SC.93/Conf.003/22
Paris, 30 June 1993
Original : English

World Solar Summit
Sommet solaire mondial

UNESCO Headquarters
Paris, 5 - 9 July 1993

Siège de l'UNESCO
Paris, 5 - 9 juillet 1993

Wind Energy - Present Situation and Future Prospects

L'Énergie éolienne - la situation actuelle et les perspectives d'avenir

High-level Expert Meeting
Réunion d'experts de haut niveau

ISES
CEE
Ademe

SC-93/CONF.003/LD.10

Wind Energy - Present Situation and Future Prospects

L'Énergie éolienne - la situation actuelle et les perspectives d'avenir

Co-ordinator : **Sesto**
Ezio
Manager, Head of the Advanced Techniques Service, ENEL
President, European Wind Energy Association, EWEA
Italy

Co-Authors : **Casale**
Claudio
Researcher, Dr., ENEL S.p.A/CRE1
Italy

Mari
Giuseppe
Researcher, Dr., ENEL S.p.A/CRE1
Italy

The authors are responsible for the choice and the presentation of the facts of this discussion paper submitted to the High-level Expert Meeting of the World Solar Summit, as well as for the opinions which are expressed therein. These do not bind the Organisers of the World Solar Summit. Les auteurs de ce document de discussion soumis à la réunion d'experts de haut niveau du Sommet solaire mondial sont responsables du choix et de la présentation des faits figurant dans leurs contributions, ainsi que des opinions qui y sont exprimées, lesquelles n'engagent pas les organisateurs du Sommet *solaire mondial.*

© WSS 1993

WIND ENERGY - PRESENT SITUATION AND FUTURE PROSPECTS

L'ENERGIE EOLIENNE - LA SITUATION ACTUELLE ET LES PERSPECTIVES D'AVENIR

Co-ordinator: SESTO
Ezio
Manager, Head of the Advanced Techniques Service, Dr., ENEL S.p.A./CRE1
Italy
President of the European Wind Energy Association (EWEA)

Authors: CASALE
Claudio
Researcher, Dr., ENEL S.p.A./CRE1
Italy

MARI
Giuseppe
Researcher, Dr., CESI S.p.A.
Italy

1. INTRODUCTION

Wind energy can also be considered a form of solar energy, in that wind, as everybody knows, is caused by differences in atmospheric pressure due in turn to the sun heating adjacent areas of land to a different degree.

Wind energy has been widely used by Man from ancient times, both for sailing and for driving actual machines. A good example are windmills, which were used on a large scale first in China and in the Middle East and then, from the Middle Ages, also in many countries in Europe and America, for a variety of uses such as grinding corn, powering saw-mills and pumping water.

Wind provides Man with a flow of air whose kinetic energy can be transformed directly by a wind turbine into mechanical energy made available on a rotating shaft. This energy can then be used for driving a machine such as a mill, pump or electric generator. In the latter case, the machine which consists of the combination of a wind turbine with an electric generator is called a wind turbine generator.

The first wind turbine generators appeared at the beginning of this century and were developed up to around the second world war. In the postwar years, however, the wide availability of low cost fossil fuels meant that such machines were almost totally abandoned, with consequent loss of the experience gained hitherto.

Interest in wind as a potential integrative source for producing electricity returned around the mid-'seventies when the well-known oil crisis drew the public's attention to the importance of exploiting renewable and freely available energy sources as far as possible. From then onwards the U.S.A., Canada and various European countries started up important programmes of research and experiments, at the same time as incentivation policies aimed at encouraging the installation of wind power plants by private individuals.

More recently this interest has gained increasing momentum due to the growing concern about the environmental problems that the large-scale use of fossil fuels and nuclear energy inevitably involves.

In industrialised countries the production of significant quantities of electric energy from wind can only be planned via wind power plants, also known colloquially, particularly in America, as "wind farms". These consist of a number of wind turbine generators and are connected to large existing electric networks, parallel to traditional generating plants.

In developing countries, as also in industrialised ones with low population density, the installation of wind turbine generators in small local, isolated networks, parallel to generator sets powered by the diesel engines generally used in these situations, would also appear to be highly promising.

Importance is also placed, above all in developing countries, on the use of "stand-alone" wind turbine generators with storage batteries for supplying isolated dwellings, as well as the use of wind pumps, i.e. pumps driven directly, or by means of an electric transmission (generator plus motor), by a wind turbine for raising water for reclaiming and irrigation purposes.

In general it cannot be denied that the wind has characteristics which make its exploitation more difficult compared to "traditional" sources, above all if account is taken of the special needs of electricity producers. The following in particular should be recalled:

- Its low energy concentration.
- Its high variability over time.
- The random nature of its availability.

The low energy concentration is apparent when we consider the formula which gives power P (in watts) of an air flow with a transverse section A (in square metres) and velocity v (in metres per second), evenly distributed over this section:

$$P = \frac{1}{2} \rho A v^3$$

where ρ is the density of the air (in standard conditions of 1.225 kg/m^3). For example this formula indicates that, with wind of 10 m/s, power P is only 612 W/m^2, of which only a part (at most 35-40% in design working conditions) can be transformed into electric power by a wind turbine generator.

Where a wind plant of significant power is to be built, the low energy concentration means that a large number of wind turbine generators have to be used, which must in turn be large in size in relation to the installed capacity, with the result that a considerable expanse of land is involved compared to traditional generating plants.

The above formula also shows that the power made available by the wind is a function of the cube of the wind speed. Therefore the variability of the speed of the wind in time leads to much greater variability of the power produced by a wind turbine generator, with obvious consequences as regards operation of the electric system of which the wind turbine generator forms part.

In addition to these aspects account must also be taken that the wind source:

- Is available on the Earth in very large quantities.
- Its use does not cause emission of polluting substances, as in the case of fossil fuels.
- It does not produce residues which require disposal, as occurs for example in nuclear plants.
- It allows further diversification of the energy sources, with consequent advantages for the reliability of supplies and for the balance of trade.

Global warming is one of the major problems facing mankind. As a result of the evidence presented at the Toronto Conference in 1988, leading industrial countries agreed to reduce carbon dioxide emissions by 20% by the year 2005. An important contribution towards the achievement of this goal can be made by renewable sources, including wind energy.

In Europe, approximately one third of CO_2 emissions comes from electricity generating plants, for which mainly fossil fuels are used. Bearing in mind the fact that, for every kilowatt-hour of electricity generated by renewable sources rather than coal, the emission of one kilogram of CO_2 is avoided, it follows that, for every 1% of "conventional" generating capacity replaced by a wind energy plant a 0.3% reduction in total CO_2 emission can be achieved. Wind energy can therefore be used to bridge the gap between CO_2 reduction targets and energy-saving programmes [1].

The reduction of sulphur and nitrous oxide emissions, which contribute to acid rains, is another important environmental benefit of wind energy; in addition, there is the saving of finite natural resources such as fossil fuels, which could be better used to produce other commodities rather than being burnt.

Lastly, it is worth pointing out that, given a suitable site, a wind turbine can generate the energy consumed in its manufacture in less than one year. Since the expected design life is 20 years, according to manufacturers, a well-sited wind turbine generator can have a net productive life of 19 years.

Bearing in mind these fundamental aspects, the subsequent chapters in this report set out to provide a summary of the present situation and of the future prospects of the use of wind as energy source, with special reference, in line with present world trends, to the use of wind energy for producing electricity to be supplied via the network.

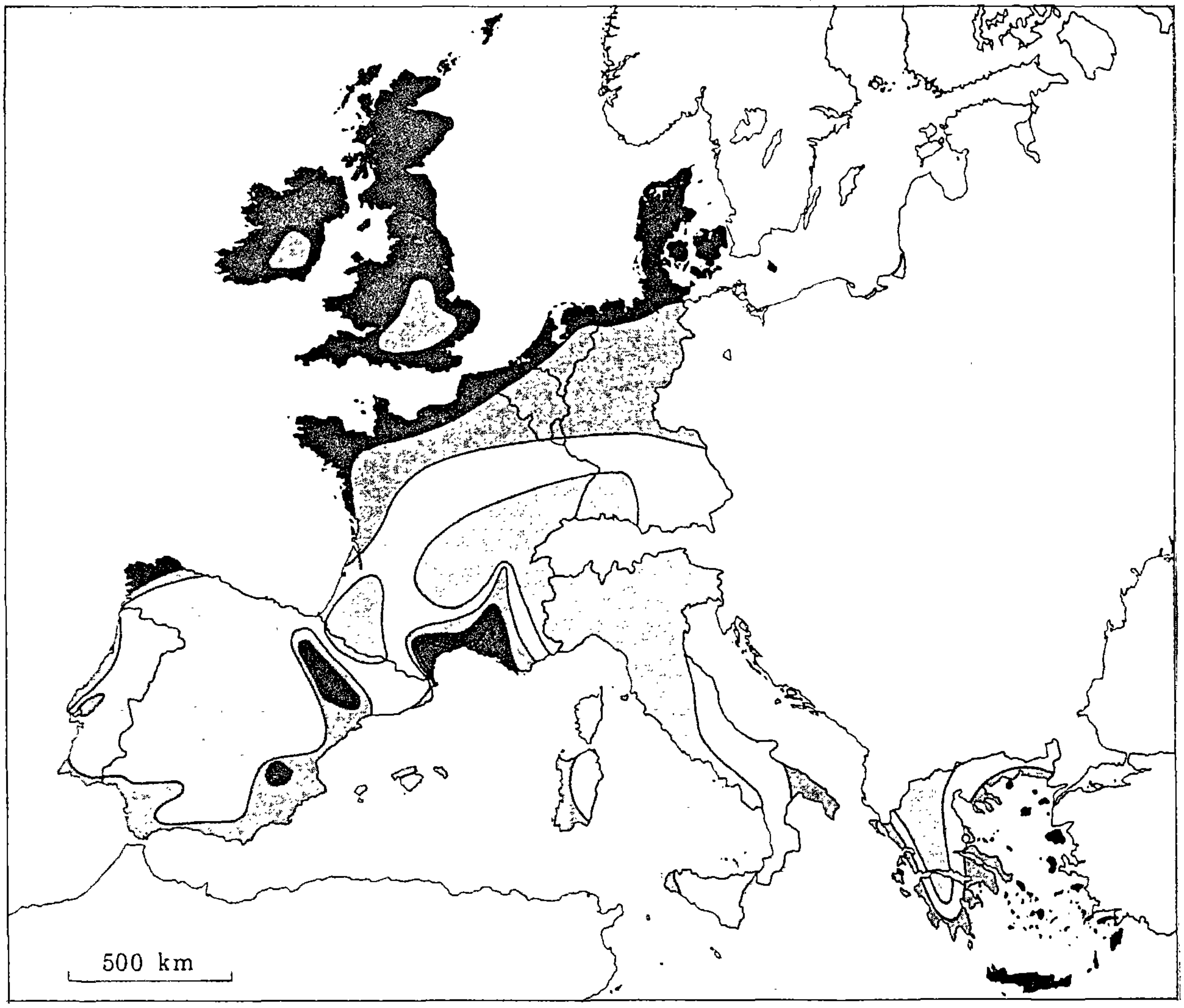
2. WIND ENERGY TODAY

The aim of this chapter is to present a picture of the current state of the art of wind energy, in respect of both available resources and machinery technology.

2.1 Available Resources

It is not easy to estimate the wind energy resources in the world, although calculations have been made. Ignoring technical, environmental and financial aspects, it can be demonstrated that wind could, in theory, meet all the world's electric energy needs. However, in practice, this calculation has little meaning, except to establish that the resources are there.

By way of an example, a useful, indicative idea of where Europe's land-based wind energy potential lies can be drawn from the European Wind Atlas, published under the patronage and support of the Directorate General for Science, Research and Development (DG XII) of the Commission of the European Communities (Fig.1) [2]. Additionally, an even higher potential seems to exist offshore, where there is the advantage of better wind speeds, but the disadvantage of more difficult access.



Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	m s^{-1}	Wm^{-2}	m s^{-1}	Wm^{-2}	m s^{-1}	Wm^{-2}	m s^{-1}	Wm^{-2}	m s^{-1}	Wm^{-2}
(darkest shading)	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
(dark shading)	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
(light stipple)	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
(white)	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
(white)	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Fig.1 - Potential of wind energy in Europe according to the European Wind Atlas.

Fig.1 - Potentiel d'énergie éolienne en Europe suivant L'Atlas Européen du Vent.

In actual fact, estimating the wind energy which can be effectively exploited is a highly complex process, which cannot be performed absolutely on the basis of general wind maps of the type mentioned above. This is because the production of a wind plant strongly depends, as observed previously, on the wind conditions at the installation site. These conditions, at the heights from the ground which concern the wind machine, are in turn influenced quite appreciably by the local terrain features, so that reference to wind data measured at a certain distance from the site in question is of little significance.

Moreover, for the evaluations of producibility of plants and the relative technical-economic considerations, wind data having real statistical significance are required, i.e. data acquired over long periods of time. This aim can only be achieved by carrying out systematic recordings of wind speed and direction in each of the relevant sites for a potential wind plant, for a period of at least 3 - 5 years.

Processing of the data acquired enables results to be obtained such as the frequency distribution of wind speeds, with its main parameters such as annual average wind speed, maximum speed, standard deviation etc., as well as the wind speed duration curve and the wind rose, which enable a first assessment to be made on the producibility and optimum layout of the machines of a possible wind plant at the site considered.

The check on the existence of interesting wind resources must however be combined with the ascertaining of the availability, at the site, of an area of adequate extension for housing the plant which is to be built, and which is also free of environmental restrictions of whatsoever type which would prevent the installation of wind turbine generators.

The area must also be easily accessible by heavy vehicles, and have a sufficiently smooth and regular land surface so that the wind is not excessively discontinuous from point to point and there are no unsurmountable problems in the transport, installation and maintenance of the machines.

Furthermore the area must be sufficiently close to the existing electricity network so as to limit length, cost and environmental impact of the new line which is to connect the wind plant to the network itself.

Once the general suitability of the site has been ascertained, the construction of the plant requires a subsequent survey performed in greater depth (known as a "micrositing study"), aimed at defining, through experimental campaigns and mathematical models, the typical wind data in the various points of the area considered, so as to determine the optimum positioning of the various wind turbine generators on the land.

The choice of the arrangement and distance between the machines, as is known, must also be such as to limit as far as possible aerodynamic interference among the various units, otherwise greater stress would be exerted on the latter with a drop in the overall energy output of the plant. Naturally, in taking into account this need, a suitable compromise with the need to contain the extent of the land involved within reasonable limits has to be reached.

The above considerations clearly indicate that an evaluation, however approximate, of the effective wind resources of a country requires not so much a wind map as a true and proper map of the wind sites covering the whole of that country. On the other hand, preparation of a map of this kind is lengthy and requires considerable technical, organisational and financial commitments. This is the reason why this goal is still far from being achieved even in countries more involved in wind technology.

2.2 Wind Turbine Technology

According to the arrangement of the rotor in relation to the direction of the wind, wind turbines can be classified in two broad categories:

- Horizontal-axis wind turbines, in which the direction of the wind is parallel to the axis.

- Vertical-axis wind turbines, in which the axis of the rotor is perpendicular to the ground and to the direction of the wind.

The horizontal-axis machines (Fig.2) are those which have to date been most developed technologically and are most widely available commercially. At present horizontal-axis wind turbine generators represent approximately 95% of the capacity installed at production plants. They are composed schematically by the following parts:

- Foundation.

- Tower.

- Nacelle, which in a wind turbine generator contains the electric generator and the gearbox. The latter is necessary since wind machines usually rotate at lower speeds than the electric generators currently in use.

- Rotor, which is the part used to collect the wind energy and which can be positioned upwind or downwind in relation to the tower. The rotor consists of a hub, on which the blades are mounted. The latter can vary in number, affecting machine features and performances to an appreciable extent in that rotors with less blades rotate

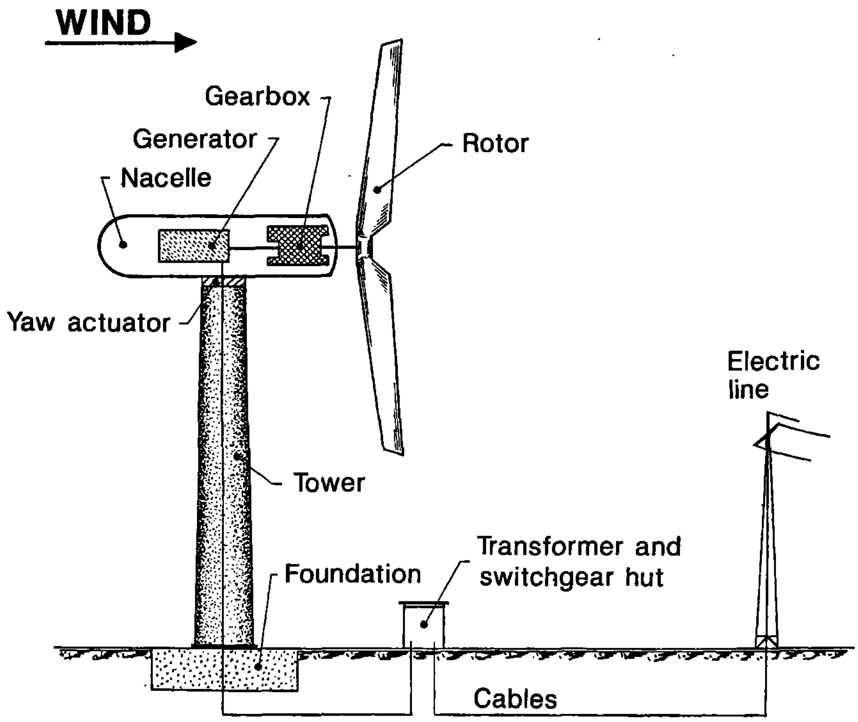


Fig.2 - Typical horizontal-axis wind turbine generator.

Fig.2 - Aérogénérateur typique à axe horizontal.

faster but produce very low starting torques and hence cannot be started up under load. The rotor can be fitted with devices for varying the pitch of the blades in order to regulate the power output. This regulation capability can also be achieved more simply in constructional terms by appropriately designing the profile of the blades (stall regulation).

- Yaw control device for positioning the nacelle according to the wind direction.

- Control systems and instruments.

- Cables, for conveying the electric energy produced to ground level (in the case of wind turbine generators) and for transmitting the necessary signals.

The advantage of vertical-axis machines, compared to those with horizontal axis, is that their generation and control equipment is located at ground level, thus considerably simplifying maintenance operations.

Currently Darrieus machines (Fig.3), consisting of a tubular shaft maintained in position vertically by stays, are being

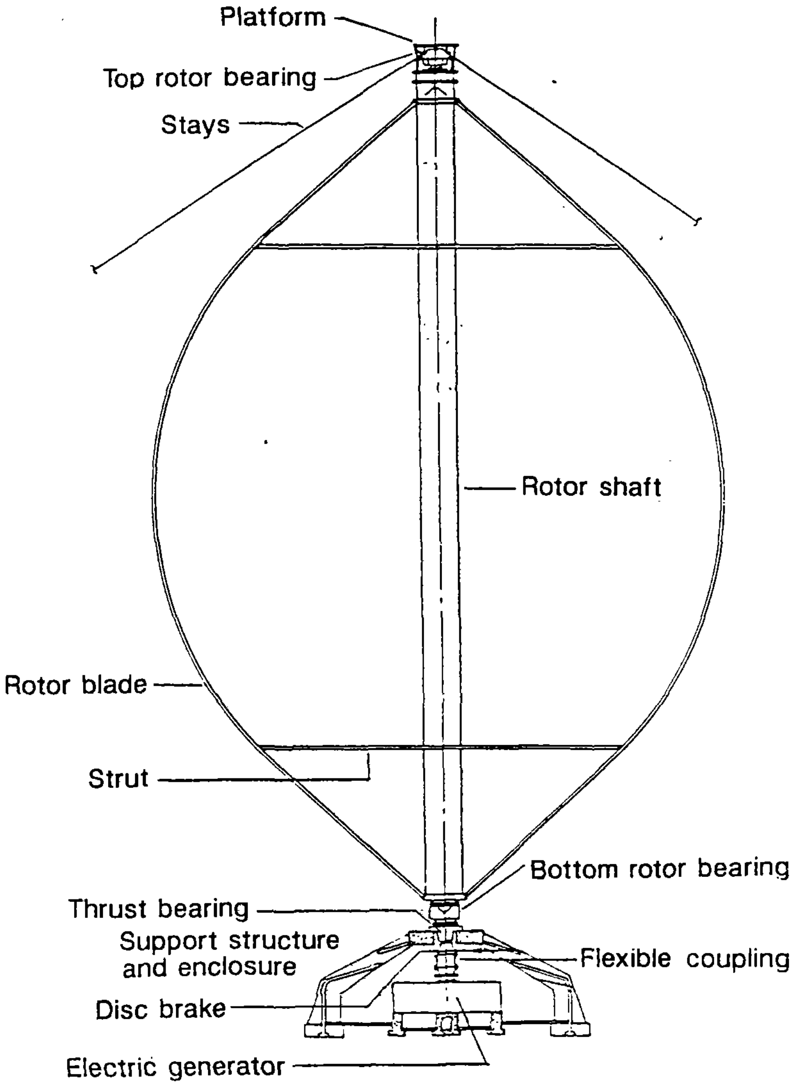


Fig.3 - Darrieus-type, vertical-axis wind turbine generator.

Fig.3 - Aérogénérateur à axe vertical de type Darrieus.

developed to the greatest extent. Two or three curved blades are fixed to the shaft so that both their ends are connected to the axis. The base contains the gearbox and the generator. The machine does not have to be positioned in relation to the wind direction. Given its very low starting torque, it is usually necessary to provide an auxiliary motor for starting. Furthermore the pitch of the blades, which are fixed to the shaft, cannot be altered.

A variation on this model is the variable-geometry Darrieus rotor, whose blades are straight and jointed. The centrifugal force exerted on the blades during motion causes a change in the swept area, allowing the power output to be regulated.

For the time being relatively few vertical-axis machines are installed in wind plants, since they are still at an early stage of industrialisation. For this reason reference will only be made from now on to horizontal-axis machines.

To sum up, by referring to the case of wind turbine generators which are currently the most important machines for application purposes, it has to be borne in mind that the turbine starts producing useful electric power only if the wind blows at a minimum speed, known as the cut-in speed.

This power gradually increases as the speed of the wind rises (Fig.4), and only reaches the rated value when the speed of the wind exceeds an appropriate value (rated wind speed). The wind turbine generator is then disconnected from the network at a maximum wind speed, known as cut-out, for safety reasons.

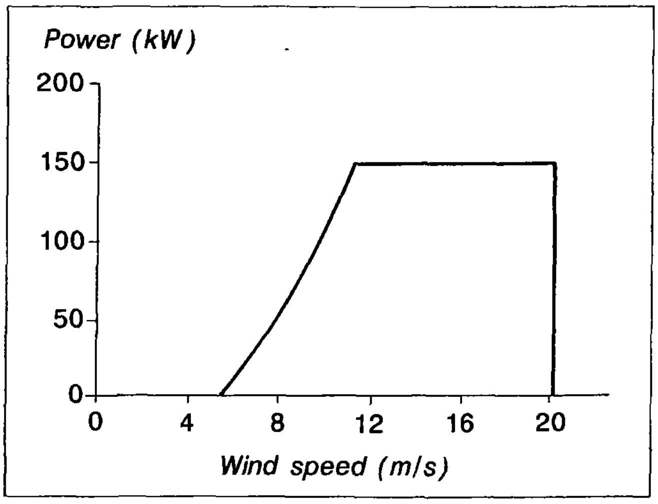


Fig.4 - Power curve (showing the trend of power output versus wind speed) of a pitch-controlled wind turbine generator.

Fig.4 - Courbe de puissance (montrant l'évolution de la puissance de sortie en fonction de la vitesse du vent) d'un aérogénérateur avec réglage du pas d'hélice.

The above is true not only for wind turbine generators but also for any wind machine. It should therefore be remembered that these devices are only able to produce useful power at wind speeds in a suitable working range which is typical of each machine model.

The energy that can be produced annually by a wind turbine generator must be maximised by appropriately combining machines with suitable features at sites having different wind speeds.

We will now consider the developments in the technology of horizontal-axis wind turbine generators. The latter should normally be classified as:

- Small-sized wind turbine generators (capacity of up to 100 kW and rotor diameter of up to 20 m).
- Medium-sized wind turbine generators (capacity of between 100 kW and 1 MW and rotor diameter of between 20 and 50 m).
- Large-sized wind turbine generators (capacity equal to or higher than 1 MW and rotor diameter of over 50 m).

2.2.1 Technology of Medium-Sized Wind Turbine Generators

Over the past ten years, there has been a constant increase [3] in the size of commercial wind turbine generators installed at grid-connected wind power plants (Fig.5). Whereas the machines installed up to a few years ago had unit capacities of 50 - 100 kW, the models installed over the past two - three years generally have rotor diameters of 25 - 30 m and capacities of 250 - 300 kW [4].

Their configuration is conventional and has moved towards increasingly large sizes: three-bladed rotor with rigid hub (only in a few cases two-bladed, or even single-bladed, with teetering hub); blades in glass fibre reinforced plastic, or

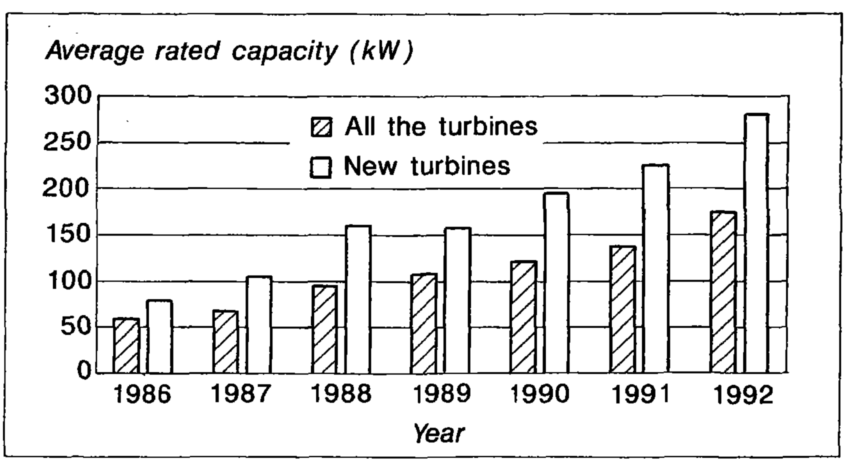


Fig.5 - Average size of wind turbine generators installed in the European Community (all the turbines and new turbines) in the period 1986 - 1992.

Fig.5 - Taille moyenne des aérogénérateurs installés dans la Communauté Européenne (toutes les machines et les machines nouvelles) durant la période 1986 - 1992.

less frequently in laminated wood bonded by epoxy resin, fixed to the hub by steel inserts; power regulation by adjusting the pitch of the blades (stall regulation, typical of several smaller machines, has been abandoned at least temporarily on larger models); asynchronous (induction) generator; steel tubular or steel truss tower (the latter above all in the U.S.A., due to the lower cost and less aesthetic demands).

The increase in size, retaining the classic configuration, is still underway: several manufacturers have introduced new models currently undergoing industrialisation, with a power of 500 kW (some even of 600-750 kW) and rotor diameters of up to around forty metres.

Considerable progress has been made as regards performances (Fig.6 and Fig.7). At the most modern and best-sited plants, values have been recorded of up to 30% for the "capacity factor" or "plant factor" (annual net energy output divided by the output of the system if operating at its rated capacity for 8760 hours per year) and 95% or even higher for machine availability (time fraction of the year the wind turbine is technically ready for operation, regardless of wind conditions).

In Denmark the first offshore wind power plant has been in operation for a year and a half, with eleven 450 kW machines

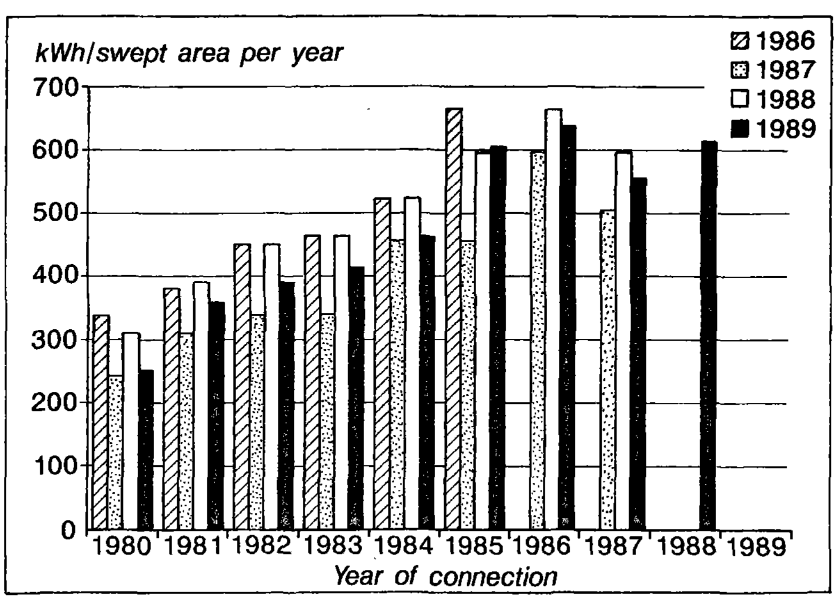


Fig.6 - The growth in wind turbine generator energy output in the period 1980 - 1989.

Fig.6 - Croissance de la production d'énergie par les aérogénérateurs dans la période 1980 - 1989.

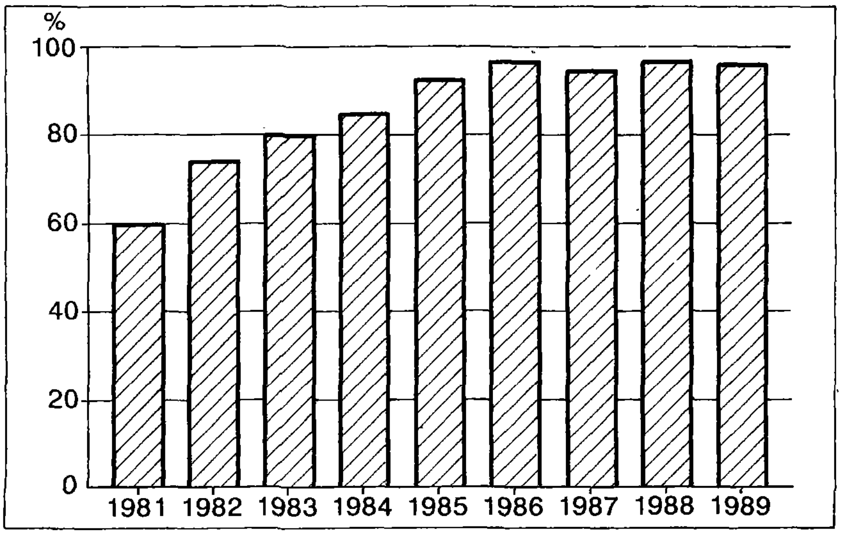


Fig.7 - Increase in the availability of top-performing wind power plants in California.

Fig.7 - Augmentation de la disponibilité de centrales éoliennes très performantes en Californie.

which are fully mass-produced, apart from a few modifications (for example to the paintwork) aimed at adapting them and increasing their resistance to the marine environment. The experience in operation has been satisfactory to date.

The present objective of manufacturers is to increase further the energy output, reliability and working life of machines of around 500 kW, also by introducing new concepts if necessary, such as direct drive of the generator without the gearbox, passive control of blade pitch and, above all, operation of the rotor at variable speed, which allows operation to be continued in optimal aerodynamic efficiency conditions as the wind speed changes (in the latter case, naturally, the wind turbine generator must be connected to the network via a frequency converter).

A decisive contribution to the development of medium-sized wind turbine technology has been given and is still being given by the Commission of the European Communities, with programmes such as JOULE 1 and 2 of DG XII and the demonstration programmes (the latest of which is THERMIE) launched by the Directorate General for Energy (DG XVII).

Efforts in this direction are also being made in the U.S.A., where last autumn the Department of Energy (DOE) launched a programme which, in collaboration with the Electric Power Research Institute (EPRI) and the utilities, aims at encouraging the development of a new generation of industrial wind turbine generators in the next 5 years (see subsection 4.2.1).

A second, more ambitious, objective is however been pursued: develop industrialised machines of around one megawatt or even greater, able to compete with the medium-sized ones in the second half of this decade.

2.2.2 Technology of Large-Sized Wind Turbine Generators

After the pioneering age, which ten years ago had led to the construction of large, but clearly uncompetitive, prototypes (capacities of up to 4 MW and rotor diameters of up to 100 m) in the U.S.A., Sweden, Germany etc., greater interest in large wind turbine generators has recently been revived in Europe, thanks also to the boost from the European Community (more particularly from DG XII). This comes as no surprise if we consider that European countries, densely populated, are those most aware of problems such as exploitation of land and visual impact, which the use of a relatively smaller number of larger-sized machines could partly resolve.

Worthy of special mention in this respect is the programme launched by DG XII with the WEGA 1 and WEGA 2 actions, performed as part of the programmes JOULE 1 and 2 respectively. WEGA 1, aimed merely at ascertaining the effective feasibility of large turbines, has entailed an in-depth campaign of tests on European prototypes (the Danish 2 MW one at Esbjerg, the Spanish 1.2 MW one at Cabo Villano and the British 1 MW one at Richborough).

The results obtained and recently published [5] have confirmed the substantial feasibility of large wind turbine generators, but have also shown that the machines examined, all built according to a traditional technology, i.e. heavy and rigid structure, fixed speed, three-bladed rotor with rigid hub etc., are still far from being competitive with medium-sized machines.

This led to the launching of a new scheme, WEGA 2, aimed at identifying and developing the technology which enables machines of more modern design, of around one megawatt capacity and with 50-60 m rotors, to become commercially competitive in the short-medium term.

This new objective is also based on the results of a 1990 EC study (sponsored by DG XII) according to which, for modern machines, flexible and lightweight in structure, the cost of the energy produced remains virtually constant with rotors ranging from 30 to 80 m in diameter (Fig.8) [6].

Seven projects from 6 countries, concerning machines with widely differing technical solutions, have been granted EC funding. The relevant prototypes are to be installed in mid-

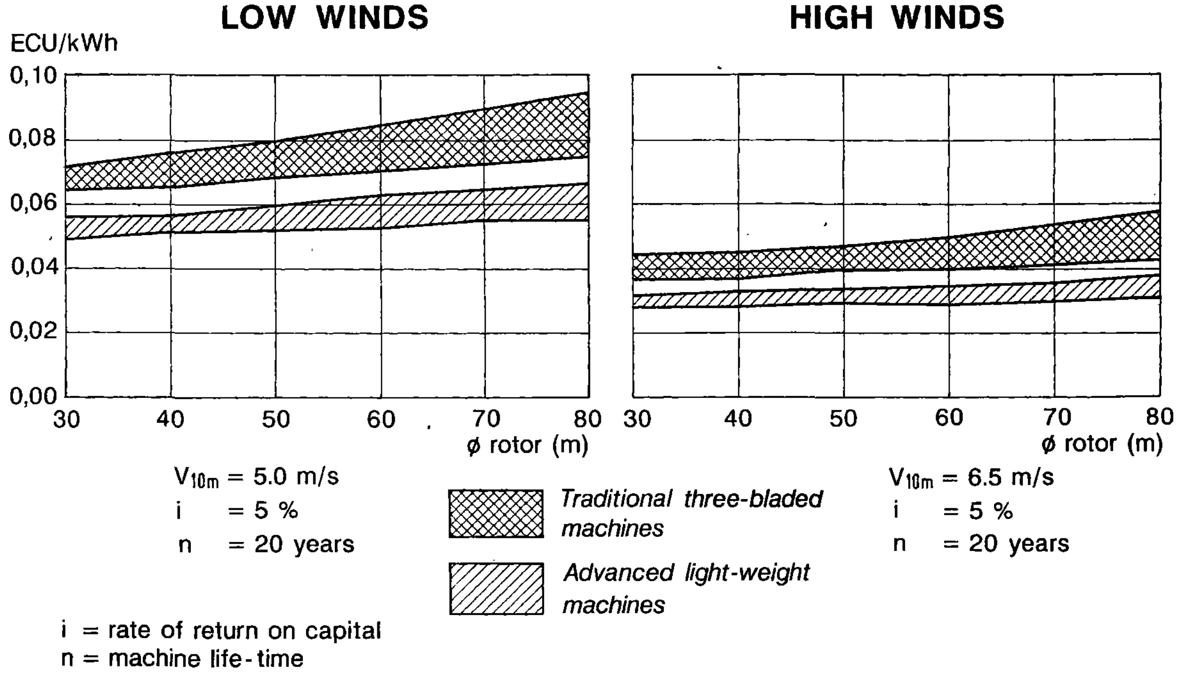


Fig.8 - Unit costs of energy produced by wind turbine generators with rotor diameters ranging from 30 to 80 m (study by DG XII of the EC). The diagrams refer to sites with annual mean wind speed of 5 and 6.5 m/s, respectively.

Fig.8 - Coûts unitaires de l'énergie produite par des aérogénérateurs avec des diamètres de rotor allant de 30 à 80 m (étude DG XII de la CE). Les diagrammes se réfèrent à des sites ayant une vitesse de vent moyenne annuelle de 5 et 6,5 m/s, respectivement.

1995 and then experimented in parallel under EC supervision. The results should allow the optimal solution (or solutions) to be found for large and economically competitive machines.

In addition to the new projects funded as part of WEGA 2, it is worth remembering, as regards Europe, other recent large-sized machines [4], including in particular: the twins Aeolus II and Näsudden II, 3 MW and 80 m in diameter, recently installed in Germany and Sweden respectively and derived from the experience obtained with the German-Swedish prototype of Näsudden in the 'eighties, and the Italian GAMMA 60 prototype, 1.5 MW and 60 m in diameter, featuring a particularly innovative configuration, in which the broad range variable speed operation is combined with regulation of power output by means of yaw control.

2.2.3 Technology of Small-Sized Machines

The technology of small-sized wind turbine generators has to be considered at present as fairly advanced, although still a poorly-defined area due to the large number of technologies employed and often based on widely differing operating logics.

Above all the applications considered to be promising for the spread of small-sized wind turbine generators are generally those linked to the supply of isolated dwellings: pumping, desalination, integration with diesel, storage, integration with other renewable sources (biomasses, photovoltaic plants, etc.). In all these cases storage capacity is an essential factor for the correct technical-economical dimensioning of the plant.

As far as wind pumps are concerned, it has to be remembered that in the past twenty years machines of new design and greater constructional simplicity have been designed to be subsequently produced in developing countries, where there is greatest demand. This approach has not yet achieved the success hoped for, mainly due to two reasons: firstly because the new machines are not yet fully reliable and secondly because lack of funds and know-how in developing countries prevents mass production and also routine maintenance of the existing park.

3. FACTORS CONDITIONING WIND ENERGY DEVELOPMENT

As mentioned previously, the production of significant amounts of electricity from wind can only be envisaged for grid-connected wind power plants made up of a number of medium-sized or large units.

However, the widespread use of such plants in the future is conditioned by a series of social, environmental, technical and economic factors, the most important of which are briefly recalled below.

3.1 Public Acceptance

The public's attitude to a non-polluting technology such as wind power is, in principle, very positive everywhere, but opposition may arise among those people directly involved when a specific project is announced in a given place due to fears that the environment may be irretrievably damaged, or merely due to fear of the unknown.

It has however been found that such opposition largely subsides once the plant has been built. It is therefore strongly recommended that:

- The inhabitants of areas close to the potential sites for wind power plants are made aware of the project as soon as possible through illustrative material and meetings which provide correct information both on the plant being built and on wind energy in general.

- Both planning authorities and local inhabitants be involved, from the very outset, in any decisions to be taken on a particular project. It must be taken into account that local public opinion and political opinions influence each other.

- Incentives be granted, wherever possible, to the local population.

3.2 Land Requirements

As stated in section 2.1, apart from the large number required, the wind turbine generators of a wind power plant have to be laid out according to certain patterns, and properly spaced, so as to minimise the effects of aerodynamic interference. This means taking over vast areas of land that have to be free from any kind of constraint that would prevent the installation of wind turbines.

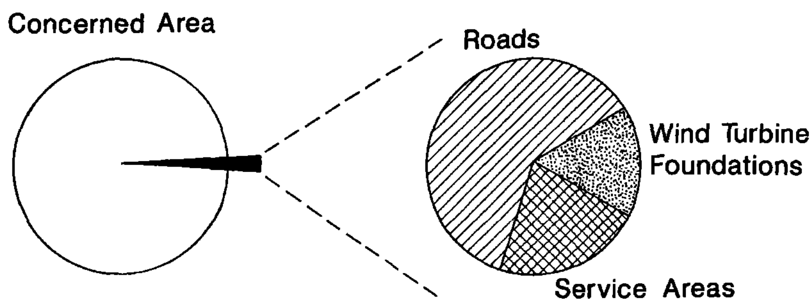
To give a general indication, a square-meshed layout with an inter-machine distance of about 7 times the machine rotor diameter can be chosen for areas with a multi-directional wind pattern, whereas in the case of a prevailing wind direction, units are usually laid out in parallel rows (perpendicular to the prevailing wind), with a 3-5-diameter distance between machines in the same row and a 10-diameter distance between rows.

The power density that can be installed ranges approximately from 5 to 8 MW per square kilometre of land involved, depending on the layout and inter-machine distance chosen, as well as on the actual availability of the area, which may be reduced by the presence, at some points, of excessively rough terrain or natural obstacles.

However, it should be noted (Fig.9) that the structures of a wind power plant only actually occupy 1% of all the land concerned, unlike, for example, photovoltaic plants. Indeed, the actual wind turbines take up only 0.2% of the land, while the remaining 0.8% is accounted for by road links and service areas. After plant construction work at the site has finished, 99% of the land in question can then continue to be used for agriculture (e.g. cultivation of crops, grazing) or remain a natural habitat.

3.3 Visual Impact

The visual impact of wind turbines on the countryside is one of the most contentious aspects of the siting of wind power



The plant actually occupies only 1% of the land concerned (wind turbines only 0,2%)

Fig.9 - Land concerned and land actually occupied by a wind power plant.

Fig.9 - Territoire concerné et territoire effectivement occupé par une centrale éolienne.

plants. It depends not only on the shape, colour and layout of the wind turbines and on the landscape into which they have to fit, but also, to an appreciable extent, on the subjective reactions of individual onlookers. The latter are in turn influenced by their own attitude towards the plant.

It is an unavoidable fact that the windiest places are often the most beautiful and show the least sign of human interference. Hence the importance of involving local members of the public in decisions affecting the compatibility of machines with their environment.

From a survey carried out in various European countries (above all Denmark, Holland, Germany and Great Britain) it was found [7] that the majority of the interviewees preferred: three-bladed wind turbine generators with tubular tower and neutral colour; a few large-sized units rather than many small-sized ones; machines laid out in one single row rather than in several rows, particularly on flat land.

3.4 Audible Noise

Like visual impact, the noise issue has a strongly subjective aspect, since the level of noise acceptable to an individual will also depend on his or her general attitude towards the wind plant. More specifically the disturbance depends on two factors:

- The sound emission of the wind turbine.

- The acceptable level of noise emission to the environment.

The distance between the wind machines and the residential areas is calculated from knowledge of noise levels emitted and from acceptable emission levels.

As regards the source of the noise, in machines with a rotor greater than 20 m in diameter, this is mainly due to the aerodynamic effect of the wind on the blades and, to a lesser extent, to the motion of the gearbox. In smaller-sized machines the noise caused by moving mechanical parts prevails.

In order to give an idea of how much noise a wind plant produces, it can be said [1] that a typical modern, 300 kW wind turbine generator, operating at a wind speed of 8 m/s, produces, at a distance of about 200 m, a noise level of about 45 dB(A) (Fig.10), a level that is commonly considered acceptable, internationally, for rural dwellings.

If we then consider the case of several turbines, it has been found that, for a wind farm with thirty 300 kW units, the

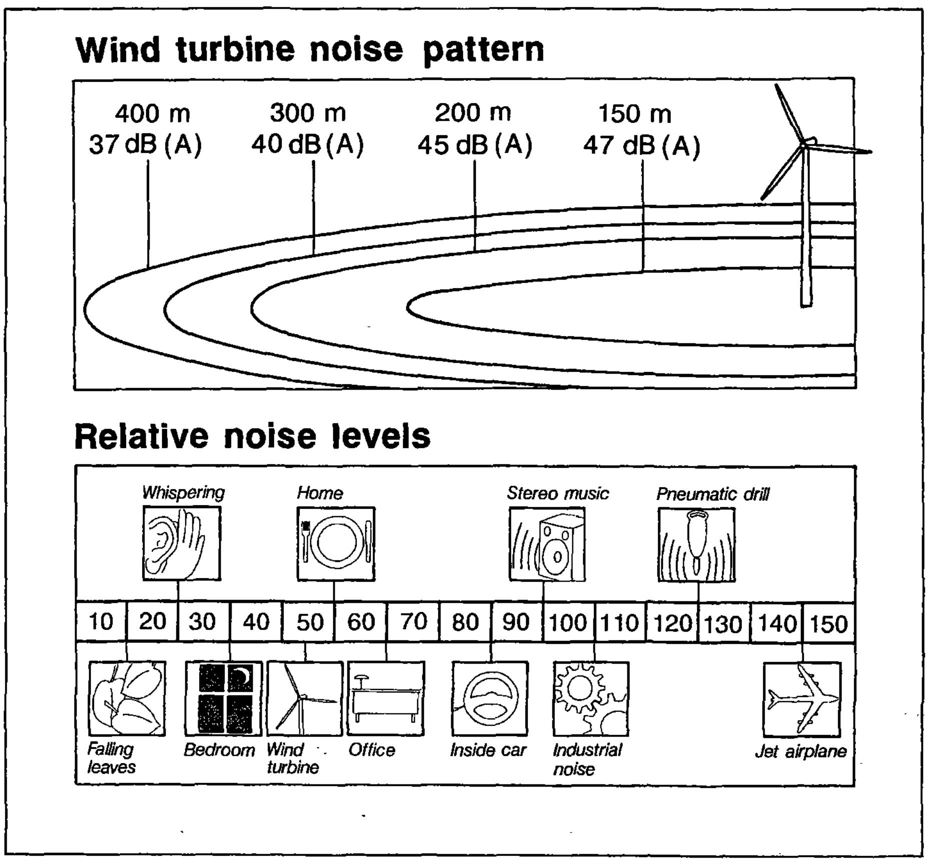


Fig.10 - Wind turbine noise pattern, based on actual measurements.

Fig.10 - Schéma des niveaux de bruit produit par une turbine éolienne, basé sur des mesurages effectifs.

typical noise level is 45 dB(A) at a distance of 500 metres from the nearest machine [1].

As regards the acceptable noise emission level, this varies according to the area and to the time of day. What is found to be acceptable in an industrial area is not so in a rural one and what is acceptable during the day is not so during the night. Legislation on admissible noise levels is strongly local in nature: there are widely differing limits of acceptability within Europe and, naturally, the problem then arises of standardising regulations.

3.5 Telecommunications Interference

Wind turbines may interfere with telecommunications. However, experience has so far shown that these effects are strictly local and limited to areas nearest the machines, and that they become entirely negligible when the rotor blades are made of materials other than metal.

Interference with TV reception should not, therefore, be considered an issue. As for radio links and other telecommunications, any problems can be easily overcome provided microwave routes are avoided and the installation of large machines is suitably limited around airports and other sensitive areas.

3.6 Impact on Natural Habitat and Wildlife

The possible effects of wind turbines on natural habitat and wildlife (especially on birds) have been the subject of studies in several countries [8].

As far as bird life is concerned, possible damage can be attributed mainly to:

- Birds colliding with towers and blades.
- Noise and generally proximity of the moving rotor, as sources of disturbance during breeding, nesting or feeding.

As regards deaths following collision with a wind turbine, a recent study [9] carried out at a Dutch wind power plant with twenty-five 300 kW units has shown that, from this point of view, a 1 km line of wind turbines is comparable to 1 km of motorway and, in certain circumstances, could be only 10% as damaging as 1 km of high voltage line.

In Denmark too it was found that birds do not actually appear disturbed by wind turbine generators. They in fact seem to be accustomed to the presence of the machines and learn to fly around them without coming to any harm.

Nevertheless objections have been raised by naturalists in the U.S.A. and Europe. Further studies are in progress or planned, for the purpose of going deeper into the possible effects on some aspects of bird life, such as migration, breeding, nesting and foraging. It should however be noted that the attitude of wildlife protection associations has now become generally more positive, provided that natural protected areas are not involved.

Finally we should point out that negative effects of wind power plants on crops have not been recorded, even if they are on the same land where the plant is located.

3.7 Safety Aspects

Clearly wind turbine generators, being generators of electricity and systems made up of moving parts, may pose a hazard to humans.

Nevertheless it has to be acknowledged that the safety record of wind energy technology has so far been very good, and the few accidents causing human injury have been the result of poor management or non-observance of safety regulations, rather than technical faults.

As confirmation of this, insurance companies in the United States, in spite of the large number of wind turbine generators in the country, appear to agree that this does not represent a particularly great problem.

Modern wind turbines are equipped with monitoring systems which give early warning of potential failures. Moreover a large number of machines have been tested by certification organisations which issue quality certificates only after having subjected the machines to very strict tests.

Nevertheless it should not be forgotten that possible hazards to persons can have a serious bearing on the use of wind power plants. At present there are no internationally agreed technical standards for the design, manufacture, installation and operation of wind turbines, although various states have drafted their own requirements, which are used in testing, certification and building licences. However this approach can lead to trade barriers and is inhibiting the development of a free market.

An important contribution is at present being made in this area, together with the ISO, by the International Electrotechnical Commission (IEC) through its Technical Committee 88 "Wind Turbine Systems", which has been set up to prepare standards on safety, measurement techniques and procedures for testing wind turbines. Specifically, the preparation of an IEC standard on the safety of wind turbine generators is already at an advanced stage.

3.8 Acceptable Penetration of Electricity Systems

Inclusion in an existing electric power system of substantial amounts of wind generating capacity can lead to problems for the system itself, particularly as regards regulation of voltage and frequency, as a consequence of the variable and random nature of the source.

The addition of wind power plants could affect the system frequency regulation in two ways:

- Wind turbine output fluctuations are additional random events which the so-called "spinning reserve" of the system would have to cope with.

- Wind turbine generators increase that part of the generating equipment which cannot take part in frequency control (such as thermal base-load units, run-of-river plants etc.).

As far as voltage regulation is concerned, the connection of wind power plants to distribution networks could require significant changes to the voltage regulators of substation transformers, to make up for possible operating conditions where energy production exceeds demand (e.g. low-load conditions during the night). Moreover, wind power could also bring about transient disturbances, specifically:

- Fluctuations in wind turbine output could cause flicker.

- In the common case of machines with induction generators, the high transient magnetizing current, absorbed when starting, could cause unacceptable voltage dips.

- The switching-off of a wind power plant to isolate it from the system in the event of a fault on the distribution network could build up dangerous overvoltages.

Special research is therefore called for, to look into the maximum level of penetration by wind-generated power which does not cause unacceptable disturbance to correct operation of the system or, alternatively, unacceptably high costs of alterations to the system itself.

In this connection, a study on wind energy penetration, promoted by DG XII of the Commission of the European Communities, is being conducted in co-operation with experts from some of the leading European utilities. The first part of this study has already shown that national systems in European countries can, without any need for major technical alterations, stand a degree of wind power penetration equal to 5% of their total electric energy production. Research is still proceeding, however, to ascertain the effect of higher degrees of penetration (10%).

Special attention is required when inserting wind turbine generators into small isolated grids fed by diesel generating plants. Each of these cases, in which wind power may even represent an appreciable share of the overall generating capacity, has to be studied very carefully, taking into account the time trend of the electric loads and wind conditions, in order to check whether frequency and voltage variations are always kept within the prescribed limits.

3.9 Cost of Wind-Generated Electricity

Estimating the unit cost of the energy produced, a decisive factor for the future development of wind resources, is still one of the topics most debated. This is due to the fact that there is still some uncertainty as to some of the parameters required for calculating the cost of the kilowatt-hour (reference is generally made to the production of electricity), even though recent experience has begun to provide more accurate indications on various aspects.

The unit cost of the electric energy (COE) produced by grid-connected wind power plants, whatever cost data are initially assumed, is generally calculated by a method based on the following formula:

$$COE = \frac{A + B}{E}$$

where A + B is the total cost borne in one year and E is the net energy supplied to the electricity system over the same period of time. More specifically, A is the annual plant cost and B is the annual operation and maintenance cost.

As a first approximation, A can be considered equal to the amount of annual depreciation of the capital cost of the plant, of which wind turbines are a major, but not predominant, part. By way of an example, Fig.11 shows the breakdown of plant costs for seven Danish wind power plants [1].

Since the energy produced by a wind turbine generator depends strongly on the wind speed at the site and the area swept by the rotor blades, a very useful parameter that describes the cost effectiveness of a wind turbine fairly is the cost per unit of swept area expressed in ECU/m^2, rather than the cost per kilowatt of rated power of the electric generator installed. For mass-produced, medium-sized machines this cost (ex factory) is currently of the order of 300-400 ECU/m^2.

Additional costs, concerning the transportation and installation of wind turbine generators and electrical and civil engineering infrastructures, vary considerably from country to country and from site to site. The windiest sites

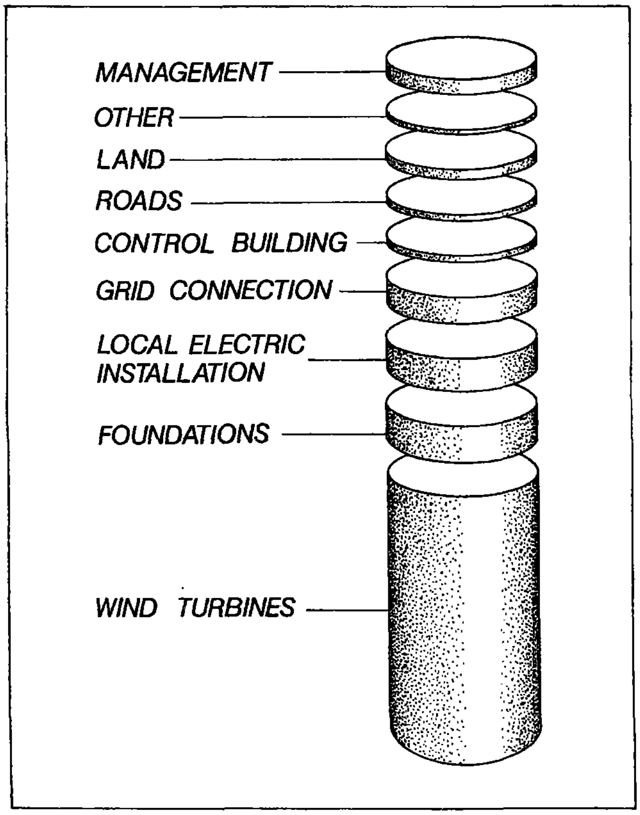


Fig.11 - Breakdown of plant costs for seven Danish wind power stations.

Fig.11 - Détail des coûts d'usine pour sept centrales éoliennes danoises.

are often the least accessible. These costs can be between 25 and 50% of the ex-factory price of the machines.

The total capital cost of a grid-connected wind power plant may therefore be put at between 400 and 600 ECU per square metre of rotor area and per machine installed.

The amount of annual depreciation is obtained by multiplying the total capital cost by the annualization factor (or capital recovery factor), obtained from a well-known formula as a function of the rate of return required on the capital invested and the time (in years) during which the capital cost is amortized, depending, in turn, on the expected useful lifetime of the machines.

The amount of annual depreciation and, consequently, the cost of energy therefore depends on the way the plant is financed, and this is an area particularly sensitive to political strategies. Typical power station projects in the public sector require a 5% rate net of inflation. Higher real interest rates may, however, be applied to private ventures on the free market (i.e. 8%). Another key factor is obviously the useful lifetime of machines, which decides the term of financial loans. Manufacturers usually state a lifetime of 20 years.

The annual operating and maintenance cost B is mostly made up of the cost of operating staff and the cost of scheduled and extraordinary maintenance. Replacements of parts having a shorter lifetime than the total wind turbine generator should be taken into account when estimating this cost. Based on current evaluations and available experience, and neglecting the effects of inflation, the annual operating and maintenance cost may be put at a constant value equal to 2.5% of capital cost, on an average.

The annual energy output E strongly depends on wind conditions at the site. Good windy sites have annual average wind speeds of at least 6.5 m/s, even though sites with lower wind speeds may be worth exploiting. To obtain the net amount of energy yield, it is necessary to multiply theoretical productivity by reduction factors accounting for machine availability as well as losses resulting from the wind shadow effect of machines sited in arrays.

After making conservative allowances for availability (90%) and array losses (5%), by combining a number of likely values of the factors listed above, the cost of a wind-generated kilowatt-hour is calculated at between 0.05 and 0.08 ECU/kWh [1].

These estimates are now being confirmed by current experience. Data from a number of wind power stations provided by Danish utilities [10] put the generating cost at 0.06 ECU/kWh, at sites whose typical annual average wind speeds are around 6.5 m/s at 10 m above ground level. As for American wind plants, in October 1992 the U.S. Department of Energy (DOE) reported [11] generating costs ranging from 7 to 9 cents/kWh at sites with annual average wind speed of 7 m/s at 10 m.

The estimates given above refer, as already underlined, to wind power plants with grid-connected medium-sized machines for industrial production. As regards stand-alone wind power systems however, the estimates of the costs of the kilowatt-hour supplied to consumers provide much higher values compared to the previous case, due to the higher specific cost of small-sized wind turbine generators, the cost of the storage batteries and of the inverter, where necessary, as well as the considerable costs of the maintenance required by systems of this type, which are almost always located in remote areas.

A further reason which contributes to increasing the cost of the kilowatt-hour actually supplied to the user by the stand-alone systems is the fact that, in these systems, operating conditions may occur in which a part of the power which could be made available by the wind turbine generator is inevitably lost, for example through regulating the latter's blade pitch or by connecting dump loads within the system. This may occur, for example, when, with useful wind power, the storage batteries are completely charged and the electric power absorbed by the user is lower than the amount which the source could supply.

3.10 Value of Wind-Generated Electricity

To estimate the profitability of the wind as a power source, the unit cost of energy has to be set against its value. In principle, the value of a wind-generated kilowatt-hour is given by the sum of a few different factors, which are dealt with further on.

3.10.1 Energy Credit

The connection of wind power plants to an existing electric power system may result in a saving in annual operating costs, due in the main to reduced fuel consumption by thermal power plants whenever wind power is available. The overall saving, divided by the number of kilowatt-hours that can be produced annually from wind energy, is called "energy credit", and is basically the same as the marginal cost of the kilowatt-hour produced by "conventional" power stations involved in this replacement.

It should be stressed that, when quantifying energy credit, appropriate consideration must be made of the different marginal costs of the kilowatt-hour produced by the various plants effectively replaced, from time to time, by wind generation. The energy credit can vary even appreciably according to both the specific type of plants which supply the electricity system in question, and the particular time of day in which the wind source makes its contribution to the system itself.

Clearly if the wind-generated kilowatt-hour replaces, at low-load times of the system, that produced by a large base-load coal-fired plant, its energy credit is equal to the marginal cost of generation from coal, i.e. to approximately 1.8 ECU cents per kilowatt-hour. If the kilowatt-hour replaced is produced from fuel oil, again in a large base-load plant, the marginal cost (and hence energy credit) rises to 2.2 ECU cents (and to 2.8 ECU cents if produced by natural gas).

The situation is much more interesting if the wind-generated kilowatt-hour replaces, during a peak load, that produced by gas turbine plants fuelled by diesel oil (plants which are typically placed in service in these circumstances). In this case its energy credit rises to around 5 ECU cents per kilowatt-hour.

An even more favourable situation than the previous one then occurs with the wind-generated kilowatt-hour supplied within small isolated electric systems powered by generation units with diesel engines, since in these cases the cost of diesel oil may rise considerably due to the high transport costs, as in the case of small islands or particularly remote areas.

3.10.2 Capacity Credit

The connection of wind power plants may result in improved reliability of the electric power system or, should it be intended to expand that system, it may, given the same degree of reliability, allow reductions in the new amount of "conventional" capacity to be installed. The annual charge corresponding to any capital expenditure thus saved, divided by the kilowatt-hours producible annually from wind, is called "capacity credit".

Considering the random nature of the source, it is still widely discussed whether, and to what extent, wind power plants may be allowed a certain capacity credit, although the computation of this parameter is anything but simple. Analyses performed on this subject have shown, among other things, that this capacity credit is not a constant value, but one that tends to decrease as the wind generating capacity installed in a given electric power system increases.

An example of this is given by the results of the capacity credit evaluation provided by the Irish contribution to the aforementioned Wind Energy Penetration Study promoted by DG XII of the Commission of the European Communities. In this connection, an estimate was made of the amount of traditional generating capacity that can be displaced by wind power plants while providing the same total reliability level of the power system. The results underline the fact that 100 MW of wind capacity may contribute as much as 30 MW of "conventional" generating capacity for providing the adequate system reliability level, and, what is more, this contribution decreases as the wind power penetration level increases. This does not mean that the "firm power" concept cannot be applied to wind plants as well, but that the whole matter has to be looked into with the utmost care in order to avoid over-hasty conclusions.

3.10.3 Credit for Avoided External Costs

Whenever electricity is produced by "conventional" means, the public has to bear additional costs that have not yet been included in electricity prices. These costs are called "external costs", and are, for example, the costs of air pollution, damage to public health, military protection of fuel supplies, cleaning up after oil spillage, disposal of radioactive waste, etc.. The use of renewable sources such as solar and wind power enables some of these costs to be avoided.

In addition to avoiding external costs, the use of indigenous, renewable sources such as solar and wind power also brings about benefits to society, as it reduces dependence on energy imports, thus boosting security of supplies, may have positive effects on employment, and saves an amount of finite, non-renewable resources such as fossil and nuclear fuels.

A systematic quantification and monetarization of both avoided external costs and their counterpart, the social benefits (referred to as a whole as external effects, since they are external to the market process and to the economic agents producing them) has proved to be quite difficult. Indeed, these external effects depend on a very large number of variables, in particular the mix of plants in the specific system considered, and, what is more, several aspects are not so easy to quantify immediately. Nevertheless research on this subject has been undertaken on both sides of the Atlantic.

Of particular importance in this context is the work of O. Hohmeyer [12], carried out under contract to DG XII of the Commission of the European Communities. Referring to the specific case of Germany, Hohmeyer set out to consider both the external costs of producing electricity by fossil fuels and nuclear power, and the social benefits of using renewable energies. Taking a conservative estimate of Hohmeyer's figures, wind-generated electricity may be allowed a credit in respect of external effects (avoided external costs and social benefits) of at least 0.04 ECU/kWh at 1990 rates.

Similar figures have also been obtained in another study conducted (with reference to the Netherlands) by A.J.M. van Wijk [13] through a different approach. This approach concerns the direct technical costs of avoiding polluting emissions in compliance with environmental legislation, and, therefore, avoids some of the more intangible aspects of Hohmeyer's work and is closer to the methods currently used by utilities. In spite of this, van Wijk has obtained figures that are slightly lower, but similar to Hohmeyer's results, considering that he excluded some external costs and social benefits.

Another study was conducted in the U.S.A. by the Pace University Center for Environmental Legal Studies (R. L. Ottinger, et al.) [14], considering only the costs of environmental damage caused by electricity production. Other non-environmental external costs were excluded, as well as environmental costs from the front end of the fuel cycle (mining, oil drilling, etc.). Here too, taking into account the difference in scope, the results obtained are of the same order of magnitude as those of Hohmeyer.

3.10.4 Prospects of Competitiveness

From what has been said previously about the cost and value of a kilowatt-hour produced by wind, it can be inferred that wind-generated electricity is at present nearing competitiveness with "conventional" sources, at least as far as grid-connected plants are concerned. On the other hand, it should be taken into account that the convenience of using stand-alone plants in some particular situations should also be assessed on the basis of other, not strictly financial, considerations.

While there is no doubt that wind-generated electricity can be allowed an energy credit (although the actual amount of it depends on the specific situation), the issues of capacity credit and credit for avoided external costs are still the subject of much discussion.

The extreme importance of going deeper into these matters is self-evident: should the figures reported for the credit for avoided external costs be confirmed by further research, this alone would mean that wind-generated electricity can already be considered as fully competitive today.

4. WIND ENERGY DEVELOPMENT FROM 1995 TO 2005

The technology of the wind turbine generators currently in use is only fifteen years old, and investment in it has so far been rather modest, compared with other energy sources. Despite these slow beginnings, the total wind generating capacity connected to the grid worldwide is now approaching 3,000 MW, not to mention the tens of thousands of very small machines used for pumping water and charging batteries. The electric energy generated by the wind worldwide in 1992 can be estimated at a total of 4.3 billion kWh [15].

Two quite distinct approaches have been used so far to stimulate the wind industry: the market-led route, and the route of capital investment by governments in research and development. The market-led approach, promoted by the Americans and the Danes, developed designs from small machines rated at around 20 kW up to 200-300 kW. The capital-intensive, research approach initially produced, both in America and in Europe, a number of giant machines, rated at 2-4 MW and up to 100 m in rotor diameter, which proved uneconomical. The two approaches have now met at rated capacities of 300-500 kW and diameters of 30-35 m, and look set to merge in a single technology that is gradually increasing the size again.

As compared with the large amount of raw resources available, the present wind energy market is, however, still a relatively small one. The size of the future market will be determined by the extent to which policies are adopted for encouraging exploitation of renewable energy sources.

The following sections provide an overview of the present situation of the world wind energy market, and suggest a number of actions that could be undertaken by governments and international organisations to prime further, substantial development of this market in the decade to come.

4.1 <u>The Present Market</u>

At present, the biggest factor in the world wind energy market is the supply of wind turbine generators for connecting up to large power systems. The situation in the spring of 1993, as regards grid-connected machines, may be summed up as follows.

In the USA (Fig.12)[4], installed power stood at about 1600 MW,

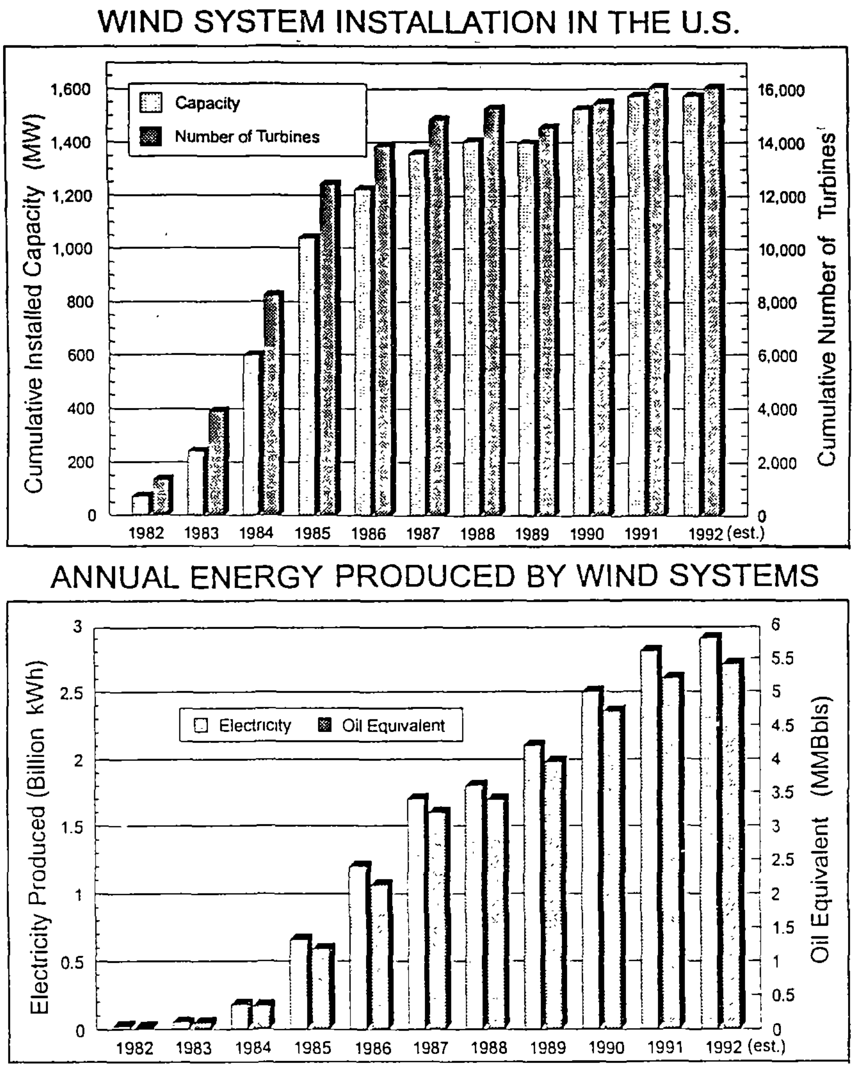


Fig.12.- Wind power plant installation and energy production in the United States of America.

Fig.12 - Installation de centrales éoliennes et production d'énergie aux Etats-Unis d'Amérique.

with energy production, in 1992, of nearly 3 TWh (i.e., billions of kilowatt-hours), equivalent to nearly 3/4 of world production in the same year. Almost all installed capacity in the U.S.A. is located in California, where it is concentrated in very large wind turbine clusters in the areas of Altamont Pass, Tehachapi Mountains and San Gorgonio Pass. The year 1992 saw a very slight increase in overall wind capacity in the U.S.A., mainly due to the fact that the newly-installed machines replaced smaller, less effective units that had been set up in the mid-eighties. A rapid growth in total capacity is however expected from 1994 onwards as a result of new, more efficient machine designs and financial incentives.

In Western Europe installed capacity was approaching 1,000 MW in the spring of 1993, and is expected to exceed 1100 MW by the end of the year. A more detailed situation of installed capacity in West European states in the spring of 1993 is given in Table 1 below [15].

Table 1 - Grid-connected wind turbine capacity (MW) in Europe.

Tableau 1 - Puissance éolienne (MW) connectée aux réseaux en Europe

Country	1991	1992	1993 (*)
Denmark	418	470	520
Netherlands	83	116	120
Germany	90	170	220
United Kingdom	10	30	131
Spain	15	45	57
Belgium	6	6	6
Italy	5	10	20
Greece	5	26	26
Portugal	2	2	2
Sweden	8	12	12
France	1	1	1
Ireland	-	7	8
Total	643	891	1123
Installed capacity/year	166	247	232

(*) Projection

It should be noted that over half of Western Europe's wind turbine generators have been installed in three years, i.e. 1991, 1992 and 1993. At the current rate of installation, Western Europe might have a larger wind generating capacity than the U.S.A. by the end of 1995 [15].

This rapid growth in Europe has also depended on the fact that those European countries traditionally involved in the wind energy sector, such as Denmark and Holland, have recently been joined by others such as Germany, the United Kingdom and Spain, in which decisive incentivation policies have led to an extremely rapid increase in wind installations over the past two years.

In 1992 Denmark produced almost 3% of its own total electricity needs from wind sources. For 1993 it can be foreseen [15] that the production of energy from wind sources in Denmark, Germany and the Netherlands alone will reach 1.25 billion kWh. The rapid increase in wind installations in the United Kingdom will presumably lead to annual domestic production from wind sources of around 0.5 billion kWh as from the end of 1993.

The grid-connected production plants in the U.S.A. and Western Europe are installed by private individuals or by private-sector companies set up for this purpose, as well as by municipal electricity utilities. Nevertheless, in Denmark and Holland (as also, more recently, in the United Kingdom, Sweden, Spain and Italy) the large utilities have also entered the wind sector with a growing commitment which has already led to highly significant achievements.

Together with the incentivation policies, the attitude shown by the world of banking and insurance has played (and may have above all in the future) a decisive role in the development of wind power. First in California and more recently in Europe, a number of banks have begun granting loans for wind power projects, thus demonstrating their present belief that the risk connected with this technology is no less acceptable than that of other forms of investment.

Interest in wind resources is also apparent in Canada (where wind power plants are at present being installed for a total generating capacity of 20 MW), as well as in Japan, Australia and Israel. As regards Canada, it should also be remembered that this country has been particularly active for several years in developing Darrieus vertical-axis wind turbine generators of which models with capacity of up to 4 MW have been built (EOLE prototype at Cap Chat, Québec).

Substantial use of wind power plants is being made in developing countries as well. India [16] has already installed 50 MW of wind generating capacity in plants mostly equipped with European machines appropriately adapted in order to operate under local conditions. Other countries such as China and Mongolia are however, for the time being, interested above all in small and extremely small wind power systems for isolated operation: 100,000 units are reported to be already in service.

As for today's wind energy industry, there are about 30 manufacturers of commercial machines in the world, only a few of which are outside Europe (in the USA and in Japan). Most of these manufacturers are very well-known in their field, but virtually unknown in the outside world, especially among the major electricity utilities. However, they are now being joined by companies of world renown that have acquired considerable expertise in mechanical and aerospace engineering.

The presence of these companies augurs particularly well for the development of new generations of wind turbines with advanced characteristics. On the other hand, the electricity utilities, true to their traditions, expect to be able to count on manufacturing companies that are financially sound and in a position to guarantee continuity in the supply of machines and post-sales servicing.

4.2 Suggested Initiatives for the Years 1995 - 2005

For wind energy to make a more significant contribution to world electricity requirements in the forthcoming decade, 1995 - 2005, its development should be stimulated by suitable strategies aimed at developing the market. There are several ways of achieving this, all of which play a vital role and should be promoted and co-ordinated by both individual governments and international organisations, such as, for instance, the European Community. This subsection considers a number of possible actions for encouraging the development of wind power and evaluates the likely success of each measure.

4.2.1 Research and Development Programmes

Up to now, the U.S.A. and, in Europe, Germany and the United Kingdom have invested most heavily in this area. Although the construction of large-sized prototypes in the U.S.A. and Europe has not resulted in the mass production of units of the same size, the level of technology achieved in these programmes has been quite high, and the machines developed from it may become competitive with those resulting from stimulation of the market. The relationship between research and market stimulation needs to be constantly maintained; otherwise, even a repeat of some negative aspects of the early Californian experience may be expected.

The Commission of the European Communities is supporting wind energy development through two of its Directorates General: the Directorate for Science, Research and Development (DG XII), which finances research and development within the framework of programmes such as JOULE, and the Directorate for Energy (DG XVII), which finances technology demonstration and dissemination within the THERMIE programme. This subject will be dealt with in more detail in chapter 5, with special reference to the THERMIE programme.

In the U.S.A., the Department of Energy (DOE) is currently supporting an expanding research and development programme, the goals of which are to assist utilities and industry in developing new markets and to develop, by 1998, a new generation of utility-grade, advanced wind turbines, capable of producing electricity at a cost of 5 cents/kWh in areas with a 5.7 m/s average wind speed. A further phase of the programme is to develop another generation of technology, which would be available by about the year 2000 and would cut costs another 20%, to 4 cents/kWh with 5.7 m/s winds [11].

In addition to traditional fields such as technology development and plant siting, research programmes should also provide for investigation of other aspects, on which local interest in wind-generated electricity may depend quite strongly. This is, for instance, the case of avoided external costs (dealt with in subsection 3.10.3) which may vary markedly from country to country and seem, in principle, to be able to affect the value of the wind-generated kilowatt-hour even to a decisive extent. In-depth investigation of this vital issue is therefore to be strongly recommended, as clearing this aspect would enable governments to come to a better, grounded assessment of the actual benefits of wind energy to their country and, consequently, decide to what extent wind energy development deserves financial support.

4.2.2 Market Stimulation

The wind energy market can be primed by:

- Direct subsidization of installation costs.

- Premium payments for the energy produced.

- Tax relief on wind plant investments.

Subsidizing installation costs may take the form of a percentage on the capital cost of plant, as formerly the case in Denmark, or of a cash sum per kilowatt of installed capacity, as formerly in the Netherlands and in California. Both systems may be open to abuse, however, and therefore require careful administration. To avoid such problems, subsidies are now calculated by more complicated formulas, based on rotor-swept area and generator capacity (in the Netherlands) or hub height and rotor diameter (in Germany). In the Netherlands, an additional incentive is granted to machines with low noise emission levels.

The system of premium payments, on the other hand, is not open to abuse and can easily be justified. In principle, two extra charges should be added to the price paid for a wind-generated kilowatt-hour: one that would take into account the social and environmental advantages of wind energy and would remain constant over the years; and a second charge, that would be in proportion to the difference in cost of wind as opposed to "conventional" sources, and would decrease in time until it eventually disappeared as the two sources became competitive.

In a number of countries (e.g. the United Kingdom, Denmark, Germany, Italy, and the U.S.A.) wind-generated power tariffs are going some way towards acknowledging these concepts [4].

The most recent and sensational case is that of the United Kingdom where, by using funds collected through the surtax on energy as part of the NFFO (Non Fossil Fuel Obligation) programme, a tariff of 11 pence/kWh is set until 1998 for wind energy produced by plants admitted to the programme [4] [17]. Over 50 plant projects have so far become part of the NFFO programme, all relating to sites with average annual wind speeds of around 7.5 m/s at 10 m from ground level (Britain undoubtedly has the largest wind resources in Europe). In a country where, up until two years ago, there were virtually no wind power plants, plants for approximately 200 MW capacity are now installed or being built or planned.

A similar situation is to be found in Germany, where the tariff for wind energy is 16.6 pfennig/kWh, to which up to a further 6 pfennig/kWh [4] can be added if the plant participates in the "250 MW Wind" federal programme currently underway (subsidies on capital cost can also be contributed by the governments of the various "Länder").

In Italy, the latest Directive issued by the CIP, the Interministerial Committee on Prices, (Directive No. 6 of 29th April 1992) has, among other things, allowed a price of 150 - 166 lire/kWh for those plants that have come on stream after 30th January 1991 and make their full capacity available. This price will be allowed over the first 8 years of plant operation.

In the U.S.A. (where capital cost subsidies expired at the end of 1985) the Public Utilities Regulatory Policy Act (widely known as PURPA) required utilities to give renewable energies a fair deal. Besides giving wind energy plant developers reasonable access to their grid, utilities were bound to pay very favourable tariffs for the wind-generated kilowatt-hour, periodically fixed in accordance with a given procedure.

More recently, another step forward was the passing of the Energy Policy Act (EPACT) by the U.S. Congress in October 1992. Among other things, the new law provides for a federal tax credit of 0.015 U.S. dollars/kWh for a 10-year period for wind energy plants placed in service between 1st January 1994 and 1st July 1999.

It should be remembered that tax relief, granted as a subsidy to plant capital cost (see above), formerly created the large wind power market in California during the early 'eighties. This development also gave European manufacturers, who exported machines worth 640 MECU during the Californian boom period, an enormous boost [1]. The return of this kind of incentive, albeit with reference to energy produced rather than capital cost, is likely to contribute to a renewed expansion of the potentially large American market, with ensuing benefits for the whole wind energy industry worldwide.

In Denmark, too, an incentive in the form of tax relief is provided and is vital for continued wind plant development. Energy tax is refunded to renewable energy producers at the rate of 0.27 krone/kWh, thus reflecting the costs saved by the public through the use of wind energy. Since November 1992, Danish utilities pay private wind turbine owners a total amount of 0.65 krone/kWh (including the above-mentioned tax relief) for the energy fed into their grid [4].

4.2.3 Introduction of Wind Turbine Generator Standards

As already said, there are no internationally agreed technical standards for the design, manufacture, installation, operation and testing of wind turbines, and this lack of standards can create obstacles to wind plant diffusion, hamper the development of a free market and, as a consequence of poor competition, even slow down the progress of the technology.

In this area, as described in section 3.7, an important role is at present being played, at world level, by the International Electrotechnical Commission (IEC), through its Technical Committee 88 "Wind Turbine Systems", in co-operation with ISO. This role should be regarded as a key factor towards the setting-up of a generally agreed basis of standards covering the various aspects of wind energy exploitation. At present, all countries playing a significant part in the wind energy field are also participating in the IEC work.

To avoid duplication, overlapping and ensuing confusion, it seems, therefore, to be advisable that national standards organisations (or even organisations covering a specific world area like CEN/CENELEC in the European Community) make continuous reference to the IEC/ISO standards and implement them at local level without any alterations that are not strictly necessary in order to take into account special situations.

4.2.4 Physical Planning Guidelines

Physical planning authorities should take the initiative in establishing land areas suitable for siting a wind plant, and issue planning guidelines on the matter. This would enable a realistic estimate to be made of a region's likely resources, give guidance to wind project planners such as utilities, private investors and local authorities, speed up the planning permit process and prevent bad wind plant siting.

4.2.5 Involvement of Electricity Utilities

The method by which power is generated will determine whether or not the pollution reduction goals are met. Utilities can choose either to replace fossil fuel power plants by a technology which the environment can better sustain, or buy power from independent operators of renewable energy plants. Utilities can restrict or allow free access to their grid, and can also encourage consumers to save energy.

For wind energy to be given a fair deal by the utility sector, a change of general attitude is required. Utilities should no longer be expected to supply power at the lowest possible cash price, therefore passing on the costs of environmental damage, of securing fuel supplies, and of damage to health. These costs should, as far as possible, be investigated and quantified, and then included in the cost of electricity, and utilities should be expected to supply power at the lowest possible total cost to the public.

Thus, they should be required to offer long-term power-purchase contracts to private wind plant operators, ensure development of a wind turbine market through investment programmes, allow access to the grid, stimulate development of technology towards increased cost effectiveness, better quality and new generations of machines and co-operate with physical planning authorities on resource assessment studies and defining areas of land suitable for wind plants.

4.2.6 Legislative Measures

If physical planning authorities and electricity utilities do not take the above steps, then they should be required to do so by legislation. In California, the utilities were forced to give renewable energies a fair deal by the Public Utilities Regulatory Policies Act (PURPA). PURPA-type regulations would be an excellent means of stimulating a market for clean power production. Germany has already progressed some way in this direction, as has the United Kingdom with its Non Fossil Fuel Obligation. The Commission of the European Communities has issued a recommendation [18] that encourages utilities to co-operate in exploiting renewable energies. This recommendation has already been reflected, for instance, in Italy's power sector regulations (Laws No.9 and No.10 passed in January 1991).

Until pollution taxes and external costs of power production become a part of the energy pricing structure, a carbon tax could be levied to finance measures aimed at encouraging the use of renewable energies. The possible introduction of a carbon tax (already under discussion within the European Community, for example) would better reflect the real costs of conventionally-generated power to society, including pollution costs. Such a measure would clearly make wind energy more competitive and help its promotion. The volume of wind turbine manufacture would increase, bringing down the unit cost and thus increasing the prospective wind energy market.

4.3 Wind Energy Development Forecast for 1995 to 2005

In several countries governments have launched, in the last few years, programmes aimed at developing wind energy installations, which set some specific targets for the short and medium term. Taking into account these targets, as well as the actions already taken to encourage their attainment (see section 4.2), some possible developments of the use of wind energy can be outlined for the period from 1995 to 2005.

With regard to Europe, mention should be made of the following [19].

In Denmark, the parliament passed, in 1981, the first of two national energy plans, the "Energy Plan '81", which stated among other things that, by the year 2000, 10% of Denmark's electric energy needs would be met by renewable energies. This commitment was reaffirmed in 1990 in the subsequent plan "Energy 2000", which, depending on various scenarios, contemplates a total wind capacity in the range of 800 to 1350 MW by the year 2000. In compliance with these goals, the Danish government launched two programmes (1986-1991 and 1991-1993), each providing for installation of 100 MW of wind capacity by utilities.

In the Netherlands, the government's Integral Programme for Wind Energy (IPW), launched in 1985, set as goals the installation of 100 to 150 MW by 1990 and 1000 MW by the year 2000. Another initiative of the government was the National Environmental Policy Plan (NMP) issued in 1989. The Dutch distribution utilities, as part of their response to the NMP, have agreed to install 250 MW of wind capacity by the end of 1995.

In Germany, the government initiated, in 1989, the "100 MW Wind" programme, which was subsequently expanded to "250 MW", providing for installation of the latter capacity by the end of 1994. The "250 MW Wind" programme is a long-term one, since every plant will be scientifically evaluated over a period of 10 years.

In the United Kingdom, wind plant projects totalling nearly 200 MW have been admitted to participate in the 1990 and 1991 tranches of NFFO incentives (see subsection 4.2.2). The Renewable Energy Advisory Group (REAG), set up by the British government in 1991 to review its renewable energy strategy, has recently produced a report [20]. Wind energy is shown to have the largest potential of all renewable sources in the U.K.: a total "accessible" potential of 375 TWh/year onshore and 350 TWh/year offshore has been estimated. On this basis, REAG has recommended that the NFFO should be maintained and extended to Scotland and Northern Ireland. If so, new wind plant installations at a rate of 100 MW/year may be expected from 1995 up to the end of the decade [15].

In Italy, in late 1988, the government issued the final version of the National Energy Plan (PEN), which, as far as wind energy is concerned, sets a target of 300 MW of generating capacity to be installed by the year 2000. This target might even be raised to 600 MW, in case large machines (1 MW and above) should become industrially available.

In Spain, the 1989 Renewable Energy Plan set a target of 100 MW of wind power to be installed by 1995. This goal now seems to be amply fulfilled, and some plans exist for a total of 250 MW by the year 2000 [21].

In Sweden, a wind energy programme has been in progress since 1975, mainly concerning research and development of large wind turbine generators. Since 1991, there has also been a market stimulation programme with subsidies for investment costs. This programme is estimated to provide around 100 MW of wind capacity over a five-year period [4].

Taking into account the programmes already approved by governments, and assuming that the utilities play a significant part in this development, a target of 4000 MW of overall wind capacity installed in Western Europe by the year 2000 can therefore be considered reasonable. The same target was set by the European Wind Energy Association (EWEA) in its strategy document "Wind Energy in Europe - Time for Action" published in late 1991 [1].

Based on this situation, taking into account the estimated wind resource and the acceptable penetration of wind power into Europe's electricity system, and assuming a steady commitment by the utilities, the same EWEA study proposed a target of 11,500 MW to be installed in Western Europe by the year 2005. Targets in the EWEA study are based on a projected annual growth rate of 25 - 30%.

As regards the U.S.A., although 1992 saw a very slight increase in overall wind capacity, a rapid growth in new installations is expected from 1993/94 onwards as a result of the new market incentives provided by the Energy Policy Act passed by Congress in 1992, and the new initiatives sponsored by the Department of Energy for developing advanced machines. The U.S. wind energy industry is preparing for strong growth in the second half of this decade, as they also see the opening of opportunities for wind technology in areas outside California [22].

Specifically, wind energy development is beginning to take place in the Pacific Northwest, the upper Midwest, and the Northeast, because of both large resources and increased concern for the environment. In the Northwest, a number of major utilities have already expressed their interest in installing wind power plants for a total of over 600 MW by the year 2000. In the upper Midwest, Minnesota has led the way through years of resource assessment and favourable policies;

the state's main utility plans to set up at least 100 MW by 2000. Wisconsin has requested utilities to set up 800 MW from renewable energy by 2010, with wind being one of the most likely options. In the Northeast states, wind projects for a total of 150 MW are now being considered; the state of New York is also going to ask utilities to purchase a total of 300 MW of renewable energy capacity (including wind), with plants on line by 1998.

A recent study by the Union of Concerned Scientists [23] has shown that the 12 states of the Midwest possess, in principle, an exceptionally large wind energy potential, corresponding to a total generating capacity of 2,800,000 MW at sites with an annual average wind speed of over 5.6 m/s, considering environmental and urban exclusions. The bulk of the U.S. wind resource seems therefore to be in the Great Plains, far removed from the load centres on either coast. Access to transmission lines to bring wind-generated electricity to load centres is therefore a vital problem.

Taking into account the country's present situation and likely developments, the Energy Information Administration (EIA, the independent statistical agency within the U.S. Department of Energy) has recently drawn up its projections on the use of renewable energies in electricity supply for the year 2010 [24]. As for wind power, EIA forecasts a total installed capacity of 6,300 MW, and an energy output of about 16 TWh/year, corresponding to an annual average growth rate of more than 10%.

In Canada, too, the technical potential for grid-connected wind plants is very large, and has been estimated to be about 28,000 MW of installed capacity by the year 2015. Small diesel-powered, remote communities are considered a further, major field of wind turbine application, as most of them are judged to have suitable wind resources [25]. A prospectus submitted by Canadian representatives to the International Energy Agency (IEA) indicates a possible target of 1050 MW of wind generating capacity by the year 2004; of this, 50 MW would be installed at remote communities and the remainder at grid-connected plants.

Even though very poor information is available on existing programmes, East European countries, including the members of the former Soviet Union [15], seem at present to have a keen interest in wind power as a possible, albeit limited, solution to their heavy pollution problems combined with an electric power shortage. Indeed, wind energy plants are easy to develop in gradual stages, which is particularly advantageous to countries which at present are unable to make very substantial investments.

A very large wind energy potential seems, in principle, to exist in wide areas of these countries, but careful surveys of exploitable resources are still to be made. In addition, it might even be necessary to develop a suitable technology for wind turbines that can continue operating efficiently even in very harsh winter conditions.

For partly similar reasons, there is a large potential market in developing countries as well. According to the EWEA strategy document [1], a target of 500 MW of wind power has been set in India for the end of the century; in Egypt, too, the target is for wind power to supply 5% of electricity by 2005. Moreover, a programme has recently been launched in China [16] providing for the setting up of 20,000 stand-alone units per year for pumping water and charging batteries. Information on existing programmes is, however, rather poor also with regard to developing countries.

5. ACTION CARRIED OUT BY THE EUROPEAN COMMUNITY THROUGH THE THERMIE PROGRAMME

With reference to the specific case of Europe, it is worthwhile providing some detailed information on the efforts made by the Community executive, i.e. the Commission of the European Communities, to support wind energy development.

In accordance with the Community's energy policy aimed at ensuring security of supplies and environmentally-sound production and consumption of energy, the development of renewable sources has been promoted for several years now both by the Directorate General for Science, Research and Development (DG XII) through the JOULE I and II programmes, and by the Directorate General for Energy (DG XVII) through the THERMIE programme as well as other recent initiatives (ALTENER, etc.). Lastly, mention should also be made of the appreciable number of wind energy plants set up in many areas of Europe within the framework of the VALOREN programme.

In the following sections, a more detailed description is given of the activities conducted by DG XVII, with special regard to the THERMIE programme.

5.1 The European Community's Energy Policy

The European Community has a common policy on energy, mainly aimed at ensuring the security of energy supplies: indeed, about half of the Community's total energy supplies comes from third countries. This policy [26] has two objectives.

The first objective is to complete the setting-up of the internal energy market in order to establish a single market within the twelve member states, which will certainly contribute to security of supplies. To this end, a number of flanking measures are being taken, specifically:

- Promotion of energy efficiency and conservation, as well as of renewable energies, with a view to improving the environment. Two programmes have been launched: SAVE, which encourages different policies in the field of rational use of energy through regulatory actions and information exchange; and ALTENER, which is aimed at developing penetration of renewable energy sources through actions such as harmonisation of legislation and technical standards, promotion of financing by third parties, and training and information activities.

- Proposal of a "CO_2 Tax" on energy, with a view to stabilising carbon dioxide emissions at 1990 levels by the year 2000. This tax would apply to all energy sources with the exception of renewable energies, and would come into force only when similar measures were adopted also in the rest of the industrialised world.

- Development and promotion of new energy technologies through the THERMIE programme.

- Strengthening of energy infrastructures throughout the Community by the REGEN programme.

The second objective is to establish co-operative relations with third countries, with special regard to neighbouring countries in Eastern Europe and in the Mediterranean area, which are essential for safeguarding the security and reliability of supplies.

In this connection, mention should be made of the European Energy Charter, signed in December 1991 at The Hague by 44 countries: all the West and East European countries, including those of the former Soviet Union, and the non-European OECD countries. The chief aim of the Charter was to support economic recovery in Eastern Europe by joint efforts to cover the region's energy needs and achieve, at the same time, better protection of the common environment.

This opening up to neighbouring countries saw the launch of some programmes such as PHARE for East Europe, the technical assistance programme for the former Soviet Union, and the programme for the new Mediterranean policy.

5.2 The THERMIE Programme

Within the framework of the energy policy described above, an important part is played in the technical field by the THERMIE programme [26]. THERMIE covers a period of five years starting in 1990. The budget allocated is 700 million ECU.

It is worth recalling that the Commission's action in the field of innovative energy technology goes back to 1975. During the period 1975 - 1992 (Fig.13), the Community assisted over 2857 projects for a total amount of 1.74 billion ECU; of these, 141 were wind energy projects, attracting a total support of 48.9 million ECU.

THERMIE covers a number of areas, namely the rational use of energy in all economic sectors; renewable energies (thermal and photovoltaic solar energy, biomass and waste, wind, hydroelectric and geothermal energy); solid fuels (including

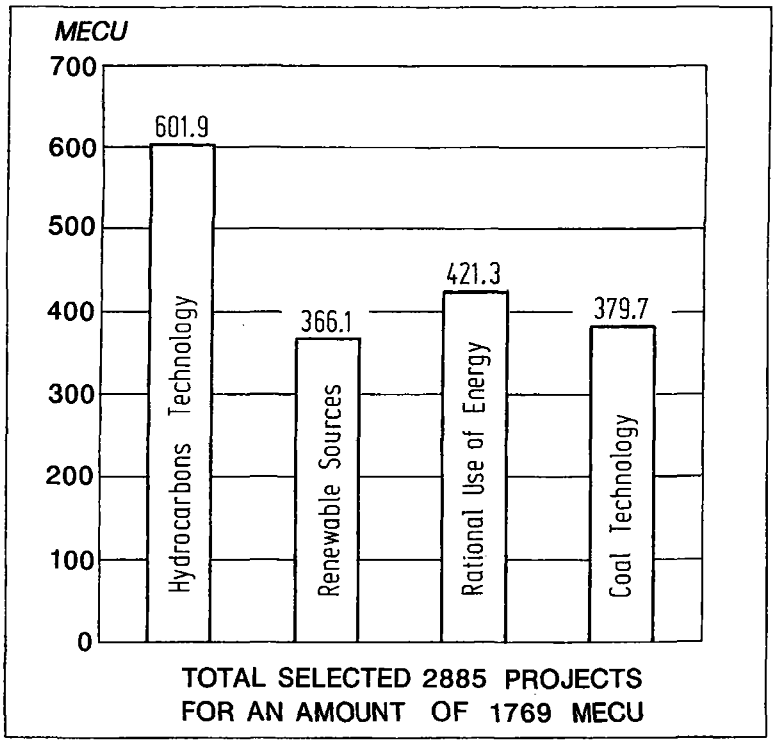


Fig.13 - Energy technology support programmes launched by the European Community. Support in millions of ECU to selected projects in the period 1975 - 1992. Actually assisted projects totalled 2857 (141 wind projects) for an amount of 1740 million ECU (48.9 million ECU to wind projects).

Fig.13 - Programmes de subvention de la technologie de l'énergie lancés par la Communauté Européenne. Subvention en millions d'ECU pour des projets sélectionnés durant la période 1975 - 1992. Les projets qui ont effectivement reçu des subsides sont au nombre de 2.857 (141 projets éoliens) pour un montant de 1.740 millions d'ECU (48,9 millions d'ECUs pour les projets éoliens).

clean use of coal); and hydrocarbons (exploration, production, transport and storage).

Financed projects fall into three categories:

- Innovative projects, which concern a first application of a market size process or new product (maximum financial support is 40% of the eligible cost).

- Dissemination projects, which consist of a second demonstration of innovative projects, provided that the economic and geographical context is different from the original one (maximum support is 35%). These projects are generally carried out in the less developed areas of the Community.

- Targeted projects, which are encouraged or promoted by the Community itself in special cases of possible technological breakthrough.

One of the basic stipulations for a project to be eligible for THERMIE funding is that it must present important technical and financial risks that act as a deterrent to investment according to normal commercial criteria. The chief aim of THERMIE is commercial exploitation of the technology concerned.

In addition to project support, 10 to 15% of the THERMIE funds have been allocated to the financing of a number of activities called "associated measures", aimed at increasing the potential of innovative technologies through dissemination of information. Dissemination actions are carried out by means of technical seminars, forums of technological co-operation, participation in technical fairs, brochures, data bases, etc.. To this end, the OPET network has been set up, consisting of 40 local organisations acting in the various E.C. member countries.

Third countries can also be included in the THERMIE dissemination action through independent agreements. The OPET network has already extended its action to Eastern Europe, some of the former Soviet republics and other countries.

The wind energy sector has been an area of application of DG XVII demonstration programmes since 1983. Over the period 1983 - 1992, the Community selected 186 out of 564 proposals (Fig.14); the actual uptake of support was a little less due to some projects being cancelled. Wind energy projects account for almost 20% of support to all renewable energy projects, i.e. 67.5 million ECU out of 369 million over the period. These projects represent a total investment of more than 300 million ECU.

Looking at these projects, a move towards increasingly larger machines (400 kW and more) is apparent. Commercial megawatt-

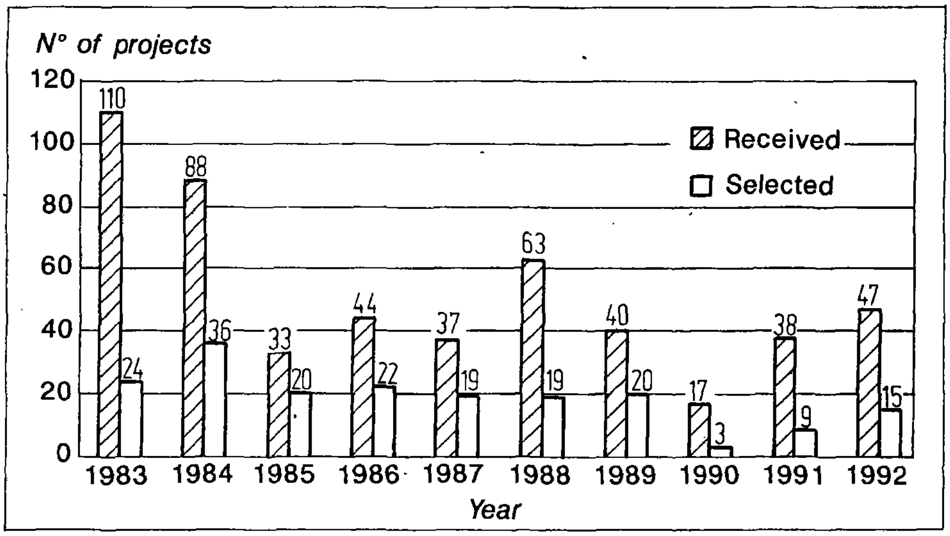


Fig.14 - The European Community's wind energy demonstration programmes. Received and selected proposals.

Fig.14 - Programmes de démonstration de l'énergie éolienne de la Communauté Européenne. Propositions reçues et sélectionnées.

scale units are awaited with interest. However, there is still considerable scope for smaller wind turbines for stand-alone operation or integration into energy supply systems.

As for associated measures, the OPET network is, among other things, helping to promote wind energy application to specific target groups (e.g. users on islands) and co-operating with the Commission in activities such as organisation of wind energy events, market studies, publications, etc..

In conclusion, wind energy is at present considered by the Commission a proven resource which can actually make a contribution to achieving the main objectives of the European Community's energy policy.

REFERENCES

[1] The European Wind Energy Association, Wind Energy in Europe - Time for Action, October 1991, available from EWEA, Via Bormida 2, I-00198 Roma RM, Italy.

[2] The European Wind Atlas, published for the Commission of the European Communities by Risoe National Laboratory, Roskilde, Denmark, 1989.

[3] K. Diamantaras, G.L. Ferrero, State of the Art of Wind Technology and the THERMIE European Community Programme in the Sector of Wind Energy, EURES Seminar, Seville, Spain, June 1992.

[4] The International Energy Agency, IEA Wind Energy - Annual Report 1992, published by NUTEK, Stockholm, Sweden, 1993.

[5] E. Hau, J. Langenbrinck, W. Palz, WEGA Large Wind Turbines, Springer-Verlag, Berlin.

[6] E. Hau, Study of the Next Generation of Large Wind Turbines, Proceedings of the European Community Wind Energy Conference and Exhibition, Madrid, Spain, 10-14 September 1990, published by H.S. Stephens & Ass..

[7] C.A. Westra, Environmental Impact of Wind Energy Installations, Proceedings of the European Community Wind Energy Conference and Exhibition, Travemünde, Germany, 8-12 March 1993, published by H.S. Stephens & Ass..

[8] J.H.B. Benner, Impact of Wind Turbines on Birdlife - Results of a Study for the European Community, Proceedings of the European Community Wind Energy Conference and Exhibition, Travemünde, Germany, 8-12 March 1993, published by H.S. Stephens & Ass..

[9] J.E. Winkelman, Birds and Wind-Farms, Institute for Nature Management, RIN Report 89/15 (in Dutch).

[10] J.K. Vesterdal, Experience with Wind Farms in Denmark, Proceedings of the European Wind Energy Association's Special Topic Conference on the Potential of Wind Farms, Denmark, 8-11 September 1992, published by FDV (Association of Danish Wind Turbine Manufacturers), Herning, Denmark.

[11] DOE, DOE and EPRI Join Forces to advance Wind Energy Technology, DOE News, Press Release by the U.S. Department of Energy, 20 October 1992.

[12] O. Hohmeyer, Social Costs of Energy Consumption, Springer Verlag, Berlin, 1988.

[13] A.J.M. van Wijk, Wind Energy and Electricity Production, PhD Thesis, University of Utrecht, The Netherlands, 1990.

[14] Pace University Center for Environmental Legal Studies (R.L. Ottinger et al.), Environmental Costs of Electricity, Oceana Publications, New York, 1991.

[15] D. Lindley, Wind Energy - Where are we Now?, Proceedings of the European Community Wind Energy Conference and

Exhibition, Travemünde, Germany, 8-12 March 1993, published by H.S. Stephens & Ass..

[16] R.K. Pachauri, Activities in Developing Countries, Proceedings of the European Community Wind Energy Conference and Exhibition, Travemünde, Germany, 8-12 March 1993, published by H.S. Stephens & Ass..

[17] F. Browne, Boom Time for U.K. Wind Farms, WINDirections, Volume XI, No. 4, Spring 1992.

[18] Commission of the European Communities, Recommendation of the Council of November 8th 1988, DJL 3357, December 1988.

[19] J.C. Chapman, European Wind Technology, Report by OEM Development Corporation to the Electric Power Research Institute, Boston, U.S.A., March 1993.

[20] Renewable Energy Advisory Group, Report to the President of the Board of Trade, Energy Paper No.60, published by HMSO, United Kingdom, November 1992.

[21] Press Release at the Inauguration of Tarifa Wind Power Plants, Spain, 11 January 1993 (in Spanish).

[22] R. Swisher, U.S. Windfarms: Current Performance and Future Development, Proceedings of the European Wind Energy Association's Special Topic Conference on the Potential of Wind Farms, Denmark, 8-11 September 1992, published by FDV (Association of Danish Wind Turbine Manufacturers), Herning, Denmark.

[23] Windletter, the Monthly Newsletter of the American Wind Energy Association, Volume 20, Issue No. 3, March 1993.

[24] Energy Information Administration, Report on Renewable Resources in the U.S. Electricity Supply, February 1993, available from U.S. Government Printing Office.

[25] R. Rangi, R.J. Templin, M. Carpentier, D. Argue, Canadian Wind Energy Technical and Market Potential, October 1992, available from Energy, Mines and Resources Canada, Ottawa, Ontario.

[26] H. Nacfaire, P. Naghten, THERMIE Programme and Energy Policy, Proceedings of the European Community Wind Energy Conference and Exhibition, Travemünde, Germany, 8-12 March 1993, published by H.S. Stephens & Ass..

SUMMARY

Interest in the wind as a possible supplementary source of energy for the production of electricity dates, as is known, from the mid-seventies, when the attention of the public was drawn to the importance of having energy sources that are, as far as possible, renewable and freely available. More recently, this interest has gained increasing momentum from the growing concern about the environmental problems that the large-scale use of fossil fuels and nuclear energy inevitably involves.

The wind has some characteristics, such as low energy concentration, high variability, and extremely random availability, that make it more difficult to exploit than "conventional" sources. On the other hand, it has a very large energy potential which, in theory, could meet all the world's electricity needs, even though it must be pointed out that such calculations have little practical meaning, since they fail to consider quite a number of technical, environmental and financial factors that strongly limit the amount of actually exploitable resource. In addition, wind energy conversion gives no polluting emissions or radioactive waste and contributes to diversifying energy sources.

Today's major application of wind energy takes place through wind power plants (sometimes called wind farms) connected to electric grids. The total wind generating capacity connected to the grid worldwide is, by now, approaching 3,000 MW. Nearly all the wind turbines (also named wind turbine generators when the output is electric power) manufactured by industry are of the horizontal-axis type, and have a three, two, or single-bladed rotor. Units with a rotor diameter of up to 25-30 m and an installed power of up to 250-300 kW have been mass-produced for a number of years. More recently, units with a rotor of the order of 30-40 m, and a power of up to 500 kW, have also begun to be produced in series, whilst a number of large prototypes with a rotor between 50 and 60 m and a power of 1-1.5 MW are currently being developed, especially in Europe.

Major improvements have been achieved in wind turbine efficiency (capacity factors of up to 30% have been reached at the best sited plants). Other striking improvements have been recorded in yearly availability of wind turbines (up to 95% and even more).

Widespread use of wind generating plants is conditioned by acceptance by the public. Another major problem is occupation of land, as wind turbines must be properly spaced: the installed power density ranges from 5 to 8 MW per square kilometre of land involved (it should, however, be noticed that the structures of a wind plant only actually occupy 1% of all the land concerned). The wind turbines also have a visual

impact, which depends on their features, the landscape, and the reactions of individual onlookers. Concerns about people safety can have a serious bearing on the use of wind power, although the safety record of wind technology has so far been very good. The problem of noise can be controlled if wind turbines are properly designed. Interference with telecommunications is strictly limited to areas nearest the machines. Impact on wildlife (especially birds) seems to be comparable to that of motorways and high voltage lines.

Inclusion of wind generating capacity in a power system can cause problems with voltage and frequency regulation, due to the random nature of the source. A study on wind energy penetration, promoted by the Commission of the European Communities, has shown that European systems can stand a degree of penetration equal to 5% of their total electric energy production without the need for major technical alterations. Studies on higher penetration levels are under way.

As regards economic aspects, the parameter that fairly describes the cost effectiveness of a wind turbine generator is the cost per unit of rotor swept area expressed in ECU/m^2, rather than the cost per kilowatt installed. The total capital cost of a wind power plant also depends strongly on the installation site, and may be put at between 400 and 600 ECU per square metre of rotor area and per machine installed. By combining a number of likely values of the other factors involved, such as the rate of return on the capital invested, the wind turbine generator lifetime (manufacturers state 20 years), and the annual operating and maintenance costs (estimated at around 2.5% of capital cost), at good windy sites (annual mean wind speeds of at least 6.5 m/s) the cost of energy comes out at between 0.05 and 0.08 ECU/kWh.

The unit cost of energy has then to be set against its value, which is the sum of three factors. The first is the energy credit, which is basically the same as the marginal cost of the kilowatt-hour produced by "conventional" power stations. The second is the capacity credit, which results from the capital costs saved by replacing "conventional" plants by wind energy plants, given the same system reliability. The third factor is the credit for avoided external costs, i.e. costs of air pollution, military protection of fuel supplies, cleaning up after oil spillage, etc., that the public would have to bear if the same energy were produced from "conventional" sources, and that are, generally, not included into electricity prices.

At present, while the energy credit of wind-generated power is generally recognized, the actual weight of the last two credits is still the subject of debate. It goes without saying that, if the vital issue of avoided external costs is taken into account (according to a study performed by O. Hohmeyer with reference to Germany, wind-generated electricity may be allowed a credit for avoided external costs of at least 0.04 ECU at 1990 rates) the wind can be considered a competitive source even today.

In the spring of 1993, installed power in the U.S.A. stood at about 1600 MW, with energy production, in 1992, of about 3000 GWh. In Europe, installed power was about 1000 MW; of this, 500 MW was in Denmark, 120 in the Netherlands, 200 in Germany, 50 in Spain, 50 in the United Kingdom, and the remainder in Sweden, Greece, Belgium, Italy and Portugal; in 1992, Denmark produced from the wind 3% of its electricity needs. Substantial use of wind plants is also being made in India (50 MW of wind farms) and China (about 100,000 small stand-alone systems for water pumping and battery charging).

At present, there are about 30 manufacturers of grid-connected wind turbines, only few of which are outside Europe (in the U.S.A. and Japan). European manufacturers are mainly from Denmark, the Netherlands, Germany, Belgium, the United Kingdom, Spain and Italy. Utility companies, on their part, expect manufacturers to be financially sound and able to guarantee continuity in machine supply and post-sale servicing.

For wind energy to make any significant contribution to the world's electricity requirements in the future, its development should be primed by both state governments and international organisations by means of suitable strategies, such as:

- Research and development programmes.
- Market stimulation through: direct subsidization of installation costs; premium payments for the energy produced; and tax relief on wind plant investments.
- Introduction of standards, as lack of standards can lead to trade barriers (the International Electrotechnical Commission, IEC, in co-operation with ISO, is now preparing a standard on the safety of wind turbines).
- Involvement of physical planning authorities and electricity utilities.
- Legislative measures.

A number of countries, such as Denmark, Germany, Italy, the Netherlands, Spain, the United Kingdom and the U.S.A., are already going some way towards acknowledging these concepts.

As regards the targets that could be proposed for wind power development over the next few decades, mention should be made of the studies performed by the European Wind Energy Association (EWEA). Based on Europe's estimated wind resource and penetration limits, and taking into account the programmes already approved by governments, and assuming that the utilities play a significant part, the following targets have been proposed by EWEA for wind power plants in the European Community: 4,000 MW by the year 2000 and 11,500 MW by 2005. In this connection, mention should also be made of the encouraging attitude of the Commission of the European Communities towards renewable energy sources (see below).

As for the U.S.A., although 1992 saw a very slight increase in overall wind capacity, a rapid growth in new installations is expected from 1993/94 on as a result of the new market incentives provided by the Energy Policy Act passed by the Congress in 1992, and the new initiatives sponsored by the Department of Energy for developing advanced machines. The U.S. wind energy industry is preparing for a strong growth in the last half of this decade, as interest in wind plants spreads also outside California. A recent study by the Union of Concerned Scientists has shown that the 12 states of the Midwest possess, in principle, an exceptionally large wind energy potential, corresponding to a total generating capacity of 2,800,000 MW at sites with an annual average wind speed above 5,6 m/s, considering environmental and urban exclusions. EIA (Energy Information Administration) forecasts, for the U.S.A., a total installed capacity of 6,300 MW and an energy output of about 16 TWh/year by the year 2010.

There is a large potential market for grid-connected plants in the developing world as well. Wind energy plants are easy to develop in gradual stages, which is particularly advantageous to countries unable to make very substantial investments. In India, a target of 500 MW of wind power has been set for the end of the century. In Egypt, too, the target is for wind power to supply 5% of electricity by 2005. Moreover, a programme has recently been launched in China providing for the setting up of 20,000 stand-alone units per year.

In Eastern Europe, pollution problems combined with power shortage also make these countries a very attractive market for wind energy technology, at least in principle.

Going back to Europe, it is worthwhile providing information on the efforts made by the Community executive, i.e. the Commission of the European Communities, to support wind energy development. In accordance with the Community's energy policy aimed at ensuring security of supplies and environmentally-sound production and consumption of energy, the development of renewable sources has been promoted both by the Directorate General for Science, Research and Development (DG XII) through the JOULE I and II programmes, and by the Directorate General for Energy (DG XVII) through the THERMIE programme as well as other recent initiatives (ALTENER, etc.). Lastly, mention should also be made of the significant number of installations carried out within the VALOREN programme.

In the following, special attention is given to the THERMIE programme, which covers a five-year period starting in 1990, with an allocated budget of 700 million ECU. It should however be borne in mind that the Commission's demonstration programmes in the field of innovative energy technologies date back to 1975. During the period 1975-1992, the Community assisted over 2857 projects for a total amount of 1.74 billion ECU.

THERMIE covers areas such as rational use of energy, renewable energies, solid fuels (including clean use of coal), and hydrocarbons. Financed projects cover three categories: innovative projects (maximum support of 40%); dissemination projects (maximum 35%); and targeted projects encouraged or promoted by the Commission itself in special cases. One of the basic stipulations for a project to be eligible for THERMIE funding is that its realisation must present important technical and financial risks that act as a deterrent to investment according to normal commercial criteria. The chief aim of THERMIE is commercial exploitation of the technology concerned. THERMIE also provides for additional actions (e.g. dissemination of information), called associated measures, carried out through a network of 40 organisations named OPET.

With specific reference to wind energy, over the period 1983-1992 the Community selected 186 out of 564 proposals for support. The actual uptake of support was a little less (about 150 projects). In terms of support granted, wind energy projects account for almost 20% of the overall amount allocated to renewable energy projects, i.e. 67.5 million ECU out of 360 million, over the period 1983-1992. It is calculated that these wind energy projects represent a total investment of more than 300 million ECU.

RESUME

C'est vers la moitié des années '70 que surgit l'intérêt du vent en tant que source potentielle supplémentaire d'énergie pour la production d'électricité: à ce moment-là l'opinion publique reconnut l'importance de disposer de sources d'énergie qui soient, autant que possible, renouvelables et librement disponibles. Plus récemment cet intérêt s'est nettement accru à cause du souci de plus en plus poussé pour les problèmes écologiques dérivant de l'emploi sur grande échelle des combustibles fossiles et de l'énergie nucléaire.

Le vent est caractérisé par une faible concentration d'énergie, une variabilité soutenue et une disponibilité extrêmement aléatoire, ce qui fait que cette ressource est plus difficile à exploiter que les sources "conventionnelles". D'autre part le vent a un potentiel énergétique très vaste qui, théoriquement, pourrait satisfaire tous les besoins en électricité du monde entier. Il faut pourtant souligner que ces évaluations n'ont guère d'importance sur le plan pratique, puisqu'elles ne tiennent pas compte de plusieurs facteurs d'ordre technique, environnemental et financier qui limitent fortement la quantité de ressources réellement disponibles. Enfin la conversion de l'énergie éolienne ne produit ni d'émissions polluantes ni de déchets radioactifs et elle contribue à la diversification des sources d'énergie.

Aujourd'hui l'énergie éolienne est appliquée essentiellememt dans les centrales éoliennes (appelées parfois, en anglais, "wind farms") connectées aux réseaux de distribution électriques. La puissance électrique totale des centrales éoliennes connectées au réseau de distribution dans le monde entier est aujourd'hui près de 3.000 MW. Presque toutes les turbines éoliennes (appelées aussi aérogénérateurs lors qu'elles produisent de l'électricité) réalisées par l'industrie sont du type à axe horizontal, équipées d'un rotor à trois, deux ou une seule aube. Les unités munies d'un rotor ayant un diamètre maximal de 25-30 m et une puissance installée maximale de 250-300 kW ont été produites sur grande échelle pendant plusieurs années. Plus récemment on a commencé à produire en série des unités dotées d'un rotor ayant un diamètre de 30-40 m et une puissance installée maximale de 500 kW. D'autre part on est en train de développer, surtout en Europe, toute une série de prototypes de grandes dimensions disposant d'un rotor dont le diamètre est de 50 à 60 m et la puissance de 1-1,5 MW.

Des progrès importants ont été réalisés dans le domaine du rendement des turbines éoliennes (des facteurs d'utilisation de 30% ont même été atteints dans les centrales les mieux situées). On enregistre d'autres résultats importants en matière de disponibilité annuelle des turbines éoliennes (jusqu'à 95%, voire plus).

L'emploi répandu des centrales éoliennes est conditionné par l'approbation de l'opinion publique. Un autre problème important surgit, à savoir l'occupation du sol, les turbines éoliennes nécessitant d'un espacement correct: la densité de puissance installée varie de 5 à 8 MW par kilomètre carré de terrain concerné (il faut pourtant remarquer que les structures d'une centrale éolienne n'occupent en fait que 1% de toute la surface concernée). Les turbines éoliennes ont également un impact visuel, qui dépend de leurs caractéristiques, du paysage et des réactions individuelles des "spectateurs". Les préoccupations concernant la sécurité des citoyens peuvent peser lourd sur l'emploi de l'énergie éolienne, bien que jusqu'à présent cette technologie se soit révélée très fiable du point de vue de la sécurité. Le problème du bruit peut être maîtrisé, pourvu que les turbines soient bien conçues. L'interférence avec les télécommunications se limite aux aires à proximité des machines. L'impact sur la flore et la faune (surtout les oiseaux) semble être comparable à l'effet produit par les autoroutes et les lignes à haute tension.

L'introduction de l'énergie éolienne dans un système de production électrique peut poser des problèmes en termes de régulation de tension et de fréquence à cause de la nature aléatoire de cette source d'énergie. Une étude sur la pénétration de l'énergie éolienne, promue par la Commission des Communautés Européennes, a montré que les systèmes européens peuvent supporter un niveau de pénétration équivalant à 5% de leur production totale d'énergie électrique, sans qu'aucune modification technique importante ne s'impose. Des études sur des niveaux de pénétration plus élevés sont actuellement en cours.

Quant aux aspects économiques, le paramètre qui décrit assez bien l'efficience économique d'une turbine éolienne n'est pas tellement le coût par kilowatt installé mais plutôt le coût par unité de la surface balayée par le rotor, exprimé en ECU/m^2. Les frais d'installation globaux d'une centrale éolienne dépendent aussi beaucoup de son emplacement et peuvent être estimés à 400-600 ECU par machine installée et par mètre carré de surface balayée par le rotor. En évaluant toute une série de valeurs probables se rapportant aux autres facteurs concernés, tels que le taux de rendement des sommes investies, la vie moyenne des aérogénérateurs (que les producteurs estiment s'élever à 20 ans) et les frais annuels de fonctionnement et d'entretien (estimées à environ 2,5% des frais de capital), le coût de l'énergie, dans le cas de sites particulièrement éventés, se situe entre 0,05 et 0,08 ECU/kWh.

Le coût de l'énergie produite par chaque unité doit être rapporté à sa valeur, qui est le résultat de trois facteurs. Le premier facteur est représenté par le crédit d'énergie, qui est égal au coût marginal du kilowatt/heure produit par les centrales électriques "conventionnelles". Le deuxième facteur est le crédit de puissance, c'est-à-dire la possibilité d'économiser sur les frais d'installation en remplaçant les centrales "conventionnelles" par des centrales éoliennes, étant donné le même niveau de fiabilité du système. Le troisième facteur consiste dans la possibilité de supprimer des frais extérieurs, à savoir les frais dérivant de la pollution, de la protection militaire des réserves de combustibles, des opérations de nettoyage en cas de fuites de pétrole, etc.. Il s'agît de frais qui pèseraient sur les citoyens si la même quantité d'énergie était produite à partir de sources "conventionnelles" et qui normalement ne sont pas inclus dans les prix de l'électricité.

A présent, alors que le premier facteur est largement reconnu, le poids réel des deux autres facteurs fait encore l'objet de débats. Il va de soi que si l'on tient compte d'un aspect crucial, c'est à dire de la possibilité de supprimer des frais extérieurs (d'après une étude conduite par O. Hohmeyer à propos de l'Allemagne, l'électricité produite en exploitant la force du vent pourrait contribuer à réduire les frais extérieurs pour un montant de 0,04 ECU au moins, aux taux de 1990), le vent peut être considéré comme une source compétitive même de nos jours.

Au printemps 1993 la puissance installée aux Etats-Unis était environ de 1600 MW, avec une production énergétique se situant autour de 3000 GWh pour l'année 1992. En Europe la puissance installée était de 1000 MW environ, dont 500 MW au Danemark, 120 aux Pays-Bas, 200 en Allemagne, 50 en Espagne, 50 au Royaume-Uni et le restant en Suède, en Grèce, en Belgique, en Italie et au Portugal. En 1992 au Danemark l'énergie éolienne a permis de couvrir 3% des besoins en électricité du pays. Les centrales éoliennes sont de plus en plus utilisées également en Inde (50 MW de puissance installée) et en Chine (environ 100.000 petits systèmes indépendants pour le pompage de l'eau et la charge des batteries).

Aujourd'hui on compte à peu près 30 producteurs de turbines éoliennes connectées au réseau de distribution, dont un petit nombre seulement se trouve hors d'Europe (aux Etats-Unis et au Japon). La production européenne a lieu surtout au Danemark, aux Pays-Bas, en Allemagne, en Belgique, au Royaume-Uni, en Espagne et en Italie. Les compagnies d'électricité, de leur côté, s'attendent à ce que les sociétés de production soient financièrement solides et en mesure d'assurer une certaine continuité dans la livraison des machines et dans le service après-vente.

Afin que l'énergie éolienne puisse à l'avenir contribuer d'une manière importante à satisfaire les besoins mondiaux en électricité, il faut que son développement soit encouragé aussi bien par les gouvernements d'Etat que par les organisations internationales par le biais de stratégies appropriées, telles que:

- Programmes de recherche et développement.

- Stimulation du marché par: des subventions directes pour couvrir les frais d'installation; des primes de production d'énergie; des dégrèvements d'impôts sur les capitaux placés dans les centrales éoliennes.

- Introduction de normes, des barrières commerciales pouvant surgir faute de normes appropriées (La Commission Electrotechnique Internationale - IEC - en collaboration avec ISO, est en train de mettre au point une norme sur la sécurité des turbines éoliennes).

- Intervention des organismes d'aménagement du territoire et des compagnies d'électricité.

- Mesures legislatives.

Certains pays, tels que le Danemark, l'Allemagne, l'Italie, les Pays-Bas, l'Espagne, le Royaume-Uni et les Etats-Unis, sont déjà en train de s'engager dans cette voie, en acceptant les principes dont ci-dessus.

Quant aux objectifs possibles pour le développement de l'énergie éolienne dans les toutes prochaines décénnies, il faut mentionner les études conduites par l'EWEA (European Wind Energy Association, Association Européenne pour l'Energie Eolienne). Sur la base des limites estimées de pénétration et de disponibilité du vent en Europe, en tenant compte des programmes déjà adoptés par les gouvernements et en supposant que les services publics jouent un rôle essentiel, l'EWEA a proposé les objectifs suivants pour ce qui est des centrales éoliennes dans la Communauté Européenne: 4.000 MW pour l'année 2000 et 11.500 MW pour l'année 2005. A ce propos, il vaut la peine de remarquer l'attitude positive de la Commission des Communautés Européennes vis-à-vis des sources d'énergie renouvelables (voir ci-dessous).

Quant aux Etats-Unis, même si l'année 1992 a été marquée par une très faible augmentation de la puissance éolienne dans son ensemble, on prévoit une montée rapide des nouvelles installations à partir de 1993/94. Ce processus va être le résultat des nouvelles stimulations du marché introduites par l'Energy Policy Act (Loi sur la Politique Energétique) adoptée par le Congrès américain en 1992, ainsi que des nouvelles initiatives soutenues par le Département de l'Energie visant le développement de machines avancées. L'industrie américaine de l'énergie éolienne est en train de s'organiser en vue d'une forte croissance qui se produira dans la seconde moitié de cette décennie, alors que l'intérêt dans les centrales éoliennes se répand également hors de Californie. Une étude récente conduite par l'Union of Concerned Scientists (Union des Scientifiques Concernés) a montré que les 12 Etats du Midwest possèdent, en principe, un potentiel d'énergie éolienne extrêmement vaste qui correspond à une puissance de génération totale de 2.800.000 MW pour les sites où la vitesse moyenne annuelle du vent dépasse 5,6 m/s, compte tenu des exclusions urbaines et environnementales. L'EIA (Energy Information Administration) prévoit, aux Etats-Unis, une puissance éolienne installée de 6.300 MW et une production d'électricité de 16 TWh par an pour l'année 2010.

Les pays en voie de développement représentent eux-aussi un vaste marché potentiel pour les centrales connectées au réseau. Les centrales éoliennes peuvent être facilement développées par étapes, ce qui est particulièrement avantageux pour les pays qui ne peuvent pas investir des sommes importantes. En Inde, le but est d'atteindre une puissance de 500 MW d'ici la fin du siècle. En Egypte aussi on vise à ce qu'en l'an 2005 l'énergie éolienne représente 5% de la production électrique. En plus un programme vient d'être lancé en Chine dont l'objectif est l'installation de 20.000 unités indépendantes par an.

A cause des problèmes liés à la pollution et à cause de la pénurie d'énergie les pays de l'Europe de l'Est représentent eux-aussi un marché très alléchant pour la technologie éolienne, du moins en principe.

Pour revenir à l'Europe, il est important de citer les efforts déployées par la Commission des Communautés Européennes en faveur du développement de l'énergie éolienne. Dans le droit fil de la politique énergétique communautaire visant à assurer la conservation des réserves ainsi que la production et la consommation énergétique dans le respect de l'environnement, le développement de sources d'énergie renouvelables a été promu par le Directorate General for Science, Research and Development (Direction Générale pour la Science, la Recherche et le Développement) (DG XII) à travers les programmes JOULE I et II, ainsi que par le Directorate General for Energy (Direction Générale pour l'Energie) (DG XVII) à travers le programme THERMIE et d'autres initiatives plus récentes (ALTENER etc.). Pour conclure, il suffit de rappeler que de nombreuses installations ont été réalisées dans le cadre du programme VALOREN.

Dans ce document l'attention est consacrée surtout au programme THERMIE, qui s'étale sur une période de cinq ans à partir de 1990 et dispose d'un budget de 700 millions d'ECU. Il ne faut pourtant pas oublier que les programmes de démonstration lancés par la Commission dans le domaine des technologies énergétiques innovatives remontent à 1975. Dans la période 1975-1992 la Communauté s'est occupée de 2857 projets pour un montant global de 1,74 milliards d'ECU.

Le programme THERMIE concerne des secteurs tels que l'utilisation rationnelle de l'énergie, les énergies renouvelables, les combustibles fossiles (y inclus l'utilisation propre du charbon) et les hydrocarbures. Les projets financés sont de trois types: les projets innovatifs (aide max. de 40%); les projets de diffusion (aide max. de 35%);

les projets ponctuels encouragés ou promus par la Commission elle-même en des circonstances spéciales. Afin qu'un projet soit jugé valable et puisse obtenir les fonds dégagés par le programme THERMIE il est essentiel que sa réalisation implique des risques techniques et financiers trop importants selon de simples critères commerciaux. Le but principal du programme THERMIE consiste dans l'exploitation commerciale de la technologie concernée. THERMIE envisage également la mise en place d'actions supplémentaires (par exemple la diffusion des informations), dénommées "mesures associées", qui sont du ressort de l'OPET, un réseau réunissant 40 organisations.

En ce qui concerne l'énergie éolienne en particulier, dans la période 1983-1992 la Communauté a sélectionné 186 des 564 propositions d'aide. En fait les projets aidés ont été moins nombreux (environ 150 projets). En termes d'aides octroyées, les projets sur l'énergie éolienne absorbent presque 20% des sommes globalement affectées aux projets concernant les énergies renouvelables, soit 67,5 millions d'ECU sur 360 millions pour la période 1983-1992. On estime que ces projets sur l'énergie éolienne représentent un investissement total de plus de 300 millions d'ECU.