Alternative Sources of Energy for Lift Irrigation in Indian Agriculture: A Case Study of Uttar Pradesh

S. Ramesh and K. Thukral
Tata Energy Research Institute, New Delhi, India

ABSTRACT

In India, an alternative policy approach to mechanized lift irrigation using decentralized energy options requires serious consideration. This is especially true for some states like Uttar Pradesh where the electric power supply is insufficient or unavailable to power electric pumpsets in rural areas. Therefore this study considers three alternative pumpimg systems : photovoltaic, windmill and biogas. The costs of using these options for lift irrigation are estimated and compared with conventional technologies. The study reveals that these decentralized options are technically and economically suitable for meeting the small and scattered loads in the rural areas. Therefore, it is concluded that at least part of the agricultural load should be met using renewable energy options, even if they are more expensive to the farmer in the immediate future.

INTRODUCTION

During the past decade, farm mechanization has provided a powerful stimulus to agricultural productivity in India. Increased use of mechanized lift irrigation devices, and to a lesser extent, of mechanized land preparation equipment, are the major factors responsible for India's comfortable food supply situation today.

Mechanized pumping offers certain advantages over both non-mechanized pumping as well as canal irrigation. Perhaps the greatest benefit to the farmer who employs an electric or a diesel pump, is that it makes more water available to him when he needs it most. Compared to an animal-powered water lift, a mechanized pump raises more water from greater depths; and compared to canal irrigation, mechanized pumping not only entails a shorter gestation period, but also is within the operational control of the farmer.

Owning to such reasons, mechanized pumping has progressed more rapidly than other irrigation schemes in India, since the early 1970s. The combined number of electric and diesel pumpsets more than doubled from just over 3 million in 1970/71 to nearly 7.2 million in 1980/81. As a result, the share of area irrigated by ground water pumping to total net irrigated area, rose form 38% to 43% during the same ten year period; although the number of animal powered water lifts decreased by over 1 million.

There were an estimated 5.3 million electric pumpsets and about 3.1 million diesel pumpsets in the country in March 1984. According to recent estimates [5], the number of electric pumpsets in March 1985 was just over 6 million. The number of electric pumpsets has increased much faster than that of diesel pumpsets over the past 15 years, largely because of a concerted effort by the Rural Electrification Corporation (REC) to energize electric pumpsets. However, diesel pumpsets still continue to be used even in electrified rural areas (as back-ups for ground water pumping in the event of a failure of utility electricity supply); and they may of course be used in areas that have not yet been electrified.

ENERGY DEMAND OF LIFT IRRIGATION

With an increase in the number of mechanized pumps, the demand for electricity and diesel has also increased substantially since the early 1970s. However, even in 1980/81, electricity sales for pumping accounted for just over 13% of total electricity sales in the entire country; while diesel sales accounted for only an estimated 5% of sales of all petroleum products.

Although it is thus clear that lift irrigation is not a major energy consuming activity for India as a whole, a closer look at the state (province) level data and seasonal variations is nevertheless necessary. In 1980/81, the agricultural sector accounted for over 25% of total annual electricity sales in the Northern states of Haryana, Punjab and Uttar Pradesh (UP) — and in the peak irrigation months, this share would have been substantially higher. Furthermore, as nearly 33% of all diesel pumpsets in India are in UP alone, it is evident that diesel demand for lift irrigation in that state is also quite significant.

IRRIGATION IN UP

The fact that less than 60% of UP's 112,000 villages are electrified (compared to nearly 100% electrification in other major agricultural states such as Haryana, Punjab and Tamil Nadu) perhaps explains the relatively larger concentration of diesel pumpsets in UP. Therefore, a study of UP would highlight the implications of the declared Government policy of phasing out diesel pumpsets already in use — and replacing them by electric pumpsets. Furthermore, owing to its wide geographical area

Table 1 Uttar Pradesh — land utilization for agriculture (1980/81).

Zone	Cultivable area (x1000 ha)	Net cultivated area (x1000 ha)	Gross cropped area (x1000 ha)	Cropping intensity (%)
a. Hilly	1163	705	1148	163
b. Western	6674	6039	9105	151
c. Central	3594	3002	4063	135
d. Eastern	6354	5649	7897	140
e. Bundelkhand	2147	1824	2056	113
All UP	19932	17219	24269	141

a. Certain areas of the Hilly zone are partly in the plains, near foothills. This zone has certain features in common with Jammu and Kashmir, Himachal Pradesh and other hilly states.
b. The Western zone has witnessed agricultural growth that is similar to that of Haryana and Punjab.
c. The Eastern zone can be compared directly with Bihar.
d. The Bundelkhand (Southern) zone is similar to parts of Madhya Pradesh.
Source: [13]

(nearly 10% of that of the entire country), agricultural practices and agroclimatic conditions in different parts of UP vary considerably, and may be compared directly with other Indian states (Table 1). It therefore becomes relevant and meaningful to study the implications of increased energy demand for lift irrigation in UP.

With UP's surface water resources of 160 billion cubic metres (which are considered exploitable for irrigation), and with an annual recharge of ground water of about 79 bcm, an area of 39 million hectares may be irrigated per annum, according to REC estimates. With a total cultivable area of about 19.9 million hectares, a cropping intensity of about 200% is therefore feasible.

The ground water utilization in each of the five zones of UP is presented in Table 2. In 1983/84, it was highest in the Eastern zone at 46%, and the least in the Bundelkhand zone. Both mechanized and non-mechanized water lifting devices are responsible for ground water utilization. From published time series data (from Central Electricity Authority, viz. CEA) on the electricity sales for lift irrigation, pumpset capacities, their utilization rates and other related information, it is estimated that electric pumpsets (wherever installed in UP) are used for pumping about 80% of the water required; the rest may be pumped by diesel pumpsets — or, in certain cases, by animal-powered water lifts.

Table 2 Uttar Pradesh — ground water utilization.

	Hilly zone	Western zone	Central zone	Eastern zone	Bundelkhand zone	All UP
Number of pumpsets in March 1983 (x1000)*						
Electric	4.4	232.8	47.2	149.9	4.5	438.8
Diesel	13.2	474.7	217.4	309.0	16.7	1031.0
Annual recharge of ground water (bcm)*	1.3	29.9	14.9	26.0	6.9	79.0
Ground water utilization in 1983/84 (%)						
Total*	23.5	46.0	24.0	26.0	9.9	31.7
Electric pumpsets**	10.8	25.6	10.4	18.9	2.1	18.2
Diesel pumpsets	12.7	20.4	13.6	7.1	7.8	13.5

* Source: [13]

** Estimated by authors based on information from CEA's Annual Statistics.

As the use of animal-powered lifting devices is not considered, the use of diesel pumpsets is overestimated, at least for 1983/84. This may not be a serious limitation for analytical purposes, because there were only about 230,000 Persian-wheel type animal-drawn water lifts operating in UP in 1977 (the most recent year for which data were available), and their number may have reduced significantly by 1983/84. And even if the number of Persian-wheels in operation remained at 230,000 in 1983/84, there were still about 4.5 diesel pumpsets for every single animal-drawn lifting device in that year. Furthermore, as non-mechanized devices lift less water than mechanized ones, it is clear that the use of diesel pumpsets may have been overestimated only marginally. Another point of uncertainty in the use of diesel pumpsets relates to the fact that a certain (unknown) fraction is used only as back-up for irrigation in electrified areas. The information gap regarding diesel pumpset utilization can, of course, be removed largely if a representative sample survey is conducted in each of UP's five zones.

ENERGY DEMAND PROJECTIONS FOR LIFT IRRIGATION IN UP: ACCORDING TO PRESENT GOVERNMENT POLICIES

According to the REC, the maximum number of pumpsets that may be installed in UP, is about 1.93 million. This estimate takes into account not only ground water structures, but other factors also, including surface water potential, rainfall conditions, land holding patterns, soil characteristics, topology, etc. in various zones of the state.

According to targets for rural electrification laid down in 1983, all villages in UP were to be electrified by 1990, and an optimal utilization of ground water potential (through the use of electric pumpsets) was to be ensured by the year 1995. These targets have since been revised, and it now appears that the target of installing electric pumpsets will be achieved later, perhaps by the turn of the century [5].

The number of electric and diesel pumpsets, and energy demand for lift irrigation, is therefore projected on the assumption that the target is met by the year 2000/01 (Table 3 and Table 5). In making these projections, it is assumed that: (i) all diesel pumpsets in use today in electrified areas, are replaced by electric pumpsets; and (ii) the reliability of grid electricity supply increases gradually, so that the need to use diesel pumpsets as back-up units, also diminishes gradually, and becomes negligible by 2000/01. Both the number of diesel pumpsets, and diesel demand for lift irrigation, are therefore projected to be negligible in the year 2000/01.

Table 3 Projected number of pumpsets – according to present government policies.

	Hilly zone	Western zone	Central zone	Eastern zone	Bundelkhand zone	All UP
March 1983						
Total	17611	707459	264581	458961	21247	1469859
Electric	4387	232789	47185	149945	4540	438846
Diesel	13224	474670	217396	309016	16707	1031013
March 1992						
Total	24334	718445	312346	544669	63737	1663541
Electric	12350	425817	138766	321736	30831	929500
Diesel	11994	292628	173580	222933	32906	734041
March 2001						
Total	32460	728354	361998	634201	169231	1926244
Electric	32460	728354	361998	634201	169231	1926244
Diesel	0	0	0	0	0	0

Although the number of diesel pumpsets is projected to increase marginally until 1986/87 in the Hilly zone, and until 1994/95 in the Bundelkhand zone, the total number of diesel pumpsets in the state will never exceed 1.03 million — the number in March 1983. It is therefore assumed that there is no new national investment in diesel pumpsets after 1983/84; and that any increase in number in one zone occurs only through a transfer of the equipment from another zone (for instance, from the Eastern zone to Bundelkhand zone until 1994/95). As the economic life of a diesel pumpset is in the range of 10 to 15 years, this assumption appears reasonable.

Table 4 Bundelkhand zone – sample computation of number of hours of operation per annum of electric pumpsets.

	1983/84	1992/93	2000/01
a. Engine BHP	7.28	7.28	7.28
b. BHP	6.06	6.06	6.06
c. Water HP	0.97	0.97	0.97
d. Discharge (litres/sec)	7.372	7.372	7.372
e. Annual water requirements (x1000 m^3)	32.8	36.924	41.0
f. No. of hours of operation per annum	1236.3	1391.3	1545.4

b. Engine BHP = 1.2 BHP.

c. Water HP = e.BHP where e = 0.16 is the combined efficiency of the pump and transmission.

d. Discharge (litres/sec) = (water HP x 76)/h, where h = 10 metres (total head). The total head varies from one zone to another. On the average, it is 16 metres in the Hilly zone, 14 metres in the Western zone, 12 metres in the Central zone, and 10 metres in both Eastern and Bundelkhand zones.

e. Assumed that electric pumpsets in 1983/84 fulfil only 80% of the requirement for lifting water. Their utilization increases at a rate of 1.3% p.a., so that 100% water lifting requirements are met by the year 2000/01.

f. No. of hours = (annual water lifted) x 1000/discharge (litres/sec) x 3600.

Note: Computation based on [2].

Simultaneously, beginning 1983/84, the average quantity of water lifted by an electric pumpset is also projected to increase gradually and attain a peak in 2000/01. This is in keeping with the assumption that the reliability of grid supply improves in future years. To compute the energy requirements for lifting water, it is assumed that the average capacity of an electric pumpset, which was about 7.28 hp in 1982/83, remains unchanged over the time horizon under consideration. Taking the combined efficiency of the pump and transmission at about 16%, and given the quantity of water to be lifted per annum as well as the total head (depth of water table plus drawdown plus friction losses plus height above the ground to which the water is lifted), the number of hours of operation per annum may be determined. This is done separately for each zone, and sample computations for the Bundelkhand zone are presented in Table 4. It may be noted in Table 4, that the quantity of water to be lifted per annum will increase from 32,800 m^3 in 1983/84 to 41,000 m^3 in 2000/01, with a corresponding increase in the hours of operation – in line with the assumption regarding the improvements in the reliability of grid supply.

Table 5 Energy demand projections.

	1983/84	1992/93	2000/01
Electric pumpsets			
Connected load (MW)	2383	5048	10461
Energy demand (GWh)	3653	8580	19383
Diesel pumpsets			
Diesel demand (x1000 kl)	2308	2273	0

Similarly, the number of hours of operation of a 10 hp diesel pumpset (which has a discharge rate that is approximately equal to that of a 7.28 hp electric pumpset), may also be determined. These calculations are repeated on an annual basis, and are used to project the demand for electricity and diesel. The results are summarized in Table 5.

THE NEED FOR AN ALTERNATIVE APPROACH TO LIFT IRRIGATION

Table 5 indicates that, if present policies regarding rural electrification and pumpset energization continue, electrical energy demand for lift irrigation will increase at the rate of over 10% per annum to the year 2000/01. On the other hand, the requirement for electrical energy in UP will increase at a rate of 11.6% per annum, from 13,108 GWh in 1983/84 to 84,731 GWh in 2000/01 [1]. Therefore, if the utility grid in UP is able to meet all requirements of electricity, the share of electricity sales for lift irrigation may actually decline from 27.9% in 1983/84 to 22.9% in 2000/01.

This observation however, may not be too realistic. Its basic assumption is that adequate generation capacity will be installed to meet all electrical energy generation requirements; which means that the UP State Electricity Board will be able to mobilize enough resources to step up investments substantially. However, slippages in commissioning power sector projects still continue to occur, and one of the prime reasons is the scarcity of financial resources. It is estimated that even if no such slippages occur, electricity energy shortage in the Northern Region (which includes UP) in the year 1989/90 will be about 8.1% of the requirements [11]. This merely indicates that the shortage of electrical energy since the early 1980s may well continue more or less unchanged at least for another 2 to 3 years. And if slippages do occur, the situation would deteriorate further.

Furthermore, it is important to note that electricity demand for lift irrigation is characterized by low load factors, ranging from about 4% to 19% in various electricity supply systems in India [11]. Owing to this marked seasonality in electricity demand for lift irrigation, the state utilities have found it generally difficult to meet all power demand in certain months. The utility in UP is no exception; and in times of such power shortages, the agricultural consumers are (as a matter of policy) given preference over industrial, commercial and residential consumers in urban areas. Several industrial and commercial establishments have thus found it privately profitable to invest in captive generation facilities, which are not economically optimal from society's viewpoint [10].

Besides, because of longer transmission and distribution (T/D) lines per kilowatt (kW) of connected load, and higher distribution losses, electricity supply to rural agricultural consumers is very expensive. Through sample computations presented in Table 6, this is illustrated for the Bundelkhand zone.

The analysis in Table 6 may be briefly summarized as follows. It is assumed that each of the 100 electric pumpsets works for 1,545.4 hours per annum; that is, all water requirements are met from electric pumpsets alone, without using diesel pumpsets as back-ups (Table 4). Furthermore, it is estimated that, for supplying 839,288 kWh of electricity per annum, the gross generation in a thermal power station (TPS) should be 1,195,567 kWh if T/D losses are 22%. It is also assumed that the 0.4 kV distribution line is 1 km long, while an 11 kV line extends over the remainder of the 10 km distance from the utility grid. All costs pertaining to power system expansion are obtained from the CEA.

The results in Table 7 are based on the same assumptions as in Table 6; and clearly show that, as the distance from the utility grid increases and the connected load decreases, the cost of pumping water (and consequently, of supplying electricity) rises. It is seen that, even if there are 100 electric pumpsets, each of rating 7.28 hp, connected within a distance of 10 km from the utility grid, the cost of supplying electricity is estimated at Rs 1.55/kWh — more than five times the tariff for agricultural

Table 6 Bundelkhand zone – cost of lifting water if there are 100 pumpsets 10 km away from the utility grid.

a. Capital costs (Rs)	6,478,000
a.1 Thermal generation capacity	5,431,000
a.2 Pumpsets	700,000
a.3 Pump-houses	80,000
a.4 11 kV line	225,000
a.5 11 kV/0.4 kV transformer	20,000
a.6 0.4 kV line	22,000
b. Annual operating costs (Rs)	505,610
b.1 Repair/maintenance of power system	142,450
b.2 Repair/maintenance of pumpsets	70,000
b.3 Coal extraction	164,270
b.4 Coal transport	86,080
b.5 Fuel oils	42,810
c. Annualized costs (Rs)	1,301,258
d. Levelized annualized cost (Rs/kWh)	1.550
e. Levelized annualized cost (Rs/m^3)	0.317

a.2 Cost of one pumpset of about 7.28 hp (5.43 kW) capacity is about Rs 7000 (Personal communications : Regional Distributors of Kirloskar Oil Engines and Kirloskar Brothers Ltd., New Delhi).

a.3 Cost of one pump-house is Rs 800. Based on field survey [2].

b.3 Coal utilization is 0.6 kg/kWh of gross generation (Source: CEA). Weighted average levelized cost of extracting coal from 12 selected/recently sanctioned open-cast mining projects is Rs 229/tonne [9].

b.4 Average cost of transporting coal by rail over a distance of about 600 km (say from Singrauli coal fields in Eastern UP to Jhansi in Bundelkhand) is about Rs 0.20/tonne-km [12].

b.5 Fuel oils/LSHS/HHS utilization is about 15 ml/kWh of gross generation (Source: CEA). The cost of fuel oils/LSHS/HHS is about Rs 2000/tonne [4]. Specific gravity = 0.955 kg/litre.

c. Assuming 30 years life time for all major capital equipment; and a social discount rate of 12% per annum.

consumers in UP.

However, the costs of pumping ground water by using electric pumpsets are underestimated in Table 6 and Table 7 on at least three accounts: (i) only an average level of T/D losses experienced in the entire UP state are assumed for analytical purposes, while in reality, the losses are substantially higher over the 11 kV extension lines; (ii) it is assumed that the generating capacity added to meet increased agricultural loads equals the agricultural load; while in actual practice, more capacity needs to be added (if power supply is to remain reliable) to take into account line losses, generating plant

Table 7 Levelized cost of lifting water by varying number of electric pumpsets in the vicinity of Jhansi in Bundelkhand zone – at varying distances from the utility grid (Rs/m³).

Distance from utility grid (km)*	Number of pumpsets in village cluster			
	100	50	25	10
10	0.317	0.327	0.347	0.405
20	0.326	0.345	0.383	0.496
30	0.336	0.363	0.419	0.587
40	0.345	0.382	0.456	0.678
50	0.354	0.400	0.492	0.769
100	0.399	0.491	0.674	1.223

* Although T/D losses may in fact increase with distance, for sake of simplicity, it is assumed that they remain at about 22% only for all the distances considered.

unavailability, etc., because farmers would usually prefer to irrigate their crop at more-or-less the same time during the day in the agricultural season; and (iii) in computing coal transport costs, only the financial costs are considered, which are known to be much below economic or marginal costs. The financial costs do not take into account rail track capacity constraints and shortages of rolling stock in the Indian railway system.

All sample computations have been presented only for the Bundelkhand zone, largely because rural electrification in this zone has proceeded at the lowest rate so far (Table 2); which implies that the REC and UP State Electricity Board still have an option of not investing in the rather expensive rural electrification schemes in Bundelkhand. Alternative lift irrigation devices, including certain renewable energy based systems may be considered in the future, as discussed in the following section. It is for this reason that the levelized annualized costs in Table 7 are presented in terms of "Rs/m³ of ground water pumped" rather than "Rs/kWh of electrical energy supplied". Use of such units will facilitate a direct comparison of costs pertaining to various technologies.

The observations made so far, although specific for the Jhansi area in Bundelkhand zone, are generally valid for other parts of Bundelkhand zone as well as for other zones. In particular, the case of only 10 pumpsets (which irrigate about 40-50 hectares of net sown area) may be very pertinent to the Hilly zone of UP.

AN ALTERNATIVE APPROACH TO LIFT IRRIGATION

Farmers today find it more profitable to use electric pumpsets than diesel ones [2, 11]. However, several farmers in UP alone, in areas which are not yet electrified, have been using diesel pumpsets. This observation suggests that if the farmers are made aware of the possibilities of employing other technologies for pumping, they may adopt them, albeit at higher private costs. Renewable energy options, such as photovoltaic, windmill, and biogas are three options that may be considered.

Certainly, the relative economics (from the viewpoint of the farmer) of the various options will play an important role. It is our hypothesis that an approach which is different from the one adopted currently by the Government, may help reduce investments in long transmission and distribution lines, reduce losses, and not foreclose the use of renewable energy options. This alternative approach would view energy requirement for lift irrigation from an integrated energy perspective, instead of equating it to electricity requirements.

The costs of using the three renewable energy options (with diesel back-ups) for lift irrigation are estimated from the society's viewpoint; and the results of some calculations for UP's Bundelkhand zone are presented in Table 11. The calculations are based on the assumption that 41,000 m^3 of water is lifted per annum through the use of all options considered — that is, the same as a 7.28 hp electric pumpset operating for 1,545.4 hours per annum. It is also assumed that the annual requirements for lifting water are spread equally over nine months — two cropping seasons viz. July to October (Kharif) and November to March (Rabi). This is only a simplifying assumption, as detailed data on cropping patterns in various parts of UP, and corresponding water requirements per month for each type of crop, are not readily available.

Sample computations for determining the capacity of a photovoltaic (PV) pump and a windmill pump, are presented in Tables 8 and 9 respectively. These are based on meteorological data on mean daily global solar radiation (GSR) and mean daily windspeeds. Similar computations may be made for other zones as well.

Table 8 Bundelkhand zone – use of PV pumps with diesel back-up.

	Global solar radiation[1] (kWh/m^2)	Hydraulic output from $1m^2$ of array[2] (kWh/month)	Gross cell area to meet water req.[3] (m^2)	Water lifted by PV pump[4] (m^3)	Water lifted by diesel pumpset (m^3)
Jan	4.718	4.551	27.3	3507.2	1048.8
Feb	5.627	4.902	25.3	3777.7	778.3
Mar	6.126	5.909	21.0	4556.0	0
Jul	5.024	4.846	25.6	3734.5	821.5
Aug	4.780	4.611	26.9	3553.4	1002.6
Sep	5.334	4.979	24.9	3837.0	719.0
Oct	5.712	5.509	22.5	4245.5	310.5
Nov	5.034	4.699	26.4	3621.2	934.8
Dec	4.425	4.268	29.1	3289.1	1266.9

1) On a horizontal plane. GSR is not monitored in the Bundelkhand Zone. Average GSR over Bhopal (23° 16'N; 77° 25'E) and Lucknow (26° 45' N; 80° 53'E); assumed for Jhansi (25° 27'N; 78° 35'E) in the Bundelkhand zone. Source: [7].

2) (GSR) x (efficiency) x (no. of days)/sin (lat.+15°); where efficiency = 0.02.

3) Assuming array efficiency of 9.2% in terms of gross cell area, with 1000 watts/m^2 for peak solar radiation as referrence.

4) When gross cell area is 21 m^2; corresponding to a rating of 1932 peak-watt.

Table 9 Bundelkhand zone – use of wind pumping systems with diesel back-up.

	Mean windspeed[1] (km/hour)	Water lifted by 1 windpump[2] (m^3)	Water lifted by 7.9 windpumps (m^3)	Water lifted by diesel pumpset (m^3)
Jan	3.7	78.6	622.4	3933.6
Feb	4.3	91.9	727.7	3828.3
Mar	5.5	280.4	2200.2	2355.8
Jul	6.9	575.4	4556.0	0
Aug	6.5	415.5	3289.9	1266.1
Sep	5.0	238.1	1885.3	2670.7
Oct	3.7	80.8	639.8	3916.2
Nov	3.4	56.7	448.9	4107.1
Dec	3.3	37.5	296.9	4259.1

1) Data for Jhansi. Source: [7].
2) Estimate based on predicted monthly outputs of a TOOL-ORP type windmill pump [15]. Computations reflect changes in average wind speeds and water table from base line data in [15]. The estimates account for a 50% reduction in output while computing monthly outputs from short term test data.

Capacity and Cost Assumptions

PV Pumping Systems

The underlying assumption in sizing the PV pump is that it should meet all water requirements during the month of maximum mean daily GSR (March), and that diesel is used for pumping the requisite quantity of water in other months.

Although prices of PV modules range from US$ 9/peak-watt for modules manufactured by ARCO solar to about US$ 33/peak-watt for a module obtained from RTC, costs of PV modules manufactured indigenously are not readily available. However, it is known that the foreign exchange component of PV arrays manufactured in India, is about 33%. Assuming that the total cost of a PV array in India is about US$ 9/peak-watt (the lowest cost available), an exchange rate of Rs. 12 to a US$, and a factor of 25% to reflect the scarcity of foreign exchange in India, the cost of a PV array comes to about Rs. 117/peak-watt.

It is reported that the motor and pump combination supplied by the Central Electronics Limited (CEL) in its demonstration programme costs about Rs. 6000. As the demonstration units are 300 peak-watt systems, a figure of about Rs. 20 per peak-watt is assumed for analytical purposes. Prices of PV sub-systems obtained from manufacturers overseas, range from US$ 1.7 to US$ 20.6/peak-watt. Therefore, a figure of Rs. 20/peak-watt, although on the low side, seems to be a reasonable assumption.

Therefore, for the lowest cost configuration of a PV pumping system (PV module, DC motor and pump), the capital cost is estimated at Rs. 137/peak-watt. Assuming an array efficiency of 9.2% in terms of gross cell area, the rating of 21m^2 of PV array comes to 1,932 peak-watt. At present prices therefore, the cost of the PV pumping system comes to about Rs. 264,700. As CEL's PV pump demonstration programme has known that the repair/maintenance problems encountered in using PV pumps are similar to those of electric pumpsets, the annual repair/maintenance costs are assumed as Rs. 700 — same as for electric pumpsets of 7.28 hp capacity.

Owing to the large scale R&D effort globally to reduce the costs of PV arrays, an alternative scenario is analyzed, in which it is assumed that PV arrays at US$ 2/peak-watt are imported. This is a realistic and a likely level of prices in the future, particularly as Sumitomo Electric Industry Co., Tokyo has announced its target of marketing thin-film and amorphous-silicon/germanium solar cells at US$ 1.13/peak-watt by 1990 [14]. No further reduction in the cost of balance-of-system components is assumed.

Windmill Pumping Systems

As for PV pumping systems, the underlying assumption here is that the wind pump meets all water requirements only in the month when mean daily wind speeds are maximum (July); and that diesel is also used during the other eight months.

Given the mean daily wind speeds, the output that may be obtained from a TOOL-ORP type windmill is predicted (Table 9). A TOOL-ORP type windmill, which costs Rs. 12,000, is a low cost design with a rotor diametre of 5 metres, and rather large maintenance requirements. Apart from routine lubrication, its main bearing shaft needs to be replaced after 5 years, its crank and cross head each after one year of use, and its wooden pump rod guides after only 6 months.

It is estimated that 7.9 of TOOL-ORP type windmills would be required to meet the water pumping requirements in July. For analytical purposes however, it is assumed that a "similar" windmill of a larger or smaller size can be constructed to suit the wind regimes in Jhansi (Bundelkhand zone), with no significant changes in cost per unit swept area.

Biogas Pumping Systems

For analytical purposes, it is assumed that the biogas digester is of capacity 10 m^3/day. Its biogas

Table 10 Bundelkhand zone – use of biogas pumps with diesel back-up.

	Biogas available[1] (m^3/month)	Use in biogas-cum-diesel mode[2] (hp-hrs/m)	Diesel cons. in biogas-cum-diesel mode[2] (m^3)	Diesel cons. in diesel only mode[3] (m^3)
Jan	183	497.3	67.1	548.9
Feb	183	497.3	67.1	548.9
Mar	300	815.2	110.1	405.8
Jul	300	815.2	110.1	405.8
Aug	300	815.2	110.1	405.8
Sep	300	815.2	110.1	405.8
Oct	300	815.2	110.1	405.8
Nov	183	497.3	67.1	548.9
Dec	183	497.3	67.1	548.9

1) Assuming 10 m^3 biogas digester. There is a 39% reduction in biogas production during the four winter months November through February [6].
2) Norms for biogas-cum-diesel mode of operation (70% biogas, 30% diesel): 13 ft^3/hp-hour biogas and 0.135 litres/hp-hour of diesel [2].
3) Norm of operation in diesel only mode: 0.45 litres/hp-hour [2].

output is however, assumed to reduce by 39% during the winter months of November, December, January and February [6]; while it remains 10 m³/day in other months. In all months however, during the time biogas is available, the pump runs in the mixed mode, using 70% biogas and 30% diesel. And when biogas is not available, the pump is assumed to switch to an all-diesel mode (Table 10).

The capital cost (including installation costs) of a 10 m³ capacity digester is estimated at Rs. 10,000 [3]; while the annual repair/maintenance charges are at about the same level as for diesel pumpsets [2].

Cost Comparisons

The implications of changing the distance of the area where lift irrigation is required, from urban areas with sizeable infrastructural facilities (such as roads, power supply etc.) on the cost of pumping 1 m³ of ground water, is not analyzed for the renewable energy options considered. This is for two reasons: (i) the cost of using a renewable energy device is not likely to be related strongly to this distance; and (ii) the cost of transporting a litre of diesel per kilometre from an area of urban

Table 11 Bundelkhand zone – cost of pumping ground water for irrigation using various renewable energy devices*.

	PV pumps		Wind pumps	Biogas pumps
	At present costs	At likely future costs		
a. Capital costs (Rs)	275,184	107,100	105,300	20,500
a.1 Pump	10,000	10,000	10,000	10,000
a.2 Renewable energy device	264,684	96,600	94,800	10,000
a.3 Infrastructure for diesel transport	500	500	500	500
b. Annual operating costs (Rs)	7,451	7,451	25,396	25,696
b.1 Repair/maintenance of pump	1,500	1,500	1,500	1,500
b.2 Repair/maintenance of renewable energy device	700	700	3,800	1,500
b.3 Diesel	5,251	5,251	20,096	22,696
c. Annualized cost (Rs)	56,154	26,406	44,032	29,324
d. Levelized annual cost (Rs/m³ of water pumped)	1.370	0.644	1.074	0.715

* With a diesel pump as a back-up.

a.3 Refer to [2] for a detailed discussion.

b.3 Diesel consumption rate of 0.45 litres/hp-hour; diesel pump of capacity 10 hp; and shadow price of diesel of Rs 4.5/litre, when c.i.f. price of diesel is Rs 3.00/litre, shadow price of foreign exchange is 25% more than its rupee equivalent, and cost of transporting diesel to rural areas equal about Rs 0.75/litre on an average [2].

c. Assuming 10 years economic life of all major capital equipment; and an annual discount rate of 12%. A life span of 10 years is assumed although there is no practical evidence to support this.

concentration is not readily available — only an average cost figure to various rural areas in the country is. Likewise, the impact of changing the concentration of pumping requirements at a given distance from an urban centre is also not analyzed.

The costs presented in Table 11 are therefore tentative, although the results do reveal that biogas pumps with diesel back-ups seem to be most attractive (from a national perspective). And that economic viability of PV pumping systems is also likely to improve substantially in the future. Although the wind pump-cum-diesel option comes out the least attractive, this may be due to the rather low windspeeds in the Bundelkhand zone.

However, it may be noted that the costs of using renewable energy options (with diesel back-ups) are being compared to the costs incurred in using electric pumpsets for the same purpose, but with no diesel back-up. The latter does not represent present day experience, and in fact suggests that the reliability of grid power supply to isolated and scattered rural locations is considerably higher than today's levels. That this is not so in reality, increases the cost of using an electric pumpset — by making it virtually necessary to use a diesel back-up.

It is not possible to project the extent to which either of the renewable energy options may substitute the conventional technologies. Only a detailed survey of the entire UP State can provide an answer. However, on the basis of the discussion above, it is relatively clear that the Government of India as well as the state Governments, should revise their policy regarding lift irrigation, which heavily depend on the continuance and extension of grid electricity supply in the future.

CONCLUDING OBSERVATIONS

The emerging power shortages in the industrial sector in UP are well documented, and need no reiteration here. The Central Electricity Authority's regular monthly bulletins "Power Supply Position" provide adequate information on this aspect. It is not merely a question of choosing the cheapest source of energy, but a question of availability of electricity for the various demands made on it. This issue is of concern not only to UP, but to other states in India also, as well as to the other developing economics.

In the search for alternatives, it is important to remember that decentralised options are (*prima facie*) technically and economically suitable for meeting the small and scattered loads in the rural agricultural sector. If this is accepted, it may well be that a part of the agricultural load should be met through decentralised renewable options, even if they are more expensive to the farmer in the immediate future.

If some electricity is "released" to the non-agricultural sectors, the resulting total benefit to the economy may well outweigh the increased costs of the decentralized system to the farmer. In India at least, the use of small, high cost, low efficiency, captive diesel generating sets for (standby) power generation may decrease significantly. It is hoped however, that the general policy conclusion of this study are also of relevance to other Third World Countries.

REFERENCES

1. Central Electricity Authority (1985), *Twelfth Electric Power Survey*, New Delhi.
2. Council of Scientific and Industrial Research and Swiss Development Cooperation (CSIRO-SDC) (1985), *Choice of Technology for Lifting Irrigation: A Comparative Study of Energy Alternatives*, New Delhi.

3. Department of Non-Conventional Energy Sources (1984), *Guide to Biogas Plants,* Government of India.
4. Department of Petroleum and Natural Gas, *Annual Petroleum and Petrochemical Statistics,* GOI, New Delhi, various issues.
5. *Government of India, Seventh Five Year Plan* (1985), New Delhi.
6. Indian Council of Agricultural Research (1978), *The Economics of Cowdung Gas,* New Delhi.
7. Mani, A. and Rangarajan (1982), *Solar Radiation Over India,* Allied Publishers Pvt. Ltd., New Delhi.
8. Mani, A. and D.A. Mooley (1983), *Wind Energy Data for India,* Allied Publishers Pvt. Ltd., New Delhi.
9. Planning Commission (1986), *Draft Report of the Expert Group on the Technology Options for the Coal Industry,* GOI, New Delhi.
10. Ramesh, S (1985), *Economics of Captive Generation in India,* Presented at the 7th Annual Meeting of IADE, Bonn.
11. Ramesh, S. and T.V. Natarajan (1987) Policy options in rural electrification in India: with special reference to pumpset energization, *Pacific and Asian Journal of Energy,* Vol. 1, No. 1, pp.44-53, New Delhi.
12. Rail India Technical and Economic Services (1986), *Study on Coal Transportation Infrastructure,* GOI, New Delhi.
13. Rural Electrification Corporation (1984), *Directional Policy Strategies and Action Plan: An Approach,* Government of India.
14. Sumitomo Electric: Predicting a-Si PV Cells at about $ 1/Wp (1986), *Solar Energy Intelligence Report,* Vol. 12, No. 12, p.98.
15. TOOL-ORP (1980), *TOOL-ORP Windmill Project Evaluation Report,* Ghazipur (India).