PRELIMINARY

Long term R&D needs for wind energy

For the time frame 2000 2020

Ad Hoc Group Report

Summary

The dawn of R&D was technologically driven whereas, when it later became more mature other topics emerged, related to noise, public attitudes and the environment. The benefit of the research to the sector has been clearly demonstrated by increasing sizes and lower prices per installed production capacity. Production cost has been reduced by a factor of four from 1981 to 1998.

Wind energy is presently cost competitive on locations with a good wind resource. The present cost level is around 4.7 USD cent/kWh. The projected cost of wind energy in 2020 is 2.5 USD cent/kWh. This projection is based on an installed capacity of 80 GW year 2010 and 1 200 GW year 2020.

The wind energy market is in a state of rapid development; it is growing faster than the personal computer industry, and almost as quickly as the cellular phone market. In the last three years a number of growth studies have been presented. In a study called Wind Force 10 almost 3000 Th electricity will be produced by year 2020, this corresponds to around 11% of the expected world consumption of electricity in that year. The annual investment requirements for achieving this goal will be USD 3 billion in 1999 reaching a peak of 78 billion in 2020. This will increase employment in the wind industry and supplying sector from 82,000 in 2005 to 180,000 in 2020. The environmental benefit from this scenario will be an annual reduction of CO_2 emissions by year 2020 of 1,780 million tonnes.

In order to make this deployment come true, it has to be supported by extensive Research and Development actions. Future R&D will support incremental improvements in e.g. understanding extreme wind situations, aerodynamics and electrical machines. But, the challenge is to try to find those evolutionary steps that can be taken to further improve wind turbine technology, for example in large scale integration incorporating wind forecasting and grid interaction with other energy sources.

Areas of major importance for the future deployment of wind energy is in the medium time scale forecasting techniques, grid integration and public attitudes and visual impact.

Forecasting techniques will increase the value of wind energy by the fact that production can be forecasted, e.g. 6 to 48 hours, in advance. Integration of grid and demand side management will be essential when large quantities of electricity from wind shall be transported in a grid. Finding new locations for wind energy will require that public attitudes and visual impact is incorporated in the deployment process.

For the long-term period it is of vital importance to take large and unconventional steps on order to make the wind turbine and its infrastructure interact in close co-operation. Adding intelligence to the complete wind system, interacting with other energy sources will be essential in areas of large deployment. Storage techniques for different time scales (minutes to months) will increase value at penetration levels above 15 to 20%.

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1. Introduction

Why wind energy?

- Energy portfolio - diverse energy supply
- Economic development - domestic and international
- Environment - minimal impact of generation

During the first 25 years of modern wind energy deployment, national R&D programs have played an important role in promoting development of wind turbines towards more cost effectiveness and reliability. The technology has been demonstrated by accompanying demonstration programs in co-operation with industry. Turbine sizes have increased from some hundreds of kW to MW machines during this period. The interaction between industry and national research has been important for the development of effective turbines.

1.1 History of R&D

The oil crisis in the middle of 1970 initiated investigations of energy sources, not based on fossils. Wind energy was at that time considered to be one such energy source that had the possibility to reduce dependency of fossils. The propeller type, horizontal axis wind turbine was identified as the most promising system for converting the kinetic energy of the wind to electricity.

The desire to develop effective wind turbines was carried out on two different front lines. The first one was developed within governmental programs. This group focused on big, multi-megawatt wind turbines that would be operated by utilities. The second group consisting of activists and entrepreneurs building small turbines, starting at 20kW. Both groups experienced that designing wind turbines was far more complicated and costly than was expected from the beginning.

The knowledge base was rudimentary and the need for R&D was identified at an early stage. National R&D programs were initiated in many countries. Inventories of related areas pointed out that existing knowledge in meteorology, electrical machinery and aeronautical fields could be applied in wind engineering. The research organisations were to a large extent coupled to meteorological and aeronautical research institutes.

As time and knowledge developed the research topics were more directed towards specific questions relevant for wind technology, such as wind modelling, resource assessment, aerodynamics and structural dynamics. In order to demonstrate the application of the technology a number of MW-size demonstration programs were realised in the beginning of the 80s. The main driver was to improve technology and system integration in order to show feasibility.

Commercial turbines appeared on the market around 1980 and coincided with the boom for small turbines, 100 – 200kW, in Denmark and California. Many companies went bankrupt due to technical problems and poor understanding of loads interacting with the wind turbine. The demo programs in USA, Germany, Denmark and Sweden, in the MW class, had mainly problems related to fatigue. A lot of useful information of system behaviour was gained from these prototypes.

Later in the 80s wind turbines became larger, 250 – 300kW. Market demand increased mainly due to subsidies and tax credits. Expected life times of 20 years was difficult to achieve due to reliability and system integration problems. The technology could not compete economically without support.

In the beginning of the 90s wind turbines became larger and were built in small groups – farms. Increasing national R&D programs were promoting the trend towards larger turbines. Size around 500kW was the standard. Engineering challenges were related to the bigger size and conditions in wind farms. Problems related to fatigue was reduced due to better understanding of interaction between loads and structures. The market was turbulent, new companies appeared. A number of smaller companies were purchased, new constellations were formed.

Sizes increased during the rest of the 90s. At good wind sites wind turbines started to become competitive with new traditional fossil fuel and nuclear generation. Wind farms grew in number of turbines. As a result the penetration of wind produced electricity was high in some areas. This resulted in a need to develop knowledge of new locations offshore and grid issues, such as power quality and interaction with weak grids. New developments in standardisation and design codes were supporting the market development and international trading.

R&D issues were discussed at an IEA Topical Expert Meeting in 1995. Some of the conclusions at that meeting were:

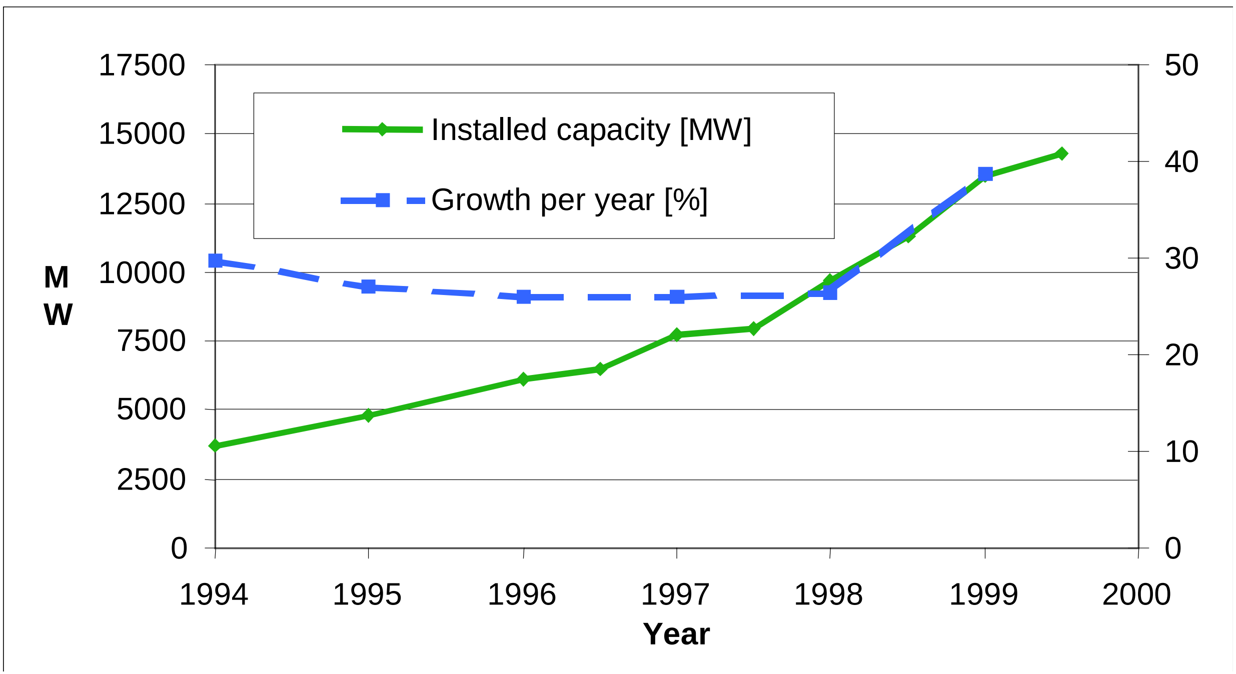
"… we have now reached a stage where the industry should be able to foot a larger share of the R&D bill. Also the fact that the industry has moved from the pre competitive phase into the competitive stage indicates, that most of the product and component development should take place within the companies.

However, there was consensus on the view, that there is still a need for basic, generic research to be carried out outside the companies and wholly or partly funded by public money, and that this need will continue as long as there is wind energy development".

The conclusions at the meeting are still valid today. During the last five years, company R&D have put emphasis in developing larger and more effective turbine systems utilising knowledge developed from national and international generic R&D programs.

1.2 Present and future markets

The Kyoto protocol has called for a decrease in the emission of CO_2 gases. Wind energy can play a major part in achieving this target and has already proven to be cost competitive. At good wind sites it is already competitive with new traditional fossil fuel and nuclear generation. During the past five years wind energy growth has been substantial, with annual growth figures of 20 - 30 %. At the turn



of year 99/00 13500 MW was installed worldwide. Production during 1999 was 30 TWh.

Figure 1, Installed cumulative capacity and growth rates year, [MW]

Predictions of global wind energy growth are published by many different organisations. In 1991 the European Union made a prognosis for the end of year 2001 of 4000 MW. This was a great underestimate compared to the situation at the end of 1999 when already 13500MW were installed. Many other previous studies have showed such under estimations of the growth.

In the last three years a number of growth studies have been presented. Four main sources are cited below.

		Cumulative installed [MW]	
Source		Year 2010	Year 2020
European Union White Paper, 1997	Europe	40 000	
EWEA, revised goals, 2000	Europe	60 000	150 000
IEA World Energy Outlook, 1998	World	25 900	
BTM World Market Update, 1999	World	130 000	
Wind Force 10, 1999	World	181 000	1 200 000

Table 1 Projections of installed cumulative capacity year 2010 and 2020

The Wind Force 10 figures for 2020 corresponds a production of almost 3000 TWh which is around 11% of the expected world consumption of electricity in that year. The annual investment requirements for achieving this goal will be US$ 3 billion in 1999 reaching a peak of 78 billion in 2020. This will increase employment in the wind industry and supplying sector from 82,000 in 2005 to 180,000 in 2020. The environmental benefit from this scenario will be an annual reduction of CO_2 emissions by year 2020 of 1,780 million tonnes.

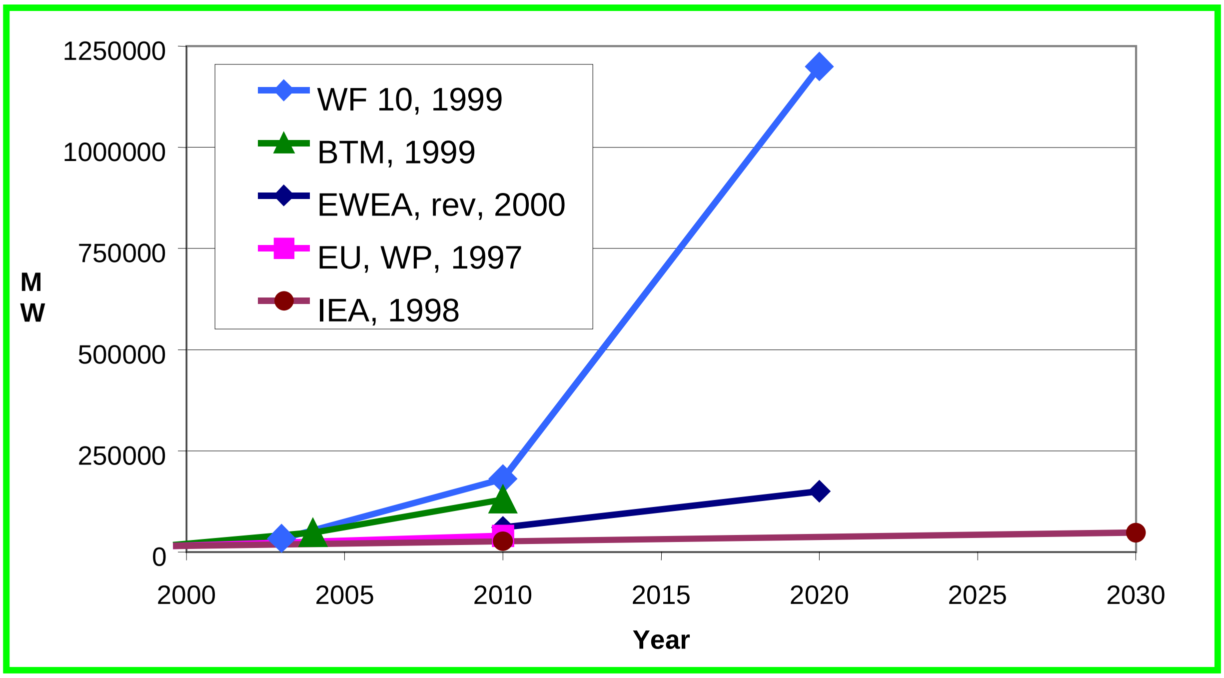


Figure 2 Predictions of installed wind energy capacity, data from different sources

As can be seen it is a great spread in the predictions ten years ahead. BTM states in their report that The latest figures from IEA seems very conservative regarding wind and do not reflect current trends in the market.

The large spread in predictions for the future is probably depending on the fact that wind energy is a relatively young technology, still trying to become mature. Compare for example trying to predict the future of the automobile in 1910 or the Internet in 1990.

Another way to formulate the current growth compared to other businesses is found in the Worldwatch Institute book Vital Signs 2000.

- The wind turbine industry is now growing faster than the personal computer industry, and almost as quickly as the cellular phone market
- As of early 2000, eight countries--all in Western Europe--had raised taxes on environmentally harmful activities and used the revenue to pay for cuts in taxes on income

For the future Worldwatch stated the following: If wind energy achieves its goal of supplying 10% of the world's electricity in 2020, this may only be part of the story. By 2020, wind-derived hydrogen could be fuelling many of the world's cars, factories and even jet airlines.

1.3 Cost reductions

To days wind turbines are similar in layout and design compared to the ones produced 10 to 15 years ago. But a number of steps have been taken in order to improve the efficiency and to reduce cost. Examples are:

- Larger size
- Directly driven generators
- System integration
- Flexible structures

The cost of energy has shown a dramatic decrease. Data from wind farms in California show a reduction from USD 0.45 in the early 1980s to less than USD 0.10 in the early 1990s. Similar experiences have been reported from Denmark where the cost has been reduced by a factor of four from 1981 to 1998 (1.20 to 0,3 DKK/kW). National research and demonstration programs combined with commercial programs have played an important role in supporting these improvements.

A common opinion about the present cost level of wind energy today is:

Total investment cost:	1000 USD/kW
Unit price, electricity:	4.7 USD cent/kWh

Recent studies, by BTM 1998, 1999, applying learning curve theory and assumptions, combining historical figures results in future cost reductions, figure 3. However, the results of the projections must be treated with caution since they are based on a number of different assumptions and do not account for large technological steps.

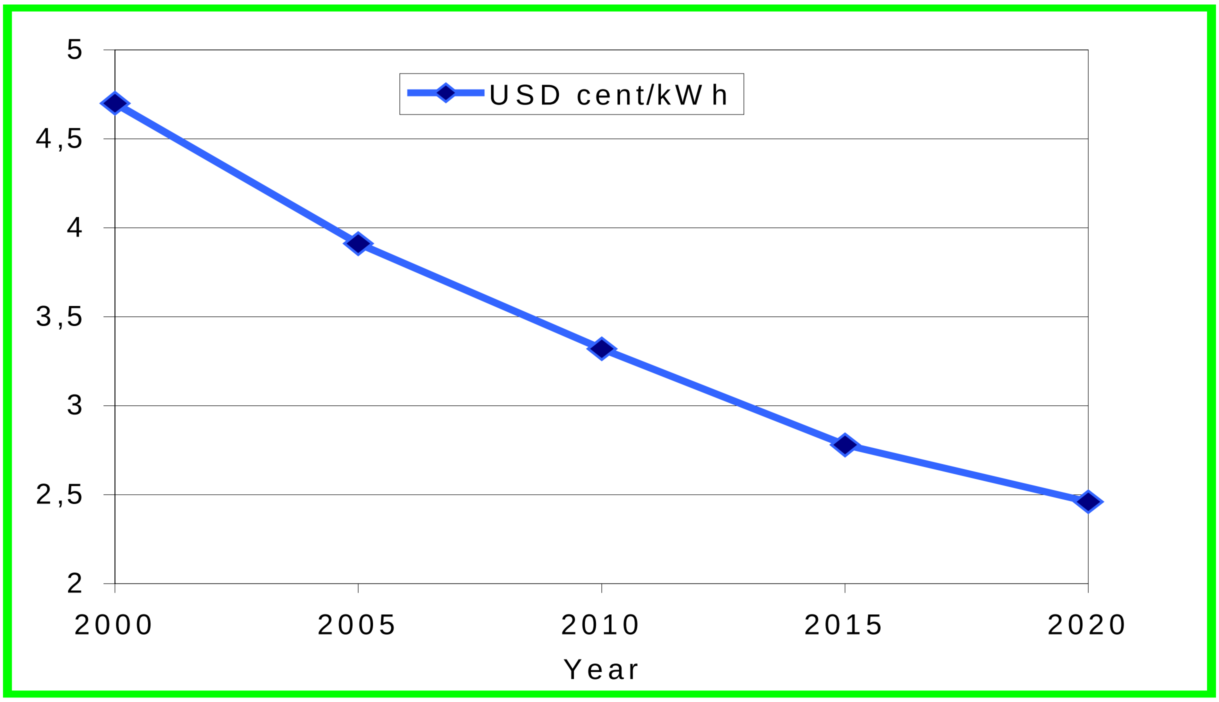


Figure 3 Projected cost of energy [BTM 1998 and 1999]

Cost reductions are based on the following installed capacities:

Year	GW
2000	14
2010	180
2020	1200

The same study estimates sources of future cost reduction on wind power until 2004. The following figures are quoted:

Source	Relative share %
Design improvements – weight reduction of WTG	35
Improved performance – improvement of conversion efficiency (aerodynamic and electric)	5
Economy of scale	50
Other contributions: foundations/grid connection/O&M cost	10

Table 2 sources of future cost reduction on wind power until 2004

The most important part is assumed to be the economy of scale, which stands for half of the relative cost reduction. Contributions from improvements in design and performance are assumed to be 40%. This figure will be dependent on how successful future R&D can be utilised in new machines.

2. Why continue long term R&D?

- Continue cost reductions

- Enable large scale use
- Minimize environmental impacts

2.1 Continue cost reductions

2.1.1 Improved site assessment and new locations

Sites with high winds are crucial for economic utilisation of wind energy. The fact that energy production is related to mean wind speed to the power of 3 is not sufficiently know. This means that a 10% increase in wind speed will result in 33% more energy gained. Improved site assessment and siting will require better models and input from measurements.

Better knowledge of extreme wind, wave and ice situations at different types of locations and in wind farms will eventually result in lighter and more reliable machines.

2.1.2 Better models for aerodynamics/aeroelasticity

Improved methods for predicting 3D aerodynamic behaviour and stall induced vibrations are essential for calculation of loads on turbines. Incorporation of such models in aeroelastic models of the whole wind turbine will eventually lower the weight and thus price

2.1.3 New intelligent structures/materials and recycling

Development of new materials that can be a part in a natural recycling process will increase the value and decrease environmental impact. New ways to decommission glass fibre blades must be developed.

Wind turbines operating in a wake of another turbine will be exposed to excessive loads due to deficits in wind speed behind the upstream turbine. Reduction of loads through improved design and adding intelligence to single wind turbines in a wind farms will give the possibility to optimise the use of land. Intelligent materials utilising adaptive control, interacting with the structure can be used to reduce strains and/or control aerodynamic forces.

2.1.4 Reduce uncertainties in mechanical loads, improved standards

The development of international standards will be essential for the successful deployment of wind energy in different countries. This work will help remove trade barriers and facilitate free trades. R&D activities in many fields of wind engineering will support background basics for standardisation work. Examples are extreme environmental conditions, safety, power performance and noise.

2.1.5 More efficient generators, converters

Improve directly driven generators. Make them lighter smaller efficient High voltage?

Combined solutions for generation and transmission, from low voltage AC to high voltage DC, adaptable power factor (cos phi), high power quality (low harmonic content and flicker frequency).

2.1.6 New concepts and specific challenges

Fly by wire concepts, adding intelligence to the turbine, incorporating aspects of reliability and maintainability.

2.1.7 Stand alone systems

New concepts, like effective passive control systems (for power and speed), free yaw, axial PMG, switched reluctance generators, self-excited induction generators concepts, flexible towers, etc., should be analysed. The following Table summarises the main areas identified.

SMALL WIND TURBINES		
Aerodynamic	*Electrical System*	*Control*
Low Reynolds Number Airfoils New blade designs	Axial PMG Switched reluctance generators	Passive regulation systems for power and rotor speed. Passive yaw

2.2 Enable large scale use

Projections indicate deployment figures from 10% in 2020 to 50% in2050. This implies that 180 GW is connected year 2010 and 1200 in year 2020. Contribution will be substantial on a local and/or national level.

2.2.1 Forecasting power performance

The value of wind energy will be increased if reliable predictions can be made on different time scales, e.g. 6 for 48 hour, in advance. This requires model development and strategies for online introduction of data from meteorological offices as well as actual production figures from wind turbines in large areas.

2.2.2 Electric load flow control and adaptive loads

Development of tools for modelling and controlling energy supply to the net will be essential, especially in areas where the share of wind energy is high. Combined technologies for generation and transport of thousands of MW's will incorporate automatic load flow controls, adaptive loads and demand side management. Extensive use of high capacity power electronic devices in national networks for HVDC links.

There will be a need to study concepts for storage and AC/DC concepts in co-operation with other energy sources.

2.2.3 Better power quality

Correction of grid deficiencies, especially in weak grids must be improved. Examples are voltage drops, flicker and other nuisances. Grid stability will also be a main concern.

2.2.4 Hybrid systems

Incorporating wind energy in an infrastructure where hydrogen is used as an energy carrier. This technology can be used in all kinds of transportation at the end of the period.

2.2.5 New storage techniques

As a method to enhance the value/ predictability through the levelling out of delivered power, especially when we are approaching penetration levels above 15% to 20%.

We need storage for different time scales (see also overview from Felix Avia).

Time scale	Function	Technology
minutes	fault protection	SMES, capacitors
hours	back up, smoothing	batteries, fly wheels
weeks	smoothing, prediction	pumped hydro, hydrogen storage
days	smoothing, prediction	regenerative fuel cells, pumped hydro
months	smoothing, prediction	hydro storage, hydrogen storage (e.g. CH4 creation from coal)

2.3 Minimize environmental impacts

Finding suitable places and general acceptance for implementation of wind turbines has become more and more complicated. Interacting use of landscape of different interest groups are becoming more and pronounced.

2.3.1 Compatible use of land and Esthetic integration

The environmental advantages of wind energy, such as reduced CO_2 emissions and other green house gases must be conveyed to the public. As well as the influence from visual impact and interacting use of the landscape by different interest groups. Public attitudes to wind energy have to be incorporated in the process of deployment.

2.3.2 Quieter turbines

Understanding of noise and noise transportation over large distances is essential. Challenges offshore are related to the acoustically hard water surface. Initial estimations that wind turbines can emit more noise offshore without disturbing on shore dwellings may not be true. Better knowledge and actual experiences will be necessary.

2.3.3 Flora and fauna

Interaction between wind turbines and the wild life must be incorporated in the deployment process. This required better understanding of background data and behaviour of different species.

3. Conclusions and recommendations

The overall aim of future research is to support development cost effective wind turbines that can be connected to an optimised and efficient grid.

Future R&D will support incremental improvements in e.g. understanding extreme wind situations and reduced weight. But, the challenge is to try to find those evolutionary steps that can be taken to further improve wind turbine technology, for example in large scale integration incorporating wind forecasting and grid interaction with other energy sources.

Other challenges are associated with the integration of the technology as a means of producing electricity and to be a part of producing other energy carriers, e.g. hydrogen.

		Priority		Presently Covered by IEA R&D Wind
Area	Focus on	Mid term	Long term	
Continue cost reductions				
Improved site assessment and new locations	Extreme wind and wave situations, forecasting techniques	X		Met yes, oca no
Better models for aerodynamics/aeroelasticity	3d effects, stall induced vibration	X		Yes
New intelligent structures/materials and recycling	Extremes, adaptive intelligent structures, re-cycling		X	No
Reduce uncertainties in mechanical loads, improved standards	Supply background material	X		Delivers back ground data
More efficient generators, converters	Combined solutions for generation and transmission	X	x	No
New concepts and specific challenges	Intelligent solutions for load reduction		X	No
- Stand alone systems	Improved system performance	X		No
Enable large scale use				
Forecasting power performance	Increase value of electricity	X		
Electric load flow control and adaptive loads	Improve models, load flow control, power electronics		X	No
Better power quality	Power electronics	X		Yes, 1
Hybrid systems	Other energy carriers		X	No
New storage techniques	storage for different time scales		X	No
Minimize environmental impacts				
Compatible use of land and Esthetic integration	Information and interaction	X		No
Quitter turbines	Offshore issues	X		Yes, 1
Flora and fauna	Back ground data	X		No

1 Recommended practice has been developed.
Capital X denotes major priority
Small x denotes minor priority

The “No” in the column “Presently covered” does not imply that the subject is less important, it only reflects the fact that it has not yet has been dealt with within IEA R&D Wind. The special topic may be of greater interest to e.g. the industry.

Wind energy technology has traditionally been used in producing electricity and will be continuing to do so in the future. But, innovative concepts in hybrid systems and storage techniques may benefit other sectors of the economy, e.g. in transportation both on land and in the air.

3.1 Medium term

Areas of major importance for the future deployment of wind energy is in the medium time scale forecasting techniques, grid integration and public attitudes and visual impact.

Forecasting techniques will increase the value of wind energy by the fact that production can be forecasted, e.g. 6 to 48 hours, in advance. Integration of grid and demand side management will be essential when large quantities of electricity from wind shall be transported in a grid which originally was not suited for such large quantities of power. Finding new locations for wind energy will require that public attitudes and visual impact is incorporated in the deployment process.

3.2 Long term

For the long-term period it is of vital importance to take large and unconventional steps on order to make the wind turbine and its infrastructure interact in close co-operation. Adding intelligence to the complete wind system, interacting with other energy sources will be essential in areas of large deployment. Storage techniques for different time scales (minutes to months) can increase value at penetration levels above 15 to 20%.

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