Wind water pumping: the forgotten option

1. Introduction

I have been repeatedly asked to make presentations or write about wind pumping in general. The last two occasions were both in the U.K. [Smulders and de Jongh, 1994; Smulders, 1995]. It seems as if little has changed since then. Financial support for wind pumping is very low. Worldwide donors and international agencies are probably contributing less – possibly much less – than a million US dollars (US$) a year. We have heard all the arguments pro wind pumping, but nobody seems interested. I find it embarrassing and frustrating to try once again to convince policy-makers, donors and others that wind pumping is worth their attention and support. The ‘‘prospects’’ in the title of my 1994 presentation became ‘‘the forgotten option’’ in the 1995 presentation, which is published here for a second time at the invitation of the Editor of this journal. A couple of numbers have been added to reflect the latest situation. My expectation is that this journal reaches more people than the conference proceedings and as such may stimulate more vigorous and promising policy changes.

Yet, in many countries small regional markets for wind pumping have developed and are showing signs of self-sustainability. This is clear from a recent market study on wind pumping [Ministry of Foreign Affairs, 1993], but also from the author’s own experiences.

2. Applications and power requirements

The fields of application for wind pumping are well known. Table 1 shows typical requirements for various applications. These requirements determine the effective average hydraulic power output P_{hydr}. It is given by

$$P_{hydr} = \rho g H \times q \quad \text{watts} \qquad (1)$$

in which ρ is the density of water, g is the acceleration of gravity, H is the pumping height and q is the average flow rate. So

$$P_{hydr} = 9.8 \times 10^3 \times H \times q \quad \text{watts} \qquad (2)$$

The product $H \times q$ is a direct measure of power requirement and can be expressed in m^4 per unit of time. A net hydraulic power output of 1 watt (1W) (continuous) is equivalent to 8.8 m^4/day. And 1 kWh hydraulic is equivalent to 367 m^4. The requirements shown in Table 1 lie in the range of 10-1000 m^4/day, equivalent to average hydraulic power outputs of a few W to just over a hundred W. These requirements are small, showing that they are not appropriate for using diesel pumps of a few kilowatts power rating!

3. Wind resources and wind pump power output

The average hydraulic power output P_{hydr} of a wind pump (at sea level) is given by

$$P_{hydr} = B\, v^3 A_{rotor} \quad \text{watts} \qquad (3)$$

in which v is the average wind speed at the site, A_{rotor} is the swept rotor area and B is a quality factor expressing the effectiveness with which wind power is converted to net hydraulic power. Normal values of B range from 0.05 to 0.15, the first being acceptable, the second value being excellent. The value B = 0.1 can be regarded as an average value for a well-designed wind pump. (As a comparison: a good value for electricity-generating wind turbines is $B \approx 0.3$; in that case maximizing power output is the major design criterion. For stand-alone systems the percentage of time that useful power is produced is of more importance than merely maximizing power output.)

The average wind speed is a crucial factor in Equation (3). It is now widely accepted that wind pumping is economically feasible at sites where

$$v \geq 3 \text{ m/s} \qquad (4)$$

In some cases v = 2.5 m/s is sufficient. Average wind speeds of 3 m/s are very moderate and sites with such wind speeds are very common.

In tropical areas wind speeds during the day are often higher than at night. Figure 1 shows a typical example at Khartoum. This daily pattern (owing to the power being proportional to the wind speed cubed) favours its economical use.

Table 1. Rough indication of water depths, required daily volume of water and typical size of the rotor for various applications.[1]

Application	Head				Daily volume (m^3/day)	Typical rotor diameter (m)
	very low < 3 m	low 3-10 m	medium 10-30 m	deep >30 m		
Community water supply			x	x	20 (500 persons)	2.5 to 7.0
Domestic water supply			x	x	1-3 (small farm)	1.5 to 2.5
Cattle watering			x	x	20 (500 head)	1.5 to 4.5
Irrigation	x	x			40-100 (≈ 1 hectare)	2.5 to 5.5
Drainage	x				100	2.5 to 3.5
Salt pans	x				?	2 to 4 (?)

Note

1. These requirements fall in the range of 10-1000 m4/day. In fact 2500 m4/day is about the upper range feasible for mechanical wind pumps (see Figure 2).

4. The niche of wind pumping

We can now describe the range of hydraulic power requirements which can, in principle, be covered by wind pumps. The result is shown in Figure 2 and also includes hand, solar and engine-driven pumps. At the lower end of the scale hand pumps are the obvious solution and are used up to 100 m^4/day. But examples are known where wind pumps are used for requirements down to 20 m^4/day (domestic water and some gardening), e.g Curaçao and the Philippines. The range of mechanical wind pumps is limited by rotor size from about 1 to 7m diameter. At larger power demands it is more convenient and economical to generate electricity, which can be used to drive a motor/pump combination. These are indicated in the figure as WEPS, i.e., wind electric pumping systems. Especially at sites with high wind speeds ($v \geq 5$ m/s), they are attractive from diameters of 3m upwards.

Engine-driven pumps are uneconomical at very low requirements, also due to the fact that diesel pumps are not made for power ratings below 2 kW. With the modular character of solar panels, solar pumping can be used from very small scale to very large requirements. There is no limit as with mechanical wind pumps: the electricity produced can drive small or large pumps.

5. Technology

We will be very brief on this subject as information is readily available elsewhere [Van Meel and Smulders, 1989; Lancashire et al., 1987]. A first distinction can be made as regards the type of transmission.

1. *Mechanical wind pumps having a* ***mechanical transmission***
   a. driving piston pumps, the most common type of wind pump, about one million still in use today.
   b. driving rotary pumps, e.g., centrifugal or screw pump. The first is used in quite large numbers in the Netherlands for drainage, the second has been developed in China for pumping sea water for prawn culture.

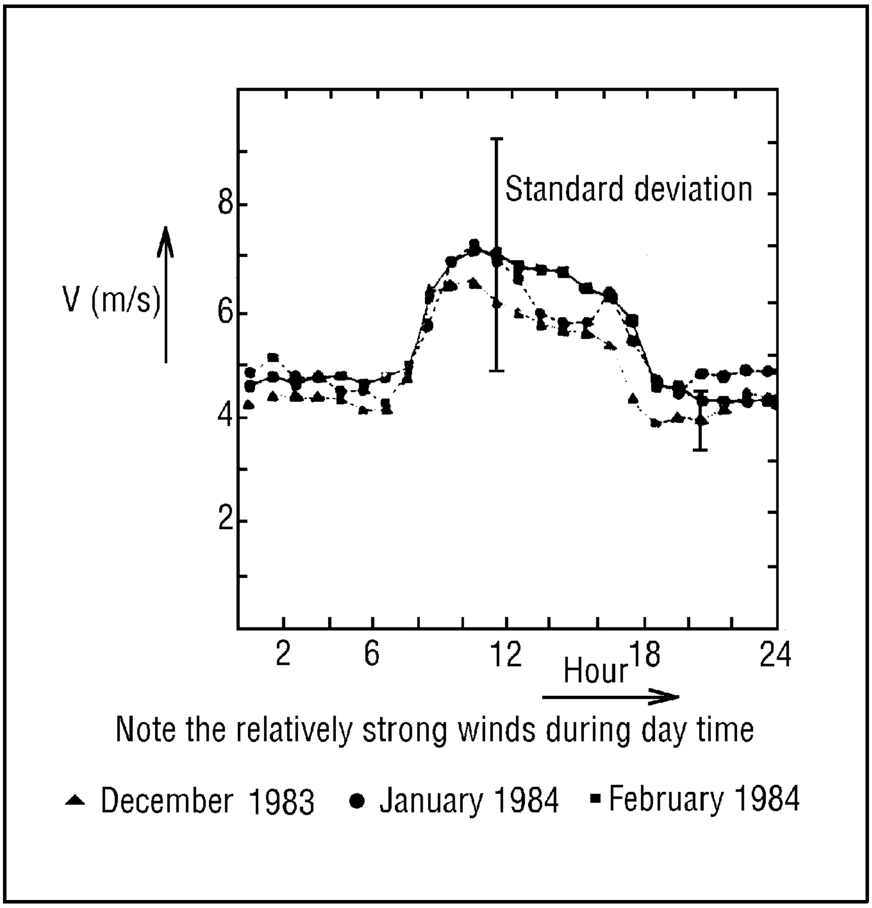

Figure 1. Diurnal pattern of wind speeds at Khartoum, Sudan [Abu Bakr et al., 1986]

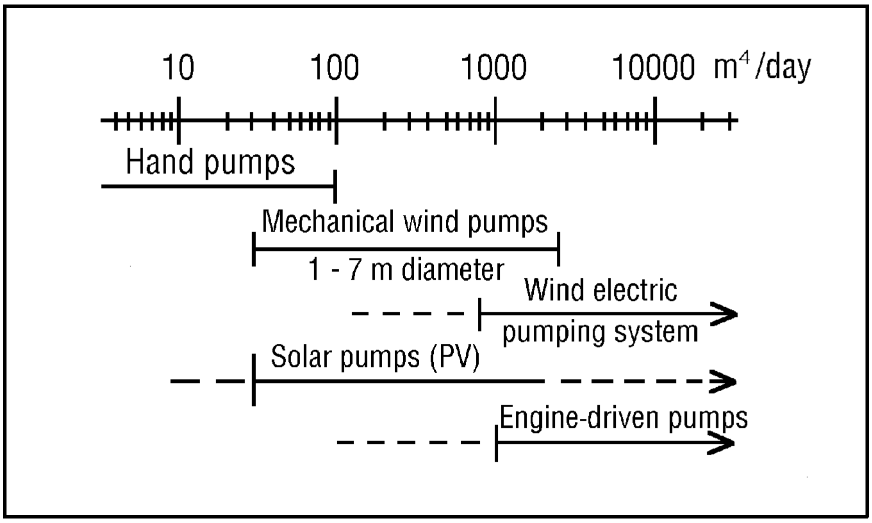

Figure 2. The wind pumping niche versus other pumping technologies. Note that 1000 m^4/day is equivalent to approximately 110W (continuous) hydraulic power output.

2. *Wind electric pumping systems (WEPS) with an* ***electric transmission*** *mostly used in combination with centrifugal pumps.* Potential seems to this author much larger than is currently realised.
3. *Wind pumps with a* ***pneumatic*** *or* ***hydraulic transmission.*** They can be useful for remote pumping similar to WEPS. Air-lift pumps are used, despite their low efficiencies, in faraway places as they virtually do not need any maintenance (e.g., northern Brazil).

A second distinction can be made with respect to the type of pump that is driven by the rotor. The two main classes are these.

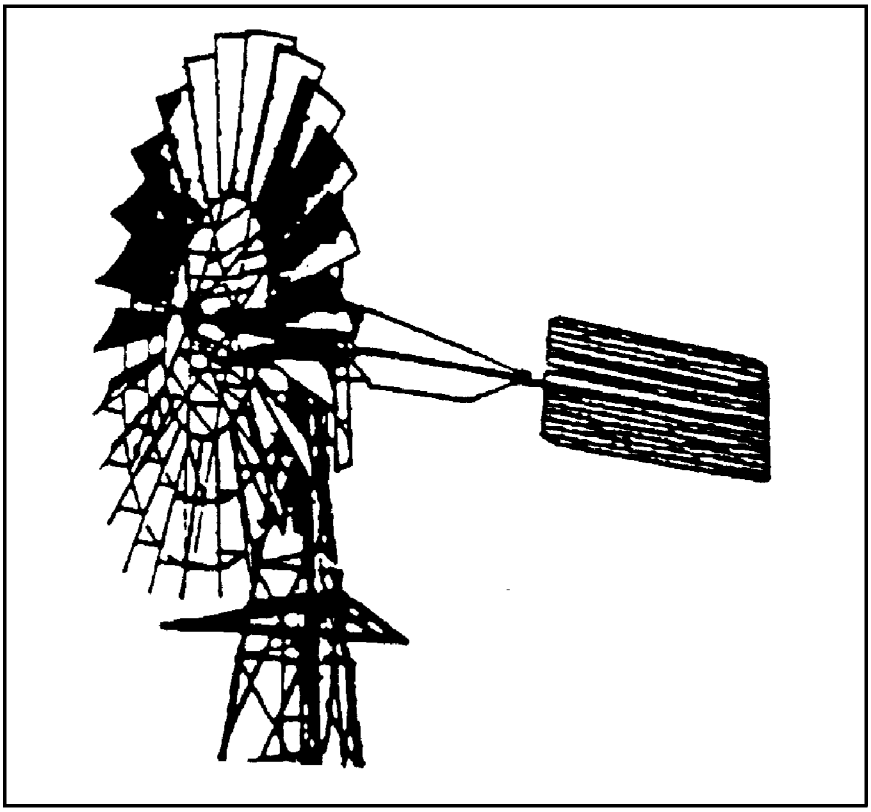

Figure 3. First generation wind pumps; the Australian Southern Cross wind pump.

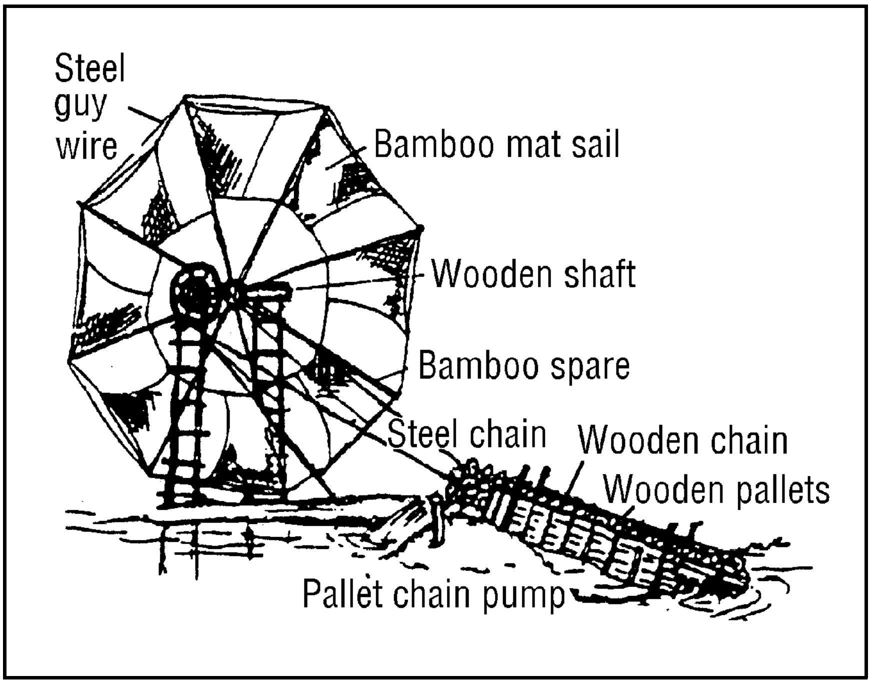

Figure 4. Low-cost wind pump: the Thai bamboo-mat wind pump.

1. *Displacement pumps*. The piston pump is the most common. However, the Archimedes screw pump which in the past was used for drainage in the Netherlands in combination with wind power, has now also been introduced in China for very low-lift (<3m), large-volume flow applications. If well designed, these pumps have efficiencies of about 70% and do not manifest starting problems as piston pumps do. Another pump which has witnessed a fantastic revival as a hand pump, e.g., in Nicaragua, where more than 6000 have been sold with no subsidies involved, is the rope-and-washer pump. This pump is now being used there in combination with a windmill. About 70 are now in the field and experience is very favourable, especially price-wise. The pump is efficient, does not have starting problems, does not constitute a dynamic load as piston pumps do, and is very easy and cheap to maintain, although maintenance may be necessary every half-year.
2. *Rotodynamic pumps,* of which the centrifugal is the most important. Their use with a mechanical transmission is restricted to low heads.

A third distinction which is also made reflects the level of technology of the wind pump (see Figures 3 to 5).

1. *First generation, classical multi-bladed (American) wind pumps with the smaller sizes incorporating a back-gearing transmission (Figure 3).* These are sturdy and reliable.
2. *Second generation, modern light-weight wind pumps which have been developed in the last 20 years (Figure 5).* Gearboxes are omitted, new control systems have been developed. Their design often reflects the specific requirements, e.g., pumping heads less than 7m, low wind speeds. Their range of application may be more restricted than that of the versatile multi-blade machine, but as they have been designed for a particular job they are also much more economical.
3. *Low-cost artisanal wind pumps, e.g., bamboo wind pumps in Thailand for low-head pumping in salt pans (Figure 4).* In general artisanal wind pumps ‘‘coincide’’ with low head requirements.

6. The market

The market situation has been well assessed two years ago [Ministry of Foreign Affairs, 1993]. Desk studies were conducted in the countries listed in Table 2. This list of countries is incomplete. For example, Jordan has activities going on in wind pumping; Argentina and South Africa are countries where multi-blade wind pumps are used in large numbers.

The general picture that emerges

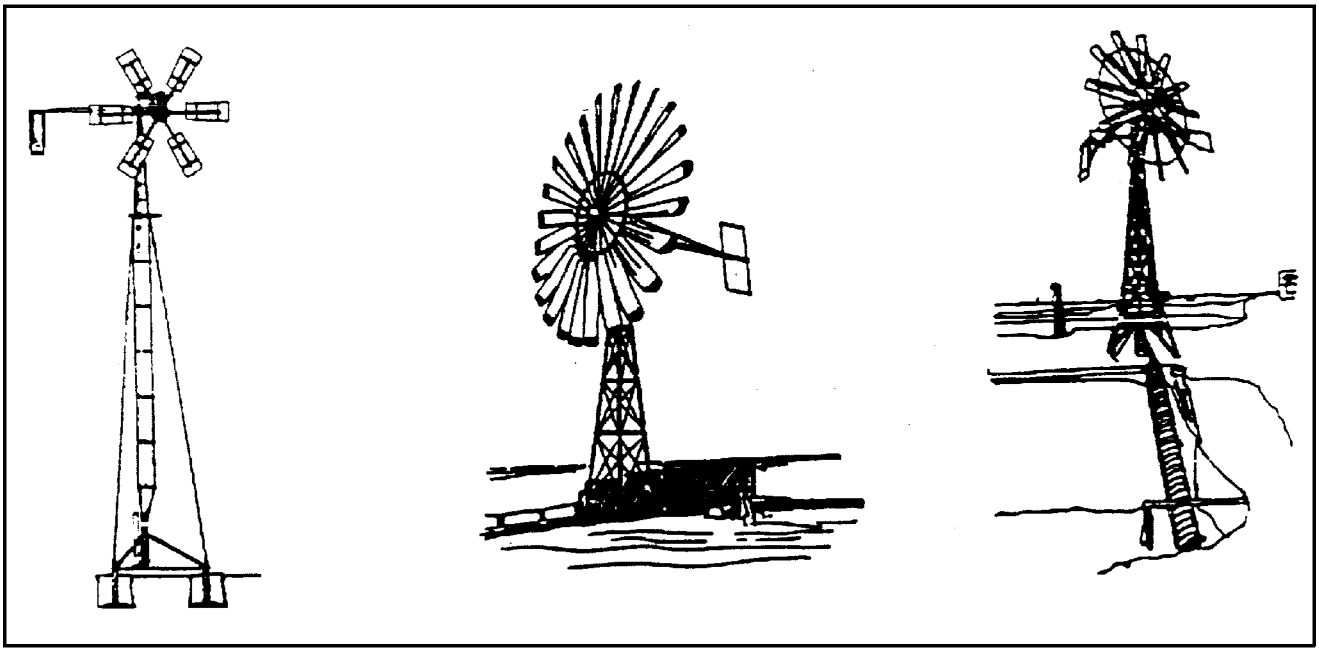

Figure 5. Second generation wind pumps; the CWD 2000, Kijito and FDG-5.

from the market study, and this is confirmed by the author's own experience, is that the market is very fragmented. Local manufacturers are the key actors in the game, but very often they have no access to literature, have no international contacts, are very restricted in their capital expenditures and in general receive little infrastructural support from their government, e.g., R&D, training, fair pricing and taxation. So in general their designs are below present standards, their marketing is a bare minimum and sometimes they have too little basic knowledge to inform their clients properly. The user is also at a loss. He has difficulty in getting an appropriate loan for the wind pump, is reluctant to take the risk of buying a wind pump without some outside support, e.g., of the government, and has difficulty in finding unbiased professional advice to help him take a good decision. The international community is hardly interested, partly because of unsuccessful projects in the past. But quick successes are not to be expected in this field, especially if local production is involved. In those places where the manufacturer is serious, tenacious and professional we see gradually that markets are developing, although some will remain small. Examples are Kenya, Colombia, Nicaragua, Niger, the Philippines, Mauritania and Jordan.

Table 2. Countries studied in 1993 in a wind pump market study commissioned by the Netherlands government.

Africa	Asia	Latin America
Egypt	China	Nicaragua
*Kenya	*India	*Colombia
Mozambique	Pakistan	Peru
Sahel	Philippines	
(Burkina Faso,	Sri Lanka	
Cape Verde,	Thailand	
Chad, Mali,	Vietnam	
Mauritania,		
Niger, Senegal)		
Tunisia		
Zimbabwe		

Note

The countries marked with an asterisk were studied in detail and visited. The other countries were reviewed on the basis of literature studies.

7. Financial analysis: who invests?

It is customary to take life-cycle costs as the major yardstick for investments, but real life makes one aware that the required investment can be a more serious worry. We will consider here the range between 100 and 1000 m^4/day, for which engine-driven pumps are less suitable (see Figure 2). It is then interesting to compare solar and wind pumps. If electricity is available, then it can't be beaten, the more so if it is subsidized, as for example in India. But frequent unpredictable blackouts of electricity supply can be a crucial factor against its use.

We will consider the example of a pumping requirement of 300 m^4/day, being equivalent to a continuous 34W hydraulic power output. The results are shown in Table 3. The power output of the wind pump (see Equation (3)) is based on B = 0.1. We consider average (say monthly) wind speeds of around 2.5 to 4 m/s, and can thus calculate the required rotor diameter.

The investment for the wind pump

Table 3. Comparison of the investment of a wind pump and a solar pump for a duty of 300 m^4/day, being equivalent to 34W average (continuous) hydraulic power output P_{hydr}.

Wind pump			Solar pump	
$P_{hydr} = 0.1\ v^3\ A_{rotor}$		$200/m^2 installed	Insolation: 5 kWh/m^{2}day Subsystem efficiency: 32%	$20/Wp installed
Average wind speed v (m/s)	Rotor diameter (m)	Investment (US$)	Peak power (Wp)	Investment (US$)
2.5	5.3	4360	510	10.200
3.0	3.9	2440		
3.5	3.1	1540		
4.0	2.6	1060		

installed is assumed to be US$ 200 per m^2 swept area of the rotor. ''American'' multi-blade wind pumps would be around $400/m^2 installed. In Sri Lanka and Nicaragua locally-produced wind pumps have been sold at $100/m^2. So $200/m^2 seems reasonable; it is just 10% higher than the costs of a manufacturer in the Philippines, who has put extra costs in his design to accommodate typhoons! We see that the total investment of the wind pump installed runs from 1000 to 4400 US$, depending on the wind site.

The solar pump for the same duty of 300 m^4/day was rated on the following assumptions: a daily insolation of 5 kWh/m^2 and an average subsystem efficiency (i.e., from module out to water out) of 32%, and maximum power point tracking (MPP) is perfect. In fact, it means a very efficient pump. So we find a solar pump with 510W peak rating. At an investment level of $20/Wp installed, the total investment is just over $10,000. The investment level at a 3 m/s site is a factor of 4 lower for a wind pump. For that difference one can accept higher maintenance costs. The essential element is that maintenance is available when required and that is one of the pillars on which successful manufacturers build (see previous section).

The author does not wish or intend to conclude from Table 3 that wind pumping is better or more attractive than solar or any other kind of pumping. The price of solar pumping will drop as that of solar modules drops. True, but total system costs are not proportional to module costs. Besides, wind pump investment costs at $200/m^2 are not at the lowest conceivable level. Better design and production methods can bring costs down. Also, the quality factor B can go up 50% to at least 0.15. So there's still a factor of 2 in cost reduction possible for wind pumping. The author only wants to stress: don't forget wind pumps, they are a very good option but need their own appropriate approach as the actors involved are local people. Solar pumping relies on solar modules and these are in the hands of multinationals, for example, BP, Shell, Siemens. And they are very successful in having donors financing part of their projects (25 million ECUs in Mali!). Their products and management are in many cases first-class. But can local people in a reasonably near future take over, not only the technology but also the financing?

8. What's wrong and what's needed?

1. In the past many wind-pumping projects did not meet the expectations. Apart from sudden changes in political conditions (e.g., Sri Lanka, Mozambique, Sudan) which disrupted a gradual dissemination and learning process, most of the problems were related to difficulties of local production, designs that had not reached a mature status, inadequate training. Success or failure depends very strongly on the capabilities of the manufacturers to adapt existing designs to potential local skills and available materials, production skills, marketing, after-sales services and of course financial resources for investments. Disappointed by past failures of wind-pumping projects, donors now prefer doing business in solar pumping with a few experienced (multinational) companies dominating the PV market. These companies know what quality control means and have vast experience in management, training and logistics. Supporting the wind-pumping market, however, means seeding money and know-how in hundreds of little places where small local manufacturers are operating, a process along a road littered with pitfalls, but with very beneficial potential in the long run: a self-reliant industry manufacturing and servicing wind pumps.
2. There's a great need to assist manufacturers in value and product engineering. There are several designs of wind pumps available, but the assessment of their quality by independent authorities is non-existent.
3. International contacts for exchange of information between actors are insufficient or hardly exist.
4. Regional test fields are a minimum requirement to promote and evaluate wind-pumping systems but they hardly exist.
5. Research and especially development are essential to keep in line with other pumping technologies. Scope for development is substantial both in improving efficiency as well as in bringing down in-

vestment costs. But who is willing to pay?

9. Conclusions

Wind pumping seems a forgotten option but merits support. Wind pumps can supply water at competitive costs especially if manufactured locally. The key actor is the manufacturer, who is responsible for choosing a design, production, marketing, after-sales service, etc. The main efforts of international support should be directed at strengthening the infrastructure, know-how, price policies, etc., in such a way that the manufacturer is able to bring a good quality product on the market for a reasonable price. This is feasible. ■

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