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EXPERT GROUP MEETING ON DESIGN,
DEVELOPMENT, MANUFACTURE AND APPLICATION OF
WINDMILL IN ENERGY GENERATION ENGINEERING



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TECHNICAL PAPER

SMALL AND LARGE SCALE APPLICATION OF WIND POWER

STATUS AND PROSPECTS

PREPARED BY

PAUL CORNELIS HENSING

Beberapa orang di kantor ini juga pernah

SMALL AND LARGE SCALE APPLICATION OF WIND POWER,
STATUS AND PROSPECTS.

Ir. P.C. Hensing,
Management Consultant,
Nassaulaan 27,
1213 BA HILVERSUM
The Netherlands.
telephone: 035-231908

1. Current and perspective activities and specific problems in the application of wind energy.

1.1. Introduction

Wind energy has been in use for thousands of years. The application of sails for propelling boats is nearly 3000 years old and early windmills for pumping water appeared 1700 years ago in China and the Near East.

In the 13th century transfer of the windmill technology took place to Western Europe, where these machines were applied to provide mechanical power and pumping water.

The dissemination of this technology progressed until the 19th century. In Holland at that time 10.000 windmills were in operation.

The application of this technology declined after the appearance of alternative systems like the steam engine and the internal combustion engine.

Mainly due to the oil crisis in 1973 a revival of interest for this ancient technology could be observed, which has been stimulated further by environmental problems and the threat of climate change related with conventional power production.

During the last 15 years enormous progress has been made in the development of modern wind turbines for electricity generation.

From this development new stimuli arose for further development of other applications like wind pumps.

The development of wind energy is to a large extent subject of political decisions.

The large scale grid connected wind farms cannot compete yet with conventional plants, but they provide clean and fuel-independent energy.

They certainly will be part of a modern pollution-free electricity production scheme.

The small scale application is also dependent of politics.

It has the potential of a high quality electricity production system in areas where the connection to the grid is very expensive. Yet governments are considering installation of big and expensive infrastructures. It must be emphasized that the funds involved are much more efficiently spent to decentralized ways of generation.

This paper aims to give a survey on the wind energy activities in the world and to describe the present status and perspectives.

1.2. Windturbine applications.

Mainly two groups of application can be pointed out, viz.

- * Grid connected windturbines generating electricity for national and regional grids as well as mini-grids in remote areas.
Most of the technical developments of the past years were directed to this application.
Starting with machine ratings around 50 kW new designs were up-graded until 5 MW.
This group of applications comprises also combinations like wind-diesel, wind-solar-diesel and wind-hydro systems.

- * Off-grid applications like battery chargers and wind pumps.
The technology development of these types is not very much affected by the events which caused the renewed interest in grid connected windturbines, although spin-offs can be observed yet.
In the following sections the market for each of these applications will be surveyed, the state of the art of the technology will be described, as well the current R & D activities.
The specific problems related to the dissemination of each of these applications will be highlighted.
An overview of the state of the art of the various wind turbine applications is presented in table 1. [1]

1.3. Off grid applications.

80% of the population of the developing countries lives in rural areas, 80% of them do not have a connection to the grid.

Estimates for 2025 show that about 2 billion people will not be connected to the grid.

	Rotor size (diameter)	Number of turbines installed	Number of manufacturers	Investment costs (\$/sqm)	kWh costs (\$/sqm kWh)	Technological phase
Battery chargers	<5 m	>100,000	50	\$200-500 without tower	-?	Commercially available
Water pumps	<5 m multi-bladed	1,000,000	50 (Local production)	\$400/m ² classical type \$200/m ² modern type	\$1-3/kWh _z * \$0.25-0.75/kWh _z *	Classical type commercially available, modern type in development
0-100 kW	<20 m	>10,000	50	\$600-1000/kW	0.05-0.10	Commercially available
100-300 kW	20-30 m	>2,000	20	\$800-1200/kW	0.05-0.10	Commercially available
300-750 kW	30-40 m	>100	20	\$1000-1500/kW	0.05-0.10	Ready for mass production
>750 kW	>40 m	24	10 (not commercial)	Commercially not yet available	-	Only prototypes available

* 1 kWh_z is the amount of energy needed to pump up 367/z m³ over a height of z meters.

Table 1 : Overview of the state of the art of wind turbines for different applications.

With a population density smaller than 2 people per km² connection costs amount more than \$ 5,000 per connection. This implies that a huge market potential for small off-grid wind turbines and wind pumps exists.

Remarkable for this market is the absence of economical constraints which are related to the competition with large scale power generation.

The energy costs of this machines may amount up to 3 \$/kWh.

Battery chargers

Battery chargers are commercially available in many countries. Also in China these machines are produced in big numbers.

These turbines are small : diameter smaller than 5 m and capacity between 40 and 150 W.

Most of the machines have two blades or three blades, variable pitch, high tip speed ratio, which makes the use of a gear superfluous and a permanent magnet generator. Fig. 1 shows a typical example of a battery charger.

The technology is mature and reliable.

The lifetime of these machines is over 10 years. Only in China more than 100,000 battery chargers are in use and a market potential of 1,000,000 of these machines is pointed out.

In the rest of the world an equal potential is estimated. That means that in 20 years the market demand is about 100,000 battery chargers per year without considering the replacement market.

The main production is located in China, where in 1990 30,000 machines per year were produced.

New markets have developed in Argentina, Brazil, New Zealand and Morocco.

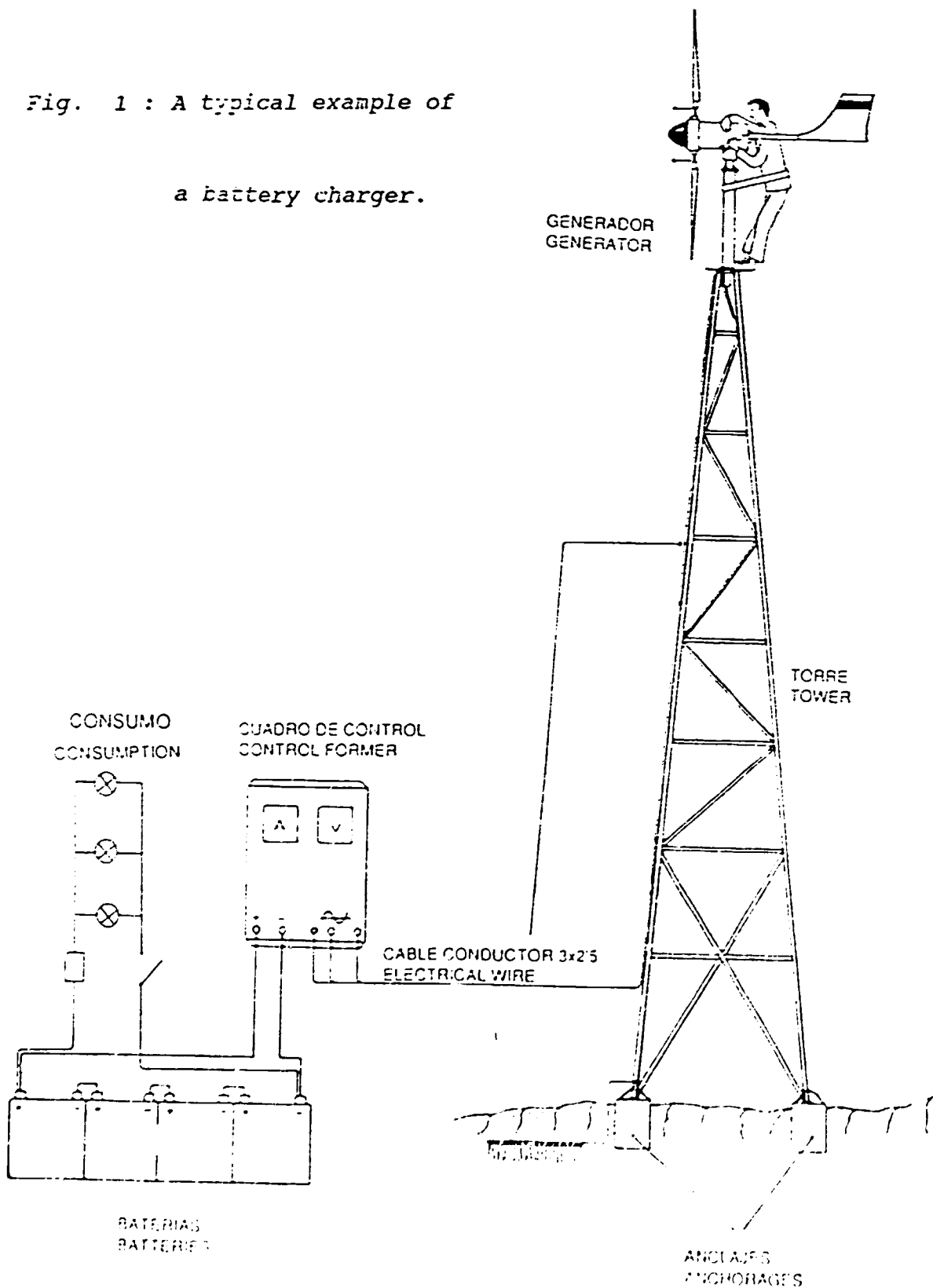
The markets in the U.S. and Europe have decreased sharply in 1987.

Fig. 2 presents an overview on the number of shipments of these machines until 1987. [2]

Further dissemination of this wind energy application does not seem to meet problems.

That this market is very sensitive to private income fluctuations appears from fig. 3 where a sharp decrease of purchased units can be observed due to the lower wool prices.

Fig. 1 : A typical example of
a battery charger.



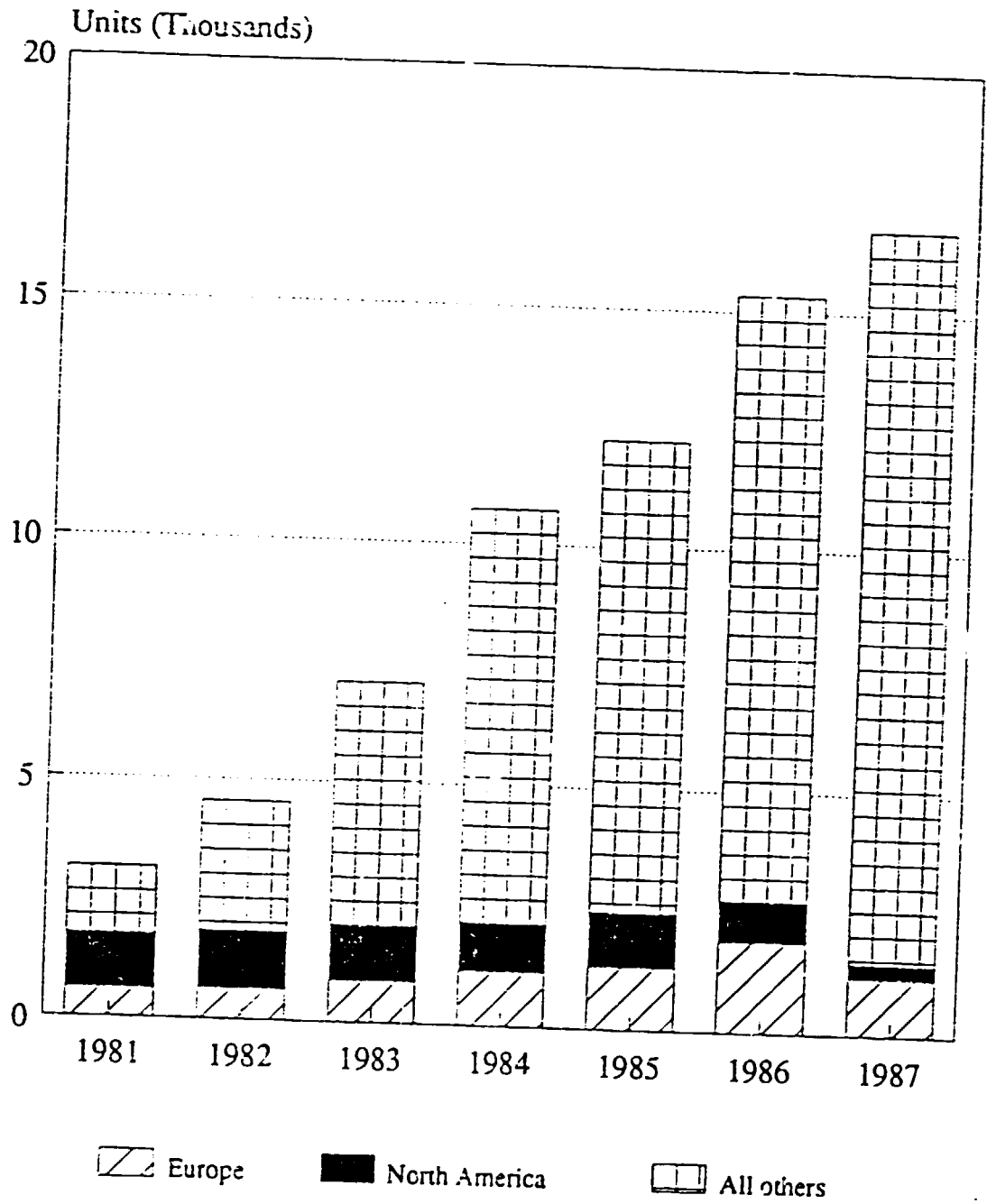


Fig. 2 : Shipments of battery chargers. [2]

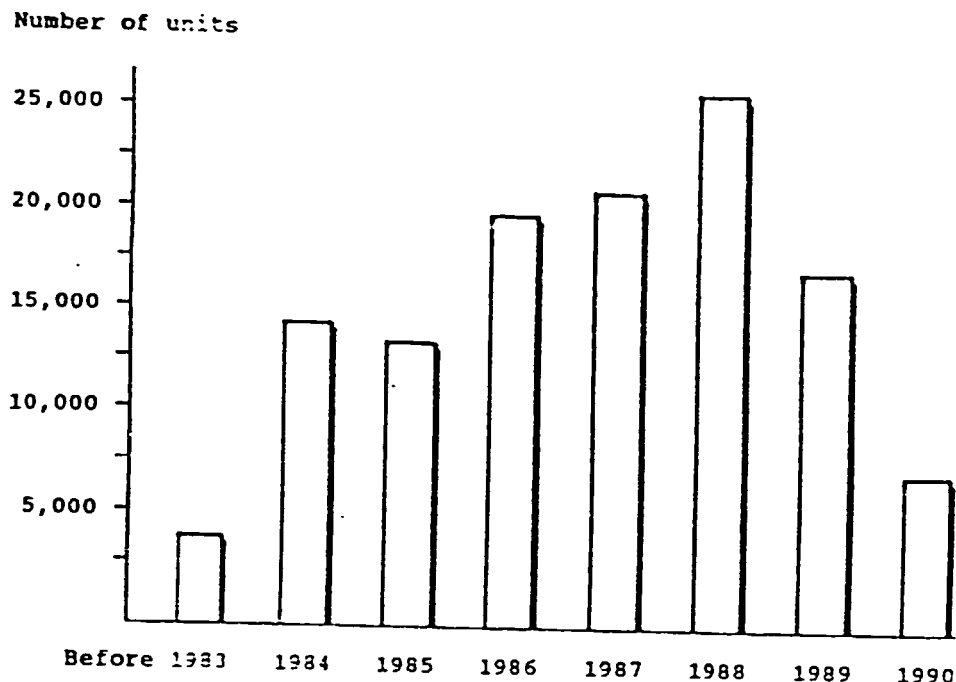


Fig. 3 : Shipments of battery chargers in China. [3]

Wind pumps.

Worldwide nowadays about 1,000,000 wind pumps are operational, 300,000 of which in the African countries (South Africa, Botswana, Namibia and Zimbabwe) and 600,000 in Latin America (mainly Argentina).

This technology came up in the U.S. in the 19th century. Application was mainly meant for domestic and livestock water supply for remote farms.

Also in Australia wind pumps were developed with the same purpose.

The technology diffused later on mainly in Africa and Latin America, where wind pumps also were applied for small scale irrigation.

The classical wind pump has a multi-bladed, fixed pitch rotor, a low tip speed ratio and therefore high torque characteristics at low winds.

The rotor diameter is generally less than 5 m.

Fig. 4 shows a typical example of a windpump.

CWD 2000

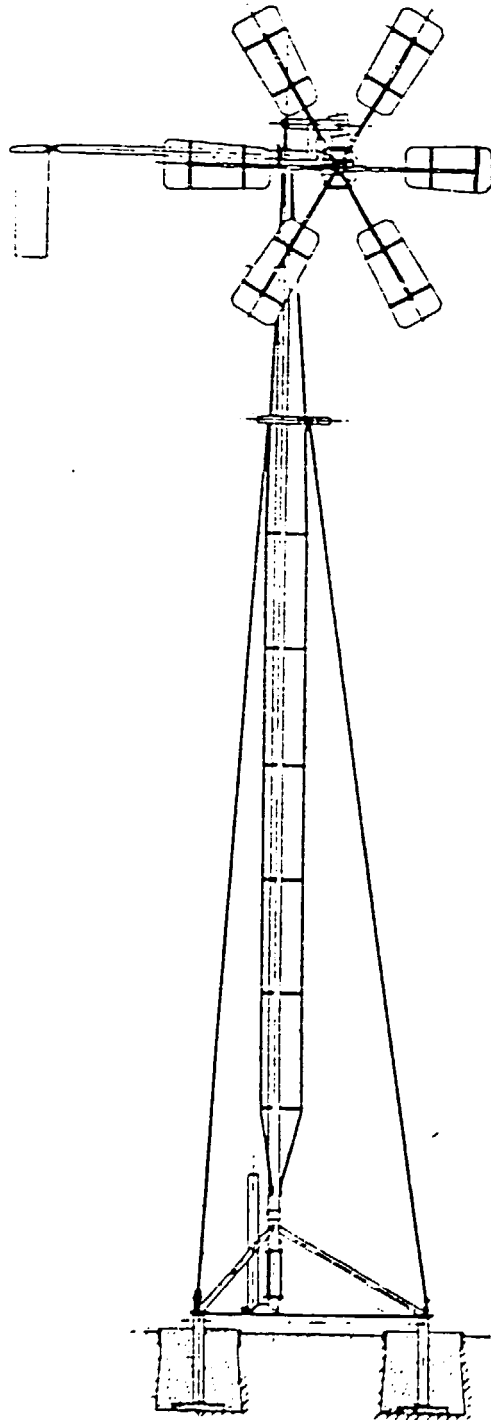


Fig. 4 : A typical example of a wind pump.

In the 1950s and 1960s the number of wind pumps decreased suddenly due to the availability of cheap fuel world wide and the decrease in price of the small engine driven pumps.

Recent installation rate is about 10,000/year, mainly produced in Australia, Argentina and the U.S..

The world market potential is estimated at 100,000/year. In fig. 5 a schematic view of the market is given. [1]

Since the relatively high costs of the classical wind pump seems to prevent further dissemination, modern wind pumps are currently in development which can be produced for 50% of the costs.

Application of high speed piston pumps is considered which makes the use of a gear between rotor and pump superfluous. Also higher tip speed ratios are considered. This new technology is however not mature yet.

Furthermore lack of funds prevents the set-up of mass production in the developing countries, which is a necessary condition to obtain further cost reduction.

The dissemination process can be stimulated by the following steps :

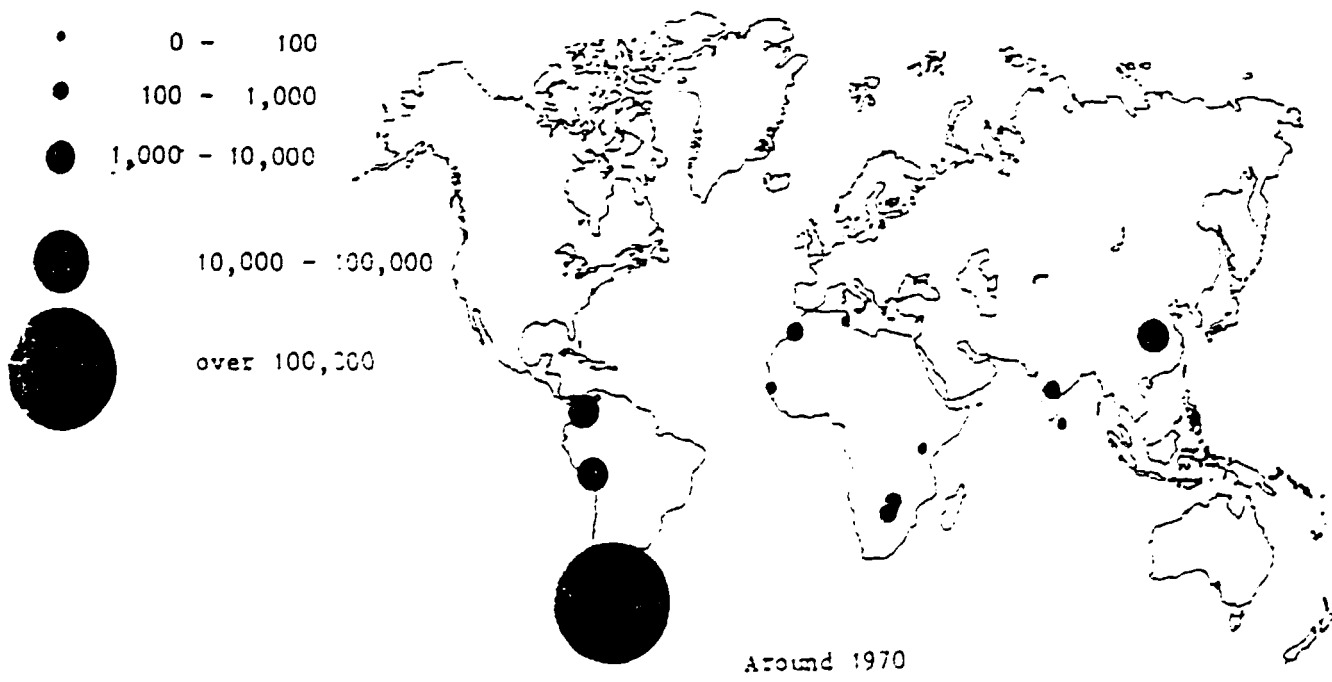


Fig. 5 : A schematic view on the market of wind pumps. [1]

- Establishment of a central project guidance and evaluation organization.
- Stimulation of the private sector to establish joint ventures or other collaboration structures in order to transfer and to develop technology and to create an industrial infrastructure for production and maintenance by locating existing facilities and necessary improvements.
- Stimulation of the market by giving credits or subsidies to purchasers. Because prices will become lower with increasing production volumes, subsidy is only needed during the market introduction phase. Also soft loans and lease arrangements can be considered.
Funds has to be raised with the World Bank and financial support can be obtained from technology exporting countries and communities.
Further dissemination of wind pump technology is difficult because new technology is involved ; it is easy because generally no other market interfering conditions are present like physical planning and environmental constraints.
In [15] an overview is given of implementation, sizing and economy of wind pumps.

1.4. Grid connected wind turbines.

Market

In this section wind farms are considered as well as small scale applications for regional and mini-grids and wind-diesel combinations.
The development of grid connected windturbines got new impulses by the oil crises in 1973 and 1979. Real markets arose in the early 1980s in the U.S. by legislation and tax credits.
Starting with 50 kW machines in 1981 the average rating in 1987 was 110 kW and in 1990 160 kW. Nowadays machines with a capacity of 250 till 500 kW are commercially available and produce electricity with the lowest price of all wind energy options.
In 1986 the Californian market declined due to the expiration of tax credits.
Since then the market shifted gradually to the Western European countries as Denmark, The Netherlands and Germany.
The preparation and implementation of environmental plans accelerated the wind energy market development further. In the plans the utilities are forced to diminish their emissions of NOx, SOx and CO2.

In 1990 about 2000 MW was installed, 1500 MW of which in the U.S. and 450 MW in Western Europe. Present installation rate is 300 MW/year (150 MW in the U.S., 150 MW in Western Europe). A recent study revealed that the market potential world wide for wind farms until the year 2020 amounts 450,000 MW. This is about 4.5% of the real wind potential on shore (excluding areas with annual mean wind speed smaller than 5.1 m/s) and supplies about 3.5% of the estimated electricity consumption in 2020.

Region	Electricity Use 1987 (TWh)	Annual growth (%/yr)	Electricity Use 2020 (TWh)	Potential Wind Capacity (GW)	Wind Penetration 2020 (GW/TWh)
North America	2,890	2	5,740	2,360	175
Latin America & Caribbean	525	4	1,315	1,000	11
Western Europe	2,101	2	4,035	535	55
Eastern Europe & USSR	2,046	3	5,421	2,090	57
Middle East & North Africa	271	5.9	1,798	930	12
Sub Saharan Africa	210	2.7	505	2,170	9
Pacific	1,371	2.4	3,032	355	33
Central & South Asia	570	4	3,177	400	48
Total	10,925	2.8	25,925	10,400	451

Table 2 : Electricity consumption and wind energy penetration by region. [1]

The results of this study are summarized in table 2 [1].

A penetration of 10% of the electricity demand is expected to be problemless with respect to the grid. For the year 2000 the market potential is about 10,000 MW in the U.S. and Western Europe and about 5,000 MW in the rest of the world.

stimulation programs R & D and market introduction.

The present wind turbine technology is the result of an effort of 18 years. From 1973 the national R & D budget for renewables increased dramatically. Between 1973 and 1979 the R & D activities were in a definition phase : development of data bases and methodology, implementation of R & D programs and development and demonstrations of components and systems.

In the 1980s more selective and well-defined programs were carried out and a shift of governmental granting to market introduction was observable.

Fig 6 shows the development of the total R & D budgets during the years. [4]

In the U.S. tax incentives created an explosive growth. In Denmark the market developed rapidly after legislation changes which resulted in 30% subsidy on investment costs.

This subsidy is terminated now, but other measures are still present as favourable pay-back rates (85% of the consumer rates), exemption from electricity tax and subsidy on grid connection costs.

In the Netherlands also subsidy on investment costs is given (50% in 1986 declining to about 30% in 1991). In Germany wind turbine owners received a pay back rate which amounts about 95% of the consumer rate and also this market is developing very rapidly.

Also the CEC has various stimulation programs, both directed to technology development and market introduction. The results of these stimulation measures are clearly visible.

The installed capacity grew up to 1950 MW in the Western European countries and the U.S..

The performance of the machines was improved with the factor 2 till 3 (see fig. 7, explanation see sec. 3.3.1.)

The availability of the best turbines increased from 60% till 95% (see fig. 8).

The machine costs decreased from 3000 \$/kW in 1981 till 300 \$/kW in 1987 (see fig. 9).

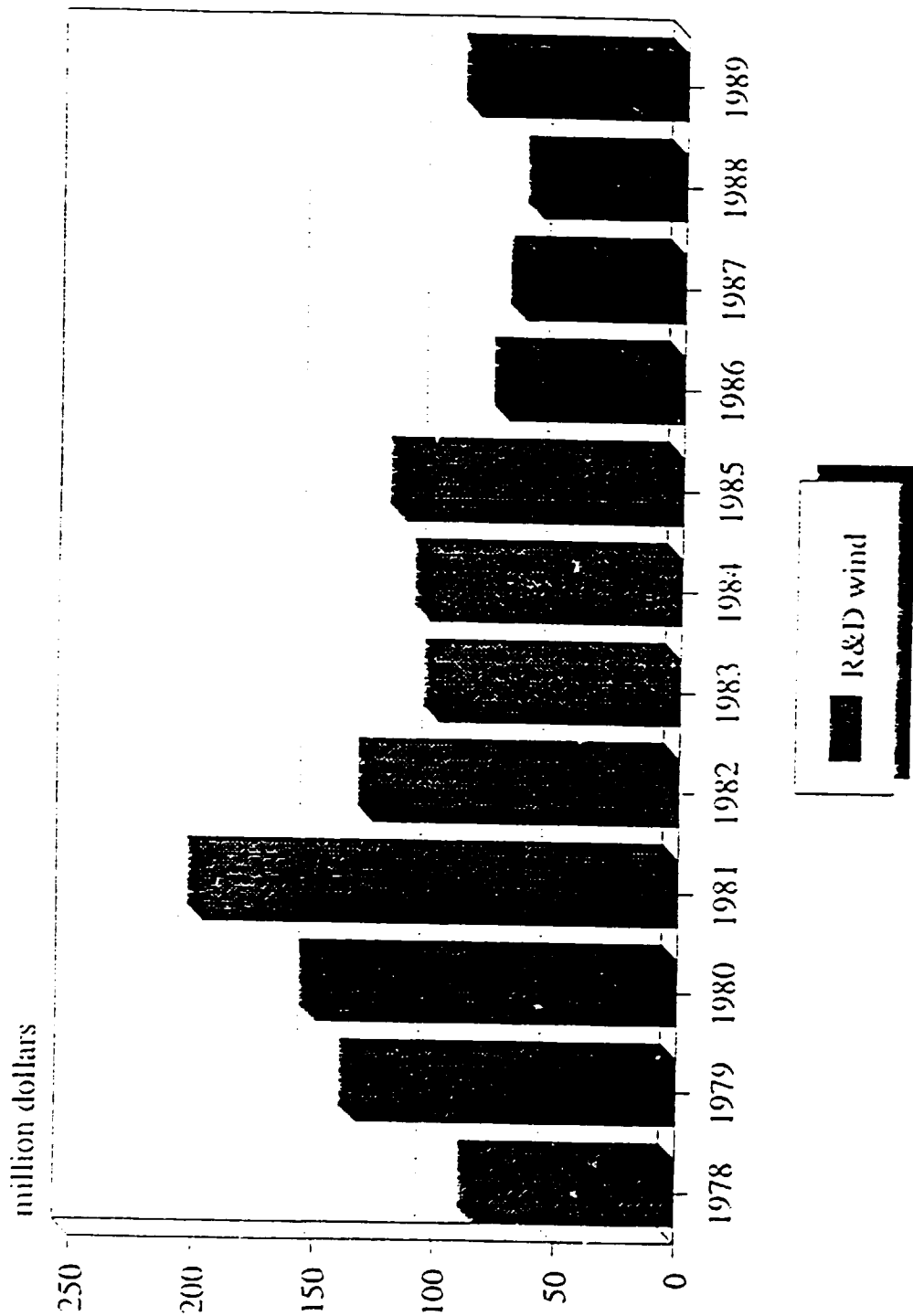


Fig. 6 : IEA government R & D expenditures for wind energy. [4]

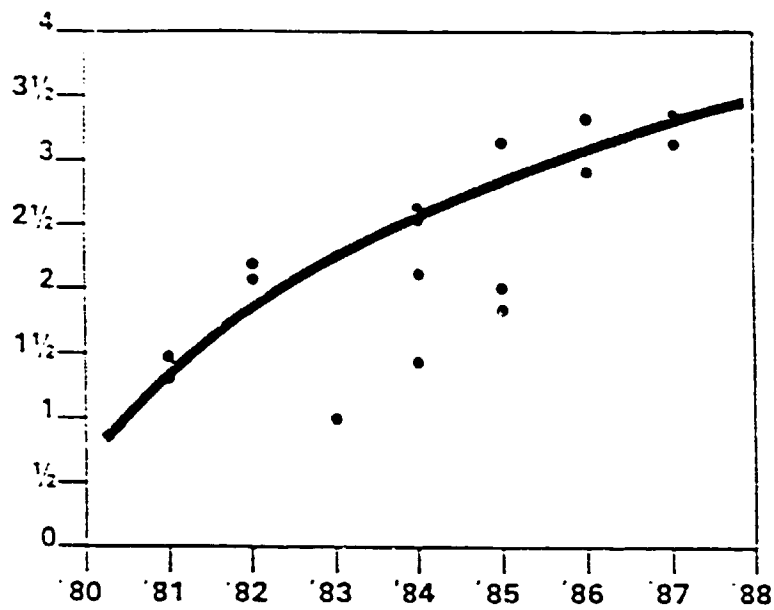


Fig. 7 : The development of the performance factor of wind turbines. [1]

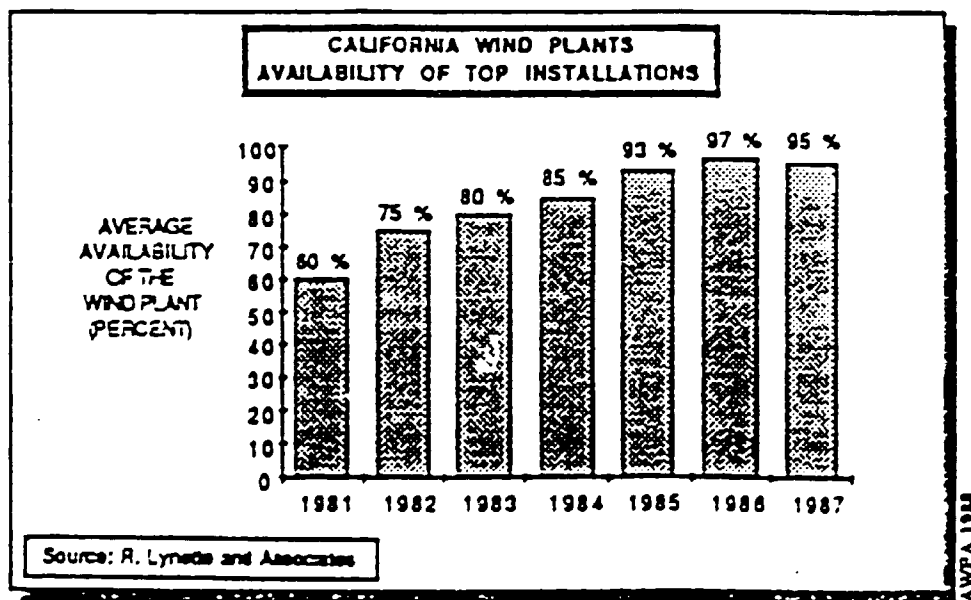


Fig. 8 : Availability of the best wind turbines in California.

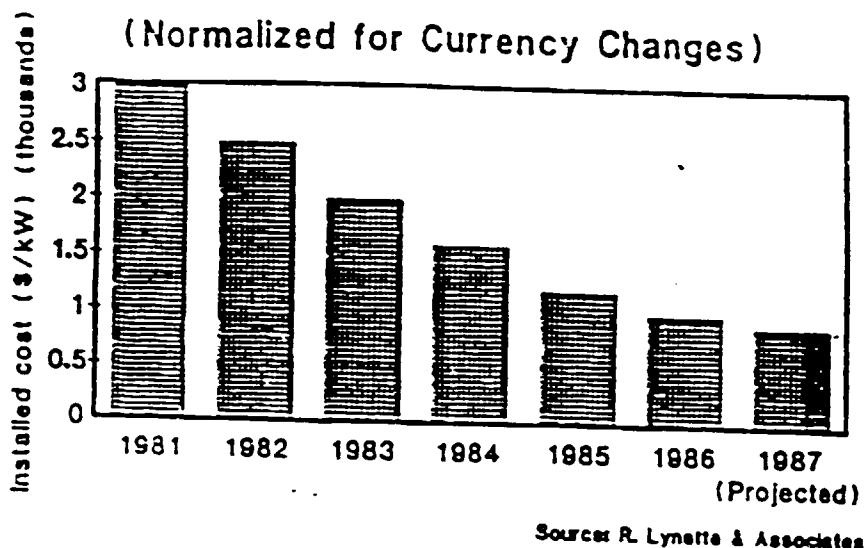


Fig. 9 : Development of turn-key costs of American Wind-plants.

Constraints and possible solutions.

Although not very much developing countries are considering implementation of large wind farms (exceptions India, China) on a short term, it is realistic to assume that these countries will apply this option within 30 years.

In the study [1] a significant part of the potential for the year 2020 is located in these countries.

For the western industrialized countries other constraints are present than in the developing countries. The main problems for the industrialized countries with implementation of large wind farms are:

1. The price of wind energy is in certain areas competitive with conventional generation, but in large parts of Western Europe it is not. Countries like Denmark, The Netherlands and Germany will need therefore continuous governmental support for further development of the market. The wind energy generation costs amount in these countries about \$ 0.10/kWh. The avoided fuel and capacity costs amounts about \$ 0.045-0.05/kWh.

These figures should suggest that wind energy is in these countries far from economically attractive yet.

However, in the calculation of the avoided costs no value is attributed to the avoided emissions of SOx, NOx and CO2.

Several studies are carried out to quantify these costs and other hidden external costs. The results of [5] indicated that the difference in external costs for electricity generated by conventional plants and electricity generated by wind turbines ranges between 0.05 - 0.09 \$/kWh.

So wind energy is one of the cheapest ways of energy generation today, also in regions with moderate wind speeds like Denmark, Germany and the Netherlands.

In order to avoid delay of the market development of wind energy it is necessary to make clear what the real costs of conventional generation are.

The external costs have to be implemented in the generation costs as taxes. Carbon tax is already in discussion in several countries. However, no method is at this time available and accepted to calculate these costs.

- 2. In the densely populated Western European countries constraints with respect to environment and physical planning are strongly felt.

From the environmental point of view noise and bird life interference are the issues as well as visual impacts. Investigation on bird life interference does not reveal dramatic results so far.

It appeared that the collision risk per km farm length is in the same order as motorways and one tenth of the risk involved with high voltage transmission lines. Also loss of biotope seems to be very limited. Nevertheless further investigations are necessary to confirm these early findings.

Noise is probably the most severe limitation in densely populated areas.

The development of silent wind turbines is therefore one of the main issues in the manufacturer's development programs.

Visual impact can be diminished by proper location selection. Large scale industrial areas as well as large scale agricultural areas seem to be suitable.

Line set-ups generally are appreciated better than clusters.

Physical planning problems are felt in difficult procedures for building permits. New legislation is needed to force physical planning authorities to adapt their infra structure to include wind power. In the mean time covenants should be established.

For the developing countries the major constraints with respect to the dissemination of wind farms are lack of funds, lack of technology and lack of industrial infra structure for production, maintenance and further development. Besides the constraints which are mentioned to be felt by the industrial countries are more or less applicable.

In my view next steps have to be taken:

- 1) Establish a central project guidance and evaluation organization.
- 2) Clean up the project development obstacles; establish pay-back rates, solve problems related to land use regulations, licensing. Shortly : show a market perspective on the short run.
- 3) Establish joint ventures or other collaboration structures between local industries and foreign industries which have the technology for structuring local production, maintenance and further development.
- 4) Establish partnerships for project financing, make use of the foreign industries involved as an intermediate for financing and their governmental and community export support and funds for developing countries.

Transfer of technology is also a problem in the industrialized countries between the scientific research institutes and the manufacturers. The only feasible way to solve this problem appeared so far to be stimulation of collaboration of both parties in concrete projects. The real value is in the people, not in books and reports.

Regional and mini-grid application, wind-diesel.

So far not very much has been said about the small scale application for regional and mini-grids and wind-diesel, the latter being very interesting for remote communities and villages. Only a few numbers of W/D systems is installed so far. No numbers are known with respect to the market volume.

In Argentina 1.1 mio. people will not ever have a connection to the grid due to the high connection costs in the remote areas involved (especially Patagonia). With no other means of electricity generation these people will move out of these areas, which will lead to desertification.

Also African countries and vast areas in Eastern Europe and China have large market potential as well as the island regions of Asia.

The main problem in the dissemination of W/D systems is the poor matching of electricity consumption (mainly in the evening hours) and wind availability (mainly on-day).

Without storage facilities this will remain the most important constraint.

Further problems involved in the dissemination of W/D systems are lack of funds and the new technology involved.

The term new technology does not concern new components, but dimensioning and configuration of standard components for a design, which is the best fit to the local conditions (wind speed distribution, load distribution, etc).

These standard components however need an industrial environment which is in many cases not present. The same problems as with wind farms can be pointed out.

The IEA is preparing a guide book about siting and implementation of W/D systems and the CEC is funding the development of a software package, with which the economy of systems for various local conditions can be investigated.

Further dissemination can be stimulated by the same measures which are mentioned with respect to wind farms.

2. Assessment of wind energy utilization.

2.1. Grid-connected wind turbines.

Although in the former session some figures are already presented, in this session the assessment will be considered in more detail on the basis of the study [1]. The results are valid for large scale grid-connected application.

In fig. 10 the methodology of this study is schematized.

The several steps will be considered below:

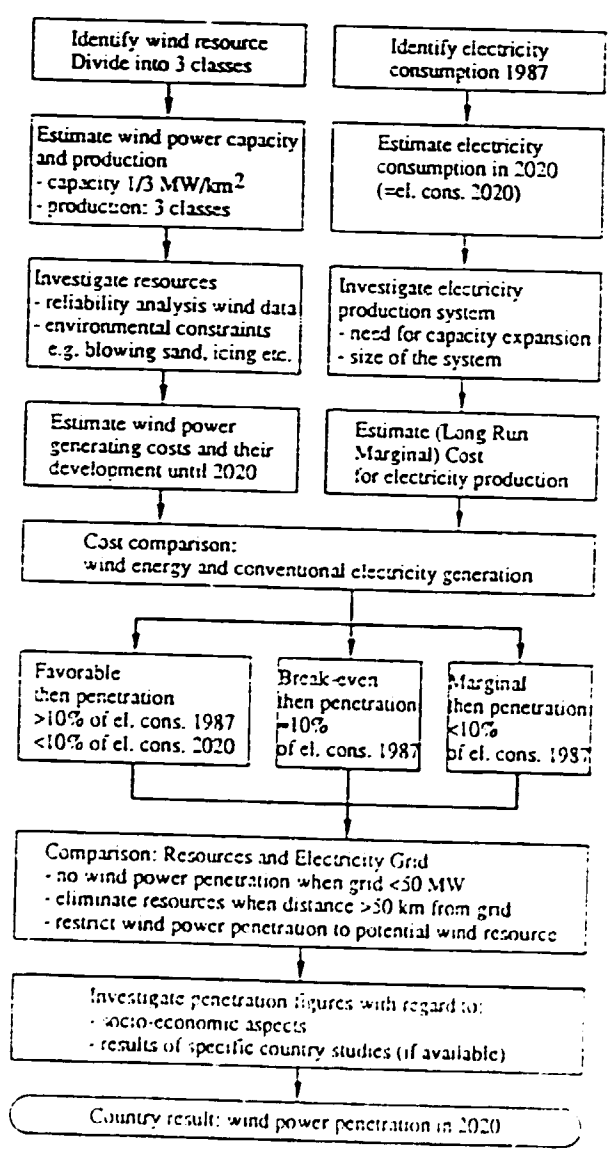


Fig. 10 : An outline of the methodology used to identify the wind power penetration per country for the year 2020.

Wind resource.

The world's resource of wind is indicated at the map presented in fig. 15. This map was conducted by Pacific Northwest Laboratory, U.S. and based on data from [6].

From this study it can be estimated that 25% of the earth's land surface (= 0.25x120 million km²) is exposed to an annual mean wind speed larger than 5.1 m/s at 10 m above the surface.

With the assumption that about 0.33 MW wind turbine capacity can be installed per km² with an estimated average production of 2,000 MWh/MW/year, the global potential on shore can be estimated at 2.3 TWe with an installed capacity of 10,000 GW. For comparison the world's electricity consumption in 1987 was 1 TWe.

In table 3 a specification is given over the six continents of the 30 million km² which is exposed to wind speeds higher than 5.1 m/s.

Continent	Class 5-7		Class 4		Class 3	
Africa	200	1%	3,350	11%	3,750	12%
Australia	550	5%	400	4%	850	8%
Asia	200	1%	450	2%	1,550	6%
North-America	3,350	15%	1,750	8%	2,550	12%
South-America	950	5%	850	5%	1,400	8%
Europe including USSR&Greenland	3,100	10%	2,750	9%	3,550	12%
Total	8,350	6%	9,550	7%	13,650	10%

Table 3 : The world's resource of wind energy. [1]
 Class 3 : annual mean wind speed between 5.1 and 5.6 m/s.
 Class 4 : annual mean wind speed between 5.6 and 6.0 m/s.
 Class 5-7 : annual mean wind speed between 6.0 and 8.8 m/s.

Electricity production and long run marginal costs.

The electricity consumption is identified in the several regions and the expected annual growth is estimated. On the basis of these figures the electricity consumption in the year 2020 can be estimated. (see table 2)

From [7] the marginal costs of electricity generation are derived as may be expected in the industrialized countries. (see also fig. 11) No capacity and emissions savings are included in these figures.

In [8] the long run marginal costs of future plants in developing are given. The results are presented in table 4.

Wind power generation costs.

The costs of electricity produced by wind power has been subject of many studies [e.g. 7, 9].

From this studies it can be concluded that wind power generation costs amount 0.04-0.07 \$/kWh at sites with a mean wind speed of 8.5 m/s at hub height and 0.06-0.10 \$/kWh at sites with a mean speed of 7.5 m/s at hub height and 0.07-0.12 \$/kWh at sites with a mean speed of 6.5 m/s.

Also the development of these costs is important to consider. From [1] it appears that a reduction with about 30% can be expected in the next 20 years and with about 10% in the period 2010-2030.

The long run marginal costs of wind energy in developing countries is derived from [3] and presented in table 4.

	LRMC of Future Marginal Plant	LRMC of Wind Energy	Seasonal profile	Time of Day profile	Wind energy
Country	(\$/Wh)*	(\$/Wh)**	Match	Match	Match
Argentina	0.04-0.08	0.05-0.21	Yes	Yes	Unlikely
Brazil	0.04-0.08	0.15-0.23	No	Yes	No
Chile	0.10-0.20	0.06-0.23	Yes	Yes	Yes
China	0.33	0.04-0.23	Yes	Yes	Yes
Colombia	0.03-0.06	0.13-0.23	No	Yes	No
Costa Rica	0.03-0.06	0.12	Yes	Yes	No
Cyprus	0.10	0.15	Yes	Yes	Unlikely
Egypt	0.06-0.07	0.13-0.18	Yes	Yes	Unlikely
India	0.15	0.09-0.23	Yes	Yes	Yes
Jamaica	0.09-0.12	0.09-0.10	Yes	Yes	Yes
Jordan	0.09	0.10	Yes	Yes	Likely
Kenya	0.06-0.09	0.13-0.19	Yes	Yes	No
Mauritania	0.15	0.10-0.23	Yes	Yes	Yes
Morocco	0.06-0.12	0.08-0.19	Yes	Yes	Likely
Pakistan	0.08-0.12	0.09-0.20	Yes	Yes	Likely
Peru	0.08-0.09	0.09-0.15	Yes	Yes	No
Portugal	0.09	0.08-0.15	Yes	Yes	Unlikely
Romania	0.09-0.12	0.04-0.13	Yes	Yes	Yes
Sri Lanka	0.06-0.13	0.10-0.18	Yes	Yes	Unlikely
Syria	0.09-0.12	0.07-0.13	Yes	Yes	Yes
Tanzania	0.06-0.10	0.08-0.09	Yes	Yes	Likely
Tunisia	0.09	0.16-0.21	Yes	Yes	No
Turkey	0.07	0.13-0.23	Yes	Yes	No
Uruguay	0.05	0.07	Yes	Yes	No
Venezuela	0.04	0.07-0.14	No	Yes	No
Yemen, Arab	0.04-0.05	0.06	Yes	Yes	No
Yemen, P.D.R.	0.11-0.22	0.07-0.23	Yes	Yes	Yes
Zambia	0.04	0.15-0.23	Yes	Yes	No
Zimbabwe	0.05	0.15	Yes	Yes	No

* The LRMC ranges presented above for the future marginal plant present alternative least cost expansion plans, as it cannot be conclusively determined which expansion path will be taken in the future.

** The ranges presented for the LRMC of wind reflect individual wind stations with differing wind resources.

Table 4 : Long Run Marginal Cost comparison of wind power in developing countries. [8]

Cost comparison.

From fig. 11 it appears that at outstanding wind sites the economic cross over occurs in 1995 for gas displacement and in 2020 for coal displacement. However, it must be kept in mind that in these figures the capacity credit and environmental benefits of wind energy have not been accounted for. From table 4 it can be seen that wind power is favourable right now for some countries, but will stay unfavourable in other countries for a long time.

For the estimation of wind power penetration in the year 2020, three classes of penetration are distinguished, viz.

- A penetration between 10% of the electricity consumption in 1987 and 10% of the electricity consumption in 2020 in favorable situations.
- A penetration of 10% of the electricity consumption in 1987 in break-even situations.
- A penetration smaller than 10% of the electricity consumption in 1987 in marginal situations.

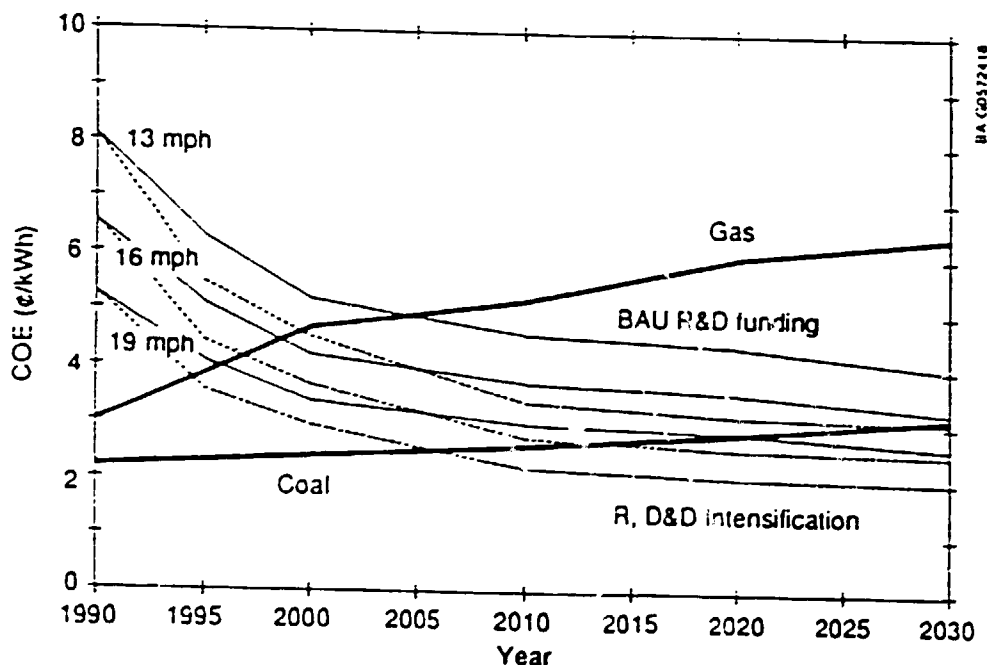


Fig. 11 : Comparison of COE (cost of electricity) projections for wind electricity production costs versus fuel and variable O & M costs for natural gas and coal power plants. [7]

Grid integration.

Wind energy is an intermittent power source. Other conventional plants or storage facilities have to deal with these variations.

Several studies are carried out regarding this problem and to identify the penetration level which is possible in grids without storage facilities.

It appears that generally no severe problems occur with a penetration level of 10% of the electricity production. For systems with a lot of hydro power or storage facilities this level can be even higher.

Other aspects concerning grid integration are:

- the existing capacity must have a certain size, as a minimum 50 MW is assumed, which means that at this moment some developing countries are not able to integrate wind power.
- the distance of the resource to the grid is also a limiting factor. For the estimate of wind potential in the year 2020 a minimum distance of 50 km is assumed.

Socio-economic aspects concerning the introduction of wind power.

Socio-economic factors also determine the development of wind energy. In a study about the market potential for developing countries [8] these aspects have been divided in technical, institutional, financial and potential market factors, and all developing countries were ranked according to these factors, as shown in table 5.

For the purpose of estimating the amount of wind power installed in 2020, these factors are analyzed and their possible influence on wind power penetration for all countries. A brief description of these factors will be given here.

Technical factors are, for example, the availability of reliable wind resource studies for a country and the confidence in these resource studies.

The actual decision on the realization of a wind farm in a specific country can not be based on a global estimate of the wind resource, such as used in this study.

More detailed analyses of the wind resource per country or region have to be made.

This can be very difficult because of a lack of data or methods to describe the wind climatology.

Almost all developing countries do not have this information. Therefore the wind regime has to be studied in more detail before a decision about the exploitation of wind power can be made.

	Chile	China	India	Jamaica	Jordan	Mauritania	Morocco	Pakistan	Romania	Sri Lanka	Syria	Tanzania	Yemen, PDR
TECHNICAL													
Wind resource	3	3	3	2	2	3	3	3	3	2	3	3	3
Wind confidence	2	2	3	2	3	2	2	2	1	2	1	1	1
Environmental sanctions	2	2	2	2	2	2	2	2	2	2	1	2	2
Average score	2.3	2.3	2.7	2.0	2.3	2.3	2.3	2.3	1.7	2.0	1.7	2.0	2.0
Factored score	19.4	19.4	22.1	16.6	19.4	19.4	19.4	19.4	13.8	16.6	13.8	16.6	16.6
INSTITUTIONAL													
Govt. programs in cogeneration	2	1	2	2	3	2	2	2	3	3	1	1	1
Govt. programs in renewables	1	3	3	2	3	1	3	1	1	2	1	1	1
Utility ownership	1	1	1	2	2	3	2	3	1	2	1	1	2
Trade relations	2	3	2	2	3	2	2	2	1	1	1	2	1
Potential for development aid financing	2	3	3	2	3	2	3	3	1	2	2	2	2
Average score	1.6	2.2	2.2	2.0	2.3	2.0	2.4	2.2	1.4	2.0	1.2	1.4	1.4
Factored score	13.3	18.3	18.3	16.6	23.2	16.6	19.9	18.3	11.6	16.6	10.0	11.6	11.6
FINANCIAL													
Potential for commercial financing	2	1	2	2	2	2	2	2	1	2	2	2	1
Cash flow of utility	3	1	1	2	3	1	2	2	1	2	2	1	1
High variable cost	3	3	2	3	3	3	2	3	2	2	2	3	3
Average score	2.7	1.7	1.7	2.3	2.7	2.0	2.0	2.3	1.3	2.0	2.0	2.0	1.7
Factored score	22.1	13.8	13.8	19.4	22.1	16.6	16.6	19.4	11.1	16.6	16.6	16.6	13.8
POTENTIAL MARKET FOR WIND TURBINES													
Growth potential for wind capacity	2	3	3	1	2	2	2	2	3	2	2	1	1
Projected need for generation	2	3	3	2	3	3	2	3	2	2	3	1	3
Average score	2.0	3.0	3.0	1.5	2.5	2.5	2.0	2.5	2.5	2.0	2.5	1.0	2.0
Factored score	16.6	24.3	24.3	12.5	20.3	20.3	16.6	20.3	20.3	16.6	20.3	8.3	16.6
Total average score	3.5	3.2	3.5	2.8	3.0	3.3	3.7	3.4	5.0	3.0	2.4	6.4	2.1
Total factored score	21	28	29	15	35	23	22	23	57	36	31	53	19
CATEGORY	2	1	1	3	1	2	2	1	3	3	3	3	1

Table 5 : Overview of wind energy potential in developing countries. [8]

Another technical aspect concerns the environmental conditions. There are areas that must be excluded because of non-favourable environmental conditions, such as extreme low or high temperatures, ice, snow, wind blown sand and airborne salts.

For example, in Morocco there is some wind potential inland but it is unlikely that in this region wind turbines will be installed because of the large content of wind blown sand in the air.

Especially in industrialized countries other environmental aspects connected to the use of wind turbines might influence the potential of wind power also.

The development of wind power is restricted because of noise problems, telecommunication interference and bird damage or hindrance.

In the calculation of the potential of wind power for the year 2020 these 'technical constraints' have been taken in to account in a global way.

Institutional factors include the following elements :

- government programmes for other renewables, cogeneration and energy saving;
- government programmes for wind power development;
- trade relationships;
- potential for development aid financing.

Of course the development of wind power will be strongly influenced by government policies concerning renewable energy, energy saving, etc. The estimate for the year 2020 is influenced by these policy aspects in such a way that countries with a strong stimulation programme for wind energy will realize a greater amount of wind power than other countries. Trade relationships and potential for development aid financing are evaluated in [8].

In this study countries have been ranked according to these two aspects. This ranking has been taken in to account in the evaluation of the amount of wind power installed in 2020.

Financial factors include potential for commercially financed wind energy programmes, the tariff structure of electricity pricing, subsidies on electricity prices, dependence on fuel imports and the variable costs of the utilities. These aspects are evaluated by ranking the countries.

Potential market factors included aspects like: is the potential for wind capacity large enough to expect economies of scale, is there a need for additional electricity generation capacity in the near future, are there local industries involved in wind energy and are there enough trained people to realize wind farms ? These aspects have also been evaluated by a ranking system.

Wind power penetration in 2020.

Having carried out all above mentioned steps and weighing the penetration levels on the bases of cost comparison and the socio-economic aspects the total penetration for the year 2020 can be established.

The results are presented in table 2.

The total projected wind capacity amount 450,000 MW, which produces about 930,000 GWh.

2.2. Small scale application.

Only rough figures are available on wind pumps and battery chargers. In China 196 million farmers and herdsman live without electricity supply.

In Inner Mongolia about 83,000 battery chargers are in use by herdsman and in the rest of China about 20,000. It is estimated that in China among these farmers and herdsman who lives in area with a reasonable wind resource, there is a demand for 1,000,000 of these battery chargers.

Using this figure for China as a rough estimate for the world it can be expected that the total market volume amounts about 2,000,000 units, which means in the coming 20 years 100,000 units/year.

A same approach is also valid for wind pumps.

A conservative estimate of the total world's potential results in a figure of 100,000 units/year.

The total capacity of these systems is negligible in comparison to the projected large scale application.

In 2020 between 200 MW and 500 MW is world wide expected.

As already pointed out in sec. 1.4. the market for W/D systems seem to be vast. However no figures are known.

3. Wind turbine technology for large scale application.

3.1. Introduction.

The complexity of wind turbine technology has been strongly underestimated throughout the past 20 years and sometimes it still is.

"Building a windmill : that can not be very complicated", was often said and even more often thought.

"What is a windmill at all : a rotor and a generator, and eh...Oh yes, probably a gear in between and eh...O.K. a pile to mount the thing upon. Eh...may be a housing around generator and gear is not a bad idea, but that's it.

What ...? What about directing into the wind ? Well, that complicates the thing may be a little bit, but the ancient mills have been in operation for centuries; with modern knowledge it cannot be difficult to design a thing which is much more efficient."

So after 1973 a lot of small entrepreneurs started enrapturedly to build small windmills. And got problems. The things did not function properly.

After some minor modifications they still did not function properly. After major modifications the things started to work. But then blades began to fly around, generators burned out, gears and bearings were destroyed. In some cases the whole thing came downwards. Then new entrepreneurs came into the field; headshaking they observed the mess which was left by these dummies and they started anew.

Not those silly small mills, but larger ones. They certainly not would make the faults of these stupid predecessors and would approach the thing professionally.

Sophisticated engineering teams were put on the design of larger machines. And failed. The wind turbines were too expensive, they did not function properly, blades flew around, generators burned out, gears and bearings were destroyed.

This story can be extended till nowadays. Experienced manufacturers are just able to build reliable and cheap wind turbines with a capacity of 250 - 300 kW (however maintenance is still a worrying aspect), they are carefully looking at 500 kW rating, when CEC is jingling with a bag of money for the development of 1 MW windturbines ... let us keep silence about the multi MW machines which are built.

Three problems can be pointed out regarding wind turbine technology :

- 1) Although the market is growing, its volume is still insufficient for manufacturers to maintain a development team which is big enough to make real progress. Collaboration with other manufacturers should be the answer, but since technology is the only added value for manufacturers, they do not like this answer.
- 2) The start of this new technology was characterized by a technology push situation, where scientific institutions received governmental funds and formulated their own research programs. They were very much interested in the scientific aspects and in work over the frontiers of knowledge, whereas the starting manufacturers stood with their feet in the mud, struggling for survival. As a result the transfer of technology from the institutions towards the manufacturers was in the starting phase very poor. This situation has been improved considerably by collaboration of institutions and manufacturers in concrete projects. Moreover manufacturers are more often involved in decisions regarding governmental R & D programs.
- 3) One of the most important issues in a learning process is repetition. By repeating things over and over one learns rapidly. In wind turbine technology development generally the funds lack to do that. Generally after one design-loop a prototype is built and often sold to an interested party. In fortunate cases the manufacturer can gather some experience from this prototype before he starts building a serie, if he obtains an order for a serie at all. If his competitor in the mean time developed a bigger machine he will loose the competition, so the manufacturer goes back to the drawing table to develop an even bigger machine. Meanwhile an increasing part of his engineering team is on the road, solving problems with prototypes. This way of development is very inefficient by lack of learning effects due to lack of repetition. A manufacturer should be able to design a prototype, to build it, to get experience, to go back to the drawing table, to redesign the machine, to modify the prototype, to get experience with the modified prototype, to go back to the drawing table, etc..

After having established the design in this way he can start building a first serie. After having gathered experience with this serie he can start building bigger numbers of units and he can carefully look at up-grading of his design. Each up-grading step has to pass the same procedure.

Manufacturers do not follow this proper way because they are afraid to loose the market when they are developing and they do not have the funds.

Resuming it can be concluded that the complexity of the technology must not be underestimated and that all parties in and around the market must be aware of their own role in an efficient development scheme:

- Governments and principals generally tend to underestimate the complexity and demand for technology which is not mature yet. These parties are important for creating rest on the market and to stimulate greater volumes of wind turbines, which proved to operate reliable: this generates the cash-flow needed by the manufacturers to finance further development. Moreover governments have to ensure that manufacturers are involved in the development of R & D programs.
- Scientific institution should inform themselves about the real problems which are encountered by the manufacturers and try to give answers which can be understood and applied by the manufacturers .
- Manufacturers should collaborate more in development and have to make mutual arrangements with the purpose to obtain rest on the market.

Where is the technology located and in what structure is it applied ?

The technology is mainly located at the manufacturers. Detailed knowledge of specific areas is present in the scientific R & D institutions. Wind turbine manufacturers generally do not actually produce components themselves. Sometimes the manufacturer produces his own blades, but most manufacturers purchase all components. That means that the added value of a wind turbine manufacturer is his system knowledge and some activities like assembly, erection on the site, commissioning, maintenance and projectmanagement.

Roughly the wind turbine price is built up as follows :

69 %	purchase components
2 %	assembly
1 %	transport, erection
1 %	commisioning
5 %	project management
22 %	R & D provision
	warranty provision
	commercial costs
	risk / profit

Specific component know-how must be found at the sub-contractors. A very intensive collaboration between wind turbine manufacturer and his sub-contractors is required, because none of the components is standard and needs wind turbine applied development (even for a generator this has appeared to be necessary).

3.2. Present technology characteristics.

3.2.1. wind data.

Knowledge of wind characteristics is indispensable for predicting the energy yield and the economical feasibility of possible sites on the one hand; on the other hand it is necessary for the prediction of turbine loads. Wind maps are available of the E.C. countries, the U.S., Latin and Central America, China, Peru, Egypt, Somalia, the Sahel countries, Ethiopia and parts of the U.S.S.R..

Also a world map is available. These maps give mean annual wind speeds in a very global sense and they are suitable to locate regions, where wind energy can be feasible. For the prediction of wind turbine energy yield such maps are insufficient.

Also knowledge of the distribution of wind speeds is needed as well as information about the wind direction and the relationship of wind speed with height. The distribution of wind speeds is climate dependent and is often schematized by a Weibull-distribution. Fig. 12 shows some examples.

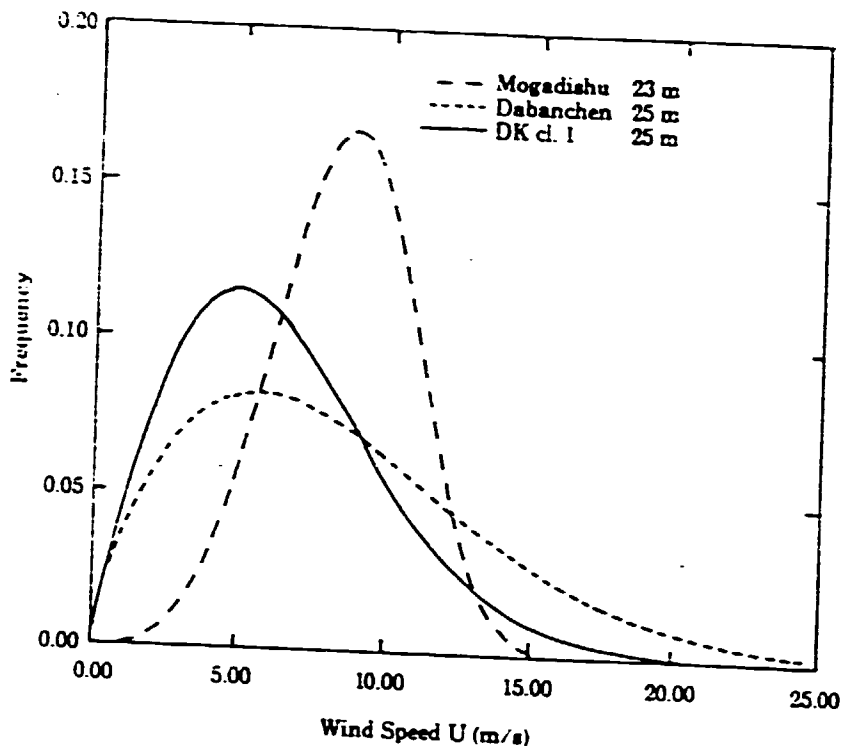


Fig. 12 : Various wind speed distributions. [10]

The relationship of wind speed with height is a logarithmic one. It depends on the surface roughness of the up wind areas, so the distribution of wind direction mostly represented in wind roses must be known. If the mean annual wind speed, the Weibull distribution factor k , the wind rose and the local roughness conditions are known, the energy yield can be calculated for given wind turbine types. Also regional and local resource maps can be established. Computer codes to perform these calculations are amply available. Also codes for complex accidented terrains are developed and give reliable results. Countries, which consider application of wind energy, but do not have a resource map, have to perform wind measurements to gather data on wind speed and wind direction distributions as a first step.

For the analysis of the energy yield of wind farms, farm efficiency has to be accounted for. Also for this purpose reliable computer codes which take into account the wake effects in wind farms are available.

For the establishment of load spectra the turbulence rate must be known, and the distribution of gusts. Both deterministic and stochastic approaches are used. In the deterministic approach a gust is assumed to have a $1 - \cos$ relationship with time. The time scale of the typical gust is dependent on the rotor diameter.

Mostly a limited number of gust classes is assumed and the frequency of occurrence is estimated. The theory behind this estimate procedure is known; in practice some modifications of the spectra thus found are necessary especially in the high cycle low magnitude and low cycle high magnitude range due to rotating sampling of turbulence and extreme gusts.

Turbulence bubbles which have as a characteristic dimension the rotor diameter or bigger dimensions, are felt by the whole rotor. Smaller turbulence bubbles are cut (sampled) by the rotorblades and give low magnitude high cycle fatigue loads. Gust spectra are known for the U.S. and the Western European countries. No information is available if these spectra also can be applied for other locations.

Deterministic methods are widely applied and validated.

Stochastic methods are applied on a smaller scale. The advantage of such methods is that they provide a more realistic gust spectrum. A disadvantage is that these methods can not be used with non-linear behaviour like stall and control non-linearities. Another disadvantage is that extreme gusts which appear very seldom are not well accounted for.

Methods to account for wake effects on wind turbine loads in wind farms are not very well developed yet.

3.2.2. Turbine loads.

A lot of computer codes are available, which all seem to provide a reasonably realistic load spectrum according to the validations established so far. Mean loads and performance as well as the fluctuating fatigue loads are predicted well. For detail analysis of transient responses these codes are less suitable due to the schematizations made in the calculation models.

Most models are based upon a combination of steady blade element theory and simple momentum theory. Generally 2-D blade section data are applied and a 3-D tip-correction is used. In some codes Viterna and Corrigan correction of 2-D data is applied. In most programs teetered or hinged blades can be accounted for.

Comparisons of calculated and measured transient responses does not show a very satisfactory correspondence.

Therefore further development of these codes is considered. Implementation of stall-characteristics (especially stall-dynamics) unsteady aerodynamics and wake induced effects are studied, as well as integrated models, in which not only the rotor characteristics are modelled but also drive train, electrical systems, tower and control dynamics.

3.2.3. The typical 1991 windturbine.

In sec. 1.4 the typical size is already indicated. In the U.S. the average unit size of wind turbines installed in 1990 was 160 kW. Also the growing trend is mentioned.

Manufacturers are able to supply reliable and cheap machines up to 250-300 kW.

Machines with a rating of 400-500 kW are already built in small series, but these machines are generally more expensive per kWh. So further design work has to be done to obtain the same price level.

How does a typical 1991 machine look like ?

A difference is observable between 250-300 kW machines and 400-500 kW machines in the number of rotorblades. Most of the 250-300 kW machines have 3 blades, the 500 kW designs tend to have two-bladed rotors.

Both pitch and stall-control is applied. The classical Danish wind turbines all have stall-control. Blades are generally made from glass fibre reinforced polyester. A tendency can be observed to apply wood-epoxy material for larger unit sizes.

The electrical system is robust and simple: an asynchronous induction generator with constant speed.

The drive-train is built up in a modular sense, so upon a rigid nacelle frame gear and generator are mounted. In the smaller designs the main bearings are integrated in the gearbox; in the larger designs a main shaft, which is separately supported by two main bearings can be observed. The tower is cylindrical or conical. Truss towers are seldom applied.

The nacelle consists of a rigid frame upon which a light GRP cap is mounted.

Yaw systems consists mostly of a bearing with inner teeth in which a hydraulically driven pinion is running. Very often these systems are passive, i.e. the rotor directs itself into the wind and the yaw system is only with special conditions in operation. No yaw brakes are applied in that case.

Pitch systems are, if applied, generally hydraulically driven. Mechanical brakes are very often mounted at the high speed shaft. For the larger designs a tendency can be observed to mount these brakes at the main shaft.

Rotor hubs are rigid, also in the 500 kW designs; a single teetered hub design is known, but it does not seem to be cost-effective.

The gear is mostly a robust parallel shaft type. Planetary gears are not cost-effective in this power range.

3.2.4. Some design details.

Materials.

As structural materials welded steel, GRP and wood-epoxy are applied.

Some components (hubs for instance) are fabricated from cast iron or steel.

The fatigue properties of welded and cast steel are well known, even at 100 million and one billion cycles. The knowledge of GRP and wood-epoxy fatigue characteristics with high cycle numbers is limited, but increasing rapidly. That is the reason that sometimes steel rotor blades are applied.

The disadvantage is, however, an extreme rotor weight, which has consequences for the dimensioning of the rest of the turbine.

Also the interference with TV and other communication signals is a disadvantage in the application of steel material for rotor blades.

GRP and wood-epoxy materials are currently investigated regarding fatigue as well as structural details made up from these materials.

The price of GRP and wood-epoxy blades do not differ very much in the ranges up to 500 kW (rotordiameter 35 m).

Wood-epoxy blades have 25% less weight and it is expected that, due to the favourable specific fatigue strength of wood-epoxy, with larger rotor diameters this difference in weight increases and consequently the wood-epoxy blades become cheaper than GRP blades.

The production of GRP and wood-epoxy rotor blades is perfectly suitable for developing countries.

Drive train set-up.

Mainly two concepts are applied, viz. an integrated and a modular concept. In the integrated concept all drive train components are bolted together and mounted upon the nacelle frame in one piece.

In the modular set-up all drive train components are separately mounted upon the frame. In my view the integrated concept must be more expensive, due to more special components with high machining costs and less commercial possibilities to shop these components as standard components from many suppliers. Furthermore maintenance of integrated drive trains is more expensive due to inaccessibility.

Gears.

Gears are a source of anxiety. Due to the fluctuating character of the loading standard gears show defects after a short period of operation.

Special attention must be paid to seals, shaft-wheel tolerances, lubrication, key-slots (fatigue!), rigidity of the housing, etc..

Moreover noise reduction measures have to be considered, like special grinding of the wheels of the last stage, special tooth shape, careful choice of the number of teeth of the last wheel, etc..

Planetary gears are rarely applied, due to the higher costs.

It could be possible that for wind turbines with a capacity of 1 MW or higher planetary gears are advantageous. They provide higher efficiency in partly loaded conditions, have less weight and produce less noise.

Generators.

Asynchronous generators are most commonly applied. No standard generator can be used. Special attention has to be paid to the insulation and salt moisture protection. The insulation must be rather flexible to prevent cracking caused by winding loads.

The wind turbine generator is loaded in a very fluctuating way. Not only wind speed fluctuations are felt, but also a relatively large number of starts and stops with peak loads are odd in a common generator application. Extra support of the windings is necessary.

The asynchronous generator is the best choice from reliability point of view, because the machine is tight. Synchronous generators have an open structure and must therefore be dissuaded.

Steel structure nacelle and tower.

These structures have to be dimensioned very carefully on the basis of the load spectrum.

The nacelle frame and some tower details (doors openings for instance) are often subject of finite element calculations.

Much knowledge is present with respect to fatigue of weldings and welding procedures are well-described.

Cylindrical towers are generally built up from plates with a width of about 4 m, which is the maximum commonly applied roll-size. A lot of horizontal weldings in the tower is the consequence.

Conical towers are built up with plates with a length of about 11 m which are composed in 12 or 18 sides. Only one or two vertical weldings are necessary and the conical parts of 11 m are connected in a slip-joint. This seems to be the most cost-effective way to manufacture a tower.

Truss towers generally are cheaper, but less aesthetic and need more land area.

Wind turbine control.

From an operational point of view the best control is no control. An active pitch control contributes in general for 15% in the total component purchase costs. The performance improvement amounts 5-10%.

Blade bearings, pitch-mechanism, hydraulics are the main components. Moreover a lot of manhours are spent on assembly, testing in the factory, testing on site and maintenance. Therefore a passive control system like stall is very attractive. In the 100-250 kW range most turbines are provided with such a system. In the 300-500 kW range pitch-controlled machines are more common. The reason is that the stall phenomenon is not modelled well in the commonly applied computer codes, so performance and loads can not be predicted reliably. Moreover dynamic problems are expected with large stall controlled wind turbines. Further development on this point is urgently needed.

Also the safety philosophy of large stall-controlled turbines deserves further consideration, since no aerodynamic brake is present.

Addition of brake-tips to the blades is expensive and destroys a big part of the cost advantage of the stall-control.

In most wind turbine safety regulations two safety systems are prescribed in normal operational conditions.

The grid keeps the asynchronous generator at a safe speed and could therefore be considered as a safety system. However since grid failure is considered as a normal condition, the grid cannot be considered as one of the two compulsory safety systems.

On the other hand it seems very unlikely that in case of a wind turbine emergency both the grid and the mechanical brake fails.

A development is observable to analyse safety on the basis of probabilities and chances and to leave these rigid rules.

3.3. Present short-comings and related development.

3.3.1. Technology developments.

Present technology suffers from lack of reliability and high maintenance costs and still too high wind turbine costs. A lifetime of minimal 20 years has not proven yet. Moreover noise is a serious problem. From the availability data in fig. 8 it could be understood that a good reliability has gained yet. However, it must be pointed out that high availability often is realized by permanent attendance, resulting in relatively high maintenance costs. For this reason off-shore applications must be rejected on the short run.

Most technology development activities are directed to lower wind turbine costs and lower noise emission.

Further improvement of performance does not seem to have big perspectives for the economy of wind turbines. Present availability is around 95% and the performance factor is around 3.1.

(performance factor b defined as $E = b \cdot V^3 \cdot S$, where E is the annual yield, V is the mean wind speed and S is the rotor surface)

In fig. 7 the development of this factor is shown during the past years.

A maximum value of 3.5 can be obtained theoretically in the Western European wind regime.

An improvement of performance with 50%, as adopted in the recently presented U.S. wind energy program [11], is therefore not realistic.

A further decrease of wind turbine costs is possible.

These reduction especially must be found in more efficient designs.

As pointed out in [12] larger production quantities does not affect the wind turbine price considerably, because most of the components are already produced in a standard way. Only with real large production numbers (thousands per year) it becomes attractive to change these standard production methods by tailoring them to the specific wind turbine components. This point will be reached over 10 years.

Reduction of 20 - 30% seem to be possible then.

In [12] also application of advanced concepts is rejected as a way to obtain lower turbine price on the short run.

Between 5 and 10 year these concepts will have reached maturity and will result in cost reduction of 15 à 20%.

On the short run clever designs of proven concepts must direct to lower costs. In the range of 150 - 250 kW no significant cost-reductions seem to be possible. In this turbine class better economy must be obtained by improvement of reliability and low maintenance costs.

In the range of 250 - 500 kW further development of the design may result in cost-reduction of 20%. The same price per m² rotor surface is possible as with the smaller turbines in the range 150 - 250 kW.

Turbines of 1 MW and larger are a factor 2 - 3 too expensive as compared with the present 150 - 250 kW turbines.

In my view it is possible to develop 1 MW wind turbines with the same kWh-price as the present 500 kW turbines and with the same technology within 5 years.

Advanced technology can improve the economy of these machines in 5 - 10 years. The result is the same kWh-price as the present small turbines in the range 150 - 250 kW.

Summarizing it can be concluded that the present average wind turbine investment costs, which are mainly determined by the 150 - 250 kW class (\$ 800-1000 kW), will not decrease very much further on a short term. On the medium run large machines can be built with the same investments per m² rotor-surface by improvement of the designs.

On the long run 35% economy improvement can be gained by cheaper maintenance (15%) and more efficient production methods (20%).

3.3.2. Development subjects on the short and long run.

On the short run the following subjects are under consideration:

- Further development 500 kW class by value-engineering and application of more efficient designs based on the same concepts.
- Application of stall-control for larger unit sizes.
- Decrease of costs per kW by enlarging the rotor diameter at the same power rating.
- Noise reduction by silent components (gear, generator) and isolated mountings on the nacelle frame and by application of silent rotor blades.
- Safety philosophy by analysis in stead of rules.
- Further improvement of reliability by further development of components.
- Grading up the designs to 750 kW and 1 MW on the basis of proven technology.

On the long run innovation of concepts can be expected. In [13] the following subjects are mentioned :

- Hinged or flexible blade roots diminish the fluctuating loads and can result in lighter structures.
On the other hand provisions have to be made for extreme excursions, which may introduce high loads.
- Integrated drive train arrangements are in [13] considered as more cost effective which can be questioned. (see sec. 3.2.3.).
- Very fast partial span control which is activated passively by centrifugal or aerodynamic forces and which also reduces the loads.
However, it is questionable if addition of such a system will decrease the overall costs.
- Soft tower design, which is already applied in some present turbines.
- Variable speed electrical system, which provides a soft coupling to the grid, (lower loading) and better system efficiency.
Such systems like AC-DC-AC are already applied, but they are relatively expensive.

4. Wind pump technology.

The development of wind pumps started around 1850 in the U.S. for domestic and livestock water supply. The classical wind pump is mature and reliable, but expensive. Since 1973 efforts has been undertaken to modernize the classical wind pump and to make it more cost-effective.

3 different applications can be distinguished [14], viz.

- low lift (< 6 m), high volume applications, mainly in China for salt pans and prawn breeding, development is in its infancy;
- medium lift applications (< 50 m), for this purpose new technology is on its way to push aside the classical wind pump;
- deep-well applications (> 50 m), for which reliability requirements are extremely demanding and where the classical wind pump still seem the best option.

Where is the technology located?

The technology is mainly located at some institutions which are involved in improvement of this technology. The manufacturers generally are not acquainted with modern knowledge about aerodynamics, pump theory, etc.

A large difference with large scale wind turbine technology is the isolation of the various parties involved. Very few contacts exist between the parties of the different countries.

The level of organization is poor as well as progress is. In this respect the recently undertaken initiative to found an international association Wind Energy for Rural Areas (WERA) must be applauded.

Such an association can be a platform for exchange of technology, moreover for exchange of ideas to remove other obstacles. It can act to politicians and financiers.

Technology development.

The development of wind pumps is mainly concentrated upon the application for low and medium lift (smaller than 50 m). Most developments are directed to obtaining better matching of pump and wind turbine.

In this respect the CWD (Consultancy Agency Wind Energy for Developing Countries, The Netherlands) played an important role, but the financing of this program lasted in 1990.

A lot of knowledge is present especially at the Eindhoven University of Technology, but no longer funds are present to transfer this knowledge in a proper way.

The following subjects were under consideration:

- Development of a piston valve which results in low start torque characteristics and which provides a high efficiency in a larger range of speeds. [16]
Such a valve can be applied in existing pumps and increases the water output with 50-100%.
Also smaller pumps can be applied with the same water output.
On the basis of this new pump technology also more cost-effective wind turbines can be designed.
Higher tip speed ratios, less blades and lower starting torque are allowed. Furthermore the need of a gear between rotor and pump is not longer present.
- Development of reliable passive control and safety systems. Hinged side vanes are successfully applied in several projects in Tunisia and Nicaragua.
- Development of a gearless wind pump by implementations of more flexibility in the pump, resulting in lower fluctuating piston rod forces.
Application of air chambers has appeared to be successful in low lift pumps (smaller than 7 m).
200 turbines in Sri Lanka and 100 in Mozambique are in operation. For deep-well purposes this solution does not work properly.
- Development of hydraulic piston seals instead of leather cups, which are subject to wear and tear.

Other developments are:

- development of low lift/high volume (smaller than 3 m) pumps, mainly for application in China for salt pans and prawn breeding [17];
- development of a low speed centrifugal pump for application at 3-6 m, mainly for the China market for desalination of land, prawn breeding and irrigation [18];
- development of Wind Electric Pumping System, WEPS [19];
- development of pneumatic system in Brazil.[20]

The performance factor of classical wind pumps is about 0.08, the modern types and good classical types reaches 0.1 and with the matching valve factors of 0.15-0.20 can be obtained.

5. Some remarks concerning economy.

About large scale wind farms figures are already mentioned. (sec. 1.4 and 2.1.)

Installation costs amount 800-1000 \$/kW and the resulting kWh costs amount about 0.05-0.10 \$/kWh dependant on the wind regime.

In [21] for the kWh price of wind farm electricity in India an amount is mentioned of \$ 0.06-0.07/kWh.

The avoided fuel and capacity costs amount 0.045-0.05 \$/kWh.

Is the difference in external costs between wind power electricity generation and conventional electricity generation taken into account, then the total avoided costs with wind energy amount

0.095-0.14 \$/kWh, so large scale wind farms are at many locations already economically attractive.

However, the calculation of external costs is not accepted yet and not implemented in conventional energy prices.

For small scale off-grid application very few figures are known.

A comparison of costs of energy generated by diesel, kerosine, solar and wind is in [15] given for water pumps and presented in fig. 13. For 1000 m³/day the costs are 0.4, 0.6, 1.3 and 0.45 \$ cts./m⁴ respectively (wind 4 m/s).

In [22] a comparison is made for electric driven, diesel driven and wind driven waterpumps. The costs mentioned are 0.016, 0.031 and 0.022 RS/m⁴.

In [22] moreover an interesting comparison was made regarding investments done by the government in these three options and investments by end users.

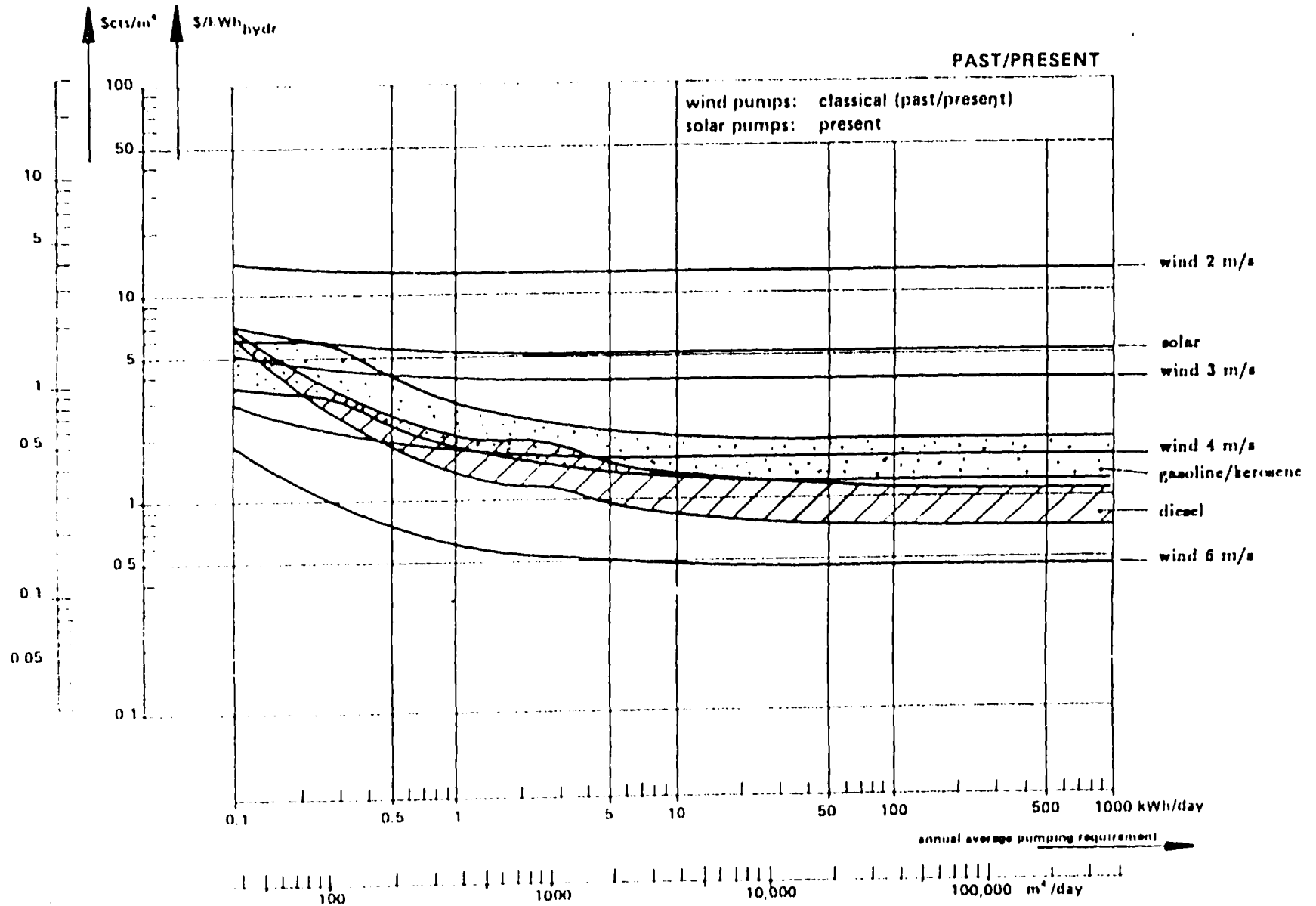
Both for electric driven pumps and diesel driven pumps investments must be made in addition to the motor or engine investment.

For diesel pumps investments must be done in exploration, production, refining, etc..

For electric motor pumps investments must be done in power generation, transmission and distribution.

For the government total investments per unit are 55,000; 54,000 and 30,000 RS, while the investments of the end user are 10,000; 12,000 and 30,000 RS for electric, diesel and wind respectively.

For battery chargers a figure is mentioned in [3] Shi Pengfei calculates a price of 0.40 \$/kWh and claims that this is cheaper than kerosine or dry batteries and also cheaper than small diesel or petrol engines, and only a half or a quarter of the costs of solar panels.



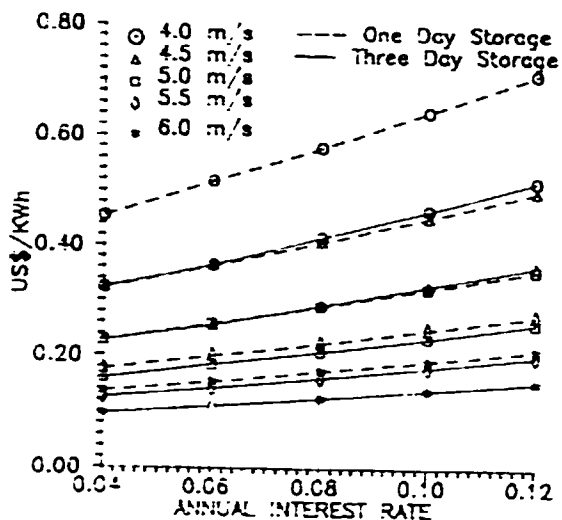
Note:

Graphs are based on average values of investment costs, fuel costs, etc. Always make your own calculations based on prevailing costs in your situation.

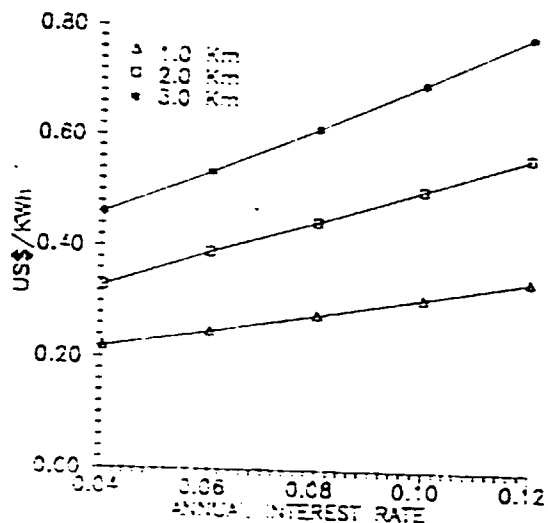
Fig. 13 : A comparison of costs of energy generated by diesel, kerosine, solar and wind [15].

In [23] costs of electricity from battery chargers are compared with the real costs of electricity with a grid connection in rural areas. In fig. 14 this comparison is presented. At 4 m/s and three days storage the kWh costs with a battery charger amount \$ 0.4/kWh.

The electricity from the grid should cost \$ 0.42/kWh at a distribution line of 3 km.



Energy price from WES at various wind speed



Real energy price in rural area connected to grid in RGS

Fig. 14 : A comparison of costs of electricity generated by battery chargers and real costs in case of a grid connection in rural areas.

For wind - diesel some figures are presented in [24].

The costs of electricity generated by a wind - diesel system appeared to be 0.17-0.19 \$/kWh on Duchan Island.

Diesel generation costs 0.16 \$/kWh and with a connection to the grid of the main land a kWh would cost 0.35 \$/kWh.

6. Conclusions.

- 1) The market potential for wind energy is very large. For centralized grid connected applications a potential of 450,000 MW is estimated for the coming 30 years.
For decentralized small scale applications a potential of 2,000,000 battery chargers and 2,000,000 wind pumps is estimated.
- 2) Implementation of wind energy is to a large extent dependant of politics. For the centralized applications it is important that the real costs of generation with conventional power plants become visible by implementation of taxes.
For the remote areas wind is a reliable source of energy of high quality but politician must become aware of that and choose for it in stead of investments in expensive infra structures.
- 3) The technology of battery chargers and classical wind pumps is mature. New technology for cheaper wind pumps is on its way.
The technology of 150 - 250 kW turbines for wind farms is growing to maturity. Larger wind turbines are in the development phase.
- 4) The kWh-costs of a modern wind farm amount about 0.10 \$.
It is expected that this price wil decrease to 0.065-0.07 \$.
The kWh-costs of a battery charger is 0.40 \$.
The cost of water from wind pumps is about 0.45 \$ ct/m³.
(this is equivalent with 1,65 \$/kWh)

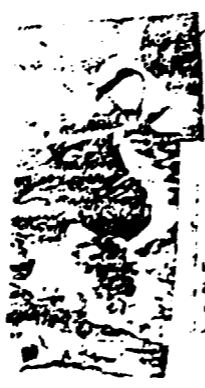
This costs can be reduced to 0.20 \$ct/m³ with modern technology.
- 5) Transfer to knowledge to developing countries must be organized and funds must be raised. The establishment of an international association Wind Energy for Rural Areas is a good step to create a platform for necessary exchange of ideas and a body which can act to politicians and financiers.

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