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REVIEW OF THE LITERATURE ON PROMOTION OF WINDPUMPS

Pilot Edition

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INTRODUCTION

The enormous potential of wind as an energy resource, mainly because of its renewable nature and decentralised characteristics, makes it a promising energy option for the developing countries.

The technology for harnessing the wind is not totally new but its widespread application in varied geographical locations imposes several constraints. An international panel of experts has recently identified these constraints as infrastructure and institutions; research and development and transfer of technology; education and training; information-flows and finance. Discussions on these aspects are elaborate and also widely scattered in the literature.

The present document is a consolidation of the views of several eminent experts, their suggestions, explanations, etc., which should be considered for the development and application of appropriate wind energy technologies, especially water pumping windmills.

It is hoped that the present pilot version of the document on wind pumps can be reviewed and tested by persons who have responsibilities or interest in consolidating information and that it can be subsequently improved and disseminated to a wider audience of specialists, particularly in the developing countries. Suggestions for improvement of either the content or presentation of the document are therefore very welcome. They should be addressed to :

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CONTENTS

1. Resources and Availability

Wind is an abundant, renewable, non-polluting and freely available source of energy :

- wind derives its energy from the differential heating of the atmosphere by the sun and the irregularities of the surface of the earth. (Ref. 36a)
- while only a small portion of the solar energy reaching the earth is converted into the kinetic energy of the winds, the total quantity is extremely large - more than ten times the present global power demand. (Ref. 8)
- nature concentrates this energy in certain regions, so that the average wind energy flux is appreciably high in many locations, making it a viable and economical source of energy. (Ref. 36a)
- small-scale applications of wind power are not likely to have any negative environmental impact on the surrounding areas. For instance, windmills do not add waste heat to the atmosphere.

The wind energy resource is perhaps the most predictable on an annual basis (Ref. 17a); however, it is variable in time and location :

- relatively large variations in wind speeds can occur over relatively small geographic locations.
- this variation is a major advantage as well as a major challenge for harnessing wind energy.

Extractable energy from the wind increases in proportion to the cube of the wind speed. For instance, when the wind speed increases from 8 to 10 km/hr, the power output almost doubles.

Wind speed data monitored by the global network of meteorological stations are usually available through the national meteorological organisations. These data could be used as (Ref. 30) :

- a basis for surveys to indicate the areas where higher wind speeds occur

- an indication of wind directions and seasonal variations
- a measure of total energy that may be available annually
- a guide to the maximum wind speeds and the duration of calm spells, frequency of severe thunderstorms, lighting, hail, etc.

Data reported by the meteorological stations are for the area surrounding the monitoring stations. The majority of these observations have been made at airports and urban areas. In practice, the actual data for a specific site may vary considerably due to site characteristics (Ref. 30). Variations are usually found in

- annual mean wind speed
- maximum wind speed
- duration of calm spells
- daily and seasonal wind velocity
- sheer and turbulant conditions
- variations due to height of the site
- direction of the wind.

Hence on-site analysis of wind regime is necessary and beneficial.

Site-specific wind data which are essential for wind energy utilization can be obtained by a number of quick and inexpensive methods such as using the Beauforts Wind Scale (Annexure I), using wind deformed vegetation as an indicator of high wind velocity (Ref. 15a) or by talking to the local people (Ref. 28a). However, these are only rough and approximate methods.

For sophisticated windmill systems it is necessary to obtain wind data for at least over an year, using wind measuring instruments like anemometers, etc. This will be useful in predicting and selecting the right type of windmill for maximum cost effectiveness and also in selecting a suitable site for the windmills.

Availability of wind at a particular site is significantly influenced by the type of terrain. (Ref. 3, 26)

- in flat terrain, wind flows uniformly unless obstructed by barriers such as trees, buildings, etc.
- in complex terrain, wind-flow patterns depend upon interaction between the topographical features, barriers, surface roughness and day-to-night variations in surface heating and cooling.
- wind speeds are low at ground level and higher wind speeds are recorded above ground level.
- mountains obtain complicated wind systems such as Katabatic and Anabatic winds which also signify reversal of wind directions during the day and night.
- islands, coastlines, hills and areas near lakes usually have higher wind potential.

Even in areas under low average wind speeds, water pumping windmills could be an attractive proposition :

- these sites are likely to have higher wind speeds, at least for a few hours a day. Water could be pumped when the wind occurs and the pumped water stored for use when needed.
- wind speed is found to accelerate when allowed to escalate over an artificially constructed earthen dam. (Ref. 17b) Installing a windmill over such a dam could help in harnessing wind power specially in plains and rural areas where wind speed is low. Alternatively, natural hillocks can also be used as sites for installing windmills.
- low wind speeds of 3 m/s and above may be adequate to energise at least some of the water pumping windmills in remote and inaccessible villages where alternate options such as petroleum fuel as well as grid electricity are not available or economically feasible. (Ref. 36)

Besides surveying the wind regime at a site, it is equally important to know the water table, salinity of water to be pumped and the soil condition.

- for a given windmill the pump size will be determined by the water depth and the wind strength. (Ref. 12) Data on water tables at various sites is normally readily available since these studies have usually been carried out by the state or central government ground water services.
- the water to be pumped must not be corrosive or damaging to the pumping equipment. (Ref. 38a)
- the soil condition will help decide the type and strength of foundation that will be required for the windmill.

Reasonable assessment of wind energy potential in developing countries calls for immediate steps to ensure (Ref. 7a):

- availability of reliable and carefully analyzed wind data. National governments should undertake projects to study the wind regime in areas well-known to have good winds. Also, setting up site stations at some of the most potential areas and creating data bank giving information on the wind regime, including daily and hourly variations of wind velocities.
- availability of standardized, simple and inexpensive wind recording devices. Wind measuring instruments should be made available on loan from meteorological stations or other such national/regional agencies.
- preparation of simple methods to estimate wind energy potential in specific areas/ regions.

An inventory of wind resources should be undertaken as soon as possible in all the countries, and windy areas may be identified and considered for maximum exploitation on a priority basis.

2. Status of Technology

History

Technologically, windmills have been well proven in the past and for centuries wind energy has been a useful source of power for pumping, grinding, sailing and milling purposes.

- the first windmills were probably simple vertical-axis panemones, such as those used in Persia as early as about 200 BC for grinding grain. The use of these windmills then spread throughout the Islamic world. By the 11th century AD windmills were in extensive use in the Middle East. They were introduced to Europe in the 13th century. Although not an indigenous technology, they soon took on an unprecedented importance in medieval Europe, first for grinding grain and later for sawing wood, making paper and draining water from low-lying farmlands. In the 17th century there were about 10,000 windmills in England.
- by early 19th century, with the invention of the steam engine, the advent of petroleum fuels and rural electrification programmes, windmills abruptly declined in development and importance. (Ref. 19)
- the post-1973 era of energy consciousness and the growth in pollution associated with energy production has revived the interest in windmills.
- today, windmills have become the subject of extensive development and the machine now emerging makes use of major technological developments that have taken place in recent years in the area of structural design, materials and control, taking advantage of an improved understanding of wind loading and rotor aerodynamic performance. (Ref. 36)

Applications

Wind energy systems are now seen to have major potential applications in rural areas especially for :

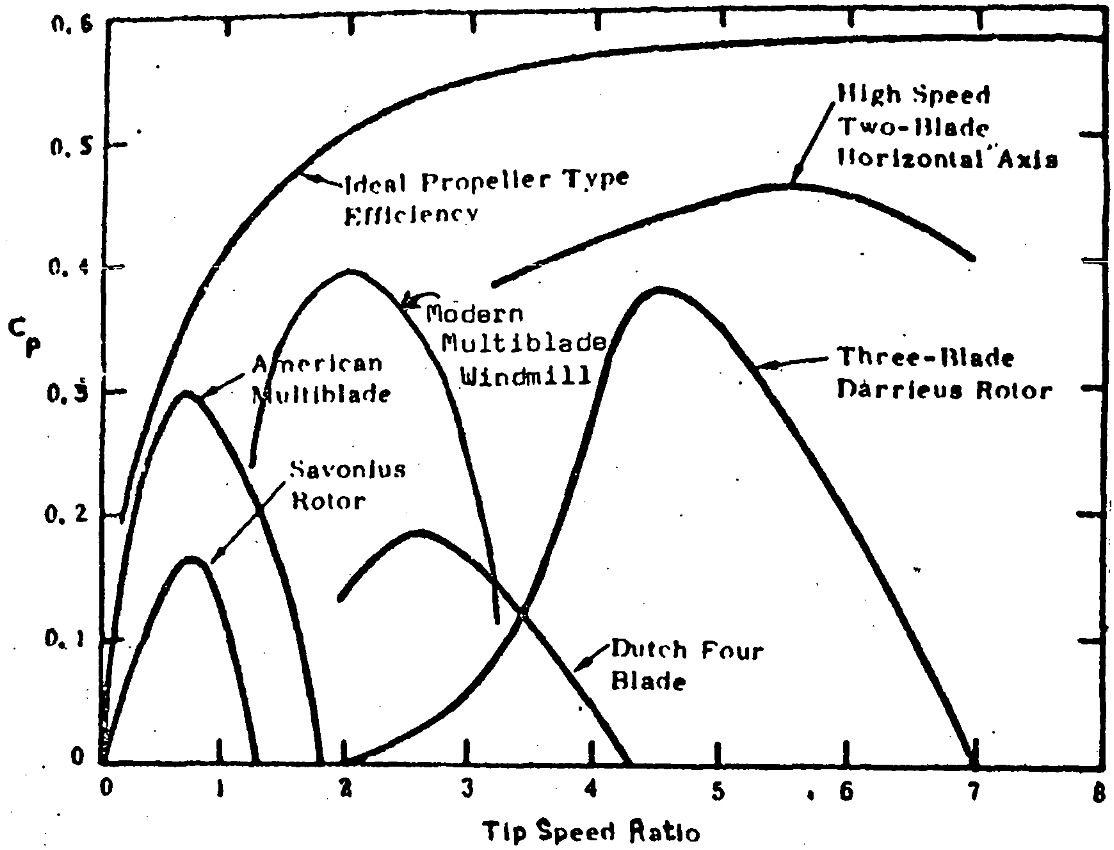
- domestic water supply
- crop irrigation
- performing agricultural tasks such as grinding corn, crushing sugarcane, threshing and wood cutting
- pumping water in salt works
- aeration and water supply for aquaculture
- generating electricity to operate water pumps for large-scale irrigation and for water pumping for small communities, in combination with diesel back-up and/or energy storage systems
- generation of electricity to assist rural electrification.

Windmill systems encompass a broad spectrum of technological sophistication (Annexure II) (Ref. 23). At one end are wind-powered electric pumps and at the other end are indigenous windmills.

- electric pumps powered by wind-generated electricity (e. g. high-speed propeller-type windmills, etc.)
- multivane windpumps using mechanical drive
- indigenous windmills, using mechanical drive (e. g. sail windmills, Savonius rotors, etc.)

Sailmills, multibladed mills and Savonius rotors are mostly rated at less than 1 KW (Ref. 36c). The efficiency characteristics for selection of wind turbines is shown in Fig. 1.

Figure 1: Efficiency Characteristics for Selection of Wind Turbines



* Cp (Power Coefficient) = the ratio between power extracted by the windmill and the power available. Theoretically the maximum value of Cp is 0.593 and is known as the Betz limit.

* Tip Speed Ratio = ratio of velocity at the tip of the blade to the velocity of the wind. Windmills with low tip speed ratio (1-3) have a high starting torque and are ideally suited for water pumping applications.

Electric Pumps

High-speed wind electric generators currently available in a wide variety of models and sizes (Ref. 37) show a number of potential advantages (Ref. 28b).

- greater flexibility in siting the wind machines in relation to the well
- use of high capacity submersible or shaft type turbine pumps instead of piston pumps
- availability of pumping powers up to 100 KW or more which can be used in large irrigation projects
- flexibility of use in conjunction with a rural electricity grid so as to permit continuous pumping, but with reduced electricity consumption.

Despite these advantages, electric pumps have not been used in developing countries because of the high capital cost of wind electric generators. Also, there is the problem of secondary storage, particularly when the aerogenerator has to be used not only for running the pumps but also for feeding power to a variety of other machines run on electricity.

Multivane Windmills

Among the commercially produced, mechanical-drive windmills, the multivane type are the most widely distributed wind pumps and have been imported and/or adapted by several developing countries (Ref. 28c).

- they are widely available on the international export market
- they are being manufactured in several countries including Argentina, Australia and S. Africa and about 1 million are still in use
- local adaptation of this design has been developed in the Philippines, India, Syria, Indonesia and Thailand
- many multivane wind pumps made in the U.S.A. and Australia are being exported to some of the developing countries on a subsidized basis.

Multivane windmills are reliable, have a high starting torque and operate well even in low winds (Ref. 22a).

- they are usually designed to have many blades, low rotation speeds, moderate size (usually 15 ft dia. or less; 30 ft is the largest manufactured) and rigid steel construction.
- since they have a high starting torque, they are well suited to drive water pumps which generally have a high starting torque.
- typically, multivane fans begin pumping water at 2.2 - 2.7 m/s are suitable for the arid and semi-arid regions in the developing countries.

Although several multivane windmills are being put to use in developing countries, they show some limitations (Ref. 36d).

- conventional multibladed design is beyond the scope of local manufacture in several countries
- costs are too high for subsistence farmers, and loans and subsidies have not generally been available
- maintenance and repair are problems despite the basic reliability of the machine, especially when local maintenance service remains unorganised.

In view of the above problems, organisations like Intermediate Technology Development Group (ITDG), London (Ref. 9, 11, 16), Steering Committee for Wind Energy in Developing Countries (SWD) and Working Group for Development Techniques (WOT) in the Netherlands (Ref. 27) are currently developing new multi-bladed windmill designs suitable for small-scale manufacture in the developing countries. The new designs, in comparison with traditional multi-bladed designs, have several advantages (Ref. 36d) :

- they are considerably lighter in weight, more simple to construct and have a slightly higher overall efficiency

- these windmills can be constructed by using locally available materials and manufactured in simply equipped workshops
- they are cheaper than commercially available mills manufactured by the advanced countries
- the resulting savings in foreign currency expenditure are appreciable.

Experience within these projects shows that extensive field testing is essential and is resulting in a number of design modifications to ensure the reliability of the machine (Ref. 16, 27).

Indigenous Windmill

A wide variety of simple handcrafted water pumping windmills developed are now in seasonal use in various parts of the world, specially in less developed countries (Ref. 29, 31). Both horizontal axis sailwing windmills and vertical axis Savonius designs have been developed for irrigation or drainage, requiring relative low lift.

The Savonius rotor (Ref. 18) has received attention as a simple windmill with a large potential for application in developing countries. Although efficiency of this design is low, its ability to accept wind from any direction, the simplicity of construction and the widespread availability of the construction materials are technical advantages that make Savonius rotors suitable for several wind energy applications in developing countries.

Sail-wing windmills are perhaps the most attractive in design for village-level construction, and this fact has been demonstrated by a number of designs being experimented within India, Ethiopia, Tanzania and Thailand (Ref. 31). In the Lessithi Valley of Crete, several thousand sail-type windmills have been operating for several decades for irrigation water pumping.

The sail-wing windmill which is simple and safe is suitable for application in developing countries (Ref. 21).

- it can be constructed out of locally available material (often wood and cloth) and is produced with local skills, using simple hand tools
- being made of wood and cloth it is inexpensive and easy to repair
- its slow speed and high rotor solidity make it responsive to low wind speeds
- with a maximum speed of about 50 rpm it is safe.

An improved type of sail windmills have been developed in Colombia, Ethiopia, India and the Netherlands (Ref. 31), to try to meet the demands of subsistence farmers. Such mills have been built in a number of countries, but their activities do not seem to have resulted in adequate dissemination of these technologies, possibly because of lack of sufficient promotion and extension services, e.g.

- the CAZRI (Ref. 31) multidirectional sail windmill has shown encouraging performance since 1976. But no steps seem to have been taken for further demonstration and possible commercialisation.

In general, small direct-drive water pumping windmills have been highly successful in the past in rural areas in many parts of the world. It continues to be so to this day in areas where they were never displaced by rural electrification and/or diesel pumps.

From the large number of such pumps still in use (around 1 million) it may be inferred that the potential is very large, perhaps running into many millions of pump sets globally.

Research and Development

Further research and development are needed to improve existing designs for local conditions. The priority areas for immediate attention are many and varied (Ref. 24) :

- material-engineering studies of existing commercial windmills, designed to improve production techniques and reduce cost.
- development of windmill systems for the production of mechanical shaft power and the generation of electricity, utilizing as many indigenous or locally available materials and technologies as possible.
- investigation and redesign, where necessary, of equipment to be powered by windmills to carry out the required unit operations such as pumping, agricultural tasks (milling, threshing, grinding) etc. with a view to enabling their fabrication in local workshops.
- development of suitable rotary, positive displacement or variable stroke reciprocating pumps.
- study on matching the rotor power and torque with that of the pumps.
- development of decentralized power systems that are simple, reliable and that may be serviced if not fabricated in villages.
- application of known technologies to adapt windmill systems to a variety of environmental conditions (such as winds, rainfall, temperature extremes) which may include development of new forms of rotors for small-scale applications, and
- a programme of education in rural areas to show what wind power can contribute to their energy budget.

Implementation

Further diffusion of the windmill technology will require institutional and financial support programmes. These would include services and facilities especially to :

- adapt the technologies to local conditions.
- prove their reliability.
- evaluate local wind regimes in relation to wind pump characteristics, water resources and cropping practices.
- demonstrate the equipment.
- train extension workers.
- organize maintenance and repair.
- provide loans and subsidies on terms acceptable to subsistence farmers.

3. Design and Fabrication

Because of the complex inter-relationship of the variables of wind characteristics, water resources and demand, the material and skill needed for construction of windmills etc. at each different locality, it is necessary to adapt the wind pump to local conditions by modification or redesign. Such interrelationships are identified and rationalized and a design procedure is presented (Fig. 2) as a sequential flow of information analysis, rational decisions and calculations (Ref. 29a).

Design Process

As indicated in the flow-chart, the three steps involved in the designing process are :

a. Preliminary Investigations

  - survey of local wind characteristics.
  - survey of local water needs and power needs. Most domestic water supplies require 100 W whereas 1 Kw may be required for typical irrigation application of 1 to 2.5 hectares.
  - classification of wind rotors (See Annexure III).
  - classification of water pumps (See Annexure IV).
  - survey of local materials and skills.

b. Data Analysis and Critical Decisions.

c. Component Design and Matching.

Design Criteria

This requirement in the rural areas of developing countries can be best satisfied by a design that can utilise an appropriately low technology. Such a design must have the following characteristics (Ref. 14) :

- it should be labour-intensive,
- it should use local material and skill to the optimum possible extent,
- the windmill should start and operate reasonably well without attention,

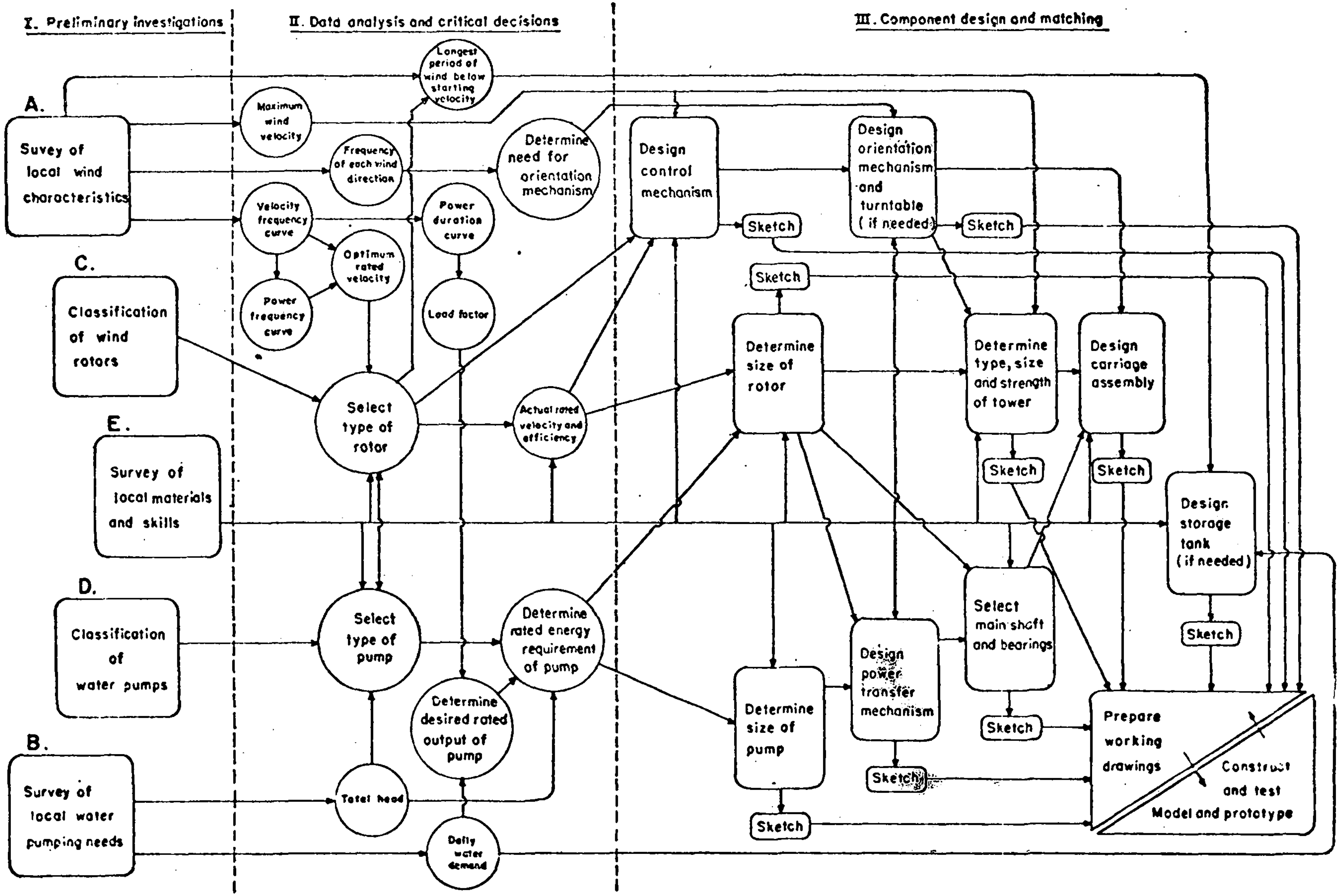


Figure 2: Sequential flow chart for design of water pumping windmill systems

- it should have a safety device built into its design,
- any maintenance or repair that may be needed should be within the skill of the villagers themselves,
- such a design should incorporate sound engineering in the sense that it should perform well at the least possible cost,
- the design should be adaptable to local circumstances with a modest variation in dimensions, materials and skills.

Orientation Mechanism

To take the maximum advantage of wind available from any direction and orientation a suitable in-built mechanism should be incorporated in the windmill design. The options for orienting the rotor into the wind include tail vane, down-wind rotor, manual orientation by tail rope or A-frame support, fan-tail rotor, etc. (Ref. 6a). In situations where the wind direction is farily constant, such as long coastlines and many equatorial regions, significant savings might result from fixed alignment of the rotor. Where change of wind direction in infrequent, manual orientation might be most economical.

Control Mechanism

To prevent windmills from being damaged or destroyed by excessively strong winds a control device is an essential component. Allowance must be made for either manual or automatic control of starting, stopping, overspeeding (governing) furling or reefing of sails and protection against unexpected high wind speeds (fail safe device) (Ref. 6b). Maximum use of manual control device can lead to saving in construction cost. However, automatic control may be necessary for unattended operations.

Matching of Wind Rotor to Pump

The matching of wind rotor to a piston-starting torque must be taken into account. The wind velocity required to move the rotor from the still stand is rather high. Once turning, it will continue at a lower wind speed. To overcome this, the following should be preferred (Ref. 5) :

- bigger blades (or more)
- lower design tip speed ratio
- small stroke (the stroke is adjustable)
- small pump
- bigger leak hole

The best solution is highly related to wind regime.

Material Availability

The local availability of materials or components needed for windmill construction in developing countries may heavily influence the preferred windmill design choice, for a specified application. A wide variety of materials, including bamboo, woven grasses, cloth, dacron, wood, steel, aluminium, fibreglass, plastic, concrete and bricks, may be used in windmill construction. Most of these materials may be available in developing countries. However, the availability of precision components (e.g. gears, chains, crankshafts) is likely to be more of a problem than access to raw materials.

Skill Requirement

Lack of the required manual skills and process capabilities for windmill fabrication may limit the choice of windmill design. In general, windmills with higher operating rotational speeds and power outputs require more sophisticated skill and power capabilities than windmills designed primarily for low lift water pumping. Skill and process capabilities for typical windmill water pump construction include (Ref. 7b) :

1. Carpentry
2. Metal drilling and cutting
3. Metal welding
4. Machine lathe operation
5. Fibreglass reinforced plastic moulding
6. Steel casting
7. Gear-making
8. Hydraulic fitting

Windmill project failures in developing countries are frequently the result of inadequate technical capabilities. Importance must be given to designs that can be constructed and looked after by local craftsmen. For a typical windmill water pump or even for a more sophisticated multibladed design, availability of the first four process capabilities may be critical.

Maintenance

One of the criteria for choosing the most appropriate pump must be ease of maintenance. Designing maintenance into the equipment is absolutely essential if it is to be used by people who have poor access to spares and skills. Use of a bearing provides a good illustration to this (Ref. 38d) :

- high-speed windmills need high-speed bearings with all the problems of sealing them against dust and grit.
- low-speed windmills (e.g. Savonius rotors) run successfully on oil-soaked wood block bearings that can be cheaply replaced.

Careful consideration should hence, be given in the course of the design to the overall conditions of location, local skills, reliability in operation and safety, along with ease of maintenance.

4. Economics

The capital cost of windmills vary widely with design and differ significantly on a per unit power output basis over the range of available power output (See Table) (Ref. 24b).

ESTIMATES OF CAPITAL COSTS (1976)

Windmill design	Rated power capacity and capital costs	
	less than 4 Kw	4 to 11 Kw
1. Commercially available mechanical power	$ 5000 to $ 10,000/Kw	$ 1,300 to $ 2,600/Kw
2. Electric power	$ 3,000 to $ 6,000/Kw	$ 1,000 to $ 2,000/Kw
3. Village constructed mechanical power	$ 1,300 to $ 2,000/Kw	

1 Kw (Kilowatt) is equal to 1.34 horsepower.

For a given capital cost, the unit cost of energy (mechanical or electric) is influenced significantly by the local wind regime, the duty cycle of the application and the anticipated lifetime of the windmill.

The cost is also dependent on pumping depth and seasonal irrigation practices, but irrigation costs by wind-pumping appear to be economic, even down to marginal wind speeds. Case studies in Indian conditions (Ref. 33), taking account of wind characteristics and seasonal water demands, confirm that even in marginal wind regimes, wind pumping is cheaper than grid-connected electric power if the real cost of rural power distribution is accounted.

Multibladed and sail windmills of improved design can be built locally in developing countries for around U.S. \$50-150/m^2 of imported models) (Ref. 36a).

Experience with these windmills indicate, on a conservative estimate, that they deliver an average hydraulic power of $0.1V^3$ W/m^2 (where V is the average windspeed) (Ref. 36e). This corresponds to about \$ 20-\$ 60 per average watt (pumping power) in a marginal average windspeed of 3 m/s and \$ 8-\$ 24 per average watt for a 4 m/s windspeeds. A steady pumping of 100 W, which is a typical requirement, for example, for irrigating 1 ha from a water table at a depth of 10 m would correspond to a capital outlay of \$ 2000-\$ 6000 for the 3 m/s case and \$ 800-\$ 2,400 for 4 m/s. By comparison, the corresponding range for a small solar pump in conditions of good solar isolation is \$15,000-\$45,000.

Several studies (Ref. 13, 20) have compared the economics of wind energy with other energy sources and some of the important findings are furnished below :

- energy prices of windmills are comparable with energy prices of diesel or electric sets. In some cases the reliability of the provision of fuel for diesel and kerosene pump sets is less than that of wind energy.
- windmills can favourably compete with diesel pump sets if total cost incurred on the operation of these two devices are comparable over a 5-10 year period of operation (Ref. 34a).
- while fossil fuel costs are likely to increase, further, the running cost of the windmill will be constant after the windmill has been installed. A study of Mara region, Tanzania shows that windmills are more economical than diesel sets for water supply (Ref. 2a). In fact economy of windmills will further improve as the fuel price rises.

Windmill installation costs vary widely with the level of owner and/or operator participation in the construction process. The cost of a commercially available windmill will, in terms of initial capital expenditure, be considerably higher than comparable designs which are built locally. A number of sources of high costs for imported wind-powered water pumps in developing countries has been identified (Ref. 23b) :

- weight and bulk of windmills result in high shipping cost,
- small sales volumes encourage high profit margins and deprive opportunities for cost reduction through mass production,
- high material requirements reflect early design considerations based on relatively inexpensive material costs,
- lack of windmill designs well matched to water pumping from deep water sources or water pumping in regions without high winds.

However, considerable potential for cost reduction appears to exist for the local construction of most windmill designs, especially designs with a relatively low level of technological sophistication (e.g., sail-wing design for low-lift water pumps). Such windmills offer exceptional opportunities in the developing countries. This idea is even more attractive in view of possible large-scale and quicker proliferation (Ref. 32a) of such windmills in remote villages.

Since high cost puts windmills beyond the reach of individual subsistence farmers (although it is already within the reach of moderately successful producers of cash crops), certain groups have begun considering community windmills (Ref. 10, 11) shared between a number of small farmers, since what farmers need is not windmills but water, which is a readily sharable commodity.

There appears another attractive possibility of developing a combination based on the low initial cost aspects of low technology windmills with high mechanical integrity and low maintenance needs of all-metal conventional windmills. This hybridization (Ref. 32b) would assist in bridging a rather large gap in terms of initial cost of the two types of windmills. It would be desirable to make the farmer responsible for the windmill installed largely at Government expense on his farm. The farmer can contribute towards the cost of periodic replenishment. The remaining parts could be contributed and owned by the Government under some easy repayment scheme. This strategy is expected to obtain a better chance of success in the rural conditions of developing countries.

Because of the high cost, windmill technologies are not currently acceptable to many poor people in developing countries. Individuals may, in some case, be able to afford a windmill if inexpensive or free materials and/or labour is available along with suitable windmill designs and external financial assistance. For most applications in developing countries, capital for the purchase or construction of a windmill may need to be pooled by some type of user cooperative or village organization or made available through low interest loan programmes supported by the Governments or other institutions (Ref. 23c).

5. Social and Environmental Considerations

One of the most pressing needs of people living in rural areas is to improve the quality and quantity of their water supplies for drinking, cooking and washing (Ref. 38b). Contaminated and insufficient water is one of the major causes of illness in the villages. Wind energy can play a significant role in helping improve the quality of life in the villages.

- water supply by windmill will reduce the time and energy spent by village women in fetching water from lakes, wells, water holes, reservoirs, etc. The time saved can be used for other activities such as education, improving agriculture, etc. (Ref. 2b)
- small-scale water pumping windmills can improve dry season irrigation and help produce extra crops annually (Ref. 10, 15)
- use of windmills will free the energy sources (animal and human-power, fossil fuels and electricity) currently dedicated to water supply for other uses.

Some local benefits can also be seen by the creation of new employment opportunities in the village itself. The jobs may be for fabrication, maintenance or operation of the windmill device.

For widespread implementation of windmills in the rural areas due consideration must be given to the environmental aspects. Currently, wind energy systems appear to be environmentally benign. However, if large-scale utilization of windmills is planned in future, the following environmental issues must be considered (Ref. 22b, 36f) :

- Social acceptance
- Aesthetics
- Siting
- Safety
- Noise
- Radio and television interference

Social Acceptance

The attitude of the local people and the manner in which they are involved in the decision process, as well as the cost and environmental consequences of other energy sources will all influence the reaction of the villagers. The following considerations will make windmills a more acceptable technology in the villages :

- they must satisfy the genuine needs of the users, for instance, they must reduce the work-load of women (Ref. 38c).
- they should be for the betterment of the total population in a locality and not for the benefit of a few.
- they should not interfere with the continued operation of the pumping device on the same well. The social importance of hand pumping (Ref. 1) should not be forgotten (the well is very often a meeting point of village women).
- windmills should not cause a significant disturbance to the existing life-style and also should not prove to be hazardous to life.
- introduction of windmills may call for changes in the agricultural practices and social life due to the need for matching the irrigation pattern with availability of wind and thus water.
- the users must be involved at all stages of windmill development (Ref. 38c). This is of special importance since villagers have poor access to centralized repair facilities.

Aesthetics

The reaction of the people to the visual effect of the windmill and its more physical presence is a locally specific issue, quite different from country to country and even from one locality to another.

However, by taking due care at the time of site selection, most of the undesirable effects could be avoided, especially in the rural and agricultural areas.

Siting

The siting of windmills in forested areas might require clear cutting so that the natural wind flow is not obstructed. These cuttings might be objectionable to the local people since they could lead to soil erosion, water pollution and destruction of faunal and floral habitats. Hence siting of windmills must consider the wishes of local inhabitants.

Safety

A major concern of windmill manufacturers and users is safety (Ref. 36f). Tower overturning in a major storm is not a serious or particularly dangerous problem. Throwing of blade or fragment is a potentially hazardous occurance.

- the high-solidity, multibladed water pumps present few problems since their slow tip speeds and external bracing preclude a major blade throw.
- the low solidity, high rpm and high tip speed, modern wind electric turbines present a potential blade hazard which must be acknowledged in both the design and siting of these machines.

Careful load assessment, stress analysis and quality control during the design phase combined with vibration and crack detection and automatic shutdown during operation are capable of reducing the probability of an actual blade throw. However, additional care and regular inspection are required.

Noise

Noise is not a serious problem with mechanically driven or indigenous windmills. Aerodynamically well designed, small or large machines may produce some noise but it can be brought within tolerable limits at a distance relatively close to the windmill by :

- regular checking, and
- improvement in blade configuration and control devices.

Radio and TV Interference

Interference with radio and television transmission (Ref. 36f) is a problem characteristic of large-scale wind turbines and do not pose a problem for sail windmills, multibladed windmills and, in general, for all indigenous windmills. Non-metallic blades (wood or fibreglass) and care in siting can reduce the potential for interference.

Socially, small wind-powered water-pumping systems are quite appropriate for irrigation. They do not call for major changes in the social pattern and are likely to be acceptable especially where their economic advantages are proved.

6. National and Institutional Measures

For the development of water pumping windmill technology and its extension to rural areas, what is required is an appropriate institutional infrastructure capable of planning and implementing a coordinated programme at all levels and of mobilizing community support for it at micro-economic levels where it would be implemented. Such an institutional framework would include institutional capacities for (Ref. 35) :

- surveying wind energy potentialities and planning
- R&D to identify windmill technology to adapt it to suit local conditions, to introduce innovations and to develop prototypes
- field testing of windmill prototypes for suitability as well as compatibility with local customs and tastes
- rural extension services and social mobilization
- training villagers in the operation, maintenance and repair as well as in the local fabrication of equipment
- promoting and encouraging the commercial production of windmills
- operating schemes of financial incentives, subsidies and assistance for both adaptation by villagers and for commercial production and marketing
- sustaining the programme at the village level.

In the initial stages it would be necessary to take up educational-cum-demonstration programmes in selected areas for popularizing the new technology.

Currently, wind energy development and utilization are facing several constraints (Ref. 36g) :

- lack of sufficient infrastructure and institutional capabilities
- inadequate research and development and transfer of technology
- low level of education and inadequate training, including extension work
- information flows
- lack of finance: loans and subsidies.

Infrastructure and Institutional Mechanism

Lack of institutional framework to develop policies, strategies and programmes, lack of rural infrastructure for promptional activities and lack of manufacturing, distribution and maintenance services focus on the need for (Ref. 36g) :

- creating focal points for wind energy policy and planning units in relevant government departments
- establishing specific programmes and goals for wind energy
- encouraging rural development programmes incorporating water pumping by wind wherever relevant
- organizing manufacturing, distribution, and maintenance services.

Research and Development and Transfer of Technology

Even after a decision has been made to proceed with the research and development of wind-energy programmes in a country, the successful transfer of technology to the country and its subsequent diffusion is dependent on a number of factors, such as (Ref. 36h) :

- access to technical information concerning water pumping windmills available in the market
- access to equipments, designs and manufacturing know-how

- access to experienced technical advise during the initial stages of the programme
- R&D facilities to adapt foreign equipment to local conditions and to local manufacturing possibilities
- test facilities for imported and local equipment under realistic conditions
- performance standards
- demonstration facilities

An appropriate wind energy centre in the country can be made responsible for the above services and facilities.

In many instances university research may lack direction and priority, small industry may lack technological capability and both may lack sufficient understanding of practical problems of local users. As wind-energy programmes or centres are developed they should be implemented in a manner to ensure close ties and effective communication between these three groups.

Education and Training

This includes advisory and consulting services for decision-makers, provision of skilled rural extension workers with relevant knowledge, and provision of wind-energy specialists and specialists qualified to train others. Help from international agencies as well as efforts at the national level can help improve the situation in several ways (Ref. 36i) :

- international agencies, particularly those of the United Nations should provide advisory and consulting services for decision-makers.
- national training courses must be arranged for extension workers to equip them with relevant knowledge and skills in wind pumping.
- provide specialists in (a) data collection and intepretation and site prospecting, (b) system design, engineering and management, (c) system analysis and economic feasibility, and (d) system operation

and maintenance. To meet these requirements it may be necessary to

  - establish national or regional training centers
  - introduce these subjects in the curricula of universities and technical training schools
  - provide practical training through fellowship.

- develop curricula and supporting text books and lecture notes for universities and technical schools.

Information Flow

There is need for sufficient, detailed wind resources data. Meteorological services can be encouraged to augment their wind measurement activities and to take account of the special needs of wind energy. Wind resource surveys along with preparation of wind energy maps for suitable sites can be of immense help (Ref. 36j). In spite of the proliferation of information services, access to reliable information is a major problem in the developing countries. Action to strengthen user access to the existing services, e.g., by the compilation and updating of directories and production of a wind energy newsletter for developing countries, is required. In particular, information should be made available on (Ref. 36j) :

- availability and capability of analytic tools, handbooks, etc. For example, there is need for a handbook which would guide the local user, if wind velocity pattern, water table and water requirements are known, to select a windmill that can be manufactured using local technology
- catalogue and equipment information
- equipment performance standards; test methods and testing services
- design and consultancy services
- training services
- manufacturing processes, including blueprints, licences, patents and know-how.

Finance

Although wind energy conversion systems are capital-intensive initially, they become cost-effective over a period of time. It is therefore essential to device suitable financial packages, including low-interest rate loans and subsidies to accelerate the pace of utilization of wind energy. Hence, the need for (Ref. 36k) :

- international technical assistance in wind energy to facilitate funds for financing institutions, technical services and training in developing countries.
- national and international funding of rural development programmes to include concessional credit facilities for wind energy for subsistence farmers and isolated communities.
- government measures to assure sensitivity of local financing institutions to the needs of wind energy users.
- international lending institutions to be urged to include financing of medium-scale and large-scale wind power projects on their merits when financing rural electrification projects.
- government should ensure that wind energy projects and equipment receive equitable treatment, in terms of subsidies, with other forms of energy.

Areas of additional effort (Ref. 23d) :

Information Dissemination and Activity Coordination

- publishing and dissemination of :

  windmill plans

  translation of available information and plans for technical information on wind system components

  addresses of contacts and places with information relevant to windmill utilization information on energy storage systems for windmills

- cooperation among and coordination of wind energy activities
- publicity of wind energy activities
- standardization of testing results
- center for distributing information on wind energy programs and projects.

Research and Development

- design improvement and development of new designs:
    cheaper designs
    improved windmill-pump matching
    more reliable designs
    designs that can be more easily built locally
    water pumping windmills
- design evaluation
- windmill project evaluations :
    economic analyses of projects
    overall evaluation of projects for strengths and weaknesses
- wind resources information :
    resource survey and wind data
    methods for predicting missing wind data
- feasibility studies

Programme Implementation

- windmill demonstration projects
- skilled personnel to work in implementation efforts

  skilled personnel capable of long-term project involvement
- funding for implementation-related programs

- governing financing encouragement of windmill utilization
- courses and implementation work in developing country schools (e.g., agricultural training schools)
- training effort in windmill construction, operation, maintenance and repair (possibly through workshops)
- prototype building and field testing
- windmill manufacturing in developing countries
- coordinated follow-up of projects for technical adjustments and management of future production
- advice for questions related to specific windmill implementation efforts.

Conclusion

A preliminary wind resource inventory should be undertaken as soon as possible in all countries having some wind energy prospects. Those countries having some prospects for wind energy should designate a national focal point for wind-energy policy-making, planning and implementation, within an appropriate department of Government (planning, finance, energy or rural development) or an agency nominated by Government. Socio-economic system studies indicate that small wind-powered water pumping systems are quite appropriate for irrigation in small farms, even in comparison with other renewable energy sources. Hence wind-powered pumps should be included in rural development programmes wherever local conditions are favourable. Because of the importance of creating national (and in certain cases subregional) centres for wind-energy technology, international assistance, through the United Nations system and other agencies active in the field, be given to countries wishing to establish such centres. Training courses should be established on a permanent basis at one or more suitable advanced wind-energy centres or other appropriate institutions. In view of the present initial use of wind power and the anticipated potential for rapidly expanded use, national focal points, wind-energy centers and appropriate international organizations should develop active information programmes to provide prompt, accurate and useful information and related material on development, technique and experience to potential users, decision-makers and other interested parties.

It is essential to devise suitable financial packages, including low-interest loans and subsidies to accelerate the pace of utilization of this energy resource.

Use of small windmills in large number in the rural areas of developing countries is feasible and it is now time to make definite commitments backed up by adequate infrastructural facilities and financial support.

/RHM

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ANNEXURE I

The Beaufort Wind Scale

Description	Kilometers per hour	Miles per hour	Specifications for estimating speed over land
Calm	1	1	Calm; smoke rises vertically.
Light air	1 5	1 - 3	Direction of wind shown by smoke-drift but not by wind vanes.
Light breeze	6 11	4 - 7	Wind felt on face; leaves rustly; ordinary vanes moved by wind.
Gentle breeze	92 - 19	8 - 12	Leaves and small twigs in constant motion; wind extends light flag.
Moderate breeze	20 - 28	13 - 18	Raises dust and loose paper; small branches are moved.
Fresh breeze	29 - 38	19 - 24	Small trees in leaf begin to sway, crested wavelets form on inland waters.
Strong breeze	39 - 49	25 - 31	Large branches in motion; whistling heard in telephone wires; umbrellas used with difficulty.
Near gale	50 - 61	32 - 38	Whole tree in motion; inconvenience felt when walking against the wind.
Gale	62 - 74	39 - 46	Breaks twigs off trees; generally impedes progress.
Strong gale	75 - 88	47 - 54	Slight structural damage occurs (chimney-pots and slates removed).
Storm	89 - 102	55 - 63	Seldom experienced inland; trees uprooted; considerable structural damage occurs.
Violent storm	103 - 117	64 - 72	Very rarely experienced accompanied by windspeed damage.
Hurricane	118 and over	73 and over	

ANNEXURE II

Typical Design and Performance Parameters for Major Windmill Designs Based on Past Windmill Installations (Ref. 23)

Windmill design	Rated power, kw	Rotor diameter, m	Operating velocities, m/sec			Tip-to-wind speed ratio	Coefficient of performance	Applications		Estimated lifetime, years
			cut-in	rated	furling			primary	secondary	
Vertical axis										
Savonius rotor	0.03 to 0.37	0.9 to 12	0.9 to 4	4.2 to 8.9	-*	≤ 1.75	0.14 to 0.23	water pumping	mechanical power, electricity generation	-
Sail	-	≤ 10	-	-	-	-	-	water pumping	mechanical power	5
Darrieus rotor	1 to 230	3.7 to 24.4	3.1 to 5.8	6.9 to 14.8	17.9 to 35.8	2 to 9	0.2 to 0.4	electricity generation		-
Horizontal axis										
Sail	0.06 to 5	3.4 to 10	1.6 to 2.9	2.2 to 5.4	4 to 9	0.84 to 4.5	≤ 0.45	water pumping	electricity generation, mechanical power	10 to 20
Multi-vane	0.04 to 7	1.4 to 9.1	1.8 to 4.5	4.4 to 12.5	8.9 to 33.5	≤ 3.5	0.15 to 0.28	water pumping	mechanical power, electricity generation	5 to 40
Medium-speed	0.1 to 45	1.0 to 10.2	2.2 to 5	4.3 to 11.2	9 to 18	1.8 to 4.5	0.15 to 0.35	water pumping	electricity generation	5 to 40
High-speed	0.4 to 1,250	0.61 to 53.4	2.7 to 6.3	5.8 to 16.5	11.1 to 67	2 to 16	0.18 to 0.47	electricity generation	water pumping	5 to 20

*No entry indicates that no information on this parameter has been located in the literature.

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ANNEXURE III

Type	*Fabrication technology*	*Initial cost*	*Maintenance*	*Control*	*Life*	*Typical application*	*Rated wind-speed*	*Diameter*
1. Slow-speed rotors								
1a. Greek sail rotor	Local	Low	Regular local	Manual	Medium	Water pumping	Low, medium	Up to 10 m
1b. Multi-vane rotor	Medium (as now made)	Medium	Trained personnel	Automatic	Long	Water pumping	Low, medium	Up to 8 m
	Could be local	Low	Local	Semi-automatic	Medium	Water pumping	Low, medium	Up to 6 m
1c. Savonius rotor	Local	Low	Local	Nil	Medium	Water pumping	Medium, high	Up to 3 m
1d. Chinese vertical-axis rotor	Local	Low	Regular local	Manual	Medium	Water pumping	Low, medium	Up to 10 m
2. Medium-speed rotors								
2a. 4-blade cambered metal plate rotor	Medium technology or local	Medium	Low, trained personnel	Automatic or semi-automatic	Long Medium	Water pumping	Medium	Up to 6 m
2b. Princeton sailwing rotor	Local, medium or high	Low, medium	Regulrr, trained personnel	Automatic	Medium	Water pumping, electricity	Medium, high	Up to 8 m
3. High-speed rotors								
3a. 3-blade rotor	Local wood or metal	Low	Regular local	Automatic	Medium	Electricity, water pumping	Medium, high	Up to 5 m
	Fibreglass reinforced plastic	Medium	Low, trained personnel	Automatic	Long	Electricity	Medium, high	Up to 10 m
3b. Darrieus rotor	Extruded aluminum or fibreglass reinforced plastic	Medium	Low, trained personnel	Automatic	Long	Electricity	High	Up to 24 m
4. Very-high-speed rotors								
4a. 2-blade rotor	Metal or fibreglass reinforced plastic	High	Low, trained personnel	Automatic	Long	Electricity	High	Greater than 10 m
4b. 1-blade rotor	Metal or fibreglass reinforced plastic	High	Low, personnel trained	Automatic	Long	Electricity	High	Greater than 10 m

Practical aspects of some rotors
(Ref. 6)

ANNEXURE IV

Pump Characteristics (Ref. 6)

Pump type	*Range of head* *Suction (m)*	 *Discharge (m)*	*Efficiency (percentage)*	*Starting torque*	*Speed (rev/min)*	*Typical material*
Piston	7	100	80	high	30	metal
Turbine	5	100	90 max.	low	1,400–2,000	metal
Ladder	0	3	35	medium	80	wood
Wood chain	0	4	50	medium	80	wood
Steel chain	0	30	50	medium	80	metal
Screw	0	5	60	low	30–400	wood
T-pump	7	0	60	low	400	metal
Inertia	0	4		low	80	metal
Piston	10	30	80	high	30	metal
Diaphragm	7	30		high	30	metal, leather
Rope and bucket	0	50	90	high	2	cloth, leather, metal
Double-acting piston	7	100	85	high	30	metal, plastic
Peristaltic	1.5	10	70	low	100	5-12 cm plastic, rubber
Paddlewheel	0	0.5	20	low	80	wood
Persian wheel	0	50	50	medium	4	metal
Spiral wheel	0	1	60	low	60	wood
Propeller	0	7	60	low	400–2,000	metal