Short Notes

Technical Note on Comparative Costs of Solar, Wind and Diesel Pumping at Village Sites in Nigeria and Somalia

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1. INTRODUCTION

Provision of potable water for villages and remote sites is a major expense in many developing countries, especially when it must be pumped from boreholes which may have a dynamic head of 50 m or more.

Diesel pumps are widely used for such service, but they have the disadvantage of high fuel costs and in many parts of the world have proved difficult to maintain. Multi-bladed mechnical wind pumps (American farm windmills) have been widely used in some countries (most notably in Australia) where the wind regime is suitable. More recently, solar photovoltaic pumps have become available and are beginning to be widely used in countries having high solar radiation. Although somewhat higher in initial cost than the alternative sources of power, their potential for reliability and long life is beginning to be realized.

In comparing the economics of different systems there are a large number of variables to take into account, including capital costs, depreciation and interest on pumps, boreholes and water storage facilties, fuel costs for diesel, maintenance costs, and wind speeds (for windmills) and insolation levels (for solar pumps). Costs are also critically dependent on the dynamic head (height through which water must be lifted) and for most purposes are roughly proportional to it. Accordingly cost estimates are highly site specific.

In this note the methodology of costs analysis is based on design studies for water pumping systems for village sites in northern Nigeria (particularly in Sokoto State in the northwest) and in Somalia, near the coast south of Mogadiscio. Both areas have similar water supply, and solar and wind conditions.

Much of the cost information for local civil works was obtained from the Water Department of Sokoto State, and some from the rural development authorities in Somalia. Prices of solar and wind pumps are based on international quotations for these systems. In order to clarify the major cost parameters, the costs have been evaluated for two slightly idealized villages having a demand for 40 m^3/d of water with manometric heads of 40 m and 80 m, respectively (see Table I).

In Sokoto State, where the main aquifer is at 40–60 m, a 40 m^3/d water supply is considered normal for villages having a population of 1000–5000 (8–40 l d^{-1} $person^{-1}$). The water department supplies the water by means of a borehole diesel pump set and storage tank. Responsibility for smaller dug wells is with the local inhabitants. Flow rates (corresponding to recharge rates for the borehole) are typically 10 m^3/h, and the normal mode of operation is to run the diesel pump for 2–3 h in the morning and 2–3 h in the evening, with water being fetched by the village women before dawn and after dusk.

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Natural Resources Forum © United Nations, New York, 1985, vol. 9, p. 77-80

TABLE I
Capital costs (in US dollars) of solar, wind and diesel pumps systems (40 m³/d water supply)

	40 m head			80 m head	
	Solar	*Wind*	*Diesel*	*Solar*	*Diesel*
Borehole at $400/m	16 000	16 000	16 000	32 000	32 000
Storage & distribution	30 000	30 000	23 000	30 000	23 000
Pump system	32 000	13 000	31 000	64 000	36 000
Total	78 000	59 000	70 000	126 000	91 000
Annual capital cost					
Amortized at 18% for 10 years	17 300	13 100	15 500	28 000	20 200
Amortized at 12% for 20 years	10 500	8 000	9 400	17 000	12 300
Water cost ($/m³)	0.72–1.18	0.55–0.90	0.80–1.22[a]	1.16–1.92	1.11–1.65[a]

[a]Diesel pump water costs include:
(a) fuel costs at $0.35/l and 125 ton m/l,
i.e. ($0.35/l)/(125 t m l⁻¹(40 m)⁻¹) = $0.11/m³
and ($0.35/l)/(125 t m l⁻¹(80 m)⁻¹) = $0.22/m³;
(b) Operating costs at $0.50/h and 10 m³/h are $0.05/m³.
This gives a running cost for diesel of $0.11 + $0.05 = $0.16/m³ for a 40 m head.
and $0.22 + $0.05 = $0.27/m³ for an 80 m head.

2. NOTES ON ASSUMPTION AND METHODOLOGY

2.1 BOREHOLES AND WELLS

Borehole costs are very close to the equivalent of US$400/m in both Nigeria and Somalia, with the cost divided equally between drilling the borehole and casing it. Dug wells are usually less costly, even when lined, but are normally limited to a depth of about 20 m. They have the additional advantage that, in the event of failure of the mechanical system, water can still be removed by traditional means. For wind pumpers, even in good wind regions there are likely to be periods of several days (typically during the transition from 'dry' to 'wet' seasons) when there is insufficient wind for pumping and an open well is practically a necessity.

2.2 STORAGE AND DISTRIBUTION

In Sokoto, steel tower-mounted storage tanks with half a day's storage capacity (corresponding to two pumping periods daily) as well as piping, faucets and animal watering troughs, are provided when borehole pump-sets are installed, but the cost is very high ($23 000 installed cost for a 20 m³ storage system). For solar and wind installations with continuous pumping, a full day's storage is required and a higher cost ($30 000) is assumed. In Somalia, somewhat lower costs are quoted for comparable storage systems (about $15 000 for a 30 m³ tank, for which the import cost is about $10 000, with the balance representing civil works and installation).

2.3 PUMP SYSTEM

2.3.1. Solar pump
Both Somalia and northern Nigeria have a high average insolation of about 6 kWh m^{-2} d^{-1}, which varies by no more than about ±15% over most of the year. On the basis of recent international bidding, the cost of a solar pump capable of lifting 1000 ton m d^{-1} (25 m³ from 40 m or 12·5 m³ from 80 m) is $16 000 plus about $2000 for civil works (posts for the modules and a security fence) and $2000 for internal transport and installation. These pump units are quite modular and an installed cost of $20 000 (1000 ton m)$^{-1}$ d^{-1} is assumed. Solar pumps for this service frequently consist of a solar array directly powering a submersible pump. A special variable frequency inverter matches the array to the pump and batteries are not required.

2.3.2. *Wind pump*

The performance of a wind pump increases with the average wind speed and, for a given wind speed, it increases as the swept area (and therefore roughly as the cost) of the wind rotor.

The wind pump size of Table I was evaluated for a particular village site in Somalia for which good velocity duration data were available to evaluate in relation to the wind pumper characteristics supplied by the manufacturer. For that site a 14 ft (4.6 m) diameter rotor wind machine mounted on a 15 m tower would provide the required output for 8 months of the year when the average wind speed was about 6 m/s, but perhaps only half the required amount for 4 months (average wind speed only 4.5 m/s).

Wind speed data obtained from airports in northern Nigeria suggests that the wind is approximately of this quality in the northwest (Sokoto State), but declines progressively towards the northeast, so that in Borno State, for example, it is probably not adequate for wind pumping duty.

Prices are based on an estimated $8000 CIF for a 14 ft wind pumper and tower $3000 for civil works (concrete footings) and $2000 for installation costs, for a total of $13 000.

A wind pumper was not included in the 80 m head evaluation because this was considered too deep for a dug well (see above).

2.3.3. *Diesel pump*

In principle, relatively small low cost diesel pumps have the capacity to provide pump service at a rate of 10 m^3/h from 40 m, but in practice they do not seem to be reliable enough. Sokoto State water department has installed a number of 6 h.p. diesel engines with direct shaft drive from the surface to a monopump (progressive cavity pump based on the Archimedean screw). These units can be supplied for only $9000 installed. However, maintenance has been such a problem (mostly because of broken drive shafts due to misalignment in the borehole) that these are now being replaced by much more expensive 17 kVA diesel generators ($25 000 installed) and submersible pumps ($11 000 for 10 m^3/h at 80 m or $6000 for 10 m^3/h at 40 m). Similar systems appear to be the standard in Somalia.

Because diesel pumps require fuel and manned operation this must be taken into account in costing. A detailed study of diesel pumps fuel consumption has been carried out by the Government of Cyprus for pumps in the range 12–40 h.p., with borehole depths in the range 24–110 m, and water flow rates in the range 7–40 m^3/h: from this it has been determined that diesel fuel consumptions are close to 8 l $(1000\ t\ m)^{-1}$ over the whole range. This is equivalent to an overall fuel to hydraulic output energy efficiency of less than 4%, which is much lower than the 6–9% overall efficiency often quoted (e.g. in World Bank studies). It has been adopted here together with an assumed cost of US$0.35/l of diesel fuel. This latter is close to world prices for diesel fuel, but it is about twice the current price in Nigeria (an oil exporting country) and only about half the price in Somalia (an oil importing country). An operator cost of $0.50/h has also been assumed.

2.3.4. *Annual capital cost*

Total capital costs have been assumed to be amortized over 20 years at 12% interest and over 10 years at 18% interest, respectively, to give a plausible range of annualized costs.

2.3.5. *Water cost*

Based on the annual capital costs for each option and the annual production assumed to be 40 m^3/d × 365 d = 14 600 m^3/year, a range of costs have been estimated for the product water. In the case of the diesel option, fuel and operator costs have also been included. However, maintenance costs are not included in the estimates although these are expected to be much higher for the diesel than for the solar and wind options.

2.3.6. *Rural electrification*

Some villages in northern Nigeria are near enough to 11 kV transmission lines of the Nigeria Electric Power Authority for a connection to be considered. For such a connection a 350 kVA step-down transformer (from 11 kV, three-phase to 415 V three-phase) would be required, at a cost of $15 000 installed, together with a 415 V feeder line at an installed cost of about $20 000/km (about half due to the cost of posts at 35 m intervals and half to the cost of conductors and insulators).

Because such a connection would substitute for a 17 kVA diesel generator set at $25 000 it could be justified for a connection distance of only about 0.5 km, if the water supply was the only expected load. However, the capacity of the connection system makes it equivalent to a much larger (350 kVA) diesel generator having an estimated cost of about

$300 000. Therefore, for a village with a sufficiently large anticipated demand (including water supply and other loads), a connection might be justified up to as much as 15 km.

3. CONCLUSIONS

In summary, the above analysis point to the following conclusions.

(a) The cost of water supply from boreholes in remote villages in Nigeria and Somalia (and probably in other parts of Africa with comparable conditions) requires a capital investment of the order of $100 000 for a 40 m^3/d supply, depending on the depth of the water table and the pump system selected. In most cases more than 50% of the cost is attributable to borehole and storage costs and the balance to the cost of the pump set.

(b) The resulting water costs, depending on detailed assumptions concerning capital charges, fuel costs, etc., are likely to be in the range of $0.50–2.00/$m^3$.

(c) The cheapest water would be associated with a wind pumper but only under conditions of steady all-year round winds averaging at least 5–6 m/s. Even in this case the wind pumper should preferably be installed on a dug well (for security of supply reasons), and this probably limits wind sites to less than 40 m head.

(d) Between a solar pump system and a diesel pump system, the former is more costly (although prices are expected to decline), but if fuel and operating costs for the diesel are taken into account, water costs are almost identical. Particularly, in view of the anticipated greater reliability and lifetime of solar pumps they are becoming the technology of choice for this application.