{1}{ld}\right)+q_d p_d(s,t)+m_d. \quad (1)$$

Somewhat similar expression has been already derived by A. Takla[6]. However, such an expression does not consider the difference in the work that can be done because of the different availabilities at night of the two alternatives being compared.

Before we consider this problem, we writê an exact formula for the discounted costs instead of the approximate form (1).

3.3 *The discounted costs for a period of service T*

The discounted cost of installing a capacity at the initial period for any option would be

$$C = K + \sum_{t=1}^{l} \frac{O(t)}{(1+d)t-1}. \quad (2)$$

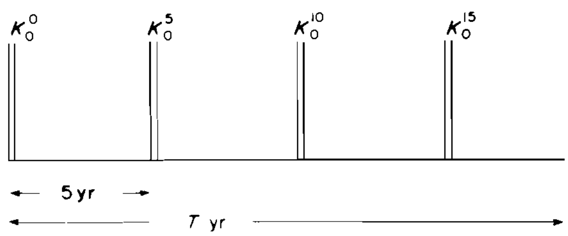
Here

$$O = m + p \cdot q. \quad (3)$$

In order to compare solar and diesel engines they must provide service over the same length of time T, since the lifetimes of both the options may be different. We choose the time T such that

$$n_s l_s = n_d l_d = T. \quad (4)$$

Thus, if the lifetimes of the solar and diesel engines are 20 and 5 yr respectively, then one would require 4 diesel engines over these 20 yr, requiring new investment every 5 yr which have to be discounted to the initial period.



A general formula for discounting this over the period T is given below.

$$c = \sum_{n=1}^{T/l}\left(K + \sum_{t=1}^{l}\frac{0}{(1+d)^{t-1}}\right)\frac{1}{(1+d)^{(n-1)}}. \quad (5)$$

On the other hand, without a storage capacity the solar pump cannot be operated for the same hours as the diesel pump. In using the formula we have to take into consideration the work that would be done by both these pumps in a day. For this we consider two cases:

(a) *The rate of pumping.* In some areas the rate at which water recharges may be slow and therefore there may be an effective limit to the *rate* at which water can be pumped. In this case, we have to compare two pumps of the same capacity. The fact that the solar pump can be operated only for about 6 hr and the diesel pump for 18–20 hr make the two pumps non-comparable. In fact, the solar pump without adequate storage may not be considered a feasible option in this case.

(b) *A comparison of equivalent work done.* A solar pump works with the average efficiency e_s for h_s equivalent hours of full capacity where a solar radiation s kWh/m^2/day is available. The collector area required for the installed capacity c_s is A.

Daily work done

$$W_s = s e_s A \quad (6)$$

in kWh.

The diesel pump on the other hand can operate for a much longer time, let us say h_d hr. This may mean higher consumption of the fuel but better utilization of the installed capacity, which is denoted by c_d.

Daily work done

$$W_d = h_d c_d \tag{7}$$

in kWh.

We must have

$$w_s = w_d. \tag{8}$$

Therefore

$$s \cdot e_s \cdot A = h_s c_s = h_d c_d. \tag{9}$$

Here $e_s = e_c \cdot e_p$ where e_c and e_p are the efficiencies of the collectors and the pump respectively.

This concept is explained in Fig. 2. Equation (4) can determine the value of c_s for equivalent work as well as the necessary area of the collectors.

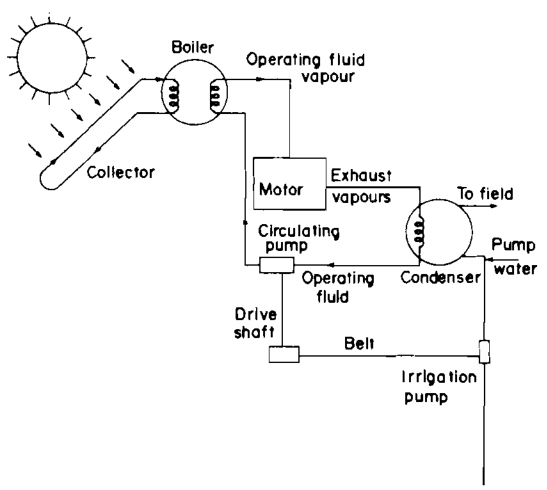


Fig. 2. Daily variation of radiation and output of solar and diesel engines.

4. NUMERICAL COMPARISON BETWEEN THE ALTERNATIVES

Having developed a general framework for a techno-economic comparison, we compare the alternatives for a user. In doing so, one should consider uncertainties in various matters such as future improvements in the efficiencies and costs of solar pumps and escalation of diesel prices, etc.

4.1 *Present design and feasible technical improvements*

As we are concerned with a pump for agricultural needs, we do not consider low temperature pump operating only on temperature differences as this technology is not yet developed enough to give the required output but consider an engine driven pump as shown in Fig. 3.

If manual tracking system operating with concentrators utilizing Fresnel lenses are developed, which seems to be a realizable goal, then an optimistic figure for the future efficiency could be taken to be 10 per cent along

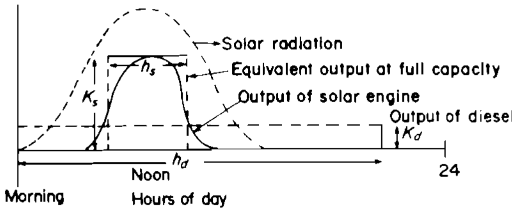


Fig. 3. A schematic design of a solar pump.

with other improvements in the design of the solar engine and collectors.

4.2 *Numerical values*

To be favourable to the solar pump, we assume that electricity is not available in the region and the alternative is to use a diesel pump. Considering the data in Table 1, it seems that on average, farmers' requirements are met by a pump of 4 kW capacity which runs 1000 kWh/yr. We compare a solar engine and a diesel engine to drive such a pump. The lifetimes l_s and l_d are 20 and 5 yr respectively. The capital cost today is about Rs6,000 ($600) for a 4 kW diesel engine (K_d = $150/kW). We consider lubrication costs separately for a diesel engine. Thus, the m_s and m_d would be $50 each per yr. The operation cost of a solar engine is only $50 per yr. The diesel oil and lubricants consumed by a 4 kW diesel pump for running 1000 hr would be 1 ton and 0.028 ton per yr respectively. The costs of diesel and lubricant at market prices P_d and P_e, are $150 and $20 respectively. Therefore, using eqn (3) we get O_d = $220. We consider three scenarios, one with no escalation, and other two with 5 and 10 per cent annual increase in the relative prices of diesel and lubricants. In the discounting procedure, costs are calculated at constant (current) dollars and only that price increase which is over and above inflation is considered.

However, operating conditions in the field are such that pumps have to run 18–20 hr, or even 24 hr. A diesel engine can be run round the clock, whereas a solar engine without storage may run for 6–9 hr/day. Using eqns (8) and (9) the capacity of solar engine, c_s, would have to be 2–3 times that of the diesel engine depending on whether it runs for 6 or 9 hr. Therefore, we consider these two possible capacities with the three scenarios of oil prices. Using eqn (5) for the discounted costs, we get the results which are summarized in Table 4.

Part A in Table 4 shows the discounted costs for a 4 kW diesel engine and an equivalent solar engine under the various assumptions. The break-even costs of solar engine required to do the same amount of work has been given in Part B. The break-even capital costs, k_s per kW, vary from $233 to $590, depending on whether one requires three times larger solar pump or two times and whether one considers 0, 5 or 10 per cent increase in oil prices at constant dollars.

The market price of a solar pump at present is 15–20 thousand per kW. Based on our analysis a reduction in price by a factor of 25–70 is required before a solar engine would be economically acceptable for driving an irrigation pump.

If the pump is only to be used for obtaining drinking

Table 4. Comparison of costs of solar and diesel engines

	Solar	Diesel engine (4 kW, 4000 kwr/yr) Annual increase in relative price of diesel		
		0%	5%	10%
(a) Present discounted costs for a 20 yr service period				
(i) Costs of capital	k_s	1348	1348	1348
(ii) Operating costs incl. fuel lubricants and maintenance	$425	1872	2543	3825
(iii) Total	k_s + $425	3220	3891	5173
(b) Break-even capital cost of a solar engine for irrigation ($/kW)				
(i) Equivalent solar capacity c_s = 8 kW		349	433	593
(ii) Equivalent solar capacity c_s = 12 kW		233	289	395
(c) Break-even capital cost of a solar engine for pumping drinking water ($/kW)				
Solar engine capacity same as diesel c_s = 4 kW		698	866	1186

Assumptions: (1) Discount Rate = 10 per cent. (2) Life time, solar 20 yr; diesel 5 yr. (3) Diesel engine is 4 kW, runs 1000 hr per yr and during peak period is required to run 18 hr. (4) Solar can operate 6–9 hr a day. (5) Diesel consumption is 0.250 l/kWh, price is $150/ton. (6) Non-fuel operating costs are $50/yr for solar as well as diesel pump.

water, then it can be of the same capacity as the diesel pump and may run 4–6 hr. This has been also compared in Part C of Table 4. This requires a reduction of price by only a factor of 10–20.

4.3 *Validity of assumptions*

Most of the assumptions made in the above analysis are quite generous to the solar engine as can be seen from the following:

(a) *Technical assumption.* A solar engine with a lifetime of 20 yr is not yet available. Besides, a solar engine with twice as much capacity of the diesel engine would also require a hydraulic pump—which is driven by the solar engine—of double the capacity as that used by the diesel engine. This additional cost of hydraulic pump for ths solar engine is not considered in the calculation.

The present analysis assumes 6–8 working hr without storage. So far, the working hours of a solar engine do not exceed 8 hr *with* storage. The engine designed by the National Physical Laboratory of India works 4 hr per day *with* storage. Storage requires additional collector area as shown in eqn (6), the costs of which should also be included.

If adequate storage were to be provided so that the solar engine can be run for 18 hr, the capacity of the solar engine need not be larger than that for the diesel engine. The break-even cost of such a solar engine with the costs of collectors and storage can be as high as $1180 per kW.

(b) *Economic assumptions.* Although an electrical pump provides a cheaper alternative, the cost comparison has been made with a diesel pump. Since we are looking into a possibility of nation-wide adoption, the question of unavailability of diesel in the individual remote areas has not been considered. These areas might find solar pump to be useful in the near future, especially for drinking water, as it may be the only feasible technology. However, we do consider an 8-fold increase in the diesel prices (10 per cent annual increase) over 20 yr relative to other prices which are kept constant.

However, if the solar pumps are manufactured in the developing countries, they could be cheaper than the current quotations. For example, the pump developed in the laboratory in India[7] has material cost of $1200/kW. However, much progress is to be expected and it has to be seen what the costs of a commercial solar pump would be in the developing countries.

5. OPERATIONAL PROBLEMS OF SOLAR PUMPS

Assuming that we have a solar pump which is of a comparable cost to the other alternatives, what are the other factors that need to be worried about? In the above mentioned analysis, only the average solar radiation had been considered for the sake of simplicity.

Moreover, the requirement of water for the crops follows a certain pattern while the demand for water depends upon the crops and cropping pattern, the supply would be determined by the arrival of the rains the depth of the water table and the rate of recharge. These are the most crucial factors which determine the acceptability of a pump.

5.1 *Climatic and local variations*

The intensity of solar radiation changes from month to

Table 5. Monthly variations of solar radiation and typical efficiencies in the two cities of India

		Nagpur			Jodhpur		
Month	Days	Average radiation cal/cm²/day	Utilization efficiency	Monthly availability cal/cm²	Average radiation cal/cm²/day	Utilization efficiency	Monthly availability cal/cm²
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Jan.	31	460	88	12549	410	84	10676
Feb.	28	510	83	11852	480	84	11290
Mar.	31	570	76	13429	560	77	13367
Apr.	30	610	72	13176	630	78	14742
May	31	630	70	13671	680	83	17496
June	30	480	40	5760	680	73	14892
July	31	400	23	2852	530	48	7886
Aug.	31	380	23	2709	480	43	6398
Sept.	30	480	51	7344	540	54	8748
Oct.	31	500	69	10695	510	84	13280
Nov.	30	480	87	12528	440	91	12012
Dec.	31	420	84	10937	380	88	10366
Total	365			117502			141155

Source: Columns 3, 4, 6 and 7 are from Ref. [8].

month. The efficiency of utilization depends on the intensity of solar radiation, the temperature, the cloud cover, etc. In Table 5, monthly variations of solar radiation, utilization efficiency (Ref. [8]) and utilizable solar energy are given for two places, namely Nagpur; Madhya Pradesh (Central India) and Jodhpur which is in the Western region near Rajastan Desert.

One can see that in Nagpur, the utilizable energy drops by a factor of 5 between the months May and August. In fact, these are the months when water is required for cultivation. The reason why the solar radiation drops is that it rains in this period. In case the rains get delayed and it is nonetheless cloudy, then the solar pump installed may not be useful, unless the collectors also collect diffused radiation and desired water is provided. Thus the availability of water at a critical period, which determines the success of a crop, is essential.

5.2 *Pumping pattern*

In hot regions, some of the farmers may prefer to pump during the evening or night time so as to save loss of water due to evaporation. In such cases, storage may be essential.

5.3 *Availability of area in the farm for solar collectors*

The collector area A per kW required for a pump capable to work h_s kWh/day is given by eqn (9) which is recasted below:

$$A = h_s/s \cdot e.$$

This could mean collector area of $100\,m^2$ for a 4 kW pump.

In the developing countries, farms are small in size and an average farmer may not be willing to allocate even a small portion of extra agricultural land for the collectors when it is in excess compared to the area required for alternative pumps. If these collectors are to be placed such that it obstructs sunlight for the other crop when it may not be preferred alternative unless the farmer is willing to grow certain types of vegetables which can be grown under the shade and grow other crops in the remaining land.

These and other factors which may be encountered in the field are summarized in Table 6.

Table 6. Factors to be considered while developing a solar pump

— Availability of land for the solar collectors.
— Compatibility of possible peak load with the quantity of water required, i.e. water pumped in comparison with its requirement over a day.
— Maintenance:
  (i) availability of spare parts and necessary services.
  (ii) availability of skills for repairs.
— Adequacy of radiation and its availability especially during cloudy days in the cropping season (seasonal and monthly fluctuations).
— Compatability of water table with the possible capacity of the presently available pump.
On the other hand, if the rate of water recharge is small, the pump would have to run at low speed but continuously.

CONCLUSIONS

In view of the interest shown by many developing countries in installing solar pumps which in the absence of electricity or in anticipation of high diesel prices are claimed to be attractive there is a need to analyze this application in detail. The performances of solar and diesel pumps or solar and diesel engines are viewed in the background of the actual field conditions, namely:

(i) The rate of water recharge;

(ii) Equivalent work to be performed in a given number of hours;

(iii) Climatic and local variations of solar radiation.

In spite of making generous assumptions about the performance of a solar pump (such as 20 yr of life time etc.) and hypothetical cases of 10 per cent annual increase in real price of diesel oil, the presently available solar pump does not compete with diesel engine and a major break-through is required before it is economically acceptable for irrigation. However, the pumps for drinking water could be of the same capacity as diesel pumps due to the nature of operation (during the day) and could compete with the diesel pumps if the price is reduced by a factor of 10, charged currently for the prototypes.

It must be noted that although to give concrete examples the numbers for India are taken for convenience, the issues raised in the analysis are valid for any developing country.

The considerations discussed here apply to most of the solar applications to be used for seasonal uses in view of the high capital costs, where diesel engines with their low capital cost and also low operational costs (due to occasional seasonal use) will be preferable.

Moreover, even when economic solar pumps are developed, other factors based on climate geography, locale, social and institutional environment have to be foreseen. Many of these are discussed at length in the text.

Thus the paper identifies the challenges that are ahead of the development of solar technologies which is in harmony with the field conditions.

RECOMMENDATIONS

It is recommended that during the development phases of solar applications for the developing countries, the actual field conditions ought to be carefully taken into consideration and this could be well accomplished only if the scientists and expected users from the developing countries are involved in the development phase and that the priority should be given to nonseasonal applications.

If produced in the developed countries, the labor costs in such applications are as important as material costs. Therefore, the costs could be reduced if the applications are manufactured within the developing countries where labor costs are less. In any case, the solar energy could not be a solution to the question of import requirements for energy if the developing countries continue to rely on outside help rather than develop the capability of indigenous manufacturing of solar applications.

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REFERENCES

1. United Nations, *Selected World Demographic Indicators*. ESA/P/WP 55, Population Division, Dept. of Economic and Social Affairs, New York (1975).
2. J. K. Parikh and K. S. Parikh, The Potential of Bio-Gas Plants and How to Realize it. *Proc. UNITAR Symp. "Microbial Energy Conversion"*, Göttingen, F.R.G. (1976).
3. Govt. of India, *Ninth Annual Power Committee Report*. Ministry of Irrigation and Power, New Delhi (1972).
4. K. S. Parikh, *Second India Studies: Energy*. McMillan Press, New Delhi (1976).
5. Central Electricity Authority, Government of India, New Nelhi (1974).
6. A. Takla, *The Development of Solar Energy Utilization in Developing Countries*. UNIDO/IOD 59, Vienna (1976).
7. V. G. Bhide, *Conversion of Solar Energy into Mechanical and Electrical Energy*. Report from National Physical Laboratory, New Delhi (1976).
8. G. A. Löf, J. A. Duffie and C. O. Smith, *World Distribution of Solar Radiation*. Solar Energy Laboratory, The University of Wisconsin (July, 1966).

Resumen—Para la población rural grade y creciente en los paises en desarrollo, las aplicaciones solares descentralizadas pueden ser apropiadas. Sin embargo, las nuevas tecnologías solares siguen desarrollándose actualmente en laboratorio para llegar a ser aceptables a las condiciones de campo. Se discuten las condiciones que deben reunirse antes que las aplicaciones sean aceptables. Se examina la bomba solar dado el interés expresado por muchos paises en desarrollo por esta aplicación específica. Se lleva a cabo un análisis tecnoeconómico comparativo para bombas solares y diesel, el cual considera el aumento de precio del diesel y factores relacionados al clima, geografía y ambiente social e institucional locales para dos tipos de uso: agua para bebida y para riego. Parece imposible que la bomba solar compita conla diesel antes de que sus costos bejen en un factor de 20–50 para propósitos de riego. Sin embargo para agua de bebida se requiere una reducción de costo en un factor menor a 10 sobre el cargado a los prototipos corrientemente. Aunque se toma el ejemplo especifico de la India, lo tratado es extrapolable a la mayoría de los paises en desarrollo. Los puntos discutidos para el caso de la bomba solar son apropiados también para otras aplicaciones solares estacionales ya que los costos de capital son grandes y operar bombas diesel durante la estación podría ser mas barato.

Résumé—Les applications solaires, donc décentralisées, devraient intéresser la population rurale importante et en expansion des pays en voie de développement. De plus, de nouvelles technologies développées actuellement en laboratorie devraient pouvoir, en fin de compte, être acceptables dans ces conditions. On discute des conditions à satisfaire avant que les applications solaires soient acceptables. On examine en détail le cas de la pompe solaire à cause, en particulier, de l'intérêt exprimé par de nopbreux pays en voie de développement pour ce genre d'applications. On en tire une analyse techno-économique comparatives pour les pompes solaires at les pompes diesel, analyse qui tient compte de l'augmentation du prix due fuel et de facteurs relatifs au climat, au site, aux conditions locales et à l'environnement institutionnel pour deux types d'utilisations à savoir l'eau potable et l'eau pour l'irrigation. Il semble peu probable qu'une pompe solaire soit compétitive avec une machine disel avant que les prix n'aient baissé d'un facteur 20–50 pour les besoins de l'irrigation. Cependant, pour obtenir l'eau potable, la diminution du prix nécessaire doit être dans un facteur inférieur à 10 au prix couramment imputé pour les prototypes. Bien que l'on prenne l'example particulier de l'Inde, ceci concerne la plupart des pays en voie de développement. Les résultats discutés dans le cas d'une pompe solaire concernent aussi les autres applications solaires ayant seulement un but saisonnier puisque les capitaux sont élevés et les pompes à fonctionnement diesel pendant la saison seraient meilleur marché.