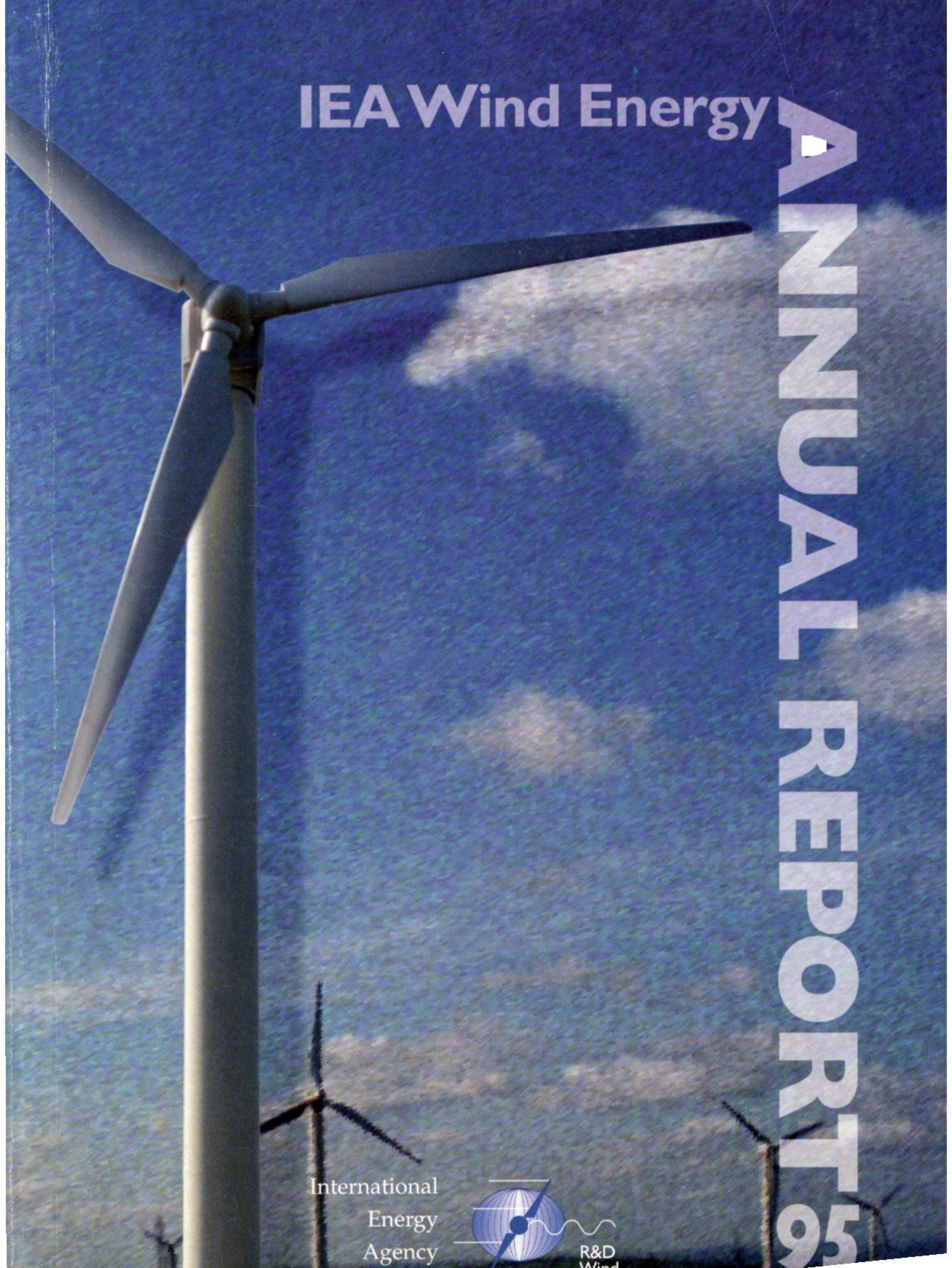
IEA Wind Energy

ANNUAL REPORT 95



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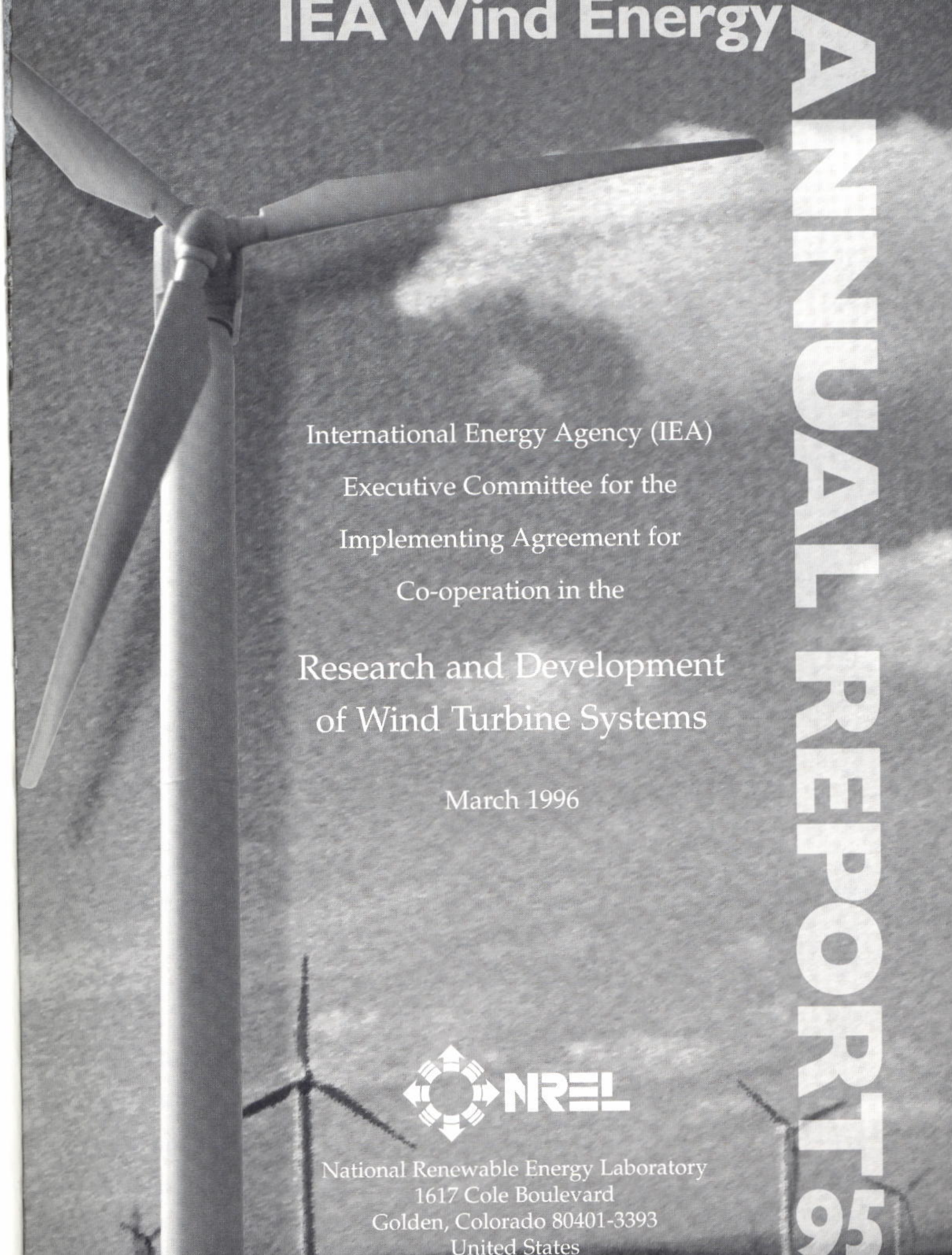

IEA Wind Energy

ANNUAL REPORT 95

International Energy Agency (IEA)
Executive Committee for the
Implementing Agreement for
Co-operation in the

Research and Development of Wind Turbine Systems

March 1996

NREL

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
United States

The eighteenth Annual Report reviews the progress during 1995 of the activities in the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems under the auspices of the International Energy Agency (IEA). The Agreement and its program, which is known as IEA R&D Wind, is a collaborative venture between parties from 16 IEA member countries.

The International Energy Agency, founded in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to collaborate on comprehensive international energy programs, carries out a comprehensive program of energy cooperation among 23 industrialized countries.

The report is published by the National Renewable Energy Laboratory (NREL) in Colorado, United States, on behalf of the IEA R&D Wind Executive Committee. It is edited by K. Steer-Dierderen with contributions from M. Carr (Australia), R. Rangi (Canada), P. Nielsen and B. Maribo Pedersen (Denmark), E. Peltola (Finland), R. Windheim (Germany), P. Vionis (Greece), C. Casale and L. Pirazzi (Italy), H. Matsumiya (Japan), J. 't Hooft (the Netherlands), E. Solberg (Norway), E. Soria (Spain), H. Ohlsson (Sweden), I. Page (United Kingdom), D. Ancona and G. Strahs (United States).

Dr. Ezio SESTO
Chairman of the
Executive Committee

Karine STEER-DIEDEREN
Secretary of the
Executive Committee

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Introduction

Commitment of the IEA to wind energy dates back to 1977, and has since been acting through the "Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems" (IEA R&D Wind). The objectives for action are directed to four main areas:

- advanced technology research;
- state-of-the-art assessment;
- information exchange;
- extended cooperation to increase the involvement of industry and utilities and non-member countries.

Production of electricity from new renewable energy forms such as wind power is increasingly attracting the public's interest in spite of the current availability of plentiful and inexpensive resources of conventional fuels. The cost-benefit ratio of wind turbines has improved considerably over the last five years, thanks to a 20-year commitment of researchers, wind turbine manufacturers and plant developers, with the support of governments and international organizations. That makes wind energy more economically competitive today. Furthermore, widespread concern about greenhouse effect and pollution by thermal power plants, as well as fears of a possible shortage of fossil fuels, with consequently heavy rise in their price, have promoted the deployment of wind energy and other renewable energies.

Today, it can be stated that wind energy has become one of the most economically practical and both technically and environmentally attractive of all the new renewable energy options. Wind can make an appreciable, albeit supplementary, contribution to a country's electricity demand mainly through power plants made up of tens or even hundreds of wind turbines connected to the grid (so-called wind power plants or wind farms). These plants run in parallel with conventional plants and make their contribution whenever exploitable wind speed is available.

The use of wind power is projected to expand rapidly during the next 10 to 20 years. The World Energy Council (WEC) projected in their July 1993 report "Renewable energy resources: opportunities and constraints 1990 - 2020" that, under an ecologically driven scenario, wind would provide 215 million tons of oil equivalent of energy annually by the year 2020 (corresponding to about 970 TWh of electricity). Recent studies project wind energy installed capacity to reach 11,500 and 10,000 MW respectively in Europe and the United States by 2010.

The continuing growth in the wind energy market is due to the increasing cost effectiveness of the technology. This is the result of several factors:

- decreasing production costs arising from improved manufacturing methods and the trend towards larger commercially available machines (currently with an electrical power output of about 1 MW);
- decreasing project development costs as the industry matures;
- increasing energy conversion efficiencies, arising from a better understanding of the technology;
- the increasing reliability of the wind power plants.

Research, development and demonstration programs funded by governments and other organizations; e.g., the European Union, have also proved to be a major factor and are set to continue in the next years. In the IEA R&D Wind member countries, overall annual funding of these programs has increased in recent years and is now (1995) the equivalent to approximately USD 180 million. In 1996, there has been a shift in some countries toward commercial research, development and demonstration using indirect government sponsored incentives.

A decisive, vigorous boost to wind energy installations has been given by substantial incentives granted by governments and local authorities to wind-generated electricity in many OECD-countries. Particularly, premium tariffs and/or tax relief for energy produced have proved to be much more effective tools, in promoting efficient wind power plants, than mere subsidies to plant capital costs.

Mention should also be made of the part played by electricity utilities, which have recently been more and more involved in this sector as technical and financial risks of wind power plant investments have been reduced. Unlike in the past, when nearly all wind power plants were installed and operated by independent producers selling energy to utilities, an increasing number of utility companies in America and Europe have recently embarked on wind power plant projects on their own or through subsidiary companies.

Export of wind turbines is also encouraged and supported by some countries in the OECD. Germany has successfully deployed turbines in Brazil, China and other countries under the Eldorado program. Denmark has offered favorable financing and other incentives that have helped with the introduction of more than 100 MW of Danish turbines into India and other countries.

National programs

The national wind energy programs are the basis for the IEA R&D Wind collaboration. These national programs are directed variously towards the evaluation, development and promotion of the technology both in the member countries and elsewhere. A summary of progress is given in the chapter NATIONAL ACTIVITIES - see page 19.

Collaborative activities

Tasks

To date, 15 projects, called Tasks, have been initiated, and 11 Tasks have been successfully completed since the start of the IEA Co-operation. The total level of effort is typically several man years per Task over a period of three years. The projects are either cost-shared and carried out in a lead country, or task-shared, when the participants contribute in-kind, usually in their home organizations, to a joint program coordinated by an Operating Agent. Reviews of progress in each active Task are given in the chapter IEA R&D Wind Program. In brief the status of current Tasks is:

TASK XI - BASE TECHNOLOGY INFORMATION EXCHANGE -
During 1995, Greece joined Task XI. There are now 13 participating countries. The main activities include the preparation of documents in the series "Recommended practices for wind turbine testing and evaluation", the undertaking of Joint Actions in specific research areas where a periodic exchange of information is considered necessary, and the organization of Topical Expert Meetings. Considering the importance of this Task the Executive Committee decided to continue the work of this Annex for two more years.

Recommended Practices

The Expert Group preparing a recommendation on "Noise emission measurements" met twice, and a final document is scheduled for 1996. A recommendation on "Point wind speed measurements" is in preparation and expected to be finalized in 1996. Work is about to begin on a guide for "Lightning protection".

Joint Actions

Within this subtask the ninth symposium on "Aerodynamics" was held on December 11/12, 1995 in Stockholm, Sweden.

Topical Expert Meetings

The 27th Topical Expert Meeting was held on September 11/12, 1995 in Utrecht, the Netherlands, on "Current R&D needs in wind energy technology".

TASK XII - UNIVERSAL WIND TURBINE FOR EXPERIMENTS (UNIWEX) -
This Task was completed in 1995 with the publication of the final report. The project comprised experimental studies of wind turbine aerodynamics, operational behavior, load spectra and control strategies, and the validation of computer codes for wind turbine design. Use has been made of the UNIWEX experimental wind turbine at the Ulrich Hütter wind test site near Schnittlingen, Germany. Three countries (Germany, the Netherlands, and Sweden) participated in the project, which included an extensive measurement program and numerical simulations.

TASK XIII - COOPERATION IN THE DEVELOPMENT OF LARGE-SCALE WIND SYSTEMS -
A final report was published 1995. This Task consisted of cooperative action and exchange of information on the planning and execution of national R,D&D programs for the development of large wind turbine systems. A computerized system was established for the collection and dissemination of information on national wind energy installations, design and operation of prototype wind turbines and selected wind power plants. The progress in the development of large-scale wind turbines and wind power plants as well as information on government funding levels will continue to be reported to the Executive Committee by its members.

TASK XIV - FIELD ROTOR AERODYNAMICS -
A joint research project involves five laboratories in four countries (Denmark, the Netherlands, United Kingdom and the United States). The project aims at coordinating measurement programs on existing experimental wind turbines, equipped with instrumented blades, to measure pressure distributions around the profiles or aerodynamic forces on blade sections. The data will be used to verify aerodynamic models.

A large number of interesting additional new measurements from the participating laboratories became available during 1995, and the Executive Committee decided to extend this Task into 1996.

TASK XV - ANNUAL REVIEW OF PROGRESS IN THE IMPLEMENTATION OF WIND ENERGY BY THE MEMBER COUNTRIES OF THE IEA -
Arising from a review of the strategic plan this new Task was initiated in 1995. The objective is to produce an annual review giving an overview of the progress in the commercial development of wind turbine systems in the IEA member countries participating in this Agreement in a form suitable for presentation to decision makers in government, planning authorities, the electricity supply industry, financial institutions and the wind industry. The aim is to identify major trends in initiatives and attitudes which are likely to be of interest to decision

makers. Key topics will include government initiatives, market growth, progress towards national targets, economic trends, progress in addressing environmental issues and public reaction. ETSU, on behalf of the United Kingdom, is the Operating Agent for this Task.

TASK XVI - WIND TURBINE ROUND ROBIN TEST PROGRAM -
This new Task was initiated in 1995. The objective of this project is to validate wind turbine testing procedures, analyze and resolve sources of discrepancies, and to improve the testing methods and procedures. A series of round robin comparison tests at participating national laboratories and other interested test stations will be the means of validating test procedures and establishing reciprocity between different certification testing laboratories. All participating laboratories will test identical machines at their own facilities, using comparable test instrumentation and data acquisition equipment. Discrepancies in the test data will be resolved and form the basis for improvements in testing procedures and calibration methods. This will also serve as justification for mutual recognition of foreign certifications. A joint report on the results of noise tests, power performance and load tests will be published.The Operating Agent is the National Renewable Energy Laboratory (NREL), the United States.

EXECUTIVE COMMITTEE ACTIVITIES

Officers

Dr. E. Sesto (Italy) and D. Ancona (United States) served as Chairman and Vice-Chairman during 1995. At the fall meeting, D. Ancona and R. Rangi (Canada) were elected Chairman and Vice-Chairman for 1996.

Participants

In 1995, the Ministry of Industry, Energy and Technology of Greece, and the Energy Research and Development Corporation (ERDC), designated by the Government of Australia signed the R&D Wind Agreement, thereby increasing the number of member countries to 16. During the year, the Executive Committee invited the European Commission to join the Agreement. Brazil, Israel, Mexico and Poland have shown interest in membership.

Several changes on the Executive Committee were announced - see Appendix III for an updated list of Members and Alternate Members.

Meetings

The Executive Committee meets traditionally twice a year to review ongoing Tasks, national wind energy R&D and deployment activities, and to plan and manage co-operative actions under the Agreement.

The 35th meeting took place on April 26 and 27, 1995 in Plympton, United Kingdom. The attendance was 22 participants, representing 12 of the 15 member countries and Operating Agents, and including observers from Australia and the CADDET Centre for Renewable Energy. The Committee stressed the need for close cooperation and coordination of CADDET activities with other IEA organizations in order to ensure consistent and high quality products.

At the meeting, final reports of Task XII "UNIWEX - universal wind turbine for experiments", and Task XIII "Cooperation in the development of large-scale wind systems" were submitted to the Executive Committee. The IEA legal office approved the new Task XV "Annual review of progress in the implementation of wind energy by the member countries of the IEA" and the Operating Agent presented the first draft review.

On April 28, 1995, the Committee visited wind power plants in Cornwall (Cold Northcott, Delabole and St. Breock).

The 36th meeting was held on October 11 and 12, 1995 in Vouliagmeni, Greece, and was attended by 22 participants, representing 11 of the 15 member countries and including observers from the European Commission and Australia.

The Executive Committee approved the 1996 budget. A new IEA R&D Wind brochure, aimed at informing the general public about the IEA's and member countries' commitment to wind energy, was presented and will be distributed widely.

Action was taken creating one new Task and extending two others. A final version of a new Task XVI "Wind turbine round robin test program" proposal was discussed and approved. Considering the importance of Task XI, the Committee decided to continue the work of this Annex for another two years. The scheduled end date of Annex XIV was October, 1995, and was extended for another year because interesting new assignments have been added to the project.

Information exchange programs with the Implementing Agreement on Photovoltaic Power Systems and GREENTIE were set up in 1995.

A visit to the 1.5 MW wind power plant on Andros took place on October 13, 1995.

At the IEA/UNIPEDE - the International Union of Producers and Distributors of Electrical Energy - conference on May 22-24, 1995 in Paris, the Chairman contributed with the paper "Present and prospective role of wind energy in electricity supply".

The Chairman presented also a report on the progress on work under the Agreement and prospects of wind energy applications and R&D wind activities at the IEA Working Party on Renewable Energy Technology (REWP) meeting on October 30-31, 1995 in Paris.

Planning Committee

The Planning Committee met on April 25, 1995 in Plympton, United Kingdom.

IEA Wind Energy Newsletter

Two issues of the *Wind Energy Newsletter* were published, reviewing the progress of the joint Tasks and the wind energy activities in the member countries. The Executive Committee acts as an editorial board for the Newsletter, which is edited by R.J. Templin and produced in Canada.

THE IMPLEMENTING AGREEMENT

The IEA cooperation in wind energy started in 1977. Presently 18 parties, designated by the governments of 16 countries, are participating. The cooperation is governed by "The Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems", or IEA R&D Wind for short. The Contracting Parties are:

Australia	The Energy Research and Development Corporation (ERDC);
Austria	The Republic of Austria;
Canada	The Department of Natural Resources Canada;
Denmark	The Ministry of Energy;
Finland	The Technical Research Centre of Finland (VTT);
Germany	Forschungszentrum Jülich GmbH;
Greece	The Ministry of Industry/Energy and Technology;
Italy	Ente per le Nuove Tecnologie, l'Energia el'Ambiente (ENEA); and ENEL, Società per Azione;
Japan	The Government of Japan;
Netherlands	The Netherlands Agency for Energy and the Environment (NOVEM);
New Zealand	The Electricity Corporation of New Zealand Ltd.;
Norway	The Norwegian Water Resources and Energy Administration (NVE);
Spain	Instituto de Energias Renovables (IER) of the Centro de Investigación; Energetica Medioambiental y Tecnologica (CIEMAT);
Sweden	The National Board for Industrial and Technical Development (NUTEK);
United Kingdom	UK Atomic Energy Authority;
United States	The Department of Energy.

The general objective of IEA R&D Wind is to undertake collaborative R&D projects, called Tasks, and to exchange information on the planning and execution of national large-scale wind systems. Each Task is managed by an Operating Agent, usually one of the Contracting Parties. Overall control of the program is vested in the Executive Committee, where each Contracting Party is represented.

The Tasks are defined in Annexes to the Implementing Agreement. To date 15 Tasks have been initiated. Eleven Tasks have been successfully completed.

Task I	Environmental and meteorological aspects of wind energy conversion systems Operating Agent: The National Swedish Board for Energy Source Development Completed in 1981.

Task II	Evaluation of wind models for wind energy siting Operating Agent: US Department of Energy - Battelle Pacific Northwest Laboratories Completed in 1983.
Task III	Integration of wind power into national electricity supply systems Operating Agent: Kernforschungsanlage Jülich GmbH, Germany Completed in 1983.
Task IV	Investigation of rotor stressing and smoothness of operation of large-scale wind energy conversion systems Operating Agent: Kernforschungsanlage Jülich GmbH, Germany Completed in 1980.
Task V	Study of wake effects behind single turbines and in wind turbine parks Operating Agent: Netherlands Energy Research Foundation Completed in 1984.
Task VI	Study of local flow at potential WECS hill sites Operating Agent: National Research Council of Canada Completed in 1985.
Task VII	Study of offshore WECS Operating Agent: UK Central Electricity Generating Board Completed in 1988.
Task VIII	Study of decentralized applications for wind energy Operating Agent: UK National Engineering Laboratory Technically completed in 1989. Final report published in 1994.
Task IX	Intensified study of wind turbine wake effects Operating Agent: UK National Power plc Completed in 1992.
Task X	Systems interaction Deferred indefinitely.
Task XI	Base technology information exchange Operating Agent: Department of Fluid Mechanics, Technical University of Denmark Continuing through 1996 and 1997.
Task XII	Universal wind turbine for experiments (UNIWEX) Operating Agent: Institute for Computer Applications, University of Stuttgart, Germany Completed in 1994. Final report published in 1995.
Task XIII	Cooperation in the development of large-scale wind systems Operating Agent: National Renewable Energy Laboratory (NREL), USA Completed in 1994. Final report published in 1995.
Task XIV	Field rotor aerodynamics Operating Agent: Stichting Energieonderzoek Centrum Nederland (ECN), the Netherlands Continuing through 1996.
Task XV	Annual review of progress in the implementation of wind energy by the member countries of the IEA Operating Agent: ETSU, on behalf of the United Kingdom To be completed in 1998.

Task XVI Wind turbine round robin test program
Operating Agent: the National Renewable Energy Laboratory (NREL), United States
To be completed in 1997.

The level of effort varies for each Task. Some Tasks involve only information exchange with each country providing less than 0.1 man years of effort, while other Tasks involve test programs needing several man years work for several years. Several Tasks are mixed cost- and task-shared. The participation in current Tasks is shown below in Table 1.

Table 1. Participation per country in current Tasks. OA indicates Operating Agent

COUNTRY	TASK			
	XI Technology information	XIV Field rotor aerodynamics	XV Annual wind energy review	XVI Round robin test program
Australia			x	
Canada	x			
Denmark	OA	x	x	x
Finland	x			
Germany	x		x	
Greece	x		x	x
Italy	x		x	x
Japan			x	
Netherlands	x	OA	x	x
New Zealand	x			
Norway	x		x	
Spain	x		x	
Sweden	x		x	
United Kingdom	x	x	OA	
United States	x	x	x	OA

TASK XI – BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote wind turbine technology by cooperative activities and information exchange on R&D topics of common interest. The Task has two subtasks:

a. Development of recommended practices for wind turbine testing and evaluation

Table 2. Documents in the series of recommended practices for wind turbine testing and evaluation

VOLUME	TITLE	1ST ED.	2ND ED.	3RD ED.
1	POWER PERFORMANCE TESTING Describes in detail in what way measurements shall be performed in order to get correct power curve for a wind turbine.	1982	1990	
2	ESTIMATION OF COST OF ENERGY FROM WIND ENERGY CONVERSION SYSTEMS States all the various elements and assumptions that enter a cost calculation.	1983	1994	
3	FATIGUE LOAD CHARACTERISTICS The correct procedure is described for getting a valid estimate of the fatigue life for the components of a wind turbine.	1984	1989	
4	MEASUREMENT OF NOISE EMISSION Noise being one of the potential nuisances caused by a wind turbine, the correct measurement of noise output is vital.	1984	1988	1994
5	ELECTROMAGNETIC INTERFERENCE This other possible source of disturbance caused by a wind turbine must be evaluated carefully and accurately.	1986		
6	STRUCTURAL SAFETY Outlines a rational procedure for setting up standards of safety.	1988		
7	QUALITY OF POWER The quality of the power output from a wind turbine needs to be described unambiguously.	1984		
8	GLOSSARY OF TERMS A comprehensive collection is compiled of the special terms used in the trade, with their proper definitions.	1987	1993	
9	POINT WIND SPEED MEASUREMENTS	in preparation		
10	NOISE EMISSION MEASUREMENTS	in preparation		
11	LIGHTNING PROTECTION OF WIND TURBINE GENERATOR SYSTEMS	in preparation		

b. Joint Actions

As part of subtask B, Topical Experts Meetings are arranged, as agreed by the participants, acting in the Executive Committee.

A. Recommended Practices for Wind Turbine Testing and Evaluation

The aim of this subtask is to propose recommendations for wind turbine testing to address the development of internationally agreed test procedures. So far, recommendations have been published in eight areas (see Table 2). The documents are available from the Operating Agent and selected representatives in the participating countries.

The Experts Group preparing a recommendation on "Noise emission measurements" held two meetings during 1995 (on March 6, in Wilhelmshaven, Germany, and on September 25, in Lyngby, Denmark). A final document is scheduled for 1996.

The Experts Group which will prepare a recommendation on "Point wind speed measurements" met on October 19-20, 1995 in Lyngby, Denmark. A final document is scheduled for 1996.

The Experts Group on "Lightning protection of wind turbine generator systems" will have their first meeting on February 6-7, 1996.

B. Joint Actions

Joint Actions are set up by the Executive Committee in a specific research area of current interest, where a periodic exchange of information is deemed necessary. The Joint Actions have taken the form of workshops or symposia. Participation is by invitation from the national members of the Executive Committee. So far, four Joint Actions have been initiated:

- Aerodynamics of wind turbines
- Fatigue of wind turbine blades
- Offshore wind systems
- Wind conditions/turbine loads

The ninth symposium within the Joint Action on "Aerodynamics" was held on December 11-12, 1995 at the Aeronautical Research Institute of Sweden in Stockholm.

Proceedings from Joint Action symposia are published by the Operating Agent.

Topical Expert Meetings

Topical Expert meetings are arranged once or twice a year, as decided by the Executive Committee. Attendance is by invitation through the national Executive Committee member, and the number of participants is limited to a few per country. The 27th Expert Meeting was held in Utrecht, the Netherlands, on September 11-12, 1995 on "Current R&D needs in wind energy technology".

Proceedings are published by the Operating Agent.

A complete list of the meetings held so far is shown in Table 3.

Participating Organizations

Canada	Department of Natural Resources Canada
Denmark	Department of Fluid Mechanics, Technical University of Denmark
Finland	VTT
Germany	KFA Jülich
Greece	CRES
Italy	ENEA
Netherlands	ECN
New Zealand	ECNZ
Norway	NVE
Spain	CIEMAT/IER
Sweden	FFA
United Kingdom	ETSU
United States	Department of Energy

Operating Agent

Department of Fluid Mechanics of the
Technical University of Denmark

Table 3. IEA wind energy expert meetings

1	Seminar on structural dynamics	12 Oct 1978	Munich, Germany
2	Control of LS WECS and adaptation of wind electricity to the network	4 Apr 1979	Copenhagen, Denmark
3	Data acquisition and analysis for LS WECS	26-27 Sept 1979	Blowing Rock, USA
4	Rotor blade technology with special respect to fatigue design	21-22 Apr 1980	Stockholm, Sweden
5	Environmental and safety aspects of the present LS WECS	25-26 Sept 1980	Munich, Germany
6	Reliability and maintenance problems of LS WECS	29-30 Apr 1981	Aalborg, Denmark
7	Costing of wind turbines	8-19 Nov 1981	Copenhagen, Denmark
8	Safety assurance and quality control of LS WECS during assembly, erection and acceptance testing	26-27 May 1982	Stockholm, Sweden
9	Structural design criteria for LS WECS	7-8 Mar 1983	Greenford, UK
10	Utility and operational experience from major wind installations	12-14 Oct 1983	Palo Alto, California
11	General environmental aspects	7-9 May 1984	Munich, Germany
12	Aerodynamic calculation methods for WECS	29-30 Oct 1984	Copenhagen, Denmark
13	Economic aspects of wind turbines	30-31 May 1985	Petten, Netherlands
14	Modelling of atmospheric turbulence for use in WECS rotor loading calculations	4-5 Dec 1985	Stockholm, Sweden
15	General planning and environmental issues of LS WECS installations	2 Dec 1987	Hamburg, Germany
16	Requirements for safety systems for LS WECS	17-18 Oct 1988	Rome, Italy
17	Integrating wind turbines into utility power systems	11-12 Apr 1989	Herndon, USA
18	Noise generating mechanisms for wind turbines	27-28 Nov 1989	Petten, Netherlands
19	Wind turbine control systems–strategy and problems	3-4 May 1990	London, England
20	Wind characteristics of relevance for wind turbine design	7-8 Mar 1991	Stockholm, Sweden
21	Electrical systems for wind turbines with constant or variable speed	7-8 Oct 1991	Gothenburg,Sweden
22	Effects of environment on wind turbine safety and performance	16-17 June 1992	Wilhelmshaven, Germany
23	Fatigue of wind turbines, full-scale blade testing and non-destructive testing	15-16 Oct 1992	Golden, Colorado, USA
24	Wind conditions for wind turbine design	29-30 Apr 1993	Risø, Denmark
25	Increased loads in wind power stations (wind farms)	3-4 May 1993	Gothenburg, Sweden
26	Lightning protection of wind turbine generator systems and EMC problems in the associated control systems	8-9 Mar 1994	Milan, Italy
27	Current R&D needs in wind energy technology	11-12 Sept 1995	Utrecht, Netherlands

TASK XII – UNIVERSAL WIND TURBINE FOR EXPERIMENTS (UNIWEX)

UNIWEX is a computer-controlled, two-bladed experimental wind turbine of 16 m diameter installed at the Ulrich Hütter wind test field near Schnittlingen, Germany. The main goals of the project were the experimental study of aerodynamics, operational behavior, load spectra and control strategies for different hub concepts, as well as the validation of computer codes.

Seven organizations from three countries were participating:

Germany	Forschungszentrum Jülich GmbH (KFA); Institute for Computer Applications (ICA), University of Stuttgart;
Netherlands	Netherlands Energy Research Foundation (ECN); Delft University of Technology (DUT); Stork Product Engineering (SPE);
Sweden	National Energy Administration Sweden (NE); Aeronautical Research Institute of Sweden (FFA).
Operating Agent	Institute for Computer Applications (ICA), University of Stuttgart.

The project was technically completed in 1992. A short summary report of 52 pages on the German contribution was submitted in 1993. The Operating Agent presented an extended and more detailed final report, including the contributions from the Netherlands and Sweden, to the Executive Committee at their meeting in April 1995.

The direct results can be listed under the headlines:

- development of hardware and software;
- validation of numerical codes (PHATAS II, FLEXLAST, DUWECS, ARLIS);
- simulation and comparison of concepts;
- experimental studies of different turbine configurations.

The results have been summarized in the above mentioned report and an ECN report, covering the work done by the Dutch participants in more detail. Results from 280 experiments have also been placed on a CD-ROM for wider dissemination and further evaluation.

Summary publications 1994/1995:

1. A.J. Brand, H. Snel, G.E. van Baars, P.M.M. Bongers, N.O.T. Hansen, G.A.M. van Kuik: "The Dutch contribution to the IEA UNIWEX project", ECN-C-94-075, September 1994.
2. K.A. Braun, M. Müller: "UNIWEX - a universal wind turbine for experiments – summary report", ICA report No. 44, University of Stuttgart, 1995.

TASK XIII – COOPERATION IN THE DEVELOPMENT OF LARGE-SCALE WIND SYSTEMS

The purpose of this Annex was to further the development of large wind turbine systems (LWTS) by means of cooperative action and exchange of information on the planning and execution of national LWTS research, development, and demonstration programs. In order to participate in the Annex it was necessary for a country to be active in projects on the development, construction, or operation of one or more LWTS. For the purposes of the Annex, a LWTS is a single wind machine of one megawatt rating, or a wind power plant whose rated output power exceeds one megawatt, provided that the wind machines forming the wind power plant exceed 25 meters in diameter. Large wind machines were usually prototypes, while machines constituting wind power plants were usually commercially available.

The major task under the Annex was the assembly and maintenance of a data base of material relevant to large wind energy systems. This included, among other things, detailed technical specifications of each machine type, wind power plant locations and characteristics, and national and local energy production records. The complete data base is available to Annex members on personal computer diskettes.

Eleven nations from the parent Wind R&D Agreement participated in Annex XIII. They were Canada, Denmark, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, United Kingdom, and United States. Data collection was facilitated by using one or more contact persons in each country who were appointed for that purpose by the Executive Committee member. The Operating Agent for this Annex was the National Renewable Energy Laboratory in the United States.

A variety of important results and conclusions were reached by the participants. Briefly summarized they are:

- dramatic growth in deployment;
- expanding R,D&D;
- growth in turbine size;
- robust international trade.

Since the Annex was established for a three year lifetime, formal Annex activity ended on December 31, 1993, but data analysis continued during 1994 and the final report was published in 1995. The original purpose of Annex XIII will now largely be subsumed into the new and broader Annex XV.

TASK XIV – FIELD ROTOR AERODYNAMICS

The objective of the Task is to coordinate programs for the measurements of blade forces and pressure distributions made on existing experimental wind turbines under actual field operating conditions.

Five parties from four countries are performing aerodynamic field experiments on full scale horizontal axis wind turbines.

The available facilities are the following:

1. Denmark
   Risø National Laboratory
   Rotor diameter 19 m
   Measurements of total sectional forces from which aerodynamic forces can be derived at three sections.

2. The Netherlands

   a. ECN (Operating Agent)
      Rotor diameter 25 m
      Pressure tap measurements around profiles at three stations. Two types of experiments are performed:

      - Measurements on a stationary test rig.
      - Measurements on a rotating test rig.

   b. Delft University of Technology
      Rotor diameter 10 m
      Pressure tap measurements at three stations.

3. United Kingdom
   Imperial College/Rutherford Appleton Laboratory
   Rotor diameter 17 m
   Pressure tap measurements at six stations.

4 United States
   National Renewable Energy Laboratory (NREL)
   Rotor diameter 10 m
   Pressure tap measurements around profiles at four stations

Since the start of the project in November 1992, four meetings have taken place between the participating laboratories. At the first meeting in December 1992, a work plan was defined. At the second meeting in September 1993, a first round of data exchange was completed. A third meeting of March 1994 discussed measurement methods including the problem of local aerodynamic angle of attack determination, and the medium and format for data exchange.

Since March 1994, the Task became closely related to the JOULE II project "Dynamic stall and 3D effects". It was agreed that the measurements which are collected in Task XIV form the basis for the model development which takes place in the JOULE project.

At the fourth meeting of April 1995, agreements have been reached on the data files to be used, and their method of transfer. All experimental facilities are operational, and the data have been stored in the data base. Several new tasks have been added to the project. Therefore, it was decided to extend Annex XIV till the end of 1996.

TASK XV – ANNUAL REVIEW OF PROGRESS IN THE IMPLEMENTATION OF WIND ENERGY BY THE IEA MEMBER COUNTRIES

This Task was initiated on June 1, 1995, and will remain in force for a period of three years. It may be extended by agreement of two or more participants acting in the Executive Committee. ETSU, on behalf of the United Kingdom, is the Operating Agent for this Task.

Objective

The objective of this Task is to produce an annual review giving an overview of the progress in the commercial development of wind turbine systems in the IEA member countries participating in this Agreement in a form suitable for presentation to decision makers in government, planning authorities, the electricity supply industry, financial institutions and the wind industry.

The aim is to identify major trends in initiatives and attitudes which are likely to be of interest to decision makers rather than to produce detailed statistics of installations and their performance.

Means

The annual review will be based on the annual national reports submitted to the Executive Committee. An initial summary of progress in the implementation of wind energy during 1995 is included in this Annual Report - see page 19, and a full review will be published shortly afterwards as a stand-alone document, with references to the annual report, for those seeking more detailed information. A final report will be prepared after three years on completion of the Annex.

TASK XVI – WIND TURBINE ROUND ROBIN TEST PROGRAM

Introduction

International recommended practices for development and testing wind turbines are being developed by the International Energy Agency (IEA). International norms and standards are being developed by the International Electrotechnical Commission Technical Committee 88 (IEC-TC88) and other agencies. When countries adopt theses new standards, a mechanism should be in place to ensure that turbines are tested and certified to common criteria. Common criteria could enable different countries to accept foreign certification in lieu of their own. However, countries have found that there can be discrepancies between tests conducted in different locations using different test equipment. A round robin test of anemometers demonstrated that even simple wind speed measurements can be significantly affected by different anemometer calibration procedures. Power curve, noise and load tests of full turbines for certification programs in different countries may reveal important differences. A basis for exchanging test reports should be established to demonstrate that these tests can be reliably conducted in different locations by different testing agencies and achieve similar results. Results from this demonstration would facilitate international certification harmonization efforts.

A series of round robin comparison tests at participating national laboratories and other interested test stations have been suggested as a means of validating test procedures and establishing reciprocity between different certification testing laboratories. All participating laboratories will test identical machines at their own facilities, using comparable test instrumentation and data acquisition equipment. Discrepancies in the test data will be resolved and form the basis for improvements in testing procedures and calibration methods. This effort could also serve as justification for mutual recognition of foreign certification.

Objective

The objective of this program is to validate wind turbine testing procedures, analyze and resolve sources of discrepancies, and to improve the testing methods and procedures.

Task descriptions

- development of test and analysis plan;
- procurement and installation of test turbines;
- preparation of test sites;
- testing of standard turbines and data analysis.

The Task was approved by the Executive Committee at their October 1995 meeting. Pending a review of the Annex by the IEA headquarters, work should begin in early 1996. The Operating Agent is the National Renewable Energy Laboratory (NREL) in the United States.

SUMMARY

The national reports in this section describe in some detail the wind energy activities and developments in the individual countries. This summary collates the information given in the national reports on the commercial development of the industry. Where information relates to a specific country, its two letter national identification code is included in parentheses.

A full review comparing all aspects of national approaches to promoting the technology will be published in the summer of 1996 as a stand-alone document for those seeking a more detailed overview.

1. MARKET STIMULATION INSTRUMENTS

The main market stimulation instruments used in participating countries are investment subsidies, tax incentives and payment of premium prices for the energy produced. About half of the countries also offer support for industrial development. The trend is towards the payment of a premium price for energy generated and away from investment subsidies. The Netherlands is the latest country to follow this trend with direct subsidies for investment ending in 1995.

The premium price is usually set in relation to the national electricity tariffs except in the United Kingdom where a bid-in system is used and contracts awarded to the lowest bidders.

2. MAIN CONSTRAINTS ON MARKET DEVELOPMENT

The primary constraint affecting market development is the low cost of conventional generation arising from cheap fuel and surplus capacity which makes wind energy economically unattractive where it has to compete on the open market (AU, CN, SF, JP, NZ, NO, US). In countries where premium buy-back prices make the generation of electricity by wind power economically viable, the main constraint on the rate of development is the difficulty of obtaining planning consent for projects, often on the grounds of environmental concern (DK, DE, IT, NL, SW, UK). Only Germany reports integration into the electricity distribution system as a potential constraint.

3. COMMERCIAL IMPLEMENTATION OF WIND POWER

3.1. Installed capacity

The rate of installation rose in most countries in 1995 with the most dramatic increase being in Germany as the "enhanced 250 MW program" came to fruition. Significant increases also occurred in Denmark and the Netherlands as difficulties in obtaining planning consents eased while the rate of installation in the United Kingdom recovered towards the end of the year as projects in the Northern Ireland Non-Fossil Fuel Obligation and the Scottish Renewables Obligation got underway. In the United States, restructuring of the electricity supply industry continued to cause delays in some projects. The aggregate numbers for all member countries are:

	TOTAL	1995	1994
Capacity (MW)	4,264	852	521
Number of turbines	27,336	1,911	1,481
Average turbine capacity (kW)	160	450	350

The upward trend in rated capacity of turbines over the years is clearly discernible.

At the end of 1995, the worldwide installed wind power capacity was:

Country	Installed capacity (MW)
Australia	3
Belgium	5
Canada	21
China	36
Denmark	630
Finland	7
France	3
Germany	1,137
Greece	28
India	550
Ireland	7
Italy	23
Japan	10
Netherlands	250
New Zealand	1
Norway	4
Portugal	8
Spain	126
Sweden	67
United Kingdom	193
United States	1,770
Rest of the world	21
TOTAL	4,900

3.2. Performance of installed plant

Electricity generation

The aggregate numbers for generation for the participating countries are 31,978 GWh totalled over all years and 7,488 GWh during 1995 compared to 6,243 GWh in 1994.

Availability and load factors

Little detailed information is available on performance as few countries have a reporting system in operation and outside of these the information is regarded as commercially sensitive. Most commercial plants are reported to be operating with availabilities in excess of 95% and load factors often as high as 0.4 and occasionally higher depending on the wind speeds at the sites.

3.3. Operational experience

In general, the installed turbines performed well with few operational difficulties. Only two problems were reported. The first, of concern to several countries, was the damage by lightning strikes to turbine structures and electrical systems. The second, specific to Finland, was the effect of extreme weather conditions (icing) on turbine operation. No other problems were reported on the operation of wind power plants and turbines.

No major problem was reported on the integration of output into the electrical distribution systems. Only Germany commented on integration problems as a potential constraint on development in sparsely populated areas. However, both Greece and Spain report positively on high levels of penetration on weak grids, in particular on the Spanish Canary Islands with 30% penetration.

4. ECONOMICS

4.1 Manufacturing, project and generation costs

Ten of the reporting countries (AU, GR, NO, NZ and SF excluded) have turbine manufacturing industries while six (US, DE, DK, ES, NL, UK) have over 100 MW of plant in operation which allows good estimates of manufacturing, project and generation costs to be made.

The ex-factory costs of turbines have fallen steadily over the past 15 years but show little change between 1994 and 1995. In 1995, the reported prices ranged from USD 780- 1,205/kW with an average of around USD 1,000/kW.

Total project costs also appear to have remained steady or maybe increased slightly in 1995 compared to 1994, with average reported costs varying in the range USD 1,126-1,570/installed kW with an overall average of around USD 1,350/installed kW. One would expect the variation in theses costs to arise from the difficulty of working in the terrain in which the wind power plant is installed and the ease of access to the electricity network.

The cost of generation by wind power ranged from USD 0.04-0.11 in those countries with over 100 MW of installed plant. The variations are accounted for mainly by differences in total project size, costs and energy yield, the latter being dependent on the available site mean wind speeds. However, operation and maintenance costs and financial factors such as interest rates and pay-back periods also influence these estimates.

4.2. Invested capital

The capital investment in commercial wind power can be calculated from the installed capacity and estimated total project costs per installed kilowatt. On the assumption that all plants are costed at an average figure of USD 1,350 per installed kW, which is recognized as being only indicative, the aggregate investments in wind energy generation by the reporting countries are very approximately USD 1,200 million during 1995 and USD 5,800 million in total.

5. MANUFACTURING INDUSTRY

5.1 Status of manufacturing industry

The status of the wind turbine manufacturing industry in the individual countries depends strongly on the support given by the government during its formative years. Established manufacturing industries exist in Denmark and the Netherlands founded on subsidies during the 1980's, in the United States based on large sales in the subsidized Californian market and in Japan due to early support of export sales of its turbines. Manufacturing companies are emerging in Germany and Spain as a result of promotional programs while other countries are seeking to establish turbine manufacturing industries through collaborative programs between government and industry.

5.2. Technical and business developments

The trend continued during 1995 of turbines with increased rated capacity for the commercial market. Several 500/600 kW machines were available and manufacturers began testing commercial prototypes rated at or over 1 MW. Smaller machines continued to be developed using new technology, usually through value engineering to make them lighter and more cost competitive.

5.3. Supporting industries

As the sales of wind turbines grow, the market has become more buoyant for component manufacturers, especially as local sourcing of components is regarded favorably in several countries. In particular, several blade manufacturing companies emerged during 1995.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

6.1. R,D&D funding

There are government sponsored programs in all the countries either funded by the central government through government departments or agencies, or funded and managed by government-owned companies. The reported 1995 annual budgets for direct R,D&D work, excluding indirect support such as premium price payments or tax incentives, range from less than USD 1.0 million (GR, SF, CN, NO), through USD 1.0-15 million (NL, ES, DK, JP, UK, IT, SW) to USD 28 million for Germany and USD 49 million for the United States.

In Europe, overall R,D&D funding levels are higher than indicated as additional funding is available through the European Union which, of course, originates from the contributions of the individual national governments. With the exception of Germany and the United States, the 1995 national funding levels show only small changes compared to those of 1994.

6.2. Priorities

The main R,D&D priorities reported by each country can basically be divided into two categories - the first concerned with national issues, such as the available resource and the impact of turbine siting, and the second concerned with the development of the technology itself. Topics of interest include:

National issues:

- resource evaluation (wind measure ments, modelling);
- planning consent (siting of turbines);
- environmental impact (noise, visual intrusion);
- electrical issues (integration, power quality);
- standards and certification.

Technology development:

- improved efficiency (aerodynamics, variable speed operation);
- cost reductions (value engineering, component development);
- advanced turbine development (new concepts);
- safety (structural loads).

In general, work on national issues is directed by government departments or agencies while technology development is undertaken in collaboration with, and often partially funded by, industry.

6.3. New R,D&D developments

The main trends in turbine development during 1995 were towards lighter, more flexible turbines, the use of direct drive generators and variable speed operation. The Netherlands reported a prototype machine based on their "Flexhat" experimental machine and using direct drive generation. The development of turbines of increased rated capacity for the commercial market also continued. New concepts under development are described in the individual national reports.

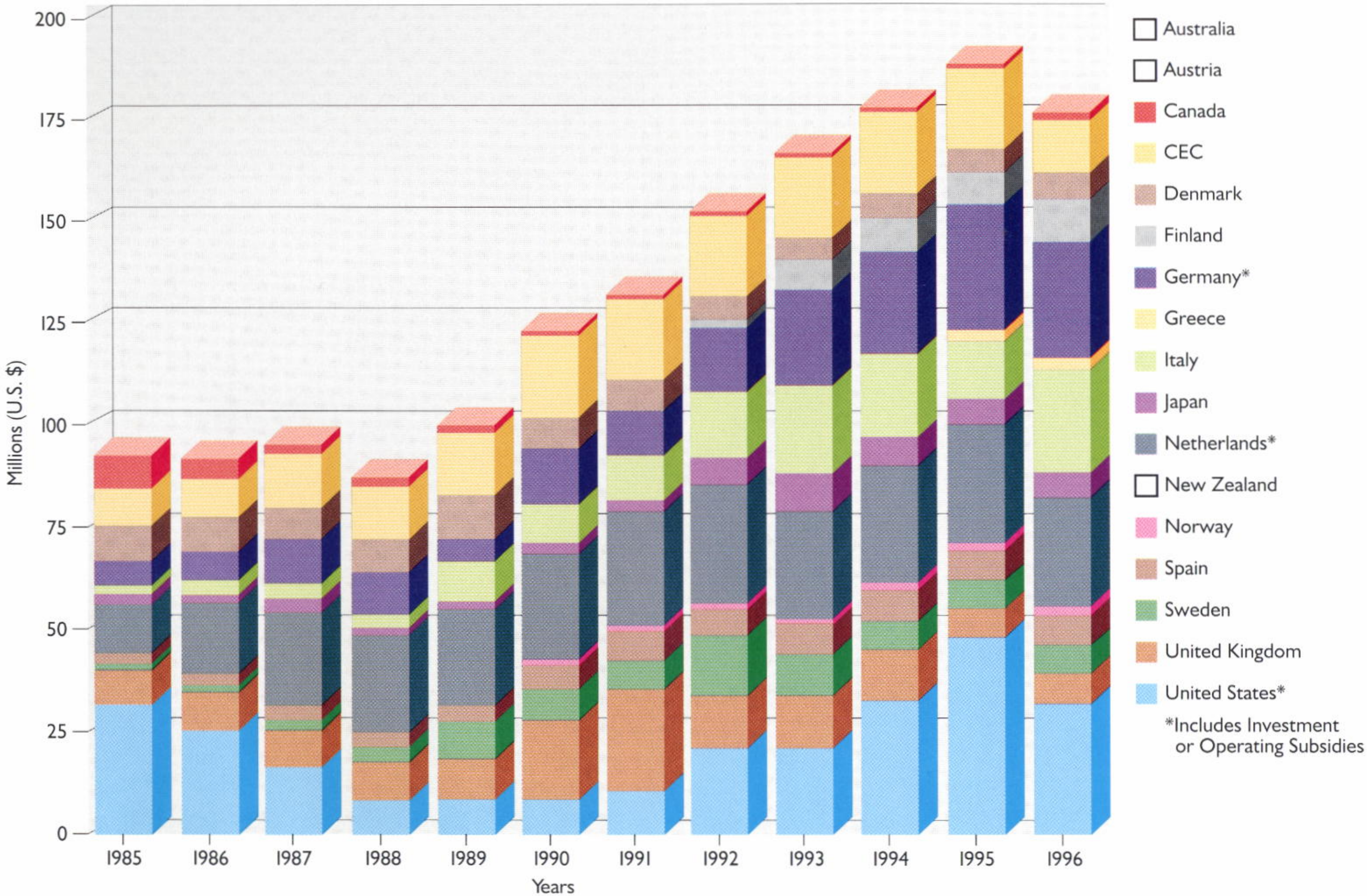
6.4. Offshore siting

Interest in the offshore siting of turbines is, in the main, limited to those countries where there is a shortage of suitable sites on land (IT, SW) or where population density precludes extensive on-land development because of environmental intrusion (DK, NL, UK). By the end of 1995, Denmark had two offshore wind power plants of 5 MW in operation while the Netherlands (4 x 500 kW) and Sweden (1 x 250 kW) had mounted demonstration projects and Italy had a small R&D program. The United Kingdom, after extensive R&D work over the last decade, had decided to maintain a watching brief.

6.5. International collaboration

For R,D&D studies there is strong multi-national collaboration in Europe through numerous JOULE and THERMIE projects which are partially funded by the European Union. The United States has bilateral agreements with several countries. In seeking to establish overseas trade, most countries are actively seeking collaboration with countries or regions with large potential markets; e.g., India, China and South America.

Wind energy research, development and demonstration government funding chart.



Source: International Energy Agency, Wind Turbine Systems Agreement, Executive Committee 01/96.

AUSTRALIA

1. GOVERNMENT PROGRAM

No widespread government support is available for renewable energy. However, there are a number of industry development programs based on remote area power system technologies.

The government aims at the development of small-scale renewable technologies for remote area power systems as an industry development measure.

State based subsidies are available for off-grid power supplies using renewable technologies.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

During 1995, no new capacity was connected. The national conventional capacity is 37,250,000 MW, and the total wind capacity is 3 MW. A total number of 18 machines are installed with an average power of 225 kW. Most of the machines are imported from Denmark.

3. COMMERCIAL IMPLEMENTATION

The 1995 energy output was 6,274.115 kWh. Availability was TBA and the load factor was 30%.

Intense studies on weak grids indicate no serious problems up to 50% penetration. Reactive power loading on diesel generators becomes a limiting factor.

4. INDUSTRY

There are no market stimulation programs for grid-connected wind turbines. Some subsidies for remote area power system turbines are available.

Electricity utilities are owned by the states.

5. MANUFACTURING INDUSTRY

There are no utility-scale turbine manufacturers, but small remote area power system turbines are manufactured in Australia.

6. ECONOMICS

Typical tariffs for private consumers are AUD 0.13/kWh, and for industrial consumers AUD 0.08/kWh. The wind energy buy-back price is AUD 0.3218/kWh.

7. MARKET DEVELOPMENT

The main factors affecting market development are the low cost of gas- and coal-based generation. However, the remote areas using diesel-fueled generation offer significant opportunities for small capacity wind energy projects.

Figure 1. View of the 2 MW Ten Mile Lagoon wind power plant (nine 225 kW Vestas machines).

CANADA

1. GOVERNMENT PROGRAM

The focus of the Canadian national program continues to be in the R&D and field trials. The main elements of the wind energy R&D program are technology development, resource assessment, test facilities and information/technology transfer. Field trial projects are selected to evaluate the performance of the equipment under special environmental conditions or for specific applications.

1.1. Research and development

Resource assessment

Resource assessment on the east shore of Lake Huron, Ontario, has been completed.

Technology development

- Development of the High-Penetration-No-Storage (HPNS) wind/diesel system by Hydro-Quebec and Atlantic Wind Test Site (AWTS) has been completed. The test-bed will be operated continuously as a small community HPNS wind/diesel system for two to three weeks.
- The Lagerwey 80 kW wind turbine is undergoing testing at the Atlantic Wind Test Site (AWTS) and is being fitted with a control system and an inverter.
- The Atlantic Orient 15/50 kW has been fitted with a new control system. The testing of the AOC has been completed. The machine performed very well with the new control system.

Wind turbine test sites

The program supports two test sites:

- Atlantic Wind Test Site (AWTS) at North Cape, Prince Edward Island, for testing electricity generating wind turbines and wind/diesel systems, and
- Alberta Renewable Energy Test Site (ARETS) at Pincher Creek, Alberta, for testing wind and PV water pumping systems.

1.2. Field trial projects

- A Lagerwey was installed at Cambridge Bay, North West Territory, in October 1994. The turbine is performing very well. The oil in the yaw mechanism became thick during very cold weather in January 1995. This slowed the rate of yaw considerably. The oil was changed to a grade more suitable for cold weather and it cured the problem.
- TACKE 600 kW HAWT
  TACKE Windpower Inc. (TWP) of Huron Park, Ontario, as per an agreement with NRCan, has installed a 600 kW turbine near Kincardine, Ontario. The turbine, modified for cold weather conditions, has been undergoing evaluation since the beginning of October 1995. The turbine has been performing trouble free. It was producing more power than the generator rating due to higher density. This was fixed by changing the blade pitch. TWP has started to manufacture and export blades for the TACKE 600 wind turbine.
- 150 kW Bonus at Haeckel Hill
  The turbine installed on the Haeckel Hill (1,450 m height) near White Horse in Yukon was commissioned in August 1993. The turbine's performance up to the end of June, 1995 was:

energy output	=	453,875 kWh
generation	=	9,376 hours
turbine availability	=	89.4% (excluding grid line outages)

The grid outages resulted in loss of 787 hours of generating time. The turbine lost 734 and 216 hours, due to down time and O&M respectively. The blade deicing equipment kept the blades free of ice down to about -20°C. Below this temperature the ice became soft and did not leave the blades, resulting in loss of power. The turbine will be tested for another winter.

The turbine is located on the west side of White Horse and near a major migrating corridor used by many thousands of large waterfowl. On the east side of White Horse, also close to this corridor, there are some microwave communication antennae and radio transmission towers on top of the Grey Mountain ridge. Both of these locations were thought to be likely sites for bird strikes since the elevations for these two mountains are similar. These two mountains are about 20 km apart. Observations of bird flights were carried out during the spring (mid-April to mid-May) and fall (September 20 to October) migrating periods of 1993, 1994 and 1995. No dead birds were found. Bird monitoring will continue for another two years.

- Two 10 kW Aerowatt at Igloolik, North West Territory
  Two 10 kW Aerowatt turbines, commissioned in August 1993, are located on the northeast corner of Melville Island (approximate long. 81 W, lat. 69.5 N) and are being monitored for cold weather performance.

  The turbines have been overhauled during November 1995, and put into service. A new blade was fitted on one of the machine.

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity

Pincher Creek, Alberta

- ADECON 1.5 MW
  The turbines were inspected thoroughly and some modifications; e.g., strengthening of the blade root have been carried out. The turbines have been put into service. The machines will be fitted with a new control system that is being designed.
- U.S. WINDPOWER 9 MW
  Kenetech 350 kW turbines have been in operation since January 1, 1994.
- PROJECT CHINOOK 9.9 MW
  Kenetech 350 kW turbines have been in operation since September 1, 1994.

2.2. Machine details

- ADECON: 150 kW VAWT with external support frame constant speed, stall controlled.
- KENETECH: 33 M-VS, 350 kW, variable speed, variable pitch blades. Lattice tower.

2.3. Performance

Performance data for the projects are not available.

2.4. Operational experience

No details are available on the Kenetech and Chinook projects.

3. CONSTRAINTS ON MARKET DEVELOPMENT

The main constraints for the wind energy development in Canada are the surplus installed capacity and the low cost of conventional energy.

3.1. Environmental impact

No bird kill has been reported at the Haeckel Hill installation and the five wind turbines at the Atlantic Wind Test Site, Prince Edward Island.

4. ECONOMICS

4.1. Economics and financing

The budget for the Wind energy R&D (WERD) program of Natural Resources Canada is about CAD 650 K, with a contribution of about CAD 1.5 million from contractors, research institutions and provinces.

4.2. Subsidies

The only subsidy for renewable energies in Canada is under the Class 43 of the Income Tax Act. This clause allows capital write-off at 30% per year on the remaining balance.

5. INDUSTRY

5.1. Manufacturing

- Dutch Industries (water pumps), Regina, Saskatchewan;
- Koenders, (water pumpers) Englefield, Saskatchewan;
- Adecon 150 kW is the only turbine designed and manufactured in Canada. CWT Power International Ltd., Calgary;
- Tacke Windpower Inc, Huron Park, Ontario, is manufacturing 100 sets of blades for TACKE 600 kW wind turbines;
- Some components for the Atlantic Orient 50 kW are also manufactured in Canada.

5.2. Other Industries

- Control system, inverter, tower manufacturers.

6. INTERNATIONAL COLLABORATION

Canada collaborates with TACKE Windtechnik of Germany, Lagerwey of the Netherlands and Atlantic Orient Corporation in Vermont, the United States.

DENMARK

1. GOVERNMENT PROGRAM

1.1. Aims and objectives

In 1973, Denmark's need for primary energy was almost totally covered by imported fuel. Therefore, the first reaction to the oil crisis was to encourage all kinds of oil-saving initiatives, such as the conversion of power stations from oil- to coal-firing and the expansion of the use of waste heat from the condensing process for district heating in urban areas. The next step was to promote research and development of renewable energy systems, wind energy conversion systems being one of them.

Due to production of Danish oil from the North Sea, the prime motivation however, has shifted in the nineties from oil saving to reduction of gaseous emissions from coal-fired power stations. Development of a competitive Danish wind industry has also become an important political issue.

1.2. Strategy

The strategy for development of wind energy systems has been implemented in two ways. Development of large-scale, electricity-producing wind turbines was jointly sponsored by the national government and the Danish electric utilities. At the same time, a number of small- and medium-sized industrial firms initiated a development process of small-scale wind turbines to be used by private individuals who were encouraged to buy and install the machines by a combination of investment and production subsidies.

From the late seventies and up to 1989, the government used both investment and production subsidies as stimulation instruments for the development of small-scale turbines. By 1989, investment subsidies were no longer needed, so today a production subsidy is the only incentive for private installation of wind turbines in Denmark.

In order to establish a steady growth of installed capacity, and a stable home market for the development of the wind turbine industry, an agreement was reached in 1985 between the government and the Danish electric utilities, committing the utilities to install 100 MW in wind power plants over the next five years. This agreement was fully implemented by the end of 1992.

A new 100 MW agreement followed in 1990 to be implemented before the end of 1993. As a first step, a joint government and utility committee, in cooperation with local authorities, recommended a number of suitable sites. In spite of this, the implementation of the 1990 agreement was delayed at least with two years due to local opposition to wind turbines. The last turbines under this agreement should be in place soon.

1.3. Targets

In April 1990, the Danish government published a plan of action concerning supply and consumption: "Energy 2000 - A plan of action for a sustainable development". According to this plan, the government's expectation for the year 2005 is 1,500 MW of installed capacity in Denmark supplying 10% of the annual Danish electricity consumption. This plan of action is presently being revised, but there is no sign of a deviation from the above-stated target.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed capacity

Installation of modern grid-connected wind turbines in Denmark began in 1976, but no significant progress was seen until ten years later. Cumulated data for number and power capacity by the end of 1986 was about 1,250 turbines and 80 MW.

As of December 31, 1995, the total number of grid-connected wind turbines in Denmark, privately as well as utility owned, was 3,893 units with a total electrical output capacity of 630 MW (provisional data).

Data on privately owned turbines were 3,245 units, totalling 425 MW installed power. The corresponding numbers for utility owned machines were 648 turbines, totalling 205 MW of capacity.

The total increase in 1995 was 199 turbines with an output capacity of 98 MW. The utilities installed 133 new turbines with an output capacity of 67 MW. Private individuals installed 66 turbines with a total capacity of 31 MW. In comparison, the total increase in 1994 was 96 turbines with a capacity of 52 MW.

The average capacity of all new installations in 1995 was 492 kW: 504 kW for utility turbines and 470 kW for private machines.

As of December 31, 1995, the maximum continuous net capacity of the Danish power generation system was 10,000 MW (including wind turbines). Installed wind power capacity was 630 MW; i.e., 6.3% of the total national capacity.

All wind turbines installed in Denmark are of Danish origin. About one fourth of installed power is installed in wind power plants, see Tables 1 and 2. The location of these wind power plants is furthermore indicated in Figure 1. As a general rule, a wind power plant or wind farm is defined as a cluster of wind turbines comprising five or more adjacent units.

2.2. Performance of installed plant

Cumulated electricity generation by wind turbines in Denmark during the years

Table 1. Utility wind power plants in Denmark

LOCATION	MANUFACTURER	NUMBER/ CAPACITY	TOTAL MW	SITING YEAR
Masnedø	Vestas/DWT	5 x 750 kW	3,750	1985
Syltholm 1-3	Vestas/DWT	25 x 400 kW	10,000	1988/90
Kyndby	Danwin	21 x 180 kW	3,780	1988
Bavnebanke	Danwin	7 x 225 kW	1,575	1990
Kappel	Vestas/DWT	24 x 400 kW	9,600	1990
Orø	Micon	5 x 200 kW	1,000	1990
Vindeby, offshore	Bonus	11 x 450 Kw	4,950	1991
Nøjsomheds Odde	Vestas	23 x 225 kW	5,175	1992
Avedøre	Bonus	6 x 300 kW	1,800	1992
Jenslev	Vestas	5 x 225 kW	1,125	1993
Utility wind power plants, Elkraft Area: 42,755 MW				

Table 1. Utility wind power plants in Denmark (continued)

LOCATION	MANUFACTURER	NUMBER/ CAPACITY	TOTAL MW	SITING YEAR
Hollandsbjerg	Nordtank	30 x 130 kW		
		2 x 300 kW	4,500	1988
Ryå	Wincon	20 x 99 kW		
		3 x 200 kW	2,580	1988
Nørrekær Enge 1	Nordtank	36 x 130 kW	4,680	1988
Nørrekær Enge 2	Nordtank	42 x 300 kW	12,600	1990
Torrild	Bonus	16 x 150 kW	2,400	1989
Velling Mærsk 1	Vestas	34 x 90 kW		
	Vestas	2 x 200 kW	3,460	1987
Velling Mærsk 2	Vestas	29 x 225 kW	6,525	1990
Vedersø Kær	Vestas	27 x 225 kW	6,075	1990
Dræby Fedsodde	Wind World	12 x 220 kW	2,640	1991
Brøns	Micon	8 x 400 kW	3,200	1992
Fjaldene	Vestas	13 x 500 kW	6,500	1994
Abild	Wind World	5 x 500 kW	2,500	1994
Rejsby Hede	Micon	39 x 600 kW	23,400	1995
Tunø Knob, offshore	Vestas	10 x 500 kW	5,000	1995

Utility wind power plants, Elsam Area: 86.060 MW

1976-1986 was about 300 GWh. By the end of 1995, the total output over all years increased to about 6,707 GWh.

In 1995, the total electricity production by wind turbines was 1,175 GWh, which supplied about 3.7% of the annual Danish electricity consumption. For privately and utility owned turbines, the numbers were respectively 957 GWh and 218 GWh (provisional data).

2.3. Operational experience

The technical availability of new Danish wind turbines is usually higher than 98%. The capacity factor, also for new turbines, is site-dependant, but a typical value is in the range of 0.23-0.27 for sites with roughness class 1. This corresponds to 2,000-2,400 full load hours per year.

On a voluntary basis, operational statistics for about 2,500 wind turbines installed in Denmark are every month reported to the Danish edition of the *Wind Stats Newsletter* published by the *Windpower Monthly News Magazine*. In addition to monthly production records, all operational incidents/accidents are reported subdivided into 15 categories. As far as possible, failure causes are also reported (frequently lightning strikes and loss-of-grid accidents).

Over the years, much work has been done on assessments of power quality. No final rules regarding number of turbines per

Table 2. Private wind power plants in Denmark

LOCATION	MANUFACTURER	NUMBER/ CAPACITY	TOTAL MW	SITING YEAR
Fanø	Vestas	13 x 55 kW	0.715	1983
Tønder	Miscellaneous	9 units	0.405	1984
Oddesund Syd	Bonus	24 x 95 kW	2.280	1985
Thyholm 1	Vestas	10 x 55 kW	0.550	1985
Thyholm 2	Bonus	10 x 55 kW	0.550	1985
Sydvestmors	Vestas	10 x 75 kW	0.750	1985
Ærø	Vestas	11 x 55 kW	0.605	1985
Ebeltoft	Nordtank	16 x 55 kW	0.880	1985
Ranum	Vestas	14 x 75 kW	1.050	1985
Åle	Wind Matic	10 x 75 kW	0.750	1985
Hebeltoft	Vestas	5 x 75 kW	0.375	1985
Tændpibe	Vestas	30 x 75 kW	2.225	1986
Hasle	Blacksmith	9 x 99 kW	0.891	1986
Blåbjerg	Vestas	5 x 75 kW	0.375	1986
Simmendrup	Wind Matic	6 x 75 kW	0.450	1986
St. Darum	Vestas	3 x 75 kW		1986
		2 x 90 kW	0.405	1988
Kornum	Vestas	6 x 90 kW	0.540	1987
Harboøre	Bonus	2 x 95 kW		1987
		3 x 150 kW	0.640	1990
Hollandsbjerg	Nordtank	5 x 65 kW	0.325	1987
Rishøj	Wind Matic	4 x 99 kW		1987
	Bonus	2 x 300 kW	0.996	1987
Rønne	Wind Matic	5 x 99 kW	0.495	1987
Aggersund	Wincon	5 x 99 kW	0.495	1987
Stampemølle	Wind Matic	4 x 99 kW		1987
			0.576	1988
Glejbjerg	Vestas	5 x 90 kW	0.450	1988
Hanstholm	Blacksmith	10 x 90 kW	0.900	1989
Dragør	Tellus	9 x 95 kW	0.855	1989
Holmslands Enge	Vestas	6 x 100 kW	0.600	1989
Hunderup	Bonus	5 x 150 kW	0.750	1990

Table 2. Private wind power plants in Denmark (continued)

LOCATION	MANUFACTURER	NUMBER/ CAPACITY	TOTAL MW	SITING YEAR
Vognkær	Vestas	13 x 225 kW	2.925	1991
Esbjerg	Wincon	5 x 200 kW	1.000	1991
Dybe	Bonus	2 x 150 kW		1990
		3 x 450 kW	1.850	1991
Tulstrup	Wind World	5 x 150 kW	0.750	1991
Krageskov	Wind World	10 x 150 kW	1.500	1991
Avedøre	Bonus	6 x 300 kW	1.800	1992
Landting	Wincon	13 x 200 kW	2.600	1992
Lundby	Wincon	5 x 200 kW	1.000	1992
Kærup Søvig	Wind World	5 x 150 kW	0.750	1992
Gøttrup	Micon	5 x 250 kW	2.225	1993
Ingstrup Sø	Wincon	6 x 200 kW	1.200	1993
Ulfborg	Vestas	5 x 225 kW	1.125	1993

Private windfarms in Denmark: 39.603 MW (five or more units)

feeder line have yet been established. Hopefully, ongoing research will lead to general guidelines.

The problem of generation of "surplus power" by wind turbines has also asked for attention. The Elsam utility has recently announced that the grid as a whole now faces that problem during about 1,000 hours each year.

3. MARKET DEVELOPMENT

3.1. Market stimulation instruments

According to a statutory order of October 1992, the cost of grid connection is split between the wind turbine owners and the electric utilities. The wind turbine owners must bear the costs of the low-voltage connections, while the utilities must carry the costs for reinforcement of the 10-20 kV power lines when improvements are needed.

The accounting rules for electricity produced by wind turbines are described in section 4.1.

3.2. Types and form of ownership

Wind turbines installed in Denmark are owned by utilities, private cooperatives and individuals. Utility projects are managed by utilities on the basis of tenders from manufacturers and subcontractors. Private individuals are normally assisted by consultants or government-financed information offices (Energy Offices).

Utility turbines are operated by utility staff. The strategy for maintenance is decided by the local power companies, which means that the work in some cases is done by utilities and in other cases by manufacturers or private service companies. Private turbines are usually

1. Brøns
2. Velling Mærsk 1
3. Velling Mærsk 2
4. Vedersø Kær
5. Nørrekær Enge 1
6. Nørrekær Enge 2
7. Ryå
8. Hollandsbjerg
9. Torrild
10. Dræby Fed
11. Abild
12. Fjaldene
13. Rejesby Hede
14. Tunø Knob
15. Bavnebanke
16. Orø
17. Kyndby
18. Jenslev
19. Avedøre
20. Vindeby
21. Nøjsomhed
22. Kappel
23. Syltholm

Figure 1. Utility prototypes and wind power plants in Denmark 1995.

operated for an initial period of two years by the manufacturers and the following years maintained by private service companies.

Developers in the United States sense of the word do not operate in Denmark.

3.3. Manufacturing industry

A Danish home market for wind turbines and a wind turbine industry was first established during the years 1979-1981, strongly stimulated by an installation subsidy of 30%, which was gradually reduced during the following years, and finally expired in August 1989 (see section 4.1). Later, the California market (1985 being the most spectacular year) offered excellent export opportunities, which in turn greatly served to stimulate the development of the Danish wind turbine technology.

The number of Danish wind turbine manufacturers has been rather steady for several years. They are in alphabetical order Bonus, Micon, Nordex, Nordtank, Vestas, Wincon and Wind World.

Sometimes wind turbine blades are imported, but as a rule, turbine blades are manufactured in Denmark. One turbine manufacturer (Vestas) is self-supplying; all other manufacturers have most of their blades supplied by LM Glasfiber A/S. This company also exports turbine blades worldwide.

As of December 1995, about 9,000 people were employed by the Danish wind turbine industry: 1,760 by manufacturers and 7,240 by subcontractors, consultants, and service companies.

The number and capacity of domestic installations was reported in section 2.1. Cumulated figures for number of turbines and capacity sold abroad are approximately 12,425 turbines with a capacity of about 1,950 MW. Total value of this production volume cumulates to about DKK 13,350 million, and, assuming 30% of this amount being the value of

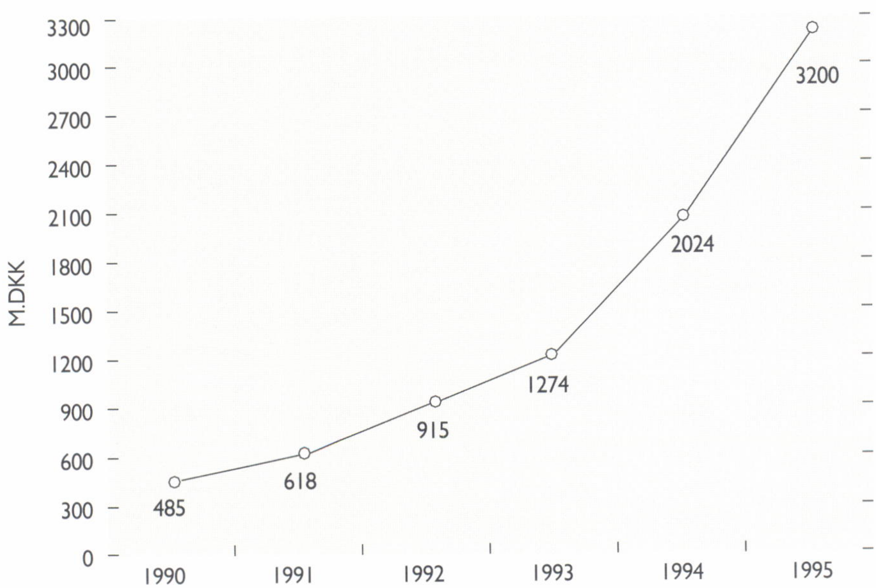


Figure 2. Value of Danish wind turbine exports.

imported components (gearboxes, generators, etc.), the net value is about DKK 9,250 million.

The export in 1995 accounted for about 1,345 wind turbines (complete units) with a total capacity of 480 MW and a total value of DKK 3,200 million. This represents an increase of 50% in relation to 1994. The same pattern was seen for the previous years (see Figure 2). The turbines are sold to about 45 countries all over the world.

As mentioned earlier, the volume of export is increasing year by year. In order to minimize transportation costs and stimulate co-production in the recipient countries, most Danish manufacturers have established local subsidiaries. This way, advantage is taken of local expertise and labor.

The latest development trend shows that the well-known "Danish design" is unchanged: three-bladed, upwind rotors, active yawing and induction generators connected to the low-voltage level at 380V. Stall regulation and pitch control are used for power limitation.

The power range is rapidly expanding. Machines with ratings of 600 kW are now commercially available, and at present, three Danish manufacturers (Bonus, Nordtank and Vestas) have designed and installed one 50 m/750 kW and two 60 m/1.5 MW prototype machines at Tjæreborg in Jutland. These prototypes were ordered by the Elsam utility in order to promote the technological development of wind turbines. They are co-funded by the European Union, DG XII and XVII.

The Test Station for Wind Turbines at Risø and the Department of Fluid Mechanics at the Technical University of Denmark have been the main consultants for the wind power industry, but other university departments and technological institutions could also be mentioned.

4. ECONOMICS

4.1. Tariffs and buy-back prices

The development of private, small-scale wind turbines is no longer promoted by public installation subsidies. Reasonable buy-back rates and exemption from electricity taxation is now the main economic incentive.

The average consumer price for a Danish low-voltage customer consuming about 3,000 kWh per year is about DKK 0.94 per kWh, including taxation and VAT (generation: 0.28, distribution: 0.10, electricity tax: 0.27, CO_2 tax: 0.10, VAT: 0.19).

The present accounting rules regulated by statutory orders issued by the Ministry of Energy can be summarized as follows: on November 1, 1992, new accounting rules for wind generated electricity came into force. On average, the electric utilities now pay private wind turbine owners about DKK 0.58 per kWh delivered to the grid. This amount is calculated as follows: 85% of pre-tax selling price to private consumers, DKK 0.31, plus a generation credit of DKK 0.27. This credit is considered to be partial reimbursement of the carbon dioxide and general electricity taxes paid by the wind turbine owners as private consumers.

The subsidy for 1995 for private production was DKK 0.27 per kWh, with a total of DKK 258 million paid out.

The utilities receive a production subsidy of DKK 0.10 per kWh of electricity generated in utility wind power plants as reimbursement of the general carbon dioxide tax. For utility production, the level of subsidy for 1995 was DKK 22 million paid out.

4.2. Development and generation costs

Recent cost data are available from the ELSAM utility operating in Jutland. The total installation costs for 500-600 kW wind turbines installed in wind power plants are currently in the range of DKK 6,000-7,000 per kW. Assuming a depreciation period of 20 years, a real interest rate of 7%, and O&M costs of 2.5% per year of installed cost, the total production cost is in the range of DKK 0.30-0.40 per kWh, depending on the wind regime at the sites.

The ex-factory cost of machines is by experience 65-70% of the total cost, including all the site costs.

4.3. Invested capital and value of generated power

It is difficult to calculate the total invested capital over the years exactly, but government subsidy figures give an indication. In the ten year period 1979-1989, cumulated installation subsidies for about 2,550 private wind turbines were DKK 275 million. As previously mentioned, the installation subsidy expired in 1989.

Invested capital in Denmark for 1995, assuming installation of 98 MW and an average cost of DKK 6,500 per kW, amounts to DKK 637 million. Assuming an average installation cost for all years of DKK 9,750 per kW, the total cost of the installed 630 MW is calculated at DKK 6,140 million.

The Danish Energy Agency has published a report in which the value of wind-generated electricity is related to cumulated savings in a conventional electricity generating system. Three cost items were taken into account: fuel savings (coal), transmission losses and capacity credit. Including costs of flue gas purification, the total savings are about DKK 0.30 per kWh.

Adding the CO_2 tax, DKK 0.10, to this figure, the value of electricity produced by utility turbines amounts to DKK 0.40 multiplied by the power generation in 1995. That is DKK 87 million.

The value of private wind-generated electricity is DKK 0.58 multiplied by the power generation in 1995. That is DKK 555 million.

4.4. Financing and warranties

Over the years, financing of new wind turbine projects at the commercial stage has not raised major problems. Utility wind power plants and clusters of wind turbines are financed in the same way as conventional power stations and transmission lines, and the costs incurred are paid by the consumers and included in the regular electricity bill.

Private wind turbines are usually owned by cooperatives, and currently the most common financing is a bank loan covering up to 100% of the total costs of the project. The security for such a bank loan is an agreement which requires that all income from electricity generation be paid directly to the bank. The depreciation period is 10-15 years, and the annual interest rate is currently about 10%.

During the depreciation period, the investors will receive a tax credit only if they have procured financing by private loans. Within certain limits, income from electricity generation by wind turbines is exempted from taxation.

For the first two years, new wind turbines are serviced by the manufacturers free of charge. Then various service agreements are entered. In addition, an all risk insurance warranty is mandatory for the first five years covering machine break-down, electricity production according to power curve and wind regime, and third-party liability. After the initial five years, the insurance warranty only covers machine break-down and third party liability.

5. MARKET INFLUENCES

5.1. Constraints

The subject is dealt with in the following two sections.

5.2. Institutional factors

Planning policy

All Danish municipalities have been requested by the Ministry of Environment to initiate planning for siting of a reasonable number of turbines within their districts. This planning material was supposed to be available by July 1, 1995, but several municipalities failed to meet this requirement. They now have been asked to finish the planning work without further delay.

However, this does not mean that planning permissions are issued on this basis. A normal planning procedure, including public hearings, is to follow. Experience shows that this tends to reduce the number of acceptable sites. For more details, see Reference 1.

Certification

In May 1991, a new approval and certification system for Danish wind turbines was introduced as the result of two years of preparation by the Danish Energy Agency, the Test Station for Wind Turbines at Risø, the Danish manufacturers, the Danish Wind Power Association and various insurance and certification companies. The previous system of type approval consisted mainly of a general design review and a review of the load and strength calculations. The general purpose of the new approval and certification system is to improve the quality level of Danish wind turbines regarding efficiency and lifetime.

The new approval system for wind turbines specifies requirements for documentation of all design criteria, such as load cases and loads, fatigue evaluation, safety levels, power curves, noise emission, quality procedure for manufacturing, transporting, installation and subsequent servicing of the wind turbines. The manufacturers must also have a fully introduced and certified quality assurance system, usually according to ISO 9001 and 9002.

All wind turbines to be installed in Denmark after July 1, 1992, must be approved and certified according to the new system. Furthermore, it is a condition for obtaining export guarantees from the Danish Wind Turbines Guarantee A/S that wind turbines must be approved and certified according to the new system.

The new approval and certification system is managed by the Danish Energy Agency assisted by the certification secretariat at Risø. Lately, Norske Veritas and Germanischer Lloyds have also been authorized to certify wind turbines in Denmark.

In case of major accidents or incidents, full information must be given to the certification secretariat at Risø.

Safety aspects

Implementation of the new certification system will also serve to fulfil the safety requirements for wind turbines. The intention is that wind turbines must be designed and manufactured in such a way that they are inherently safe. Therefore, safety distances are not siting criteria.

5.3. Environmental impact

Visual intrusion

The public attitude in Denmark is, in general, in favor of wind energy but the "not in my backyard" syndrome is becoming more widespread. This means that the planning procedure for both turbines and wind power plants is more complicated than in earlier days. Visualization studies are now normally required by authorities as part of planning applications.

Manufacturers are trying to take the public attitude into account by reducing the wind turbines' noise level and improving the aesthetic design of the turbines.

Acoustic noise emission

In 1991, a statutory order was issued by the Ministry of the Environment stating that the owner of wind turbines shall prove to the county council that the noise level from the wind turbines will not exceed preset limits. This proof shall be given prior to the installation of one or more wind turbines and shall be based on a prediction of the noise level according to an authorized, simple propagation model. A simple method for calculation of the noise emission (source strength) of the chosen wind turbine type is also specified in the order. If the county council has not objected to the development project within four weeks, construction can start, provided that all other permissions have been granted.

Noise from wind turbines must not exceed 45 dB(A) outdoors at the nearest habitation in rural areas and 40 dB(A) in residential areas and other noise-sensitive areas. Tonal noise (pure tone noise) from gearboxes is often a source of annoyance, so 5 dB(A) is added to the measured broadband noise, if tonal noise is clearly audible at the location where the noise level is being measured.

Impact on bird life

The impact of wind turbines on bird life has been studied in relation to both the Nibe turbines (1984) and the Tjæreborg wind turbine (1986-1990). In the first study, it was concluded that no birds were found whose death was attributed to collision with the turbines. In the second study, the death of seven birds could, with some certainty, be said to have been caused by collision with either the turbine itself or one of the two meteorological masts. Radar observations at this site during night hours showed that in general, birds are able to detect and avoid the wind turbine (see Reference 2).

The general conclusion from the latest study is that, compared to other human activities such as farming and traffic, a wind turbine in a bird sanctuary does not have an especially significant impact on bird life, though it does affect it. The birds in question - not birds of prey, but all kinds of waterfowls, waders, seagulls, etc. - just seem to move away from the turbine for breeding, staging, and foraging. There is some evidence, however, to indicate that when construction and commissioning are over, birds get familiar with wind turbines and tend to move back.

The latest initiative in this area is implementation of a comprehensive study of bird life around an offshore wind farm installed at Tunø Knob, see section 6.4.

Ecology

In some parts of the world, installation of wind turbines has a damaging effect on ground conditions and plantations caused by earth work and traffic. This is not so in Denmark. The sites are normally on farmland, and after installation and commissioning, the areas are brought back to initial conditions as far as possible.

6. GOVERNMENT SPONSORED R,D&D PROGRAM

6.1. Funding

Total government funding of R&D work during the years 1976-1995 was about DKK 330 million, and for demonstration projects, the funding was about DKK 150 million.

The total amount being spent by the Danish government on R&D for 1995 was DKK 40 million. Of this amount, DKK 12 million was used as support for generic research (60% of total cost). Approximately DKK 18 million was spent on support for industrial development and demonstration (with support ranging from 40%-100% of the total cost). DKK 10 million went to support of the test station at Risø and miscellaneous minor projects.

6.2. Priorities

Key areas of research and development are rotor-aerodynamics, design basis for wind turbines, structural loads, safety systems, reliability analysis, forecasting of power production, acoustic noise emission, power quality, and variable speed operation. Recently, interest is also focused on new generator concepts; i.e., gearless machines.

6.3. New developments

The three-bladed Danish wind turbine concept is still predominant, but in view of the fact that the two-bladed concept is in widespread use all over the world, the test station at Risø has, during recent years, made experiments with a small two-bladed machine. A final conclusion will not be drawn until planned work on rotor optimization is finished. It is a very flexible, downwind test machine with free yawing.

The status for the development of MW-sized machines was briefly mentioned in section 3.3., and the status for the older large-scale projects at Nibe, Masnedø and Tjæreborg has been reported regularly in the *Wind Energy Newsletter* published by the IEA.

The new 50 m diameter, 1 MW stall regulated turbine at Avedøre, south of Copenhagen was inaugurated in September 1994 and is performing well. It is still operated in the stall mode, and an additional experiment with vortex generators on the blades has increased the power production at wind speeds below rated power.

Status for the three new large-scale prototypes at the Tjæreborg site is as follows: the Bonus machine (50 m/750 kW) installed in 1994 suffered from an overspeed accident in October 1995 causing serious damage to the rotor. The failure cause is still being investigated. The Nordtank machine (60 m/1.5 MW) was installed in September 1995, and commissioning is progressing well. The Vestas machine (60 m/1.5 MW) is behind schedule, but installation is expected in the beginning of 1996.

6.4. Offshore siting

The first Danish offshore wind power plant was commissioned in 1991. The site is at Vindeby, northwest of Lolland in the Baltic Sea. The wind power plant consists of 11 turbines in two rows. Each turbine is rated at 450 kW, and hub height and rotor diameter are respectively 37.5 and 35 m. The total cost of the project, including a two-year measurement program, was about DKK 80 million. The cost of energy is about DKK 0.60. The reported availability exceeds 96%.

A second Danish offshore wind power plant has been installed by ELSAM in 1995. The selected site is at Tunø Knob in the area between Jutland and Samsø, see Figure 1. Installed capacity is 5 MW (10 Vestas, V39 turbines). The total budget was DKK 87 million, but actual cost seems to be lower. Consequently, the projected cost of energy, about DKK 0.67 per kWh, should also be at a lower level, about DKK 0.50 kWh. Commissioning is progressing well.

6.5. International collaboration

Over the years, Danish companies and institutions have been involved in a great number of projects funded by the European Union (JOULE and THERMIE programs). An updated list of projects and funding does not exist.

7. REFERENCES

(1) Ministry of the Environment and Energy, Spatial Planning Department: "Municipal planning for wind energy in Denmark - examples and experience". Published in 1995.

(2) Danish National Environmental Research Institute, Publication no. 47: "Impact of a 60 m/2 MW wind turbine on birds. Avian responses to the implementation of the Tjæreborg wind turbine at the Danish Wadden Sea". Published 1991.

FINLAND

1. NATIONAL PROGRAMS

1.1. Research and development

NEMO2 (Advanced energy systems and technologies national research program) is one of the eight major national energy research programs in Finland. It is mainly funded by the Ministry of Trade and Industry and, since 1995, by the Technology Development Centre. The total budget of the NEMO2 program is about FIM 120 million (equivalent to about ECU 20 million) in 1993-1998. The share of public funding of the total budget is about 50%. The rest is financed by companies, research institutes and universities. About 1/3 of the total funding is allocated to wind energy.

The main areas in the NEMO2 program include wind energy, solar energy and other technologies such as hydrogen technology. The objectives of the NEMO2 program are to:

- increase the utilization of wind and solar energy in Finland;
- support technology development in industries;
- build up a national base of competitive technology and know-how.

Wind energy is one of the main areas of the NEMO2 program. The present activities can be divided into the main areas of wind resources, arctic wind technology, integration studies and component development.

In 1995, public funding of all energy research was kept on an equal level as in 1994 in nominal terms. Direct research funding for universities and research institutes is expected to be cut due to the national budget deficit. Financing will be shifted to industry oriented projects.

2. NATIONAL STATISTICS ON WIND POWER

The locations of the present operational wind power plants are shown in Figure 1. Four new units, each 500 kW, were installed in 1995. The old 300 kW turbine from Danish Wind Technology on the southern coast was dismantled after almost nine years of operation. The tower and the machine bed of the turbine have been used as a base for an experimental turbine with hydraulic drive.

Most of the present turbines are now located in the northern part of the Gulf of Bothnia. In that area, the turbines are owned and operated by local distribution utilities or companies partially owned by them.

All the turbines are of Danish origin. The types and machine details are shown in Table 1.

The production statistics (Figure 2) are collected by VTT Energy. The total production in 1995 amounted to 10,770 MWh giving a mean capacity factor of about 23% for all the turbines on average.

In November and December, many turbines also in coastal sites endured problems related to cold weather and icing. Some turbines are located in harbor areas and were shut down as a safety precaution. The research turbine at Pyhätunturi had component failures in 1995.

3. ECONOMICS

In 1993, the Ministry of Trade and Industry launched a wind energy promotion program. The goals of the program are:

- to have installed 100 MW of wind power in Finland in 2005;
- to support the product development by domestic industry.

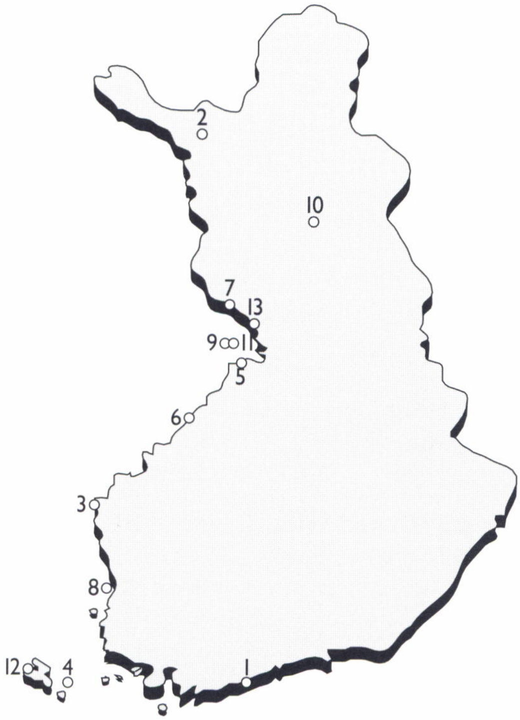


Figure 1. Locations of operational wind turbines in Finland (see Table 1 for key).

These goals are to be achieved by continuing the R&D efforts (NEMO2), by granting investment subsidies (30%-50% of total costs), by adopting land use planning options, and by looking for agreements between government and utilities, and by information dissemination.

The amount of investment subsidy to a project is depending on the novelty of the project. Projects including new developments and thus having a greater risk can receive a larger subsidy. The Ministry of Environment has set up a working group to give guidelines for land use planning and building permissions. In some of the realized projects, some delay has been caused by local authorities who have been faced with wind power plant projects without enough information about the nature of wind power. The wind energy associations play an important role in information dissemination.

4. CONSTRAINTS ON MARKET DEVELOPMENT

Despite the 100 MW program, the number of new installations in 1995 was limited to four with a total capacity of 2 MW. This means that the goal of 100 MW in 2005 will be hard to reach. The number of new projects in the planning stage is increasing, but the final planning permission is hard to receive, especially in the southern archipelago.

During the first half of the 1990's, wind technology has become more familiar to users in Finland. The first 6,7 MW is now in use. Planning is going on in many areas to build new turbines. In many of those projects 500 kW turbines are preferred for economic reasons.

The existence of a component industry and its need for a home market has also been recognized. This means that the 100 MW program launched by the Ministry of Trade and Industry can be seen partly also as a test bed for new domestic products. The cold and icing climate applications are a specialty, which could offer a small market niche in the future.

Electricity deregulation took place in the summer of 1995. It meant some uncertainty for future wind development. The market for the distribution utilities is changing making them more reluctant to invest in new technology. Some private investors, on the other hand, could benefit from the new market situation.

The Ministry of Environment set up a working group in late 1994 in order to propose guidelines for the location of wind turbines in the country. Many projects that are in the planning stage have had considerable difficulties in obtaining building permissions. A general guideline might help local authorities in deciding on the requirements for each project.

Table 1. The operational wind turbines in Finland

PROJECT	OPERATOR (TYPE)	MANUFACTURER	MACHINE P (kW)/D(m)/H(m)
1 Kopparnäs 1 x 300 kW	Utility	Danish Wind Technology	300/31/31
2 Enonetkiö 1 x 65 kW	Utility	Nordtank	65/20/26
3 Korsnäs 4 x 200 kW	Private company	Nordtank	200/25/32
4 Sottunga 1 x 225 kW	Local technology centre	Vestas	225/25/31
5 Siikajoki 2 x 300 kW	Distribution utility	Nordtank	300/31/31
6 Kalajoki 2 x 300 kW	Distribution utility	Nordtank	300/31/31
7 Kemi 3 x 300 kW	Private company	Nordtank	300/31/35
8 Pori 1 x 300 kW	Distribution utility	Nordtank	300/31/31
9 Hailuoto 2 x 300 kW	Distribution utility	Nordtank	300/31/31
10 Pyhätunturi 1 x 220 kW	Research centre and utility	Wind World	220/25/31
11 Hailuoto 2 x 500 kW	Distribution utility	Nordtank	500/37/75 (west of island) 500/37/41 (east of island)
12 Eckerö 1 x 500 kW	Cooperative	Vestas	500/
13 Kuivaniemi 1 x 500 kW	Private company	Nordtank	500/37/35

5. INDUSTRY

There is no manufacturing of wind turbines in Finland at present. Some companies are, however, component suppliers to foreign manufacturers. Valmet Oy and Kumera Oy supply gearboxes and gearwheels, ABB Strömberg makes generators and Ahlström Oy and Neste Chemicals supply raw materials to blade manufacturers. In most of the Finnish projects (Figure 1) also the tower has been supplied by Finnish industry.

A market study in NEMO2 showed that the Finnish industry has kept its share in the wind power business as component supplier. Turnover has grown steadily and is now around FIM 200 million per year.

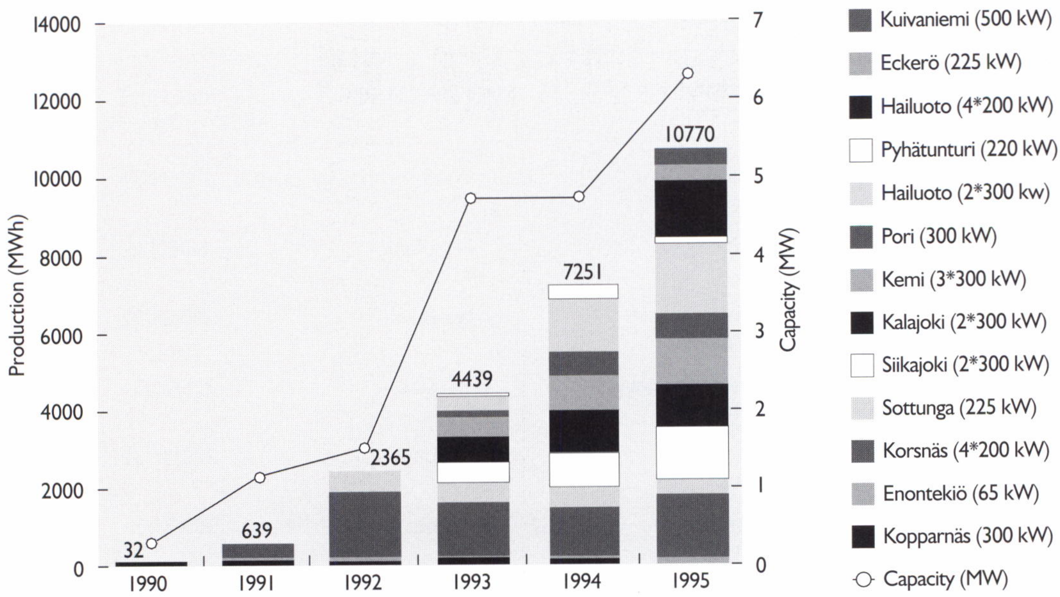


Figure 2. Wind energy production (columns) and installed wind power capacity (line) in Finland since 1990.

Wind technology is presently developing considerably, and within the R&D program more emphasis has also been placed on the needs of the component industry. Some new developments, including a direct-drive generator, are under development in cooperation between the research program and industry. As a specialty, a small development company Kone-Sampo Oy together with the national power company Imatran Voima has built a prototype wind turbine using hydraulic variable speed drive.

6. INTERNATIONAL COLLABORATION

The international cooperation has a growing role as a part of the national R&D program. Finland is now participating in some EU/JOULE-projects and in the IEA.

In 1995, Finland became a member of the European Union. As a result of active participation by submitting proposals to the JOULE/THERMIE program, new projects with Finnish coordination and partnerships started late 1995. Two projects; i.e., wind energy production in cold climates (WECO) and a feasibility study of wind power in the Kola Peninsula, Russia (KOLA WIND), are coordinated by Finland.

In 1993, Finland, represented by VTT Energy, joined the IEA Implementing Agreement for Cooperation in the R&D of wind technology. The Finnish participation is so far limited to Task XI - Base Technology Information Exchange.

Figure 3. The first 500 kW turbine in Finland was installed in April 1995 in Hailuoto close to two 300 kW turbines.

GERMANY

1. NATIONAL PROGRAMS

Since 1974, the Federal Ministry for Education, Science, Research and Technology, BMBF, has promoted wind energy in Germany by providing approximately DEM 370 million for R&D and demonstrations. The framework has been a series of "Programs for energy research and energy technologies" (currently the Third Program) of the German Federal government. The goal of this program of support is to enable wind energy, being a renewable energy source with reasonable commercial prospects, to render a long-term contribution to our energy supply, to reduce CO_2 emissions, and to expand the energy mix. In order to be able to exploit these potential renewable energy sources at acceptable costs in the long term, field tests of corresponding plants are currently promoted, and R&D continues to be supported by BMBF (Reference 1). With its potential and current economic efficiency, wind energy in Germany is among the most promising renewable energy sources, after hydroelectric power and waste combustion. The real potential anticipated for wind energy utilization for the 2000-2005 time frame is between 0.2% and 0.4% of the total power requirements of the Federal Republic of Germany. Despite their quite favorable development and governmental funding, renewable energies can altogether make only a relatively modest contribution to power generation in the future.

1.1. Research and development

After a first phase of basic and applied research and the testing of first generation prototypes, initial demonstration programs were launched to test technical reliability on a larger scale. A large variety of wind energy converter (WEC) types, rated between 5 and 300 kW, were installed in seven major demonstration plants, including four wind power plants. In the late eighties a total of 214 WECs was promoted, having a total rated power of 14.5 MW. These demonstration projects have established an adequate basis for the "250 MW Wind" program offered since 1989 (see Section 1.2.).

Today, BMBF's support of R&D reflects the trend towards WECs of the MW-class. It should be pointed out that all studies indicate that the existing wind potential in a densely populated country such as Germany can be best exploited by large WECs. Experts on the advisory committee (the Ad Hoc Committee on Large Wind Energy Converters) emphasized that the electricity production costs of future WECs in the MW range may already be comparable to those of current commercial WECs on a medium term basis, although considerable expenditure on R&D and testing must be involved.

The development of MW-scale units started in the second half of the 1980's, and has already led to the second generation of large WECS (see Figure 1). They comprise the 1.2 MW WKA-60 (three blades, 60 m rotor diameter, on the island of Heligoland), the WKA 60-II of the same size at Kaiser-Wilhelm-Koog, the three Monopteros machines (640 kW, 50 m, one blade) in Wilhelmshaven, and the HSW 750, erected in 1993 (see Figure 2). After a second severe lightning stroke on one of the rotor blades, the owner of the Heligoland turbine decided to dismantle this turbine.

Figure 1. German prototypes with a rated power of more than 400 kW (Status 12/95).

Table 1. German prototypes with a rated power of more than 400 kW*

POWER	TYPE	SITE	PROJECT BY	REALIZATION
3 à 640 kW	MON 50	Wilhelmshaven	GEW	Summer 1989
1.2 MW	WKA 60	Heligoland	Town Helig.	Autumn 1990 Dismantled 1995/96
1.2 MW	AWEC 60	Cabo Villano (Spain)	U. Fenosa	Summer 1989
3 MW	AEOLUS II	Wilhemshaven	Preussen Elektra Windkraft	Spring 1993
1.2 MW	WKA 60 II	Kaiser Wilhelm-Koog	"	Autumn 1991
750 kW	HSW 750	Kaiser Wilhelm-Koog	Husumer Schiffswerft	Autumn 1991
400 kW	E-36	Hamswehrum	EWE	Spring 1992
500 kW	TW 500	Borkum	St. Bork./Mün.	Summer 1992
500 kW	E-40/PV	Geesthacht	HEW	1994
500 kW	V-12	Wilhelmshaven	DEWI	1994
1.5 MW	E-66	Aurich	Enercon	December 1995
1.5 MW	TW1500	Emden	Tacke Windt.	April 1996
1.2 MW	A1200	Brunsbüttel	Autoflug Energie	Spring 1996
1.5 MW	TW1500	inland	RWE AG	1996/97

* Plus two 800 kW prototypes funded after 1994 by the European Union in eastern Germany (BOEHM, NORDEX), and a German/French/British 1.5 MW-class type WEGA turbine (Tacke Windtechnik) in Dunkerque, funded also by the European Union.

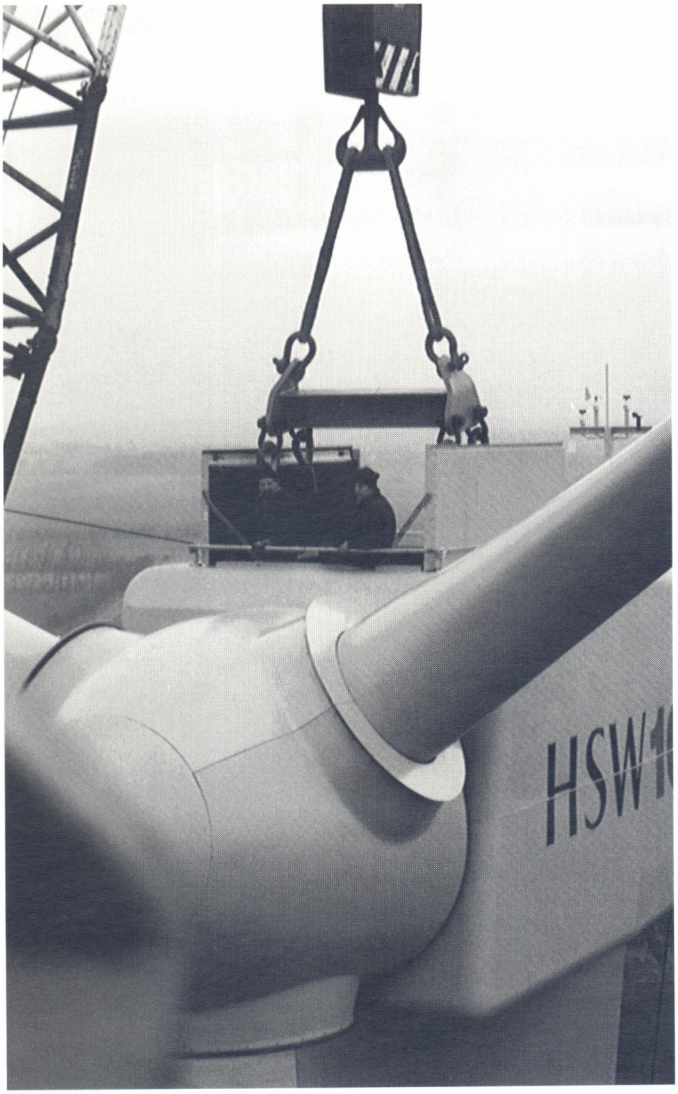


Figure 2. HSW 1000, hub height 54 m, rotor diameter 55 m; 1,000 kW version of the 750 prototype. Four of these machines form the Süd-West-Windpark near Bosbüll. One of these is funded by the "250 MW Wind" program, the three others by an investment grant of the Federal State of Schleswig-Holstein.

This second generation of large-scale (LS) WECs includes AEOLUS II with 3 MW rated power, put into operation by Preussen Elektra Windkraft Niedersachsen GmbH in December 1993 (see Figure 3). By December 20, 1995, the machine had produced a total of 11,077 MWh corresponding to around 13,000 operating hours. The availability was 93% (experimental standstill not considered). A second turbine of this type has been installed by Vattenfall in Gotland in cooperation between Swedish and German manufacturers. The measurement and evaluation program at the two AEOLUS turbines is to serve for a decision on future turbines of this type. The decision for the continuation of the Swedish/German cooperation with "AEOLUS III" is expected in 1996. Support of this project by public and utility funds will depend on a clear perspective of the two manufacturers that this type will be competitive with comparable machines.

Several German wind turbine manufacturers started constructing MW-size WECs using a different approach in

Figure 3. AEOLUS II (left) near Wilhelmshaven, seen from the nacelle of one of the three 640 kW MONOPTEROS single-bladed WECs.

order to obtain the economy of commercial medium-sized WECs (see the table in the lower part of Figure 1). This goal was to be achieved by incorporating innovative concepts and components of commercial turbines. These LS prototypes are included in a group of R&D projects by BMBF in 1995/1996 (see Table 1, Reference 2 and Figure 4).

Advanced smaller WECs (200 kW/300 kW) were developed by the wind industry without public support. Furthermore, a 600 kW machine with a direct driven generator with permanent magnet exitation was developed by Heidelberg Motor/Neptun Industrie without support.

Expert meetings with the topics "Lightning protection of WECs" and "Noise reduction of WECs" (see Reference 15) identified further research and development projects.

1.2. Demonstration

Interest is currently focused on the "250 MW Wind" program. The goal of the "250 MW Wind" program is to carry out a broad test of the application of wind energy on an industrial scale, which extends over several years. An accompanying scientific measurement and evaluation program (WMEP) functions to collect various statistical data and to prepare technical improvements (Reference 3).

As an incentive for their participation in the "250 MW Wind" program, operators of the wind turbine/wind power plant receive grants for the successful operation of their turbines (see Section 4.2).

By December 31, 1995, the number of operating turbines in the "250 MW Wind" program was calculated by ISET in the WMEP at 1,452 which corresponds to a rated power of 303 MW (see Figure 5). Further 54 MW of rated power are

Table 1. Wind energy R&D projects, 1994 ff

SUBJECT	PARTICIPANTS	PERIOD	COSTS [DEM]	BMBF (%)
Wind powered desalination plant, Rügen	Rügenwasser GmbH	06.93-05.97	3,891.5	70
Aeolus II, 3MW wind program	Preussen Elektra Windkraft NDS	09.88-12.94	21,375.5	20.51
Partial supply of the hydro pumped storage plant at Geesthacht with wind and PV	Hamburger Electricitätswerke	02.89-05.96	10,034.6	40
Construction and erection of HSW 750	Husumer Schiffswerft	04.89-06.94	7,084.8	20.40
Modelling performance of a wind farm	Universität Oldenburg	09.91-12.94	0,312.0	50.0
Evaluation of energy economics of Aeolus II	Preussen Elektra Windkraft NDS	10.91-12.96	0,577.4	50.0
Evaluation of energy economics of WKA 60	Preussen Elektra Windkraft SH	10.94-12.95	0,556.7	50.0
An analysis of the operating and grid behaviour of various wind turbine concepts	Windenergiepark Westküste	01.93-09.95	0,490.0	50.0
Processing of wind measurement data up to 150 m for a planned archive of wind data	Deutscher Wetterdienst	04.92-01.98	0,607.0	100.0
Construction and installation of a quiet and economic 1,5 MW WEC	Enercon	01.93-04.96	7,745.0	14.20
Measuring Programme HSW 70	Husumer Schiffswerft	06.93-12.95	0,604.7	50.0
Special wind data and programs for complex terrain	Deutscher Wetterdienst	07.93-06.97	1,641.9	100.0
Phase II of 250 MW wind measurement and evaluation programme WMEP	ISET	07.92-06.96	13,386.9	100.0
Operation of MW scale wind turbines	Germanischer Lloyd	04.92-12.94	0,560.0	50.0
Early recognition of turbine failure	ISET	01.94-12.96	1,431.8	50.0
Aeolus II development for cutting costs	MBB-Förder-und Hebesysteme	02.94-12.95	1,373.4	50.0

Table 1. Wind energy R&D projects, 1994 ff (continued)

SUBJECT	PARTICIPANTS	PERIOD	COSTS [DEM]	BMBF (%)
Promotion and further development of wind turbines in Germany and Europe	Fördergesellschaft Windenergie	03.94-02.95	0,129.9	50.0
Development and construction of a 1,2 MW two-bladed turbine	Autoflug Energietechnik	04.94-03.97	6,047.7	23.7
Installation and measurement programme Ventis V 12	Deutsche Windenergie Institut DEWI	04.94-03.99	1,085.0	36.9
Development and construction TW 1500 with 1 MW rated power	Tacke-Windtechnik	06.94-09.96	5,813.5	25.0
Special grid measurements and simulation	NATI GmbH	09.94-08.95	0,374.2	63.3
Detailed Investigation WT Flicker	Windtest Kaiser-Wilhelm-Koog	01.95-12.96	0,416.8	50.0
Technical and economical investigations of offshore WECs	Siemens AG	01.95-06.95	0,266.1	50.0
	Vulkan Engineering GmbH	01.95-08.95	0,730.0	50.0
Fatigue Lods WECs	VDMA	07.95-6.97	0,443.6	50.0
MW WECs inland	RWE	06.95-12.97	4,893.6	20.43
Control LS WECs	ISET	07.95-06.98	1,192.9	40
Noise reduction WEGs	Fördergesellschaft Windenergie	12.95-11.96	0,283.2	100.0

approved but the corresponding 131 machines are not yet erected. The final closing date for proposals within the "250 MW Wind" program was December 31, 1995. Around 200 proposals (mainly LS WECs) were submitted by this date to the Research Center Jülich which is managing this program. Still available are around 30 MW of rated power which will be granted in the near future. This means that in 1996/1997 the "250 MW Wind" program will be completely in operation with a total of approved 380 MW rated power corresponding to approximately 1,700 WECs. Power of the program refers to the turbine's power at 10 m/s wind speed, so that "250 MW" equals to the mentioned 380 MW rated power. The program will end around the year 2008 (see Section 4.2). It is expected that the total support will exceed DEM 320 million. The costs of the measuring program are not included in this sum and could reach an additional DEM 60-70 million. A first resume of the "250 MW Wind" program was published in November 1995 (see Reference 4).

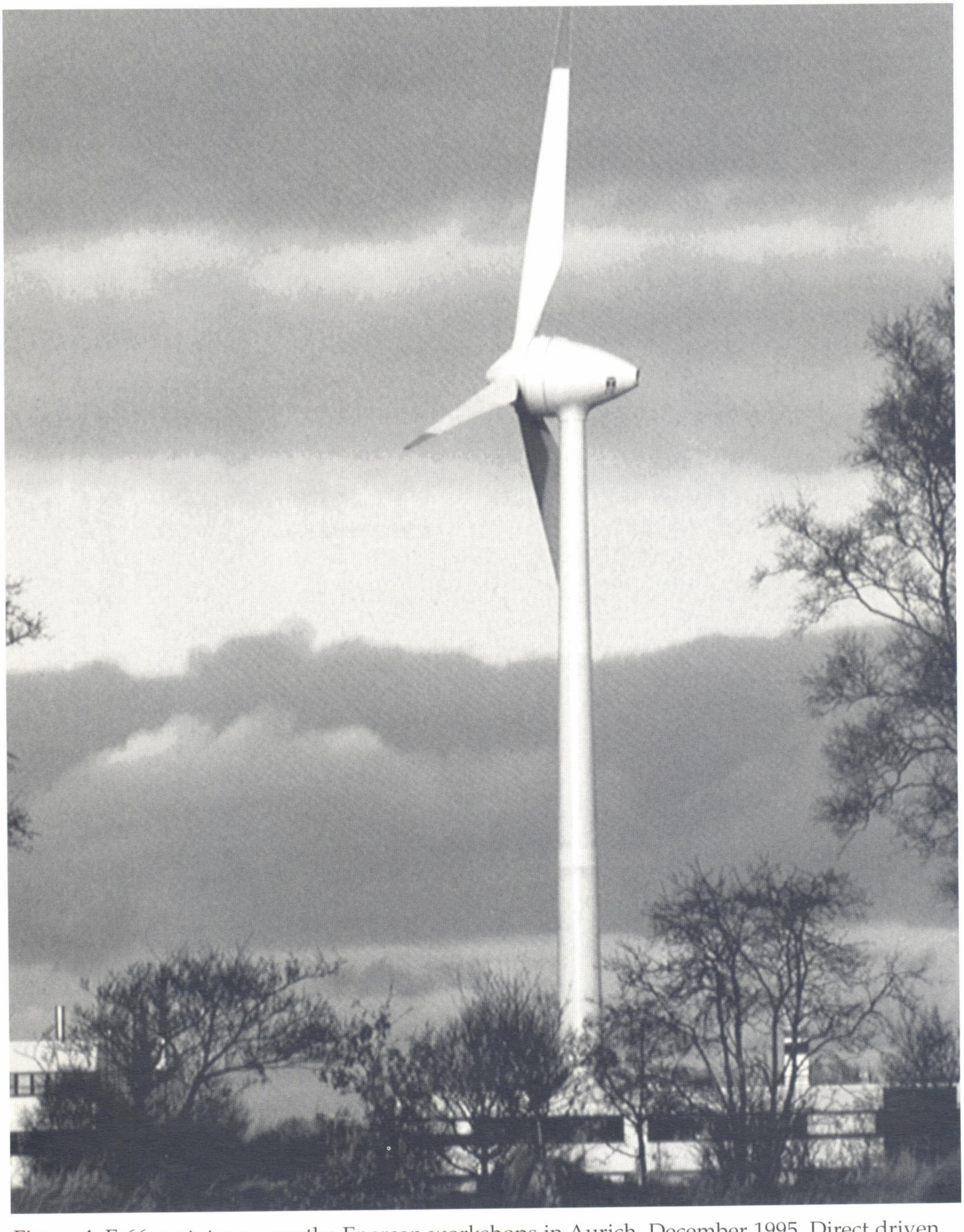


Figure 4. E-66 prototype near the Enercon workshops in Aurich, December 1995. Direct driven generator. Rated power 1,500 kW. Rotor diameter 66 m. Hub height 60 m.

A few general results of the "250 MW Wind" program should be mentioned. Figure 6 shows the distribution of the projects and the power for the different operators. At the beginning of the program, more than 90% of the applications came from the coastal states having wind speeds between 5 and 7 m/s at the 10 m level. Later more and more applications were received from central regions with less favorable wind conditions. The regional distribution of the total wind power for several power classes are shown in Figure 7. The analysis shows furthermore a tendency towards larger WECs. The average rated power of all WECs was about 160 kW around 1990 and has risen to about 210 kW today. As already mentioned, applications by the end of 1995 mainly concern MW-size machines. The average turbine size for the machines erected in 1995 was 456 kW.

A further demonstration program was offered in 1995 by the Federal Ministry of Economic Affairs for wind turbines with capacities of between 450 kW and 1 MW, at sites with wind speeds not exceeding 4.5 m/s. Depending on the size and number of turbines, the maximum investment support ranges between DEM 150.000 and DEM 450.000. The program's support for WECs is limited as wind power is only a part of this four year support program (a total of DEM 100 million) for different types of renewable energies.

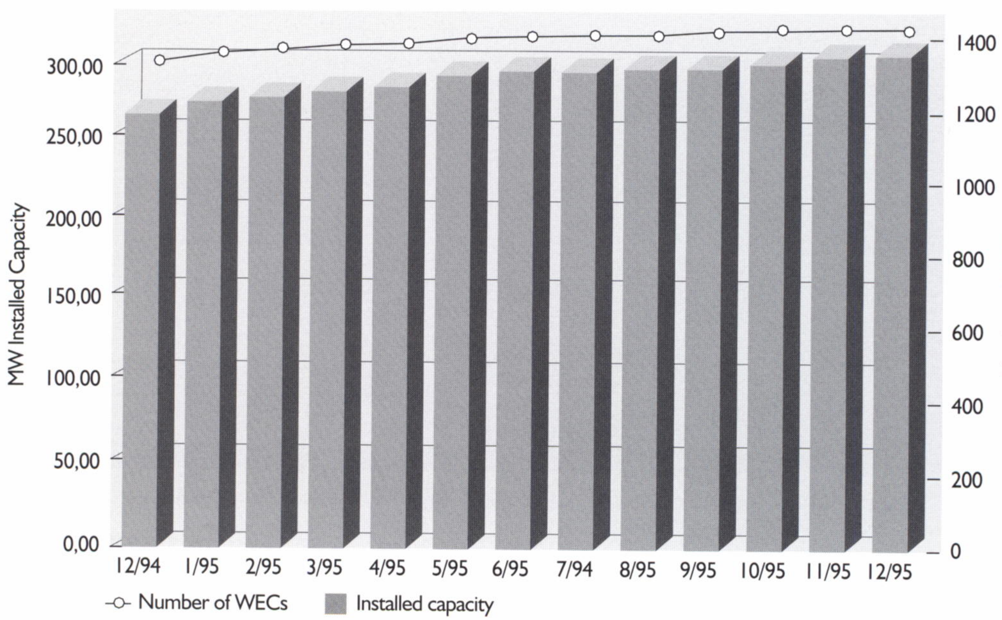


Figure 5. Scientific measurement and evaluation program WMEP. Development of installed capacity and number of WECs. By December 31, 1995, 1,452 WECs and an installed rated capacity of 303.29 MW were recorded (3).

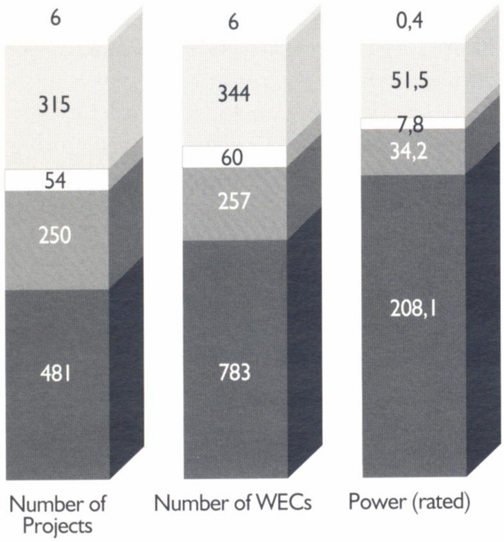


Figure 6. "250 MW-Wind" program. Distribution of number of projects, number of WECs and rated power for different operators. Status December 22, 1995.

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity

By December 31, 1995, the number of wind turbines in operation in Germany was 3,655 which corresponds to a rated power of 1,137 MW (Reference 5). A comparison with WMEP data (1,452 turbines, 303 MW) shows that up to that time, 40% of the wind turbines and 27% of the total rated wind power has been supported by the "250 MW Wind" program. Table 2 shows the development of wind power in Germany. These statistics demonstrate the rapid expansion of wind power in Germany.

Wind power plants are included in the statistics above. BMBF supports selected wind turbines within these plants (but in general not the whole plant). WMEP data are available for WECS inside the plants. In 1995, WMEP recorded 586 WECs as a part of wind power plants, corresponding to a total of 165 MW. An example is

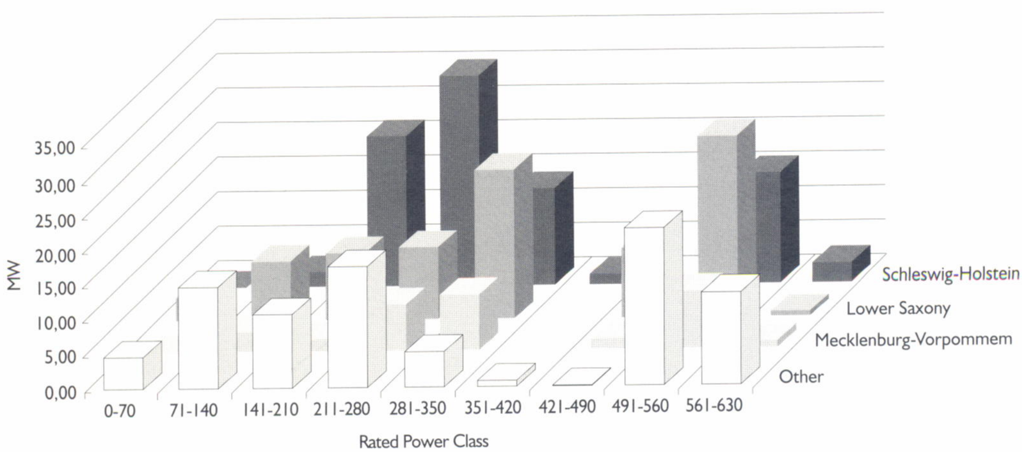


Figure 7. WMEP. Regional distribution of rated capacity for different rated power classes by December 31, 1995 (3).

shown in Figure 2. Actual statistics of the German wind power plants will be published by DEWI (see Reference 5).

2.2. Machine details

The increase of the installation rate in 1995 is related to the 500/600 kW class WECs which now dominates the market. They are highly developed turbines with maximized energy production and minimized noise emission. More detailed technical descriptions of these commercial WECs are given in Reference 6.

For details of the new turbines of the German R&D program we refer to the BMBF's Annual report (Reference 2), the proceedings of the EWEC 94 conference, and previous Annual Reports of the IEA R&D Wind Agreement.

2.3. Performance

The performance of the wind turbines promoted by the "250 MW Wind" program is measured in detail by ISET (Reference 3). For example, the technical availability was 98.4% in 1995. This means that the average medium stand-still time was approximately five days per WEC per year. So far, even after operation periods of several years, no increase in the stand-still time was observed. The turbines registered in the "250 MW Wind" program produced 462 million kWh in 1994 and about 570 million kWh in 1995; 87% of the energy was produced in the three German coastal states of Schleswig-Holstein, Lower Saxony and Mecklenburg-Vorpommern; 97.5% of the produced wind electricity was fed into the public grids, and 2.5% was self-consumed by the operators. The total electricity produced by WECs in 1994 in Germany was around 1,000 million kWh. For 1995, the total wind energy production is estimated to be about 1,450 million kWh, including the "250 MW Wind" program's production being 570 million kWh. Further statistical data will be published in the near future, see Reference 3 and 5.

2.4. Operational experience

Monthly and annual reports of operational experience of the WECs in the "250 MW Wind" program are published by ISET (Reference 3). Figure 8 shows examples of failure statistics.

Table 2. Development of wind power in Germany; "250 MW Wind": Reference (3); Total: Reference (5)

DATE	NUMBER OF WECs		RATED POWER [MW]		WIND ELECTRICITY PRODUCTION [10^9kWh]	
	250 MW WIND	TOTAL	250 MW WIND	TOTAL	250 MW WIND	TOTAL
31.12.1989	15	256	1,4	20	0,0003	—
31.12.1990	187	506	30,8	60	0,016	0,58
31.12.1991	439	806	72,2	111	0,089	0,13
31.12.1992	738	1211	121,3	183	0,201	0,28
31.12.1993	1058	1797	183,9	334	0,302	0,5
31.12.1994	1317	2617	255,5	643	0,462	1,0
31.12.1995	1452	3655	303	1137	appr. 0,57	appr. 1,45

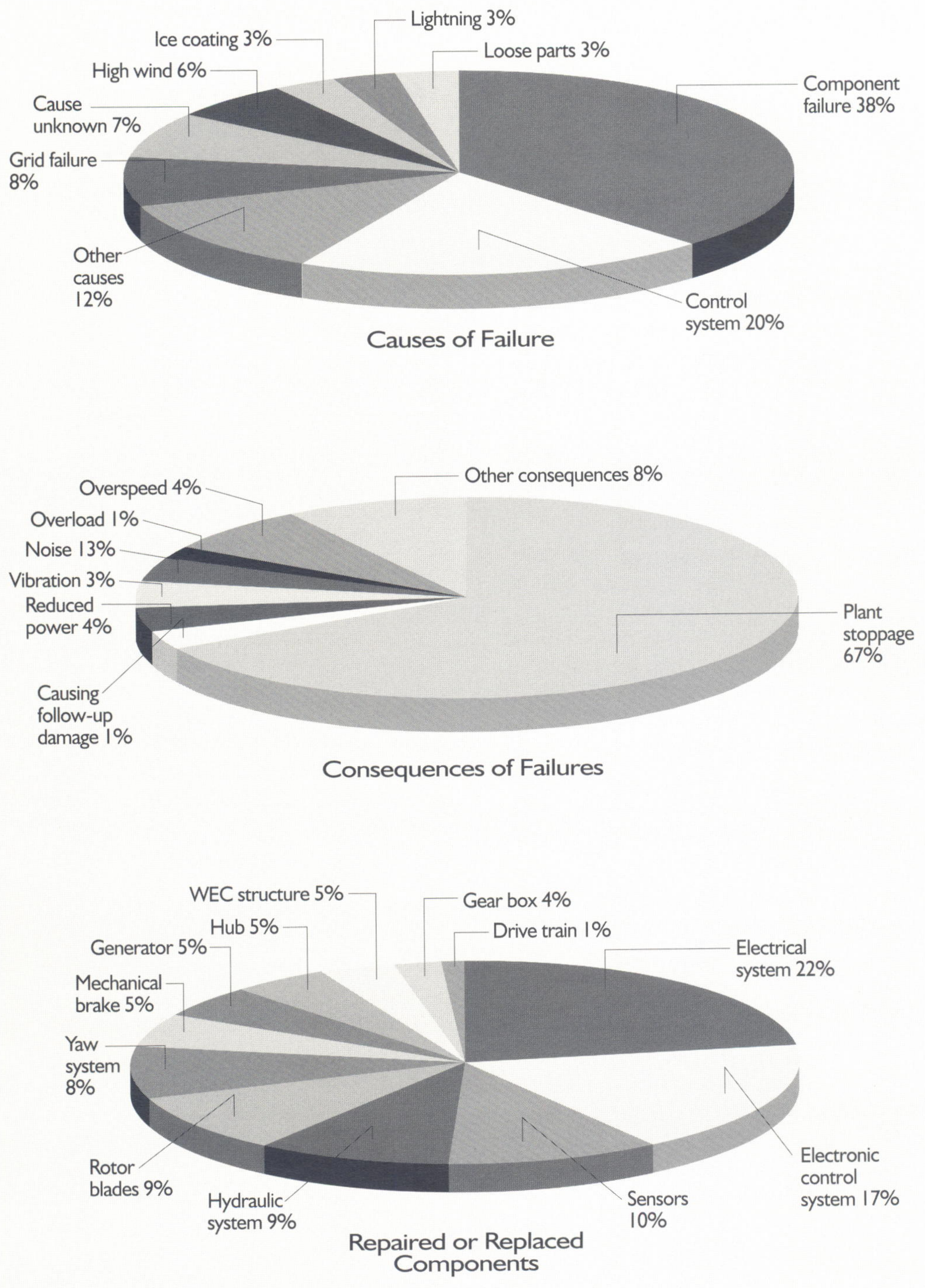


Figure 8. WMEP: examples of failure statistics in 1995 (preliminary) (3).

Figure 8. WMEP: examples of failure statistics in 1995 (preliminary) (3) continued

ELECTRICAL SYSTEM	658
Inverter	106
Fuses	226
Contactors/Switches	178
Cables	58
Others	90
ELECTRONIC CONTROL SYSTEM	487
Microprocessor	311
Relays	58
Wiring/Contacts	29
Others	89
SENSORS	285
Windspeed & Wind Direction	110
Vibration	19
Temperature	25
Oil Pressure	33
Electric Power	12
RPM	54
Others	32
HYDRAULIC SYSTEM	257
Hydraulic Pump	37
Pumpdrive	8
Valves	48
Hydraulic Pipes	46
Others	118
ROTOR BLADES	246
Blade Joints	20
Blade Body	86
Tip Brakes	87
Others	53
YAW SYSTEM	222
Azimuth Bearing	43
Motor	53
Gear	38
Others	88
MECHANICAL BRAKE	136
Brake Dick	13
Brake Lining	73
Brake Shoe	14
Others	36
GENERATOR	140
Winding	12
Collector/Brushes	40
Bearings	28
Others	60
HUB	131
Hub Body	9
Blade Adjustment	87
Blade Bearings	14
Others	21
WEC STRUCTURE	142
Foundation	6
Tower/Bolts	54
Nacelle Structure	17
Nacelle Cover	28
Others	37
GEAR BOX	106
Bearings	15
Gearwheels	8
Gear Shafts	4
Sealings	16
Others	63
DRIVE TRAIN	36
Rotor Bearings	6
Shafts	3
Couplings	21
Others	6

3. CONSTRAINTS ON MARKET DEVELOPMENT

Because BMBF focuses on R&D and demonstration of wind power utilization, investigations of constraints on market development are made by other institutions, without governmental support. Constraints certainly exist, despite the rapid increase of wind power in Germany during 1995 with more than 1,000 new turbines installed, which corresponds to nearly 500 MW, and despite the fact that the German companies may reach certain limits of production with about 1 MW wind power per working day. A special example is the utility Schleswag AG, in the Federal State Schleswig-Holstein, with good wind conditions near the coasts. As of December 31, 1995, 426 MW of wind power (corresponding to 1,196 WECs) was connected to the grid, and applications for another 2,100 MW have been submitted. Bottlenecks are perceptible at the 110 kV grid (see Reference 11).

The licensing procedure in Germany should be mentioned. Building permission of a WEC or a wind power plant is given by the local building supervisory board. The examination is based on the Federal building law, the Federal noise emission law and the German State's building orders.

Even though the German coastal states are not as densely populated as other parts of Germany, each area is used for a certain purpose or is restricted; e.g., the two Wattenmeer National Parks. Regional wind power development plans must be taken into account in many areas (Reference 7). The increasing concerns about wind power siting and building permission imply major problems to be solved by wind turbine operators or customers. This is especially true in the coastal sites where new development is becoming limited. On the west coast of Schleswig-Holstein as well as in the coastal state Mecklenburg-Vorpommern, for instance, many public reservations have been expressed toward further expansion of wind power. Public acceptance becomes more and more important.

A special project "Promotion and further development of wind turbines in Germany and Europe" has been supported by BMBF (see also Table 1). Information on trade constraints is available from FGW, see Reference 13.

4. ECONOMICS

4.1. Economics and financing

Economic calculations consider the financial consequences of an investment in a WEC. The advantages of an investment may be analyzed with different methods, yielding different results which are evaluated subjectively by an investor. One approach is a comparison of the alternative of action (purchase and operation of WECs) with the so-called alternative of omission (non-purchase). The yearly resulting differences are cumulated. Careful performance of the corresponding dynamic calculations yields two main results:

a. The relative advantage of the purchase and operation of a WEC, taking into account all subsidies and financial contributions, respectively, compared to the non-purchase case. The advantage is valued in monetary terms.

b. The amortization time of the WEC; i.e., the time required to regain the investment expenses through the running surplus of income. Calculations for turbines in the early phase of the "250 MW Wind" program yield amortization times in a broad range between 2.4 and 20 years.

An example for an economic calculation of a community has been published recently, see Reference 8. With public funds, 2,200 full load hours (see below) and a depreciation time of 15 years for the Stadtwerke Emden GmbH, the costs of wind power equal the costs of buying electricity. The plan is to have 17% of the town's electricity generated by wind power by the year 2000. For future WECs, the Stadtwerke Emden assumes the same economics even without public support as this support will be offset by lesser investment costs.

A major financial contribution for all economic calculations is given by the Law on Payment for Electricity from Renewable Energy Sources. This is connected with the obligation for utilities to purchase the wind power at a price of DEM 0,1721 per kWh in 1996.

In the meantime, the statistical results of the WMEP allow general considerations of the economics. A simple approach is to neglect the special conditions of a certain investor as for example his individual taxes, and to apply the annuity method with the following inputs: average investment costs according to price lists (see Reference 6), extras of investment 33%, average O&M costs 3% of investment, interest rate 7.5%, depreciation time ten years, financing fraction 100%, public support fraction 0%. Annual costs of a WEC are calculated as capital costs and O&M costs. These costs are compared with the earnings (DEM/kWh) by selling wind power. For this purpose the quantity "full load hours" is defined by dividing the annual energy yield and the WEC rated power. For the year 1994 within the WMEP, 1,016 WECs with more than 350 days in operation were recorded. These statistics are based mainly on WECs of the 300 kW class. Only a few WECs of the later dominant 500 kW class are recorded. Figure 9 shows the distribution of full load hours of these 1,016 WECs.

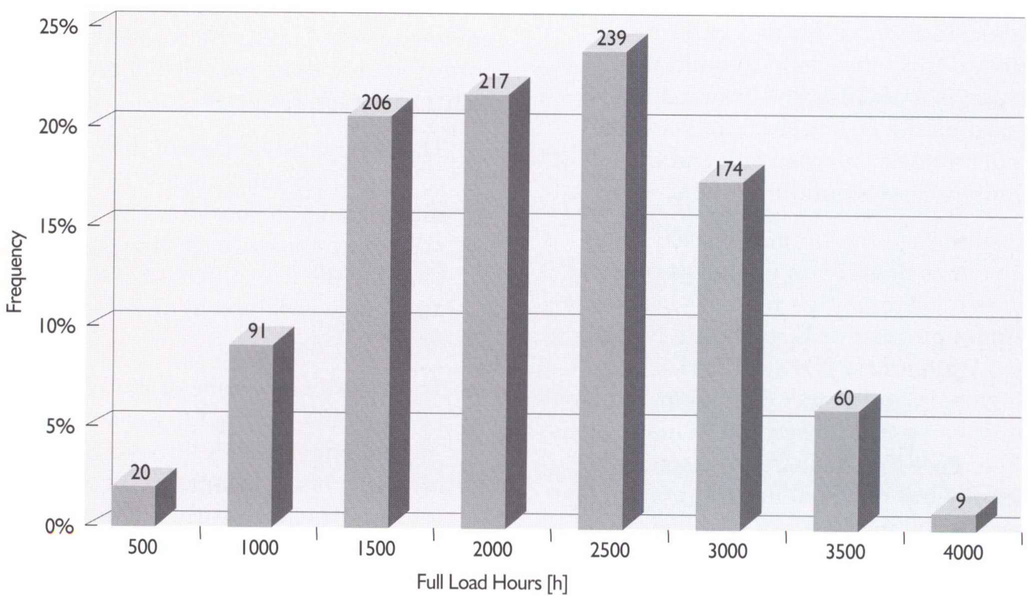


Figure 9. WMEP: distribution of full load hours in 1994 for 1,016 WECs with more than 330 days in operation (3). Numbers above bars refer to number of turbines.

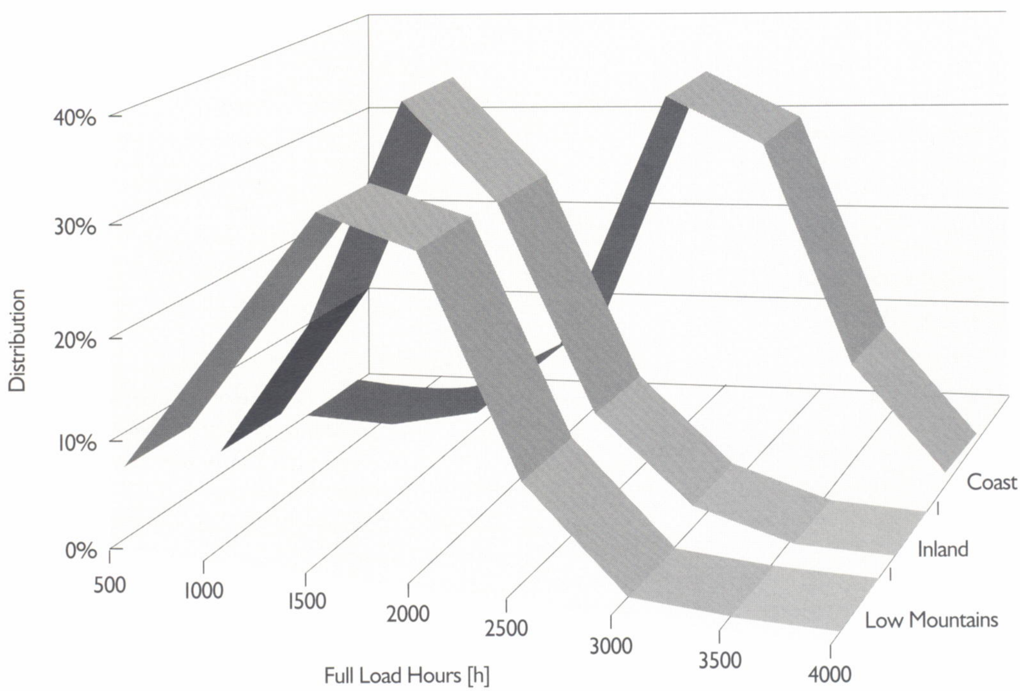


Figure 10. Distribution of full load hours in 1994 as in Figure 9 for different site categories (3).

The model calculation would require for the WECs under consideration at least 2,700 full load hours for an economical operation. The WMEP measurements show that only about 20% of the 1,016 WECs reach this limit. With support of the "250 MW Wind" program, the model calculation requires at least 2,000 full load hours for DEM 0.06/kWh or 1,900 full load hours for DEM 0.08/kWh for an economical operation. Additional investment support from a German Federal State reduces the necessary full load hours for the profitability. It is estimated that about 25% of the 1,016 WECs will not reach profitability even with additional support.

The necessary full load hours will decrease if the new 500 kW class turbines are considered as well. For profitability only with earnings by the electricity feed law, 2,500 full load hours would be required. Note: depreciation time ten years.

Furthermore, the WMEP results could be split in the different site categories; i.e., coast, inland and low mountains as shown in Figure 10. At coastal sites, about half of the WECs are operating economically without public support. For inland and at low mountain sites, this is valid for about only 10% of the machines. For details see Reference 9 and 4.

4.2. Subsidies

The funding of wind energy in Germany is summarized as follows:

a. Federal Ministry for Education, Science, Research and Technology BMBF:

- R&D (see Section 1.1 and Table 1);
- "250 MW Wind" program (see Section 1.2). Demonstration. Applications by December 31,1995;
- "ELDORADO Wind" (see Section 6.0).

b. Federal Ministry for Economic Affairs
   - Demonstration program (see Section 1.2).

c. German Federal States
   - R&D;
   - 250 MW Wind" demonstration program, additional to BMBF, depending on State.

d. European Union
   - R&D;
   - Demonstration.

The current subsidy for operators in the "250 MW Wind" program is either DEM 0.06 or DEM 0.08 DM per kWh, depending on whether the energy is fed into the grid or it is being used by the owner of the WEC. The latter applies for instance on a farm, in a factory or in a private household, and also in the case for a utility as WEC owner. The grant is limited to a maximum amount of 25% of the total investment costs. In certain cases (private individuals, farmers) a subsidy of the investment, currently limited to DEM 90,000, is possible. The owner of the example discussed in Section 4.1 received the production subsidy of DEM 0.08/kWh for electricity fed into the grid (later reduced to DEM 0.06 for new projects) with BMBF funds, plus about DEM 70,000 as an investment subsidy by the Federal State of Schleswig-Holstein. He received another DEM 30,000 through the investment benefit law (now ended) yielding the previously mentioned DEM 100,000 for capital subsidies and financial contributions.

The maximum support for projects of the ELDORADO program is 70% of project costs, granted to a WEC manufacturer.

The BMBF subsidies in 1995 were:

- DEM 6.9 million for R&D;
- DEM 26.8 million for "250 MW Wind";
- DEM 5.8 million for the ELDORADO Program.

By far the largest portion of wind power installed in Germany is financed by special low interest loans for environmental protection measures. The Federal Ministry of Economics grants long term, reduced-interest loans at about 1% below the current interest rate for the financing of environmentally relevant measures, such as wind power installations, via the Deutsche Ausgleichsbank/DtA. The payout rate for the loans depends on the percentage of the loan in the total investment and may amount up to 100%. The first two years are free of redemption and the interest is fixed for the total loan period. In June 1995, the interest rate for credits under the DtA Environmental Program was 6.5% in West Germany and 6% in East Germany. The credit period is generally ten years.

The volume of support for wind power plants by loans of the DtA has continuously increased in recent years. The types and volume of loans in the year 1992 to 1994 are compiled as follows:

Loan Program	1992	1993	1994
ERP Energy Conservation Program	66,2	213,9	439,0
DIA Environment Program	35,9	89,5	172,3
Municipal Loan Program	15,3	–	–
Total	117,4	303,4	611,3

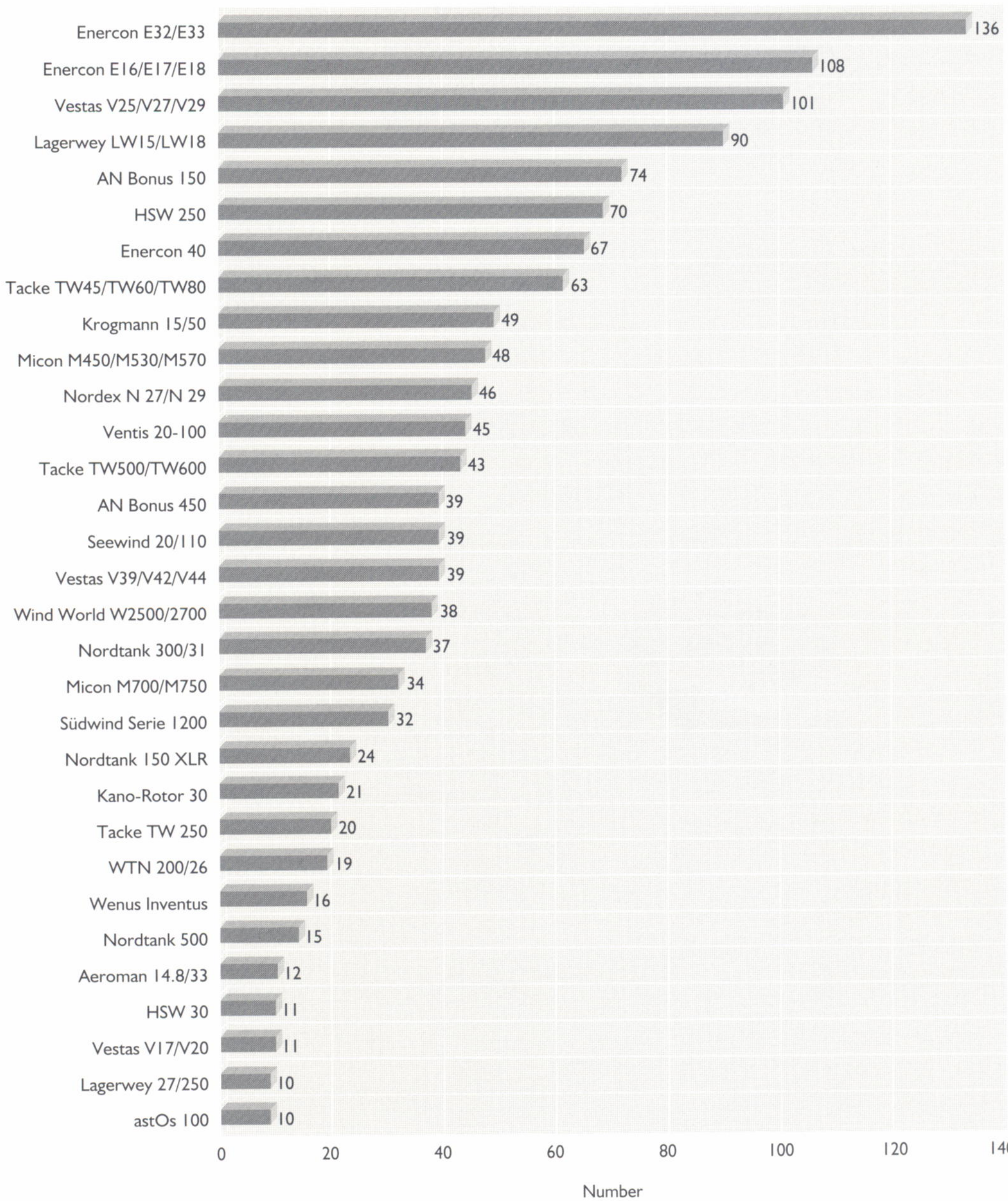


Figure 11. WMEP: WECs models by December 31, 1995 (3).

5. INDUSTRY

The actual distribution of WECs registered by the WMEP is shown in Figure 11. As already mentioned in Section 2.1, these are 40% of the operating WECs in Germany and correspond to 27% of the total rated power.

In 1995, nearly 500 MW wind power was installed in Germany. From average selling prices of DEM 1,600/kW for the turbines of the 500 kW class (see Reference 10), and about 33% extras of investment (see Section 4.1 and Reference 10), the total investment in wind power in Germany may be calculated at more than DEM 1,000 million. This sum includes the market shares of the non-German WEC manufactures, see Reference 5. Market shares of companies selling wind power in Germany have been published, see Reference 5 and 11. Related to rated power installed in 1995, the shares consist of: Enercon 30%, Tacke 21%, Micon 13%, Vestas 12%, AN-Maschinenbau 5%, other 18%.

International trade increased remarkably. German manufactures sold turbines to European countries, North America and other parts of the world. Examples are (see Reference 12):

- The cold climate version of the Tacke 600 kW wind turbine was erected on September 25, 1995, near the Bruce Nuclear Power Development Information Center of Ontario Hydro, Tiverton, Ontario. The turbine will be tested for one year. Tacke Windpower Inc. has received an export order of ±CAD 10 million to supply fibreglass blades for the Tacke 600 turbine. Four TW 600 are installed in Tehachapi, California, and four TW 600 in India.
- The first three E 40 machines left Enercon's factory in India. The company has orders from Sweden, Spain, and Greece. The U.S. market for Enercon has not fulfilled its promise yet.
- The German Bank "Kreditanstalt für Wiederaufbau" is engaged in the Chinese WEC market. The company AN Maschinenbau won a tender for a 7.2 MW wind power plant at Hainan (12 x 600 kW), to be erected in the fall of 1996.

Actual export information will be published (see Reference 5 and 11).

The German Wind Power Industry as well as German branches of companies from neighboring countries are merged in:

a. Fördergesellschaft Windenergie e.V., FGW, and in

b. Verband Deutscher Maschinen- und Anlagenbau e.V., VDMA, (see Reference 13).

6. INTERNATIONAL COLLABORATION

The German/Swedish R&D cooperation has been mentioned before (see Section 1.2). Many contacts between European partners exist in the framework of projects of the European Union. BMBF's interest also includes the application of wind energy in overseas countries. According to a study by the World Bank, almost 50% of the inhabitants in developing and threshold countries do not have access to central energy supplies (electricity, oil, gas etc.). They could be assisted by decentralized concepts, and renewable energies are considered to be an option for decentralized energy supply. Therefore, BMBF launched the ELDORADO wind program (Reference 14) in 1991, which is being jointly carried out with several partner countries. The aim of BMBF is to promote motivation of a larger number of users in southern climatic zones to construct and operate WECs in cooperation with German partners. By December 31, 1995, 20 projects were approved by BMBF, most of them with installations in operation. The total rated power is more than 70 MW (see Table 3).

Table 3. Projects of the ELDORADO Wind Program, status December 1995

COUNTRY	SITE	NO.	TECHNOLOGY	APPLICATION	TOTAL RATED POWER
ARGENTINA	Santa Cruz	10	Ventis 20-100	Wind Farm	1.000 kW
	Bariloche	3	AN-Bonus 450	Wind Farm	1.350 kW
BRAZIL	Minas Gerais	4	Tacke TW 250	Wind Farm	1.000 kW
	Ceará	4	Tacke TW 300	Wind Farm	1.200 kW
CHINA	Zhurihe	4	HSW 250	Wind Farm	1.000 kW
	Dalian	4	HSW 250	Wind Farm	1.000 kW
	Xilinhuote and Hainan	10	HSW 250	Wind Farm (4,6)	2.500 kW
	Qinghai	7	AN 150/30	Wind Farm	1.050 kW
	Qinghai	2	Tacke 600	Wind Farm	1.200kW
	Xinjiang	3	AN-Bonus 450	Wind Farm	1.350 kW
	Zhejang	5	Jacobs	Wind/Diesel	165 kW
	Inner Mongolia	10	Wenus	Wind/Diesel	80 kW
EGYPT	Zafarana	10	Ventis 20-100	Wind Farm	1.000 kW
JORDAN	Hofa/Juhfiyya	5	Vestas V27/225	Wind Farm	1.125 kW
LATVIA	Ainazai	4	Tacke 600	Wind Farm	1.200 kW
RUSSIA	Rostov/Don	10	HSW30	Wind Farm	300 kW
	Wolgograd	1	Südwind N1237	Single Turbine	37 kW
	Wolgograd Region	2	Südwind N1237	Single Turbines	74 kW
UKRAINE	Donezk	5	Südwind N3127	Wind Farm	1.350 kW
POLAND	Gdansk	2	Tacke 600	Wind Farm	1.200 kW
				TOTAL	73.159 kW

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GREECE

1. GOVERNMENT PROGRAMS

Greece is one of the European countries with high wind energy potential. It is among the aims of the government to reduce use of expensive imported fuel, currently used for electricity production in a large part of the Greek territory, by capitalizing on the country's wind potential. Government support for wind energy exploitation is part of a larger new policy concerning renewable energy sources. The major strategic goals of the national policy for the development of the renewable energy sources are:

- increase of the efficiency of the energy system;
- environmental protection by decreasing the emission of atmospheric pollutants;
- improvement of the safety of the energy system by diversifying energy supplies;
- CO_2 emissions by 2000 at the levels of 1990;
- decentralization of energy production;
- active involvement of the Greek industry - creation of new jobs;
- development of new technology.

In 1995, a target of 350 MW of installed wind energy capacity by the year 2005 was announced by the Ministry of Industry, Energy and Technology (MIET). A significant stimulus to the development of wind energy in Greece was given in 1995 by the introduction of a new legal framework. The new Law 2244/94, dealing and regulating the electricity production from renewable energies, has been followed by a ministerial decree detailing its implementation. The main features of the new framework, regarding wind energy, are the opening of the market to the private sector and the precise definition of the tariffs for the energy produced. In addition, the Public

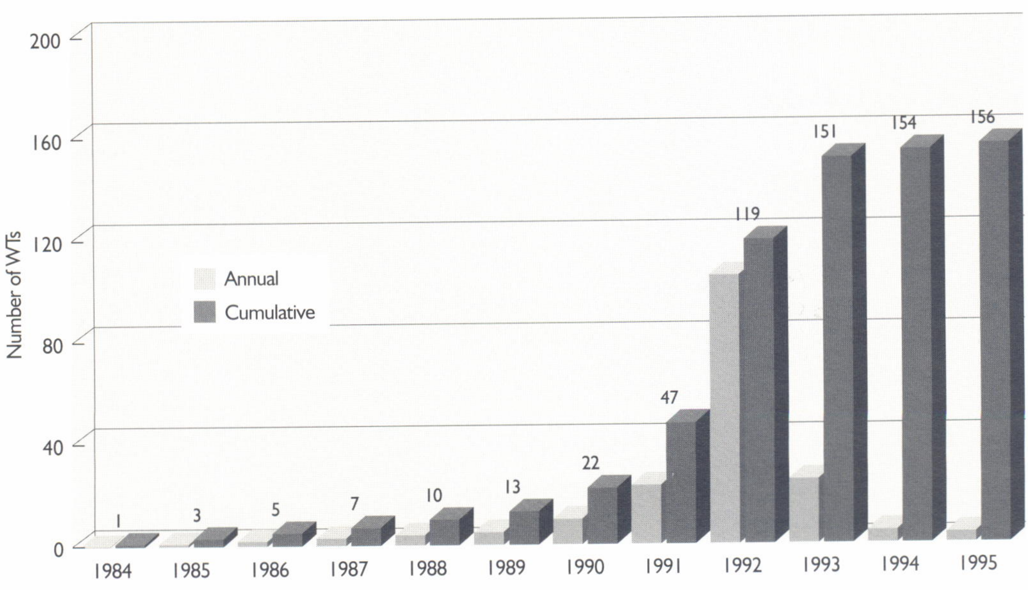

Figure 1. Installed wind turbines.

Power Corporation of Greece (PPC) is obliged to buy the wind-produced electricity with contracts having a ten year duration.

2. COMMERCIAL IMPLEMENTATION OF WIND ENERGY

The development of wind energy within the last ten years is shown in Figures 1 and 2, where the annual and cumulative number and capacity of installed wind turbines are illustrated since 1984. In the same period, the installed conventional capacity was increased from 6.7 GW in 1984 to 9.2 GW in 1994.

It is clear that in large, the development was between 1991 and 1993, when the PPC put into operation its MW scale wind power plants. The contribution of the PPC to the total installed capacity is currently as high as 88%. The rest of the capacity belongs to public companies and local authorities and only a few hundred kW are owned by individuals.

In 1995, only two wind turbines with a total capacity of 0.7 MW were installed in Greece, bringing the total installed wind energy capacity to 27.6 MW and 156 machines.

Figure 3 shows the tendency of technology expressed as the mean rated power which is the total installed capacity divided by the number of wind turbines. The parameter is increasing, since the capacity of the newly installed wind turbines is increasing.

The wind turbines installed in Greece are constant speed, stall- or pitch-regulated machines, manufactured in Denmark, Belgium and Germany. The only wind turbine of variable speed technology is a 150 kW stall regulated machine, which has been designed and manufactured in Greece and is still in monitoring. The five most important wind turbine manufacturers are presented in Figure 4, where their percentage of the total installed capacity is illustrated.

The power produced from wind turbines during 1995 is expected to total approximately 40 GWh, based on the already available data, compared to 37 GWh produced in 1994. Figure 5 shows

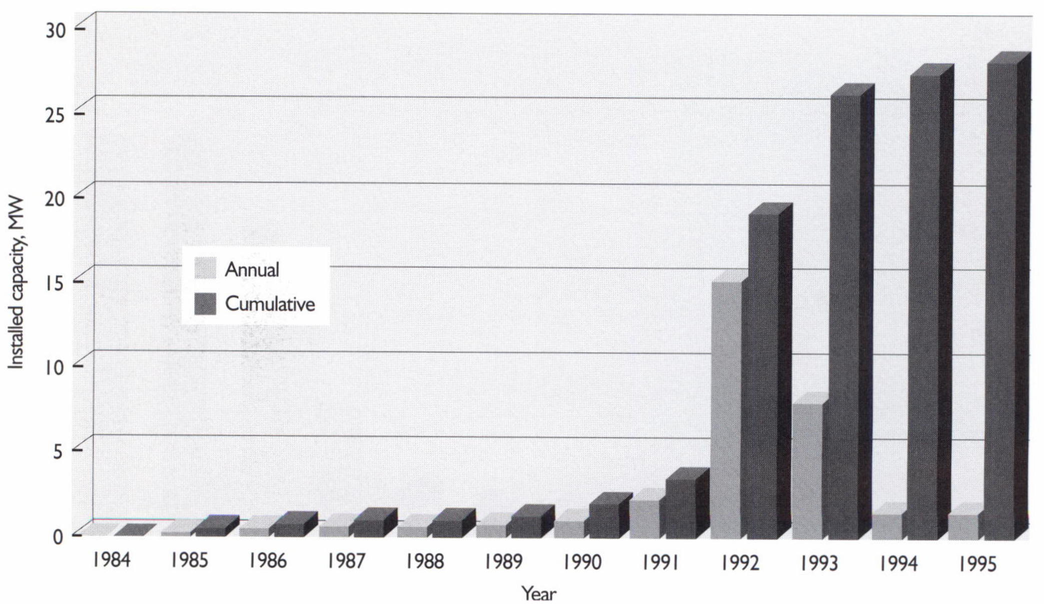

Figure 2. Installed capacity in MW.

the electricity produced from wind turbines for the last five years and the corresponding capacity factor. The last was calculated excluding the two PPC's wind power plants (10.2 MW), which have been out of operation since January 1994. The corresponding conventional net production for 1994 was 32.5 TWh.

Operational experience

The two biggest wind power plants of the PPC, 5.1 MW each, are out of operation since late 1993 due to serious damage on their rotor blades. The defect was detected during commissioning, but no viable solution has been found yet.

Lightning is another issue that has to be considered, leading to long machine breakdown periods. Numerous strikes have been recorded, and two machines are out of operation.

Often start-stops caused by grid instability of the autonomous power systems of the islands led to damages in the gearboxes.

More systematic data on failures will be available, since an appropriate data base is under development.

3. MANUFACTURING INDUSTRY

Besides one or two small wind turbine manufacturers (typical range 1.0-5.0 kW), there is no wind turbine manufacturing industry in Greece in a classic manner. However, all the tubular towers of imported machines of the PPC were constructed in Greece by two private companies, following the original drawings. Steel industry is rather developed in Greece, and is to support wind turbine manufacturing. In the past, a government supported company, the Hellenic Aerospace Industry (HAI), was involved with the construction of wind turbines for the PPC. But its activities were limited to a program of 50 machines based on imported Danish know-how.

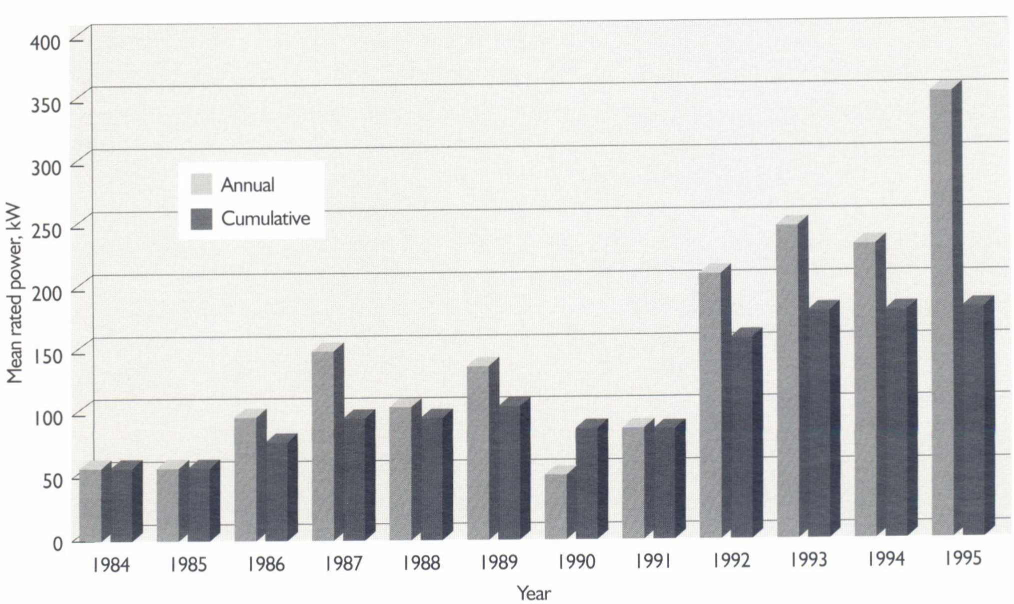

Figure 3. Mean rated power in kW.

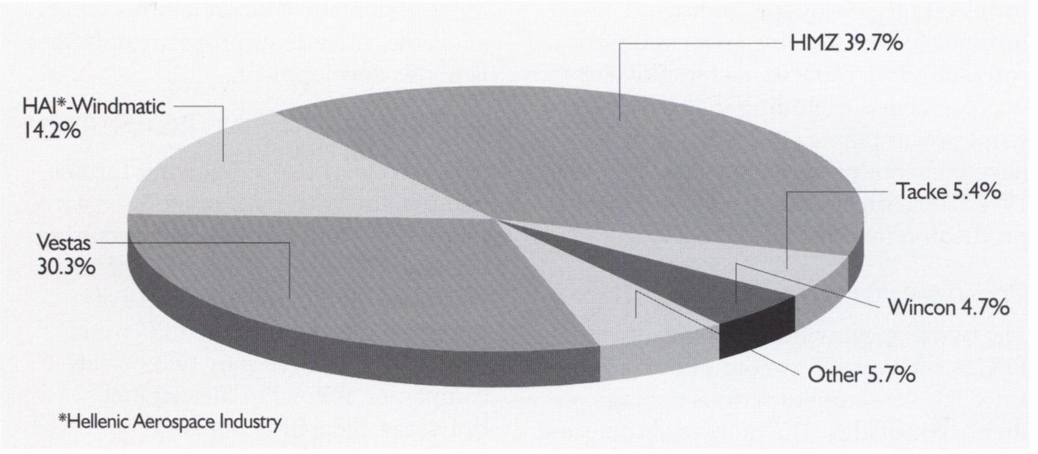

Figure 4. The five most important wind turbine manufacturers. Percentage corresponds to installed capacity.

Certification

In order to operate a wind turbine in Greece with rating of more than 10 kW, a certificate is required, unless it is owned by the PPC. The Center for Renewable Energy Sources (CRES) is, by law, the certifying authority for wind turbines in Greece. CRES is accepting those type of certificates issued by authorized institutions, while it is working on certification procedures and standards to be followed nationwide, taking into account the individual climate characteristics of Greece.

4. ECONOMICS

The system of power generation in Greece is divided into two categories: the so-called interconnected system of the mainland and the autonomous power plants of the islands. The PPC is the only utility responsible for production, distribution and exploitation of electricity. Despite the different production costs in the two systems, a single charging price exists all over the country, depending on the identity of the consumer and the voltage class. The following tariffs for the three voltages are the most typical:

low voltage	GDR 24.96/kWh;
medium voltage	GDR 20.96/kWh, and GDR 932/kW (peak power value);
high voltage	GDR 13.18/6.77/9.14/kWh, peak/min load/rest hours respectively, and GDR 2,117/kW (peak power value).

The prices paid by the PPC for renewable energies are based on the actual selling price.

For the autonomous island grids the prices are set at 90% of the low voltage tariff; i.e., GDR 22.46/kWh. For the interconnected grid, the tariffs have two components: energy and power (capacity credit). The energy component is set at 90% of the medium or high voltage tariffs, depending on the type of grid connection of the wind power plant. The power component is set at 50% of the respective PPC's power charge.

medium voltage	GDR 18.15/kWh, and GDR 233/kW x P; (P: the maximum measured power production over the billing period);
high	GDR 11.86/6.09/8.23/kWh, peak/min load/rest hours respectively; GDR 529.3/kW x P (P: the maximum measured power production between two successive measurements in the peak hour zone).

The total cost of wind power projects depends on the type of the wind turbine; the size, and accessibility, and varies between GDR 300.000-400.000/kW. This leads to a typical generated power cost of GDR 6.25/kWh.

The typical interest rate for financing any project without subsidies is about 20%. However, many investments including wind projects may be benefited by 40% reduced soft loans according to the so-called "Law for the economical development" 1892/90.

5. MARKET DEVELOPMENT

Low selling prices in conjunction with the restriction of power generation from the private sector (with the exception of auto production), strongly affected wind energy development, although the first wind turbines have been operating since 1984. As a result, wind energy was limited in the activities of the PPC and of some public organizations.

As soon as the new law 2244/94 was issued in early 1995, a great interest was shown by the private sector in developing wind power projects. According to the law, anyone can develop power plants up to 50 MW from renewable energy and sell electricity to the PPC, ending the monopoly of the PPC on power generation from wind energy. Until now, applications for a total of 385 MW have been submitted to the MIET, while four projects for a total of 25 MW have been approved and are in planning. Other features affecting the development are more simplified procedures (less

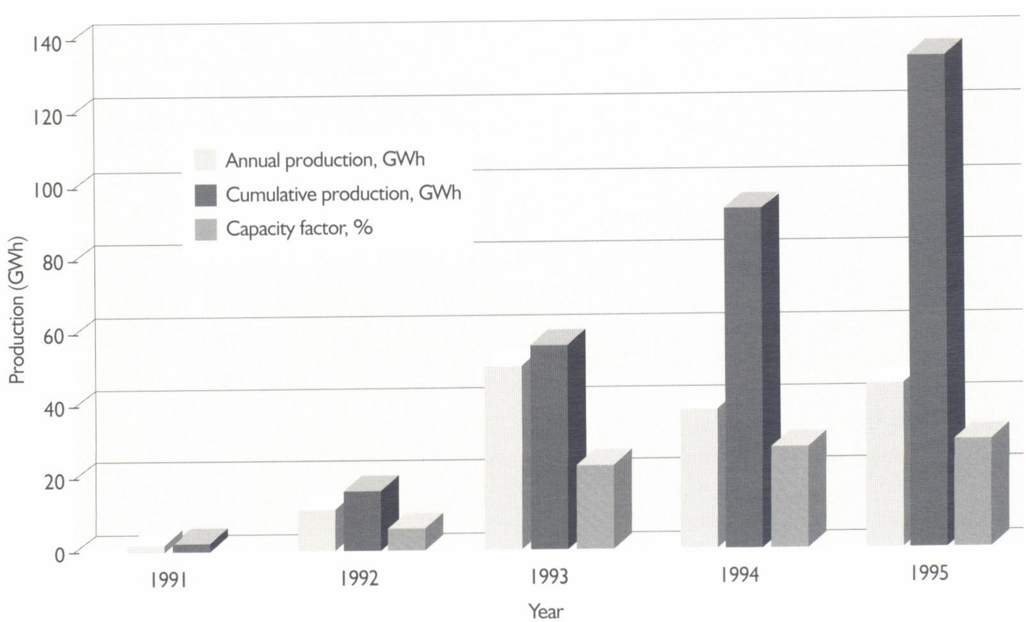

Figure 5. Wind power production.

bureaucracy) and attractive buy-back prices.

In the "Community support framework - energy", a total of ECU 100.4 million has been allocated for the development of the renewable energies in Greece, for the years 1994–1999. A significant part of this budget is expected to be used in the field of wind energy. On the other hand and according to the "Law for the economical development" 1892/90, wind projects may be subsidized up to 40% of the project cost and get a 40% reduced soft loan for the 30% of that cost. This is a 12% interest rate for a typical value of 20%.

Environmental impact

Due to the landscape characteristics of Greece, almost all wind power plants are sited in remote areas, thus minimizing both the visual impact and noise emissions. No birdkill was reported.

Although a strong opposition (due to archaeological interest of the area) forced abandonment of a projected wind power plant on the Island of Lesvos, no other significant opposition has been mentioned up to date against wind energy. The public attitude is rather positive in general. However, special attention should be given in planning projects on small touristic islands with strict traditional architecture.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

The Ministry of Industry, Energy and Technology (MIET) promotes all R,D&D activities in the country. Government sponsored R,D&D activities include applied and basic R&D as well as demonstration projects. In 1995, the total amount spent by the Greek government for R&D activities was approximately GDR 200 million compared to 250 and 150 million spent in 1994 and 1993 respectively.

Key areas of R&D in the field of wind energy in the country are wind assessment and integration, standards and certification, development of wind turbines, aerodynamics, structural loads, blade testing, noise, power quality, wind desalination and integration.

There is no activity in Greece concerning MW-size wind turbines or offshore deployment.

A project for the development of a 450 kW wind turbine was initiated within the framework of the EPET-II National Program, in 1995. A contract for ECU 1.9 million was signed last summer between a consortium of companies and the General Secretariat for Research and Technology (GSRT). The project is aiming at both the development of a 450 kW variable speed, stall regulated wind turbine, and the development of blade manufacturing technology. The contract has a duration of three years and the prototype is expected to be installed at the test site for extensive measurements by the end of 1997.

The Center for Renewable Energy Sources (CRES) is the national organization for the promotion of the renewable energies in Greece and, by law, the certifying authority for wind turbines. CRES is mainly involved in applied R&D and is active in the field of aerodynamics, structural loads, noise, power quality, variable speed, wind desalination, standards and certification, wind assessment and integration.

The development of a national certification system for wind turbines is considered as a crucial parameter for the successful implementation of new strategic plans for extensive use of wind energy in the country. In 1995, CRES initiated the procedures for the development of the national certification system. Within this framework, TC81, "Wind Turbines", has been created by the

Hellenic Organization for Standardization (ELOT), for the development of national standards in the field of wind energy. TC81 is to work within the IEC and CENELEC mandates. The effort is part of the National Program for Renewable Energy under MIET.

CRES' blade testing facility is going to be used as an integral part of the certification system underway. The facility is fully operational and the first blade tests are under preparation. The blade testing facility, which is one of the most advanced testing facilities in the world, can be used for static, dynamic or fatigue testing of blades up to 25 m long.

CRES has also developed a wind-diesel hybrid system, which simulates small autonomous grid operation, common in the islands of the Aegean sea. The system, now in commissioning, can be effectively used in optimizing the integration of the renewable energies in such systems.

A number of research programs were running or initiated at CRES during 1995, aiming at characterizing the main features of complex or mountainous sites, as most of the favorable for wind energy development sites are of such topography. In that respect, JOULE-IIA project MOUNTURB (partially funded by the European Union - DG XII) is expected to provide results on the power performance and loading conditions of wind turbines operating in complex mountainous terrain. JOULE-III project COMPTER-ID, which in 1995 gained support by DG XII, is focusing at identifying the crucial parameters affecting both the power performance and the loading of different types of wind turbines operating in such environments. In that direction, new techniques are under development for power-curve measurement of wind turbines operating in complex terrain (National wind R&D projects with partial support from DG XII).

Basic wind energy R&D is mainly performed at the country's technical universities. The Fluids Section of the Mechanical Engineering Department of the National Technical University of Athens (NTUA) is active in the field of wind modelling, rotor aerodynamics, load calculation, fatigue analysis, noise and wind power plant design.

In 1995, the R&D activities at the Fluids Section of NTUA, mainly performed in the framework of the Joule program of the European Union, have led to the development of valuable numerical tools. In siting, numerical tools that resolve the wind flow field established over complex terrain topographies have been developed. Furthermore, for the analysis of the performance and operation of wind power plants in flat terrain, a modular numerical tool has been developed and tested, taking into account the atmospheric conditions and terrain effects, providing also optimal layouts of wind power plants.

In the field of rotor aerodynamics and load calculation, tools of varying complexity have been developed and evaluated, consisting of packages containing aeroelastic modelling capable of treating non-homogeneous inflow on the rotor disk, and appropriate wind simulation that reconstructs the fluctuating wind flow. Regarding aerodynamics, advanced free-wake fully 3D flow models are available, including also stall modelling of a new vortex-type stall model based on the double-wake concept. Finally, a tool has been constructed and evaluated for the calculation of the noise emissions of stand-alone wind turbines.

The Applied Mechanics Section of the Mechanical Engineering Department of the University of Patras has since 1990 focused on educational and R&D activities involving composite materials and structures. Emphasis has been given on structural design and dynamics of composite rotor blades of wind turbines. Experience has been acquired as a result of involvement in research projects supported either by the GSRT and/or the European Union. In the framework of the EPET-I National Program, the University of Patras has successfully completed the structural design of an FRP made blade of a 30 kW wind turbine. A close collaboration with CRES on dynamic and fatigue full-scale testing of rotor blades was established several years ago and continues satisfactorily. In 1995, the Applied Mechanics Section R&D activities have mainly focused on the structural design of FRP-made rotor blades in the range of 10 to 17 m long, using FE methodology.

The Electrical Engineering Department of NTUA is actively involved in the field of wind energy since the beginning of the 1980's, participating in R&D projects sponsored by the European Union and other institutions and cooperating with universities and research centers from many European countries.

Tools and methodologies have been developed for the optimal economic exploitation of wind energy, such as logistic models for small- and medium-sized wind-diesel systems. Within this activity, an advanced control center has been developed and implemented on the Greek island of Lemnos, which manages the operation of the wind power plants and the diesel power station.

The impact from the connection of wind turbines on distribution networks and on autonomous island grids of approximately 100 kW to 100 MW has been extensively investigated and issues of network stability, voltage quality and protection coordination have been addressed.

The NTUA is also involved in the design of the electrical components of wind turbines. Electric machinery, power converters and control systems for variable speed wind turbines are studied and small simulators are developed in the electric machines laboratory.

Demonstration

The main demonstration programs in wind energy currently under way in Greece originate from the PPC and are financed within the framework of the Thermie program of the European Union. The three demonstration projects of the PPC continued or initiated in 1995 are:

- installation of three wind turbines of 500 kW each on the island of Crete;
- installation of a wind-diesel system on the island of Astypalea, and
- installation of a hybrid system on the island of Kythnos.

Three wind turbines in Moni Toplou, Crete

Two Tacke 500 kW wind turbines were commissioned in December 1993 and produced 5,173 MWh during their two years of operation. Two serious damages in the blades from lightning have occurred up to now. The third wind turbine is a Nordtank 500 kW, commissioned in April 1995. It has produced 1,148 MWh until the end of 1995.

Wind-diesel system in Astypalea

A 500 kW V-39 Vestas pitch-regulated wind turbine and a new 500 kW diesel generator will be installed in Astypalea in 1996. The aim of this project is to maximize the penetration of wind energy through a load management system based on setting the power limit of the wind turbine.

Large advanced autonomous wind/diesel/battery power supply system in Kythnos

The aim of this project is the demonstration of the technical feasibility of the integration of a very high penetration of wind energy in large supply systems. This large modular system for the island of Kythnos is designed for the combination of diesel generator sets, battery storage, rotating phase shifter, five small wind energy converters and one additional large wind energy converter. This large wind energy converter with a power output of 500 kW shall supply a great portion of the power demand. It will be the first time that such a high portion of more than 50% of the energy demand is realized by wind turbines, and due to this the diesel generators can be totally stopped when the power output of the wind turbines is sufficient. Furthermore, the already existing PV system with a nominal power of Pp = 100 kW as well as the existing five energy converters of type Aeroman (5x33 kW) will be integrated into the wind/diesel/battery system. The project will be carried out by the PPC and SMA. The construction work is expected to start in 1996.

Also in 1995, a demonstration project originating from the local authorities of Crete was initiated and received support in the framework of THERMIE program:

5 MW wind farm on complex terrain in Sitia, Crete

The project concerns the installation of a 5 MW wind farm in Sitia, Crete. Two different wind turbine technologies will be evaluated in an effort to maximize energy penetration into the island's grid. The installation site is in highly turbulent complex mountainous terrain having turbulence intensity levels in the range of 17%-25%. The wind power plant consists of four 600 kW, stall regulated machines, manufactured by Tacke Windtechnik and five 500 kW variable speed, pitch-regulated wind turbines, manufactured by Enercon. The power performance of the wind power plant will be monitored and evaluated in relation to local grid penetration capability. It is among the aims of the project to determine the optimal technical and economic way for obtaining maximum energy penetration into the local PPC island grid as well as to improve grid quality via an operational power output conditioning system.

ITALY

1. GOVERNMENT PROGRAMS

The Italian government has not been engaged directly in research, development and demonstration (R,D&D) activities in wind energy. Nevertheless, it has been encouraging the development of all renewable energy sources through the coordination role played by the Ministry of Industry, Commerce and Trade (MICA) and, more recently, by taking legislative action aimed at providing private investors with incentives to set up commercial renewable energy plants.

However, as far as wind energy is concerned, two state-owned bodies have been working on R,D&D activities since the early 1980's: the research agency ENEA (the Italian Agency for Energy, New Technology and the Environment), and the electricity utility company ENEL S.p.A. (formerly the Italian National Electricity Board).

For several years now, ENEA has supported the Italian wind energy industry by providing technical and financial assistance, while ENEL, as a potential wind turbine user, has used a number of wind turbine models at its own testing facilities. A cooperation agreement on medium- and large-sized wind turbines was signed by ENEA and ENEL in 1987. Three main projects have been developed jointly by ENEA and Italian manufacturers and the following prototypes have been tested within the framework of the ENEA/ENEL agreement: the medium-sized machines Medit and M30 (made by WEST and Riva Calzoni, respectively) and the large machine GAMMA 60 built by WEST.

Wind energy was given a stronger boost by the government in late 1988, following the 1987 referendum which actually shut down nuclear power plants. To help reducing Italy's heavy dependence on imports in electricity production (±80% of electric energy demand is met by imported fuels or, to a lesser extent, by electricity imported from neighboring countries) and to respond to growing concerns about the environment, the government issued the 1988 National Energy Plan (PEN) providing significant recourse not only to hydro power, but to all domestic renewable energy resources. As for wind energy, the 1988 PEN set a target of 300 MW capacity (600 MW if large machines should become commercially available) to be installed by 2000. This goal still holds today.

This provision had two consequences in subsequent years. Both ENEA and ENEL supplemented their R&D programs with a number of actions aimed at promoting or setting up demonstration wind power plants. In particular, the utility ENEL launched a program aimed at putting on-line two wind power plants with a total of 20 MW, with the intent to stimulate the domestic wind turbine market. Furthermore, the government devised legislative measures aimed at creating conditions for autonomous producers to undertake privately owned wind power projects. Laws No. 9 and 10 (see below) were passed by Parliament in January 1991; in addition, the Interministerial Committee for Prices (CIP) issued Directive No. 6 in April 1992, providing for premium purchase prices for the energy produced from renewable sources.

Premium tariffs, along with the possibility of obtaining also capital cost subsidies from regional authorities (see below), have actually created a growing interest among private investors in the last two years. As of November, 15, 1995, wind power projects totalling a striking 1,140 MW capacity had been submitted to

MICA and ENEL for admission to CIP No. 6 incentives and verification of compatibility with the electric system.

Another factor that should be taken into account is the impending privatization of the state utility ENEL, which has already been set up as a joint-stock company (S.p.A.). The ENEL stock (currently still held by the government) is expected to be put on the market shortly. This might affect the future energy policy of the new company. However, in this report ENEL's and ENEA's wind energy activities are still considered to be a part of the government's R,D&D programs.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

At the end of 1995, Italy's installed wind capacity was ±22.5 MW, with very little increase compared to 1994, following the installation of a 600 kW wind turbine in western Sicily. All this power is grid-connected. Reliable data on small, dispersed grid-connected installations or stand-alone plants cannot be given. However, the use of these plants has so far been very limited.

The 22.5 MW grid-connected capacity consists of 22 plants with 88 machines; the average rated power of medium-sized units is nearly 300 kW. Previously, at the end of 1991, total wind power was 2.2 MW, almost completely located in Sardinia; then, another 5 MW was installed during 1992, and a little less, ±4.5 MW, during 1993. Finally, in 1994, installed wind power capacity grew by 10.2 MW. As compared to Italy's conventional generating capacity, totalling 54 GW in 1995, the penetration of wind power still remains limited.

Up to now, most installations are from the Italian manufacturers WEST and Riva Calzoni; foreign machines include a few HMZ and Vestas units at various sites, three WEG MS-3 machines installed at ENEL's test fields, and a Markham machine in Sicily.

The size of existing wind power plants is generally small; the largest ones are:

- the 4.5 MW plant located in the area of Bassa Nurra (northern Sardinia), which consists of eight M30-A units (totalling 2 MW) and eight Medit 320 units (totalling 2.5 MW). The owner of this wind power plant is a local consortium named "Consorzio di Bonifica Nurra".
- the 3.5 MW wind power plant installed at the end of 1994 by Riva Calzoni at Casone Romano in the Apulia Region, with ten units of the M30 series (Figure 1). This plant was connected to the grid in May 1995, and is now operating. It is owned by Riva Calzoni, which has also acted as machine manufacturer and plant developer.
- the 1.3 MW wind power plant near Palena in the Abruzzo Region, with three Medit 320 and two Vestas machines; the owner is the "Consorzio di Bonifica del Sangro".
- the 2.4 MW wind power plant built during 1992-1993 at Bisaccia in the Campania Region and consisting of six Medit 320 and 16 small (30 kW) AIT-03 machines. The wind turbine manufacturer WEST also operates the plant, under concession from the regional government.
- ENEL's test site at Alta Nurra (Sardinia) which totals ±2.7 MW (one 1.5 MW machine plus four medium-sized units) and the Acqua Spruzza (Molise) test site totalling ±2.5 MW (eight medium-sized units).

The remaining plants consist of a few or even a single machine and have been set up by regional governments, small municipalities, private investors, etc.,

Figure 1. Partial view of the 3.5 MW wind power plant built by Riva Calzoni at Casone Romano (southern Italy) with ten units supplied by the same firm.

often with some financial support granted by ENEA or the European Union.

In 1996, the operative wind capacity should increase more significantly, taking into account the 20 MW of ENEL's wind power plants still under construction, and the 30-40 MW of the wind power plants that are likely to be set up this year by the Italian Vento Power Corporation (IVPC) jointly with foreign partners in the Apulia and Campania Regions. The Vestas V41 machine has been chosen for these IVPC developments.

IVPC is also monitoring 28 sites by means of wind measuring stations for evaluating wind potential. Other projects of this company totalling about 200 MW have already been declared admissible for verification of compatibility with ENEL's electric system after being submitted to MICA for financial support under CIP Directive No. 6.

As for Italy's total energy production, ±11 GWh were generated by wind power plants during 1995. Till now, it has been very difficult to acquire comprehensive information on energy production and performance of installed wind turbines, given the number of rather small and dispersed plants operated by many different bodies.

Figure 2. The 1.5 MW GAMMA 60 prototype at Alta Nurra. Fine-tuning of the GAMMA project is under way, with a possibility of manufacturing two pre-series units.

3. MANUFACTURING INDUSTRY

There are two companies involved in the manufacturing of wind turbines in Italy: WEST and Riva Calzoni. In the beginning these companies were given technical and financial support by ENEA in developing their prototypes. Additional support was also provided by ENEL during the testing and demonstration of these units.

3.1 West

WEST (Wind Energy System Taranto), formerly belonging to Alenia, has now been taken over by the Ansaldo company of the large Finmeccanica Group. WEST is currently operating in two fields: the design and manufacture of two GAMMA wind turbines in a 2 MW rated pre-series version based on the experience gained on the 1.5 MW prototype (Figure 2), and the supply of several Medit 320 units (rated at 320 kW) to the ENEL utility and to autonomous producers. The number of Medit 320 units sold so far totals about 70. WEST as a sub-contractor to third parties is also producing blades.

WEST has recently decided to enter the domestic market as a plant developer. Up to now, the company has presented MICA and ENEL with wind power projects totalling ±220 MW. The company's policy in this sector also considers the possible use of wind turbines supplied by foreign manufacturers.

3.2 Riva Calzoni

This company has long been involved in the development and manufacture of single-bladed machines of the M30 series, reaching a total production of more than 70 units of different versions. The latest product of this line is the M30-S2 wind turbine, rated at 350 kW. The first M30-S2 unit has been running for eight months at the Casone Romano wind power plant with satisfactory results.

The single-bladed M30-S2 (Figure 3) is a light and flexible machine, suitable for installation even in logistically difficult situations and for running in high-turbulence winds. The machine has a hub height of 33 m and a rotor diameter of 33 m. As compared to the former 250 kW version M30-A, it features a new blade and hub (used on the M30-S1 prototype at

Figure 3. Closer view of the 350 kW M30-S2 machine. This model is the latest issue of Riva Calzoni's single-bladed series.

ENEL's Alta Nurra test field), as well as a new energy conversion system operating at semi-variable speed (high-slip, electronically controlled induction generator).

Riva Calzoni, too, is present on the Italian market as a wind power plant developer. In this field the company has already submitted projects for a total capacity of 125 MW to MICA and the ENEL utility.

In addition to WEST and Riva Calzoni, there are a number of new private wind power plant developers, purposely established companies such as Italian Vento Power Corporation, Energy System, and a number of smaller companies. In several cases, these ventures also include non-Italian partners.

Among the main suppliers of wind turbine sub-systems and components currently on the Italian market, the following firms should be mentioned:

- De Pretto (hub, drive-train shafts, actuators, etc.);
- OTO Meccanica, Flender, Thyssen (gearbox);
- Ansaldo, Marelli (electrical sub-system);
- Siderpali, Simi, Stanisci (tower);
- Stoma (nacelle frame and transport facilities);
- MBB, Atout Vent (blades).

At present there is no wind turbine certification required in Italy. Nevertheless, this need has been recognized by all those involved in the sector (machine manufacturers, plant developers, ENEL and public authorities), who look forward to a national wind turbine certification system being set up in Italy as in other countries of Europe. ENEA, in its position of an independent state agency, has taken on the task of dealing with this matter.

Among the bodies contributing to wind energy development, Conphoebus, an Institute working since the 1980's on renewable energy and energy saving should be mentioned. Conphoebus has been engaged in wind surveys and siting activities within the framework of national and international projects (e.g., JOULE projects sponsored by the European Commission). Conphoebus has also drawn general wind maps for Italy (south of the 44th parallel), applying the simulation model AIOLOS, and has completed the selection of high wind speed areas by using the geo-territorial information system (GIS).

4. ECONOMICS

The utility ENEL sells electricity to final consumers at prices that vary over a rather wide range depending on quite a number of technical and social factors. Roughly speaking, the average selling price to private consumers can be estimated at ±ITL 215/kWh (USD 0.13/kWh), and the average selling price to industrial consumers at ±ITL 125/kWh (USD 0.08/kWh). These are net prices before tax.

CIP Directive No. 6 of April 1992 (see below) has allowed special buying prices for wind-generated electricity fed into the ENEL system. The 1995 rates have been fixed at:

- ITL 173.5/kWh (USD 0.108/kWh) for the first eight years of plant operation (to be lowered to about ITL 135 if a plant were to be granted capital cost subsidies);
- ITL 84.3/kWh (USD 0.053/kWh) for the remaining lifetime.

The latter rate is intended to pay the producer for the cost ENEL would bear in generating the same amount of energy, while the additional amount (i.e., ITL 89.2/kWh, ±USD 0.055/kWh) allowed for the first eight years is intended to help bearing the extra cost of setting up wind energy plants rather than conventional plants.

Since deployment of commercial wind power plants is still in a rather early phase in Italy, it is not yet possible to gather reliable and meaningful figures on such parameters as the invested capital per kilowatt installed, the value of total wind generated energy, unit energy cost, etc. For the same reason, no general information can be given on typical rates of interest applied to financing of wind power installations.

However, some ex-factory prices recently quoted by Italian manufacturers for their industrial products seem to set today's selling price of wind turbines at ±USD 1,000-1,100/kW. Overall plant cost per kilowatt will depend strongly on the site. Most Italian sites are located in rough mountainous terrain, so that "balance of system" costs are likely to be rather high in general.

5. MARKET DEVELOPMENT

Market stimulation instruments were first provided by Law No. 9 and Law No. 10 of January, 9, 1991. Law No. 9 allowed autonomous producers to generate electricity from renewable sources (for self-consumption or for sale to the utility ENEL), while Law No. 10 provided for plant capital cost subsidies. After the first year of application, however, Law No. 10 has no longer been funded. Law No. 10 has, nevertheless, required regional authorities to designate possible areas for renewable energy exploitation.

A much more effective boost has been given by Directive No. 6 issued by CIP (Interministerial Committee for Prices) on April 29, 1992. CIP No. 6 fixed premium prices, to be periodically updated, for wind-generated electricity fed into the ENEL system. The 1995 rates are given in the above section on Economics. With regard to grid-connection charges, the lowest charge for an autonomous producer is 1/3 of the cost (2/3 borne by ENEL). However, it should be pointed out that agreements may also be signed between ENEL and wind energy investors defining special conditions for some commercial aspects.

Regional authorities have recently shown their willingness to consider possible capital cost contributions to wind power plants. The Apulia Region has recently inserted a chapter on wind energy production into its financial program named "Documento Unico Programmatico per i Fondi Strutturali 1994-1999". In this document, investment subsidies for 60 MW wind energy capacity are foreseen. To date, only the 1994-1996 period has been funded with a regional support of ±USD 10 million. Certification of machines is not required. Through this provision, the Apulia Region intends to contribute to wind energy promotion, and to support the economic development of very marginal areas. Also the Umbria Region has approved a similar support to renewable energies within the framework of its program concerning the "Fondi Strutturali". Likewise, the Campania Region is starting similar initiatives and other regions of southern Italy are expected to define their renewable energy policy shortly.

To assure a wider range of financial instruments, ENEA is promoting the involvement of GEPI (Società Gestioni e Partecipazioni Industriali) in the wind energy sector. This financial institution grants investors very favorable loans, thus making up for the absence of bank loans. Banks have just begun to change their attitude towards wind energy technology, so far considered to be a high-risk investment.

These additional support prospects have given further momentum to private investors, who have recently put forward wind power projects totalling 1,140 MW (as of November 15, 1995).

Only a part of this power is likely to be put on line in the next few years, mainly because most projects are planned in the same area, the Apennines in southern Italy, including parts of the Campania, Molise, Apulia and Basilicata regions. Here, existing distribution networks were designed by ENEL for supplying small towns and villages in the countryside, and therefore they need to be substantially reinforced for larger amounts of generating capacity.

In addition to technical limitations, widespread wind power plant development is often confronted with environmental constraints. In general, the most suitable sites are in coastal areas or in the mountains, mainly the Apennines. Both locations may be subject to laws protecting the landscape. Seaside areas have often proved to be difficult to exploit, as they are densely populated, while mountainous sites at high altitudes may present harsh weather conditions during the winter time.

Problems are also caused by the attitude of local residents and authorities, who have sometimes shown to be rather mistrustful towards wind energy projects. The lengthy permit procedures needed by developers is another constraint.

A wind power plant requires a building permit from the municipality as any other building. No local planning regulations make reference to wind turbines, and municipalities often had difficulty in handling these procedures. In many cases, a municipality is also obliged to obtain the agreement of a number of other authorities, such as the regional government. Further difficulties may be encountered in acquiring the land, as the estate often may have several owners.

Wind power plants are not included in the Italian law governing the Assessment of Environmental Impact (VIA). The regional governments require only a visual impact study for wind power plants. However, some plant developers, such as ENEL, have undertaken environmental compatibility studies to look into all aspects of the matter; i.e., characteristics of the former environment, local physical planning, land use and human activities, general ecosystem, flora and fauna, bird life, landscape, noise, e.m. interference (this study has been described in the paper "Insertion of wind farms into the environment: the Monte Arci Plant" by B. Bellomo, presented at the Italian-German Conference held in Brescia, Italy, in June 1995).

There are laws in Italy which impose limits on acoustic emissions, but they are difficult to enforce, the more so for wind power plants. As a precaution, some plant developers have set limits on their own; for example, ENEL has fixed a provisional noise emission limit for its wind turbines (65 dB[A] measured according to the IEA Recommended Practices, as well as a minimum distance [at least 100 m] between wind turbines and the main public roads).

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

For several years now, wind energy has been an option to be considered viable for inclusion into the mix of sources used for electricity production. Under the coordination of the government (acting through the Ministry of Industry, Commerce and Trade - MICA), the state agency ENEA and the state utility ENEL have been developing a number of projects, some of which have seen a close cooperation between the two bodies and industry. These activities have included wind surveys (a total of over 200 wind measuring stations have been set up so far), the development and testing of wind turbine prototypes and the construction of demonstration plants.

ENEA's R,D&D Program

ENEA has been actively involved in the assessment of wind potential as well in the promotion and development of wind technology both on the side of offer and demand. The technical and financial collaboration provided to industrial companies led to the development of three prototypes; i.e., the medium-sized machines Medit and M30 (made by WEST and Riva Calzoni, respectively), and the large machine GAMMA 60 built by WEST.

More recently, a revision of the strategy in this field brought ENEA to reach an agreement with MICA aiming at increasing the dissemination of wind power plants in Italy. The activities under this agreement are organized in three annual plans over the period 1994-1996 and are coordinated with those of ENEL and industry.

In these plans three main areas have been specified:

- certification of wind turbines;
- siting;
- technology improvement.

ENEA's certification activities are in progress. A site has been chosen in Sardinia for testing wind turbines; from here, data will be directly transmitted to the ENEA Casaccia Centre near Rome. A wind tunnel to be used for certification has also been designed including the necessary infrastructures.

The characterization of four sites located in the Teramo province started in November 1995; also in this case, wind data will be transmitted to the ENEA Casaccia Centre by a remote system. Consideration is also given to possible offshore siting of wind power plants. ENEA, the Bologna University and Conphoebus are involved in evaluating a few potential offshore sites in Sardinia and Sicily. In addition, ENEA, jointly with

ESRIN (an ESA company), is planning to set up a Mediterranean or European atlas reporting wind and wave data. Additional activities are aimed at promoting and organizing international workshops dealing with offshore siting issues; the next one will be held on La Maddalena island (near Sardinia) in the Spring of 1997.

The technology development activities in 1995 have mainly concentrated on the characterization and design review of the large-sized, yaw-controlled, variable-speed GAMMA machine. The first step has been the evaluation of the performance of the 1.5 MW GAMMA 60 prototype at Alta Nurra by an ENEA-ENEL-WEST working group after the accident which occurred last May (see below under ENEL's activities), a verification and revision of the safety and control system of the machine was carried out. During 1996, work is foreseen on the fine-tuning of the GAMMA project in view of the possible construction of two pre-series units rated at 2 MW.

With regard to international collaborations, ENEA has been working on the development and testing of a 5 kW wind system for electrolytic hydrogen production, in cooperation with Rutherford Appleton Laboratory and the University of Leicester of the United Kingdom and the German Institute DLR. This JOULE sponsored project will be completed by 1996.

The financial resources allocated to 1995 activities under the ENEA-MICA Wind Energy Agreement have been the same as in 1994; i.e., USD 4.18 million. Priorities have been given to the same activities as in 1994.

ENEL's R,D&D program

Testing of wind turbines has continued at the Alta Nurra plant run by ENEL in Sardinia. Four medium-sized units plus the 1.5 MW GAMMA 60 prototype, with a total power of about 2.7 MW, have been in operation, even though a few of them have suffered some outages. The 1995 production of the Alta Nurra machines totalled ±865 MWh.

With regard to medium-sized machines, experiments have focused mainly on full characterization of the single-bladed M30-S1 prototype made by Riva Calzoni; special attention has been given to the new blade and hub, which has served as a test case for the new industrial model M30-S2.

ENEL has co-operated with ENEA and WEST on the characterization of the 1.5 MW GAMMA 60 prototype. Unfortunately, in May 1995, a fire broke out in the machine. At that time, the machine had nearly completed commissioning tests and measurements. In spite of this setback, the joint working group drafted a full report on all testing aspects. Repair work on GAMMA 60 started in October 1995. The prototype is expected to be put back into operation in July 1996. In 1996, ENEL and ENEA will have to make a decision on the possible continuation of the GAMMA project: this would require the construction of a plant with two GAMMA units rated at 2 MW.

ENEL's Acqua Spruzza test site near Frosolone in Molise (1,360 m above sea level) was formally inaugurated in June 1995. Here, six of the eight wind turbines (totalling nearly 2,5 kW) have been in operation during the year. At the end of 1995, overall energy production was ±2,500 MWh (200 MWh in 1994 and 2,300 MWh in 1995). As pointed out in previous reports, the main purpose of this plant (Figures 4 and 5) is to check the behavior of wind turbines under harsh

Figure 4. View of ENEL's Acqua Spruzza test site in the Apennines (1,360 m above sea level) after a snowfall, with three of the eight machines.

winter conditions, to ascertain the technical and economic feasibility of wind power plants at high-altitude mountainous terrains.

As for ENEL's wind power projects, all machine foundations and towers of the 11 MW Monte Arci plant in Sardinia have been completed, along with the electrical and civil engineering infrastructures. Only four of the 34 Medit 320 wind turbines supplied by WEST will be erected in January 1996, mainly on account of unexpected problems raised by local authorities. After a period of preliminary demonstration, the remaining units should hopefully be erected from mid-1996 onwards. Normal operation of the plant is expected to start in 1997.

Construction work has started on ENEL's second wind power plant located at Collarmele. The plant will consist of 36 machines supplied by Riva Calzoni, for a total capacity of 9 MW. Specifically, 35 machines will be of the 250 kW M30-A model and one new 350 kW M30-S2 machine. Ongoing work concerns the first 27 units. Work on the second lot of nine units, which have been shifted to a more distant location in the same area upon request from the municipality, is expected to start shortly. The plant should be completed by the end of 1996.

During 1995, ENEL has continued wind surveys and micrositing activities, which have so far led to installation of more than 150 wind stations in several regions of Italy. This sector has often seen a close cooperation with Conphoebus (see above). The aim of ENEL is to single out a number of wind sites, for which all technical, environmental and institutional conditions have also been ascertained, suitable for the construction of wind power plants.

Figure 5. Operation of the Acqua Spruzza test site shows a very good compatibility with the former use of the area as pasture land.

ENEL has been involved in a number of international projects mainly under the sponsorship of the European Commission. These projects have seen collaborations with universities, research institutes and other utilities (e.g., those participating in the EURE utility wind farm program).

The expenditure borne by ENEL for wind energy activities in 1995 has totalled ±USD 19 million. This amount has been less than was budgeted in the 1994 Annual Report because of unexpected delays in completing some activities. The wind energy budget for 1996 is ±USD 14.5 million.

JAPAN

1. GOVERNMENT PROGRAMS

1.1. Research and development

Since 1978, the Japanese wind energy R&D program, which is part of the general R&D program for renewable energy called New Sunshine Project, has been directed by the New Sunshine Program Promotion Headquarters (NSS H.Q.) in the Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI).

The New Sunshine Project for wind energy has conducted the following activities:

- wind resource measurement;
- R&D of large-scale wind turbine generator system (LS-WTGS);
- demonstration of a MW-class wind power plant;
- R&D for basic, innovative and environmental technologies.

The New Energy and Industrial Technology Development Organization (NEDO) carried out the first three, while the last one is undertaken by the Mechanical Engineering Laboratory (MEL) and the National Institute for Resources and Environment (NIRE). Both belong to AIST - MITI and support the first three activities mainly through technology evaluation (see Tables 1,2).

Wind atlas

Using the nation-wide network for local meteorological observations called AMEDAS with about 1,000 stations in Japan, NEDO has measured wind characteristics at selected sites since 1983. In 1994, NEDO completed a new wind data base for wind energy development which covers the data at 737 stations from the AMEDAS network and those at 38 NEDO locations. In total, data from 964 stations were analyzed.

The wind atlas for Japan was published by NEDO in 1995. The wind energy potential in Japan was also calculated. Three scenarios were considered in the analysis according to different restricting factors for wind power plant construction. A common condition was that the area's annual wind speed is > 5 m/s at 30 m height above the ground. Calculations of wind generation were given assuming that only one kind of WTGS of 500 kW rated power is applied. The numerical

Table 1. Wind energy activities in Japan

ACTIVITIES	ORGANIZATION/INSTITUTE
NATIONAL	
New Sunshine Project	NSS-H.Q.
1. Wind resource measurement	NEDO
2. R&D of LS-WTGS (500 kw)	NEDO/MHI/Tohoku EPC
3. Demonstration of a MW-class wind power plant	NSS/NEDO/Okinawa EPC
4. Basic, innovative research:	
WINDMEL-I, wind/diesel	MEL
WINDMEL-II, etc.	MEL
Wind anaylsis	NIRE
Field test project	MITI/NEDO
Standard (IEC, ISO, JIS)	MITI/MEL/industries/universities
INDUSTRIAL	Industries/local authorities

Table 2. Budget for wind energy in the New Sunshine Project in millions of Japanese Yen (JPY)

YEAR	1991	1992	1993	1994
NSS project	549	981	982	744

results are shown in Table 3. The minimum and maximum values correspond to the array condition of the wind power plant of 10D x 10D and 10D x 3D respectively, where D is the diameter of the WTGS.

R&D of LS-WTGS

After completion of the 100 kW pilot plant in 1986, and further research for a large-scale wind turbine, a new R&D program to develop a 500 kW-class wind turbine prototype was initiated in 1990. Conceptual design of the 500 kW prototype was completed in FY 1992. It has a three-bladed 38 m diameter rotor mounted to a rigid hub. Detailed specification of this machine is shown in Table 4.

In FY 1994 and 1995, some components of the 500 kW wind turbine were tested by Mitsubishi Heavy Industry Ltd. (MHI). A full scale fatigue test of the rotor blades was carried out to verify the blade design. Noise measurements of nacelle assembly including gear box and modal analysis of the nacelle cover by FEM were undertaken. The field test of the machine will start in 1996.

Demonstration of a MW-class wind power plant (Miyako project)

An experimental MW-class wind power plant (1.7 MW) was completed in October 1995 on Miyako Island in Okinawa. The wind power plant consists of two units of MHI 250 kW WTGS and three units of MICON 400/100 kW WTGS. The purpose of the Miyako project is to demonstrate the availability of wind energy on such islands where the grid capacity is not large. The operation is shown in Table 5, which shows the highest recorded capacity factor in Japan. In December 1994, the monthly capacity factor of two MHI-units was 53.2%.

R&D for basic, innovative and environmental technologies

Since 1978, MEL has been carrying out research of basic aspects of rotor aerodynamics, structural dynamics, vibration, wind/diesel system and acoustic noise, etc. MEL has developed and has been operating a two-bladed variable speed soft designed 15 kW experimental wind turbine (WINDMEL-I). Based on the experience with this machine, a new experimental machine,

Table 3. Wind energy potential in Japan

SCENARIO	AREA km^2 (ratio of total land surface in %)	POTENTIAL NUMBER OF UNITS	POTENTIAL CAPACITY MW (ratio in %)	POTENTIAL WIND GENERATION GW (ratio of total generation in %)
1	23,280 (6.4%)	125,519 – 465,278	—	—
2	3,599 (1%)	18,430 – 70,481	9,220 – 35,240 (4.61 – 17.62%)	8,916 – 34,127 (1 – 3.84%)
3	758 (0.2%)	2,792 – 13,743	1,440 – 6,870 (0.7 – 3.43%)	1,325 – 6,537 (0.15 – 0.74%)

Table 4. Specification of the 500 kW wind turbine

PERFORMANCE	Rated output	500 kW
	Cut-in wind speed	5.5 m/s
	Rated wind speed	12.5 m/s
	Cut-out wind speed	24 m/s
ROTOR	Orientation	Upwind
	Hub	Rigid
	Number of blades	Three
	Tilt angle	5 degrees
	Corn angle	0 degrees
	Diameter	38 m
	Rotational speed	32 rpm
BLADE	Airfoil section	NASA LS(1)-04XX
	Length	18.25 m
	Material	GFRP
TRANSMISSION	Type	Two-stage planetary
	Nominal power	500 kW
	Input speed	32 rpm
	Output speed	1500 rpm
GENERATOR	Type	Induction (4 poles)
	Rated output	550 kW
	Grid connection	AC-link
CONTROL	Pitch	Mechanical/hydraulic
	Yaw	Mechanical/motor
TOWER	Type	Rigid, taper, monopole

WINDMEL-II, was installed in March 1994 in order to compare aerodynamic performance and mechanical strength between advanced concepts and traditional concepts. This machine has a variety of options, such as teetered/rigid hub, constant/variable speed, etc. Recent operation data show not only that the advanced concept decreases mechanical stress, especially fluctuation of torque remarkably, but it decreases also fluctuation of power output. This suggests such an advanced technology is quite suitable for the WTGS to be used in hilly terrain where turbulence intensity is very high and the problem of fatigue is one of the main design factors. Furthermore, the variable speed operation improves the power quality.

NIRE is carrying out research to develop methods for numerical prediction of wind characteristics in complex terrain.

1.2. Field test project

To attain the national decision for a new energy policy, in which wind energy shall be promoted up to 150 MW capacity by the year 2010, the national NEDO's field test project was started in 1995. In this project, subsidies from the government will be available for those who are interested in developing wind power plants.

Table 5. Operational data of the Miyako wind power plant (two units of 250 kW)

FY/YEAR MONTH	WIND SPEED (m/s)	ANNUAL/ MONTHLY GENERATION (MWh)	ACCUMULATIVE GENERATION (MWh)	CAPACITY FACTOR (%)
FY 1991	8.0	6.9	6.9	1.9
FY 1992	8.0	541.5	548.4	24.7
FY 1993	7.6	1204.7	548.4	27.5
FY 1994	7.7	1321.3	3074.3	30.2
FY 1995	—	—	—	—
1995 JAN	8.6	166.5	—	44.8
1995 FEB	8.4	146.4	—	43.6
1995 MAR	8.3	135.0	—	36.3
1995 APR	6.1	98.0	3172.3	27.2
1995 MAY	4.7	85.8	3258.1	23.1
1995 JUN	5.1	113.5	3371.6	31.5
1995 JUL	5.1	83.6	3455.2	22.5
1995 AUG	5.1	39.5	3494.7	10.6
1995 SEP	6.8	82.0	3576.7	22.8
1995 OCT	8.5	129.5	3706.2	34.8
1995 NOV	9.1	146.6	3852.8	40.7
1995 DEC	—	135.6	3988.4	36.5
1995 ANNUAL	6.9	1362.0	3988.4	31.1

In the first year, meteorological measurements shall be undertaken funded by a 100% governmental subsidy. When the measured data show the site is suitable, the most appropriate wind generation system will be designed in the second year with a subsidy up to 50% of the investment. In the third year, the wind power plant will be constructed with again a 50% subsidy.

In 1995, seven candidates were selected for meteorological measurements, while two candidates were chosen for system design.

1.3. IEC standard

The national programs also include the cooperation in IEC Standard of safety requirements for WTGS. MITI prepares the Japanese standard (JIS) according to the international standards.

2. NATIONAL STATISTICS

2.1. Installed capacity

In 1995, 3,800 kW (13 units) were installed. The total capacity at the end of 1995 is nearly 10 MW with 54 units as shown in Table 6. Figure 1 shows Tappi wind power plant where five units of

Table 6. Installation of WTGS in Japan

YEAR	INSTALLED CAPACITY kW	TOTAL CAPACITY kW	NUMBER OF INSTALLED UNITS	TOTAL NUMBER OF UNITS
Before 1990	291.5	291.5	10	10
1990	633.0	924.5	5	15
1991	2625.0	3049.5	8	23
1992	33.0	3082.5	2	25
1993	1800.0	4882.5	9	34
1994	891.0	5773.7	7	41
1995	3800.0	9573.5	13	54

MHI 300 kW machines wre installed in 1995.

2.2. Machine details

A list of WTGS in Japan is shown in Table 7.

2.3. Performance and operational experience

There are not enough statistical data to discuss the performance and operational experience. Table 8 shows performance data of WTGS which indicate typical operational experiments. At high wind speed terrains some values of capacity factors higher than 30% were recorded. Siting is very important. Some developers constructed WTGS at their site where the annual mean wind speed does not comply with the rated power of the WTGS. However, the new field test project will solve this problem.

3. CONSTRAINTS ON MARKET DEVELOPMENT

3.1. Environmental impact

So far, no significant environmental problem has occurred. One of the reasons

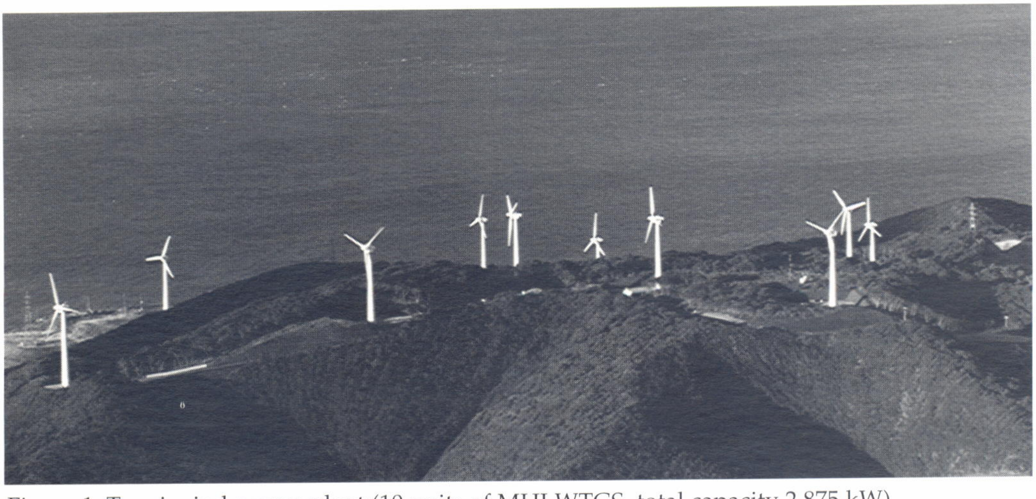

Figure 1. Tappi wind power plant (10 units of MHI WTGS, total capacity 2,875 kW).

Table 7. List of wind turbine generator systems in Japan

OPERATION	OWNER	LOCATION	MACHINE	RATED POWER kW	ROTOR DIAMETER	NO. OF UNITS m	CAPACITY kW	PURPOSE
1985-	MHI	Nagasaki	MHI	250	25	1	250	R&D
1987-	SS/MEL	Tsukuba	WINDMEL-1 (Yamaha)	15	15	1	15	R&D (SS Project)
1989-	Suttsu-machi	Suttsu	Yamaha	16.5	15	5	82.5	Power Supply
1989-	Kansai EPC	Oeyama	Sumitomo	10	7.5	2	20	R&D
1990-	Kyushu EPC	Koshiki Isl.	MHI	250	28	1	250	Demo
1990-	MHI	Nagasaki	MHI	250	28	1	250	R&D
1990-	NEDO/Kansai EPC	Rokkou Isl.	Yamaha	16.5	15	2	33	R&D
1990-	Seto-cho	Seto-cho	MHI	100	28	1	100	Demo
1991-	NSS/NEDO/ Okinawa EPC	Miyako Isl.	MHI	250	28	2	500	R&D (NSS Project)
1991-	Tohoku EPC	Tappi	MHI	275	28	5	1375	Demo
1991-	Chubu EPC	Hekinan	MHI	250	28	1	250	Demo
1992-	Izumo-shi	Izumo-shi	Yamaha	16.5	15	2	33	Power Supply
1993-	Tachikawa-machi	Tachikawa	USW	100	18	3	300	Power Supply
1993-	Toyko EPC	Futtsu	IHI	300	30	1	300	Demo
1993-	Mattso-shi	Matto-shi	Micon	100	20	1	100	Demo
1993-	Hokkaido EPC	Tomari-mura	MHI	275	28	2	1100	Demo
			IHI	300	30	1		Demo
			R.C.	250	33	1		Demo
1994-	Tohoku EPC	Onagawa	Yamaha	16.5	15	1	16.5	Demo
1994-	Hokuriku EPC	Mikuni-shi	Yamaha	16.5	15	1	16.5	Demo
1994-	Hokuriku EPC	Shiga-machi	MHI	275	28	1	275	Demo

Table 7. List of wind turbine generator systems in Japan (continued)

OPERATION	OWNER	LOCATION	MACHINE	RATED POWER kW	ROTOR DIAMETER	NO. OF UNITS m	CAPACITY kW	PURPOSE
1994-	Shikoku EPC	Murotomisaki	MHI	300	29	1	300	Demoaki
1994-	Mikamo-mura	Mikamo	Yamaha	16.5	15	1	16.5	Demo
1994-	Yamaha	Gamagori	Yamaha	16.5	15	1	16.5	R&D
1994-	NSS/MEL	Tsukuba	WINDMEL-II	16.5	15	1	16.5	R&D (NSS Project)
1994-	Kantoukokusai School	Katsuura	Micon	250/50	27.6	1	250	Power Supply
1995-	Noichi-machi	Kochi-ken	Micon	250	27.6	1	250	Power Supply
1995-	Kansai EPC	Okutataraki	Nordex	150/30	27	1	150	Power Supply
1995-	Tohoku EPC	Tappu	MHI	300	29	5	1500	Power Supply
1995-	NSS/NEDO Okinawa EPC	Miyako	Micon	400/100	311	3	1200	R&D (NSS Project)
1995-	Heiwa-Kanko	Fukushimaq	Micon	225	29.6	2	450	Power Supply
(1996-	NSS/NEDO	Tappi	MHI	500	38	1	500	R&D (NSS Project))

SS=Sunshine, NSS=New Sunshine, NEDO=New Energy & Industrial Technology Development Organization, MEL=Mechanical Engineering Laboratory, EPC=Electric Power Company, MHI-Mitsubishi Heavy Industries Co.

Table 8. Performance of WTGS in Japan

OWNER (Site)	IN 1995 G (kW)	CF (%)	V (m/s)	ACCUMULATIVE G (kW)	CF (%)	V (m/s)
Tohoku Tappi #1	2422	20.1	6.0	9859	20.5	6.3
Tohoku Tappi #2	1043	31.6	8.8	—	—	—
Miyako #1	1362	31.1	6.9	3988	—	—
Kyushu EPC	456	20.8	6.2	2554	20.1	6.3
Tachikawa	139	5.3	4.5	506	6.9	4.7
Suttsu	57	7.8	3.2	227	—	3.5
Mattso-shi	125	14.3	—	211	19.2	—
Kantokokusai	114	5.2	—	344	6.2	—
Yamaha	15	15.9	4.2	—	—	—

G=Generation, CF=Capacity Factor, V=Annual Mean Wind Speed
Tappi#1=First 5 units of MHI 275 kW WTGS, Tappi #2=New 5 units of MHI 300 kW WTGS,
Miyako #1=First 2 units of MHI 250 kW WTGS

is that the history of the wind power plant development is very young. Once a complaint was heard at the Tappi wind power plant, but is was solved by a sound proof construction. Bird life was observed at Tappi by Tohoku EPC; no birdkill by the WTGS was reported. Migratory birds recognize the rotating blades and avoid the turbines.

3.2. Institutional impact

The most important changes in electricity regulations were made in 1992. As a result, reverse current to the power grid was permitted for the first time, which created the way of actual utilization of grid-connected WTGS. As shown in Table 7, wind energy became more and more interesting. The price of electricity from wind energy is decided by negotiations between the owner and the utilities. On average, the price is approximately JPY 15-20/kWh.

4. ECONOMICS

4.1. Economics and subsidies

Statistics are not available to evaluate the economics of wind energy in Japan, because only a few wind power plants can provide information. However, a few owners computed the cost of energy to be over JPY 30/kWh.

5. INDUSTRY

5.1. Market development

The publication of the wind atlas and the new field test project will promote the development of the wind energy market.

5.2. Manufacturing

The main information can be obtained from Table 7.

6. INTERNATIONAL COLLABORATION

The main activities are the IEA Wind R&D cooperation and IEC standards of WTGS. Many individual international collaborations are undertaken at research institutes and universities.

THE NETHERLANDS

1 GOVERNMENT PROGRAMS

1.1. Aims and Objectives

The energy policy of the Netherlands is integrated in its environmental policy. Reducing CO_2 emission is one of the key objectives. The Ministry of Economic Affairs has set new targets for energy conservation and renewable energy in the Third Energy Memorandum issued in December 1995. The goal for renewables has been raised from a 3% contribution in 2000 to a 10% contribution from renewables in 2020. The targets have been set in annual saving of fossil fuels in petajoules (see Table 1). Renewables will mainly contribute to the electricity production. Diversifying energy supplies and a healthy wind turbine industry is part of the objectives.

1.2. Strategy

Various instruments are being used in order to meet these objectives. The ongoing government R,D&D program is contributing to industrial and technical development of wind turbines and blades. The Third Energy Memorandum proposes extra budgets for research and market introduction of new technologies starting in 1997. For market stimulation there is a variety of instruments consisting of tax incentives, a newly introduced CO_2 tax by January 1, 1996, and an agreement with the electricity distribution companies to buy electricity from renewables for a fixed price.

1.3. Targets

The national target for wind energy translates in a needed installed capacity of about 1,000 MW by the year 2000; 2,000 MW by the year 2007, and 2,800 MW in 2020. For the period 1996-2000, the target is an annual installed capacity of 100 MW at "traditional" sites.

Table 1. Contribution of renewables to annual savings on fossil fuels

RENEWABLE ENERGY SOURCE	ANNUAL SAVINGS ON FOSSIL FUELS Aimed Contribution in PJ				AVOIDED EMISSIONS CO_2 [kton]	NO_x/SO_2 106 ae*
	2000	2007	2020	1995	1995	1995
WIND ENERGY	16	33	45	2.9	205	15
SOLAR ENERGY PV	1	2	10	0.5	50	5
SOLAR ENERGY THERMAL	2	5	10	0.5	29	1
HYDRO POWER	1	3	3	1.0	70	5
BIOMASS (incl. waste)	54	85	120	40.0	2,368	1
TOTAL	74	128	188	44.9	2,718	29

* acid equivalents

Table 2. Installed capacity, swept area, number of turbines, 1986-1995

WIND ENERGY Year End	INSTALLED CAPACITY Accum. Total	Annual	SWEPT AREA Total	Increase	NO. OF TURBINES Total	Increase
December 31	[MW]	[MW]	[m^2]	[m^2]	[–]	[–]
1986	7	0			138	0
1987	16	9			168	30
1988	22	6			223	55
1989	33	11			255	32
1990	49	16			318	63
1991	82	33			426	108
1992	105	23			510	84
1993	132	27			636	126
1994	154	22	328.311		729	93
1995	248	94	375.750	47.439	984	255

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed wind capacity

The installed capacity of wind turbines in 1995 was about 100 MW, bringing the total installed capacity per December 31, 1995 to about 250 MW (see Table 2).

2.2. Installed conventional capacity

National capacity in 1995 was about 13,000 MW. Total installed capacity of wind turbines is 248.7 MW, which is 1.9% of the national capacity.

2.3. Numbers/type, make of turbines

There were 255 machines installed in 1995 bringing the total to 984 machines. Half of the installed capacity in 1995 was from turbines manufactured in the Netherlands, the rest from turbines produced in Denmark, the United States and Germany.

2.4. Plant types and form of plant ownership

The following types of owners/operators are operating wind turbines:

- utilities;
- public private partnerships; e.g., limited company with distribution utility, developer and bank;
- industries; e.g., industry in good wind speed sites with a large electricity consumption;
- farmers;
- farmers joining forces in limited companies or partnerships to exploit wind turbines on their property;
- cooperatives in which individuals, farmers, local authorities, or building societies share one or more wind turbines;
- associations;
- limited companies of developers with wind turbine manufacturer.

2.5. Performance of installed plant

During 1995, electricity production from wind energy was 377 GWh. The total for 1986-1995 is 1,102 GWh. Details for all years are given in Table 3. Annual production of national electricity usage in 1993 was 70.740 GWh. About 70 MW of the total installed capacity of 250 MW came on line in the last two months of 1995. These 250 MW could produce 460 GWh and avoid 4 PJ annually.

Table 3. Electricity production, avoided fuel and avoided emissions 1986-1995

WIND ENERGY	ELECTRICITY PRODUCTION			AVOIDED FUEL		AVOIDED EMISSIONS			
Year End	Total	Increase	Accum. Total	Primary	CH_4	CO_2	NO_x	SO_x	dust
December 31	GWh	GWh	GWh	PJ	Mm^3	kton	ton	ton	ton
1986	7	0	7						
1987	16	9	23						
1988	26	10	49						
1989	26	0	75						
1990	55	29	130						
1991	72	17	202						
1992	145	73	347						
1993	165	20	512	1,4	45	109	155	30	4
1994	251	86	763	2,2	68	166	236	45	6
1995	337	86	1,100	2,9	91	252	359	69	9

Performance indicators are shown in Table 4. Availability during 1994 was more than 95%.

2.6. Operational experience

Electrical network effects have been studied through an inventory of the weak grid structure in the province of Friesland and the effects on future installed capacity. Solutions are sought by relocating plans for turbines in groups and agreements between turbine owners and distribution utilities to share the cost of the new electrical infrastructure.

Table 4. Windex, specific production, load and capacity factors 1988-1994

PERFORMANCE INDICATORS				
YEAR END	WINDEX	SPECIFIC PRODUCTION	LOAD FACTOR	CAPACITY FACTOR
December 31	%	kWh/m^2	h	%
1988	100	825	1,554	18%
1989	83	652	1,263	14%
1990	98	724	1,441	16%
1991	80	792	1,558	18%
1992	93	858	1,619	18%
1993	87	829	1,553	18%
1994	94	838	1,664	19%
1995	96	851	n/a	n/a

3. MANUFACTURING INDUSTRY

3.1. Status/number/sales of manufacturers

The Dutch wind turbine manufacturers doubled their turnover from NLG 74 million in 1994 to NLG 150 million in 1995. Half of this turnover came from exports.

3.2. Warranties

Usually manufacturers give a warranty of two to five years on their products depending on price and contract negotiations. Warranties can be required in several ways. Sometimes a warranty is requested on the P(v)-curve. In other cases, a warranty is required for the amount of electricity delivered to the grid. Some investor operators demand warranties on specific components; e.g., blades, gearbox, generator.

3.3. New products/technical developments

NedWind has certified its 55 m/1000 kW turbine and the three-bladed NedWind 30 m/250 kW. Type certificate of the two-bladed 30 m/250 kW version has been finished. The performance tests, a.o. P(v)-curve and loads, were performed in Palm Springs, California. The first of a two-bladed version Nedwind 43.3 m/500 kW machine has been built and certified in Germany. Performance tests included noise and grid compliance measurements.

Lagerwey has certified its 27 m/250 kW turbine. The prototype of the 30 m/250 kW has been certified. Construction of the prototype Lagerwey 45 m/750 kW turbine is scheduled for February 1996. It will be a variable speed, direct-drive, three-bladed machine; each blade will be separately pitch-controlled. Certification is expected in March 1996.

WindMaster has certified its 43 m/750 kW turbine.

3.4. Business developments

Lagerwey started a joint venture in India for local assembly and manufacturing of towers. NedWind also initiated a joint venture, called Windia, in India for the same purpose. WindMaster Netherlands took over part of the activities for the 300 kW/27 m machine from the bankrupt WindMaster Belgium.

3.5. Support industries

Dutch blade manufacturers increased their turnover from NLG 27 million in 1994 to NLG 38 million in 1995. Aerpac started using new blade manufacturing facilities of 8,000 m^2. Their turnover in 1995 was NLG 25 million. Capacity is now 600 blades per year with 140 people employed.

3.6. Certification

To be eligible for tax incentives like Green Funds and WAMIL (free amortization of investment for wind turbines), turbines need to be certified according to NEN 6069/2 or later versions as they appear. Sometimes additional requirements are asked for special customers or projects.

4. ECONOMICS

4.1. Electricity prices

The Association of Energy Distribution Companies, EnergieNed, has reached an agreement with the Association of Privately Owned Wind Turbine Operators, PAWEX, to pay NLG 0.163/kWh for wind electricity. This holds for projects of up to 2 MW capacity for which no government subsidies have been granted and for a period of ten years. The price is composed of the standard payback rate plus a CO_2 tax and a contribution from the utilities' environmental action plan fund, the latter paid for by a small levy on electricity consumption (see Table 5).

4.2. Turbine/project/generation costs

In 1994, the typical project cost was ranging from NLG 900-1,200/m^2 installed, for a wind power plant, and NLG 800-1,000/m^2 for stand alone turbines. Turbine costs were about 70% of project costs. Generating costs show a decrease of 30% in the years 1991-1995. This is due to a decrease in investment costs, improved production methods and the effects of the "economy of scale" and competition. Also, there is a marked improvement in the performance of wind turbines. Technological developments have led to improved P(v) curves and a higher reliability.

Generating costs for 1994 ranged from NLG 0.15 to NLG 0.09/kWh with 6 to 7 m/s average wind speed for stand-alone turbines. They are typical NLG 0.15/kWh at 7 m/s wind speed for wind power plants. The higher specific costs for wind power plants are due to the fact that they require more electrical infrastructure than individual turbines. Stand-alone turbines are usually connected to the grid close to existing infrastructure with sufficient grid capacity; e.g., farms and plants.

4.3. Invested capital and value of generated power

Total invested capital at the end of 1993 at 132 MW was NLG 320 million. Based on the average of NLG 2,425 per installed kW, the calculated value at a total capacity at the end of 1994 of 154 MW is NLG 373 million, and at the end of 1995 at 248 MW is NLG 601 million. Invested capital during 1995, assuming the same per kW and an installed capacity of 94 MW, is NLG 228 million.

The value of the total wind-generated electricity during 1986-1995 of 1,110 GWh at an average payback rate of NLG 0.12/kWh was NLG 132 million. The value of wind-generated electricity during 1995 at 337 GWh and an average payback rate of NLG 0.12/kWh was NLG 40 million.

4.4. Interest rates

In 1995, interest rates came down about 1% since 1994. Interest rates depend on the way capital is secured. Farmers increase their mortgage with banks, the security is their farm, equipment, etc. Interest rates of 6%-8% are typical. When the wind turbine or wind power plant is the security, e.g., in the case of private developers, interest rates of around 9% are normal. Utilities usually use public funds and long depreciation times (20-30 years) and calculate with interest rates of 5% .

5. MARKET DEVELOPMENT

5.1. Market stimulation instruments

In 1996, there will be no investment subsidies but a variety of financial instruments and incentives. There are now two, by the Ministry of Finance recognized, "Green Funds". They can invest in green projects such as wind energy. Profits from these funds are exempted from income tax. The estimated effect is a reduction of interest rates on capital of 1.5%. In a first call for capital about NLG 500 million was collected from private investors within a week. Also under a provision of the Ministry of

Table 5. CO_2 tax in the Netherlands on fuels and electricity; VAT not included, 1996-1998

		TAX IN NLG PER UNIT*			UNITS TAXED	
ENERGY TYPE	UNIT	1996	1997	1998	Minimum	Maximum
Electricity	kWh	0.0295	0.0295	0.0295	800	50,000
Natural gas	m^3	0.0320	0.0640	0.0953	800	170,000
Liquid petroleum gas	kg	0.0336	0.0672	0.1009	—	—
Medium heavy oil	liter	0.0282	0.0564	0.0846	—	—
Gas oil	liter	0.0284	0.0568	0.0853	—	—

*Value added tax is 17.5%

Finance, companies will be allowed to randomly amortize environmental investments; e.g., profit making companies can write off the investment in a wind power plant in one fiscal year.

In December 1995, legislation was approved by Parliament for a CO_2 tax (regulatory energy tax) for small consumers. The CO_2 tax is on natural gas, medium heavy oil, gas oil, and liquid petroleum gas (LPG). Renewables are exempted from this tax. Also exempted are transport fuels. For electricity, the tax is NLG 0.0345 per kWh (including VAT) in 1996, 1997 and 1998 for a maximum consumption of 50,000 kWh/year, but the first 800 kWh are not taxed. The electricity companies are obliged to pay back the tax for wind-generated electricity.

5.2. Constraints

Presently, the main constraint is the availability of enough suitable sites for a continuous growth of around 100 MW of installed capacity per year until the year 2000. Provincial and local planning procedures are the bottlenecks. The transition from investment subsidies to tax incentives creates a disturbance in the market. The environmental targets of the distribution utilities for wind energy were decreased. There is no agreement between distribution utilities and owners of wind turbines for wind projects with a higher installed capacity than 2 MW.

5.3. Institutional factors

NOVEM has now set up six groups of regional wind energy experts who will assist local authorities with their specific know-how on planning issues. Typically these experts have specific experience with wind turbines and are local planners, representatives from utilities, bird societies, environmental groups, owners of wind turbines and people living in the vicinity of a recently installed wind power plant.

There are as yet no uniform rules at a local level for wind turbines; e.g., permitted tower heights, acceptable noise levels, distance to residential housing requirements for building and environmental permits.

5.4. Environmental impact

In 1995, a bird migratory study was started using radar for tracking bird flights at night. Results of this study are not known yet.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

6.1. Funding levels

Allocated funds for all R,D&D in the Netherlands during 1991-1996 amounted to NLG 66 million. The 1991-1995 TWIN program administered by NOVEM is now followed by the 1996-2000 program. In 1996, a slight increase in the budget has been effectuated. Levels of funding for R,D&D are expected to rise both for the TWIN program and the ECN and TUD program for the period of 1997-2000 (see Table 6).

6.2. Priorities

The priorities and focal points have been derived from the priorities for industrial product development and the objectives for general research.

The main subjects in R&D (TWIN program) are:

- further research in rotor aerodynamics, especially dynamic and 3-D effects and development of engineering rules;
- design tools for rotor development, a.o. buckling and optimization through cost routines;
- inventory of extreme wind conditions from existing wind data;
- reduction in noise emission, a.o. through design and field tests of rotor blades with serrated trailing edges, and empirical research in which serrated trailing edges and tip shapes will be tested in a wind tunnel and

on a research turbine through participation in a JOULE III project;

- standards and certification;
- design and construction of a lightweight turbine prototype based on Flexhat research.

6.3. New concepts

As a follow-up of the Flexhat research, the design and testing continued in 1994. In 1995, a feasibility study was finished. In 1996, design will be concluded and a prototype will be built in 1997. This Nedflex prototype will be based on a tower and nacelle of the NedWind 30 m/250 kW machine and will have a two-bladed, teetered rotor (up to 40 m!), an asynchronous generator (350 kW) with AC/DC/AC convertor for variable speed and active hydraulic tip pitch (power) control.

All Dutch wind turbine manufacturers are investigating the direct-drive concept. Lagerwey will finish a prototype in 1996.

6.4. MW-rated turbines

In 1995, the second NedWind 52.6 m/1 MW wind turbine was built on the existing tower of the NEWECS-45 at Medemblik. The turbine is operating above expectations. One of the projects under construction, to be finished in February 1996, consists of four 1 MW turbines from NedWind at an industrial site in the southwest. It is a low wind site with average wind speed of 4.6 m/s at 10 m height. At a hub height of 70 m, average wind speed is 6.2 m/s. With an increased rotor diameter from 52.6 m to 55 m it will reach 91.3 m, making it the highest turbine in the Netherlands. Production per turbine is estimated at 1.7 GWh, totalling 6.8 GWh per year (electricity from wind in 1995 was 337 GWh). The private investor is Windfarmers BV.

6.5. Offshore siting

It is not yet clear how much wind capacity in the Netherlands can be realized at what are now regarded traditional sites. But there is a saturation point, estimated at about 1,500 MW in the period 2005 to 2010. The possibilities are surveyed for non-traditional sites in order to meet further demand for wind capacity in the longer term; e.g.:

- large land-based sites (50-100 MW), combined with civil works;
- semi-offshore sites, such as the four NedWind 40 m/500 kW turbines

Table 6. Levels of RD&D funding in the Netherlands 1991-1996, in NLG

RD&D 1991-1996	1991	1992	1993	1994	1995	1996	Total
Market development	1.5	1.7	1.1	1.1	0.7	1.2	5.8
Product development	4.0	3.6	3.5	3.5	3.3	3.3	17.1
Technological development	3.0	3.4	3.0	3.0	2.4	2.4	14.1
Long term market development	0.1	0.2	0.4	0.3	0.2	0.3	1.4
Dissemination of know how	0.4	0.5	0.3	0.3	0.5	0.5	2.1
Total TWIN program	9.0	9.4	8.3	8.1	7.0	7.6	40.4
Applied R&D (ECN)	2.5	2.5	3.0	3.0	3.0	3.0	14.5
R&D Universities (est.)	2.0	2.0	2.0	2.0	2.0	2.0	10.0
R&D Utilities	0.6	0.6	0.6	0.4	0.0	0.0	1.6
Total	14.1	14.5	13.9	13.5	12.0	12.6	66.5

installed in the IJsselmeer (an inland lake);

- offshore sites on the North Sea are surveyed;
- inland sites (with a lower wind regime).

6.6. International collaboration

NOVEM and ECN are co-financing numerous research projects of the European Union.

The Netherlands are participating in IEA Annex XI (technology information exchange), XIV (field rotor dynamics), and XV (annual wind energy review of progress).

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NORWAY

GOVERNMENT PROGRAMS

1.1. Research and development

A combined R&D program on efficient energy technologies and new and renewable sources of energy has been managed by the Research Council of Norway (NFR) since 1994. The program covers subjects such as wind, bio, solar and wave energy, and is divided into two main areas:

- product development;
- research as a basis for industrial undertakings.

The program mainly focuses on product development for the market. It is the trade and manufacturing industries that are responsible for submitting applications for government grants from the program and implementing approved projects. The quality of the projects and the possibility for sustainable business opportunities are decisive for the priority among the different energy sectors.

The budget for government support of the program in 1995 was NOK 17 million (about USD 2.7 million). In general, up to 50% of the development costs can be covered by the program, except for basic research activities, which may be covered up to 100%.

Only a minor part of the R&D budget, about NOK 1.5 million (USD 0.24 million) has been assigned for wind energy activities in 1995. The Norwegian Water Resources and Energy Administration (NVE) has, in addition to that, completed some development projects initiated under the former wind energy R&D program, amounting to about NOK 0.1 million. This R&D program, which was managed by NVE, has thereby been brought to a final end in 1995.

The new R&D program tries to influence industries to take an interest in wind energy in order to make commercial wind turbines more reliable and safe in a harsh climate. In particular, manufacturing industries are encouraged to:

- develop reliable components for the wind turbine market; e.g., rotor blades, components for power electronics, and mechanical equipment;
- develop methods to protect wind turbines against damage by lightning;
- develop reliable and cost effective wind turbines.

Research as a basis for industrial plants are run by the industry in question in collaboration with universities and institutes.

The government budget frame for this R&D program is around NOK 18 million (USD 2.88 million) for 1996.

1.2. Demonstrations

NVE is responsible for running a market introduction program on efficient energy technologies, which also includes technologies for new and renewable sources of energy. A government grant of up to 50% of the total cost is available from NVE for such activities. About NOK 0.4 million has been used for running a wind/diesel demonstration project under this program in 1995.

2. NATIONAL STATISTICS ON WIND POWER

The national target in the former demonstration program was to have wind turbines with a nominal capacity of 3-4 MW connected to the grid system by the end of 1993.

At present, 12 wind turbines (3.9 MW, all of Danish manufacture) are installed along the Norwegian west coast, as listed in Table 1.

The wind turbines are installed as single units, except for two units at the test site Frøya and five turbines installed in a wind power plant (2.2 MW) at Vikna, northwest of Trondheim. All turbines are

Table 1. Wind turbines and output

WIND TURBINE PROJECTS	RATED POWER (kW)	YEAR OF COMMIS-SIONING	PRODUCTION IN 1995 (GWh)	TOTAL OUTPUT OVER ALL YEARS (GWh)
Frøya	1 x 55	1986	0.164	1.223
Frøya	1 x 400	1989	1.088	4.761
Vallersund	1 x 75	1987	0.173	1.560
Kleppe	1 x 55	1988	0.043	0.261
Smøla	1 x 300	1989	0.804	3.688
Andøya	1 x 400	1991	0.986	4.324
Vesterålen	1 x 400	1991	1.123	4.894
Vikna	3 x 400	1991		
Vikna	2 x 500	1993	(6.878)	(23.011)
TOTAL	3,855 kW		11.26	43.72

connected to the grid system, except for the oldest one at Frøya, which for the time being makes up part of a wind/diesel demonstration project. Ten of the wind turbines are owned by power companies. These have been installed with the help of a 50% investment subsidy from the wind energy demonstration program. The two others are privately financed and owned.

Hydro power is the dominating form of energy production in Norway. An installed capacity of about 27,450 MW provides more than 99% of the energy for electricity supply in a normal year. The energy production from wind turbines represents only a minor part of a total electricity consumption of about 116 TWh for the year 1995.

The wind power plant at Vikna (2.2 MW), yielded during 1995 an energy output of about 6.8 GWh, corresponding to 1,312 kWh/m^2 rotor area. This output was attained at an average wind speed of 7.9 m/s, a capacity factor of 0.356, and an average technical availability at the wind power plant of 93.9%.

Most of the failures and problems that have occurred with the wind turbines during 1995 are due to weak parts in the control system or other component defects, along with cracks in some turbine blades due to manufacturing defects and damage by lightning (one unit). An analysis of the lightning problems in connection with the operation of wind turbines was carried out in 1994, resulting in a brochure with recommendations on how to protect wind turbines against damage by lightning, published in 1995. The analysis and proposal for improvements was carried out by the firm Transi-Nor Technology A/S. However, the recommended relief measures appear to be somewhat expensive, and have not been carried out for all the wind turbines yet.

3. CONSTRAINTS ON MARKET DEVELOPMENT

A commercial implementation of new energy projects is the prevailing planning policy in a deregulated Norwegian electricity market.

The home market for exploitation of wind energy will obviously be quite limited as long as new hydro power plants, on an average, are able to generate electricity at a lower cost than wind turbines, even in places with favorable wind conditions. A local generation of wind power may, however, in some areas have additional benefits, which can make it a cost-effective alternative for the utilities.

The prevailing transmission tariff system represents an essential barrier for independent power producers. This system does not take into account the differences in geographical localization of the production units. It is, however, essential for the profitability of wind turbines that they are charged only for their expense in the transmission system.

It may be difficult to indicate savings in pollution or other environmental benefits with the use of wind energy in a hydro-power dominated energy market. Nevertheless, fuel oil is also used for heating purposes in Norway. If the energy output from the wind turbines in 1995 was used to substitute for fuel oil for room heating, it would be estimated to represent a saving of approximately 1,180 TOE (0.105 kg fuel oil/kWh utilized, energy efficiency 0.80).

4. ECONOMICS

The total invested capital in the Norwegian wind turbine systems may be estimated at about NOK 42 million (USD 6.7 million). About one half of this amount has been given as government grants to wind turbine owners.

The value of the total wind-generated electricity so far (43.7 GWh) may be estimated at about NOK 8.7 million. An average generating cost in the hydro power system of NOK 0.20/kWh has been used as a reference for this estimation.

The production cost of electricity from wind turbine systems in Norway may currently be estimated at NOK 0.30-0.45/kWh, depending on the wind regime and local conditions. In addition to these costs come the grid transmission cost, taxes and levies.

No general financial support scheme is available for investments in wind turbines. The investment costs and the running expenses have to be borne by the wind turbine owner under ordinary market conditions. However, a financial grant of up to 50% could be given if the plant is to be used by a Norwegian manufacturer as a test or reference site.

Since the reorganization of the wind energy program in 1994, no investment subsidies for the installation of wind turbines have been granted, but there is a possibility of financing a 1.5 MW new wind turbine demonstration plant at Vikna.

A feasibility study was carried out in 1995 with the objective to assess the benefits (and problems) of wind energy integration on the remote islands of Værøy and Røst in the Lofoten archipelago. These islands have electricity supply through sea cables from the main Lofoten. There is one 33 km cable to the island Værøy, and another 32 km cable between Værøy and Røst, both with significant electrical losses in peak periods. There is also an oil-fired gas turbine backup system for the island Røst, where the annual mean customer load was estimated at 1,150 kW in 1995. This island has excellent wind resources with an annual mean wind speed of 8.5 m/sec.

The analysis shows that local generation from wind power may have significant impact on the electrical losses, mainly in the sea cable system. An additional benefit, which is also taken into account, is the reduced fuel consumption in periods when the islands are supplied from the backup system.

Three levels of wind power integration have been studied in this project. The chosen alternatives are one, two or three standard commercial wind turbine generators of 500 kW. From an economic point of view an integration of two wind turbines (2x500 kW) on the island Røst seems to be the best one among these alternatives, giving a cost of energy production of about NOK 0.30/kWh. However, other alternatives have to be examined also in this case in order to find the optimal solution for the Røst island.

Figure 1. Wind turbines at the test site Frøya. The 55 kW turbine in the background is part of the wind/diesel system.

5. INDUSTRY

At present, there are no Norwegian manufacturers of wind turbines. The reason is that the home market for wind turbines seems to be too small. Nor is any substantial Norwegian market for wind turbines expected in the near future, except for some niches where it may be possible to obtain economical advantages by introducing wind turbines.

Generally, there is a need for cost reduction and improvements in the wind energy sector if any expansion of the wind turbine market is to be achieved. Only a few industrial companies are deeply involved in R&D projects on wind energy, except for the involvement in wind/diesel system development.

A second generation wind/diesel system was put into operation at the test site on the island Frøya (west of Trondheim) in January 1995. The new prototype system serves an isolated group of consumers in order to test long-term performance of the system.

The wind/diesel unit consists of a 55 kW standard (stall regulated) wind turbine, a 50 kW standard diesel generator set, and a forced commutated converter and control unit, including a short-term battery storage and a dump load. The 65 kVA converter and the control unit is manufactured by ABB Energy A/S and developed in cooperation with the Norwegian Electric Power Research Institute (EFI) with financial support from NVE.

Figure 1 shows the test site with two wind turbines, where the turbine in the background makes up part of the wind/diesel system. The main components of the prototype unit are indicated in Figure 2.

At the end of 1995, the prototype system had attained operating hours corresponding to 7.5 months of continuous operation. Technically, the system has operated very satisfactorily and mainly according to the design specifications. A few trivial problems have significantly limited the system availability during the first year of operation. The low availability is mainly a result of slow supply of spare parts and insufficient experience regarding the operation of the diesel generator set. The lessons learned from these problems regarding system operation and maintenance represent valuable experience for the project.

The total fuel savings in 1995 is estimated at 54.3% of the corresponding

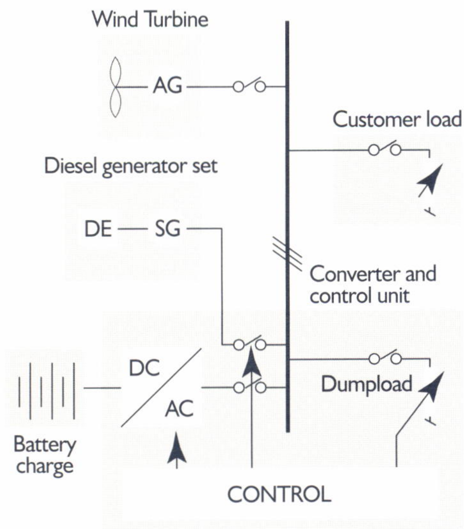


Figure 2. Diagram showing the main components of the second generation autonomous wind/diesel system.

consumption when running the diesel generator set only. The overall system performance in terms of saved fuel is a little above predictions from simulation studies. Key figures from operation of the prototype system from January 3, to November 3, 1995 are given in Tables 2 and 3.

Based on these results, the system will be kept running until at least one year of operating hours is attained. The objective of such a long-lasting test period will be:

- to be able to eliminate any weak points in the wind/diesel system and bring down the number of interruptions;
- to be able to present statistics of the system relating to energy and economy for a one year cycle of operation with a fully instrumented prototype plant;
- to attain sufficient experience in the running of the plant to be able to adjust the system to current market conditions.

The market introduction of the wind/diesel control system is the purpose for the industrial involvement in the project. Other industrial products for the wind energy sector are polyester resins for turbine blades (one company) and cast iron components for wind turbines (three companies).

The feasibility of producing wind turbine blades in Norway was investigated in 1994 from a material and structural point of view. This investigation has been continued in 1995 with a more extended study of the structural and aerodynamic design of turbine blades.

Table 2. Wind/diesel system at Frøya. Energy production and consumption in 1995

Hours of operation:	5,460	
Energy produced by the wind turbine:	107,900 kWh	Mean power: 19.8 kW
Energy produced by the diesel generator set:	53,800 kWh	Mean power: 9.8 kW (During operation: 19.1 kW)
Energy delivered to customers:	115,100 kWh	Mean power: 21.1 kW
Energy to dump load:	32,700 kWh	Mean power: 6.0 kW
Energy losses to storage:	13,900 kWh	Mean power: 2.5 kW

Table 3. Diesel operation and fuel consumption

Diesel generator set, operating hours:	51.7%	Relative to total hours of operation
Diesel fuel consumption:	17,400 liters	0.15 liter/kWh delivery 0.32 liter/kWh diesel
Estimated fuel consumption, diesel alone:	38,100 liters	0.33 liter/kWh
Estimated fuel savings:	54.3%	

5. INTERNATIONAL COLLABORATION

Participation in international collaboration under the new R&D program will be restricted to activities which are deeply rooted in national activities, and where the benefit from the participation is obvious; e.g., participation in IEA R&D and EU projects.

ABB Energy A/S is going to participate in the JOULE project "Power control for wind turbines in weak grids". Some of the experiences from the work with the second generation wind/diesel system may be exploited in this project.

The Norwegian University of Science and Technology, Trondheim, is going to participate in the JOULE project "Database on wind characteristics".

The Norwegian Electric Power Research Institute (EFI) has finished its work in 1995 with the JOULE I project "Engineering design tools for wind/diesel systems". A complete software simulation tool for analysis and design of wind/diesel power systems is developed in a joint project with participants from the United Kingdom, the Netherlands, Italy, Finland, Denmark and Norway. The complete package, including discs and eight volumes of documentation, model descriptions, user guides and model validation reports, can be purchased from EFI.

SPAIN

1. INTRODUCTION

At the end of 1995, a total capacity of 125 MW of wind energy was installed. The majority of the wind turbines were manufactured in Spain, either by Spanish wind turbine manufacturers or through agreements or joint ventures with foreign companies.

The wind turbines installed are machines with rated power of 200-300 kW. New developments of 500 kW wind turbines are in progress. In 1996, three European blade manufacturers will be establishing joint ventures with Spanish companies to manufacture blades for the wind energy market.

Following the new regulations for electricity production, which implies a good price for wind energy, and at least five year contracts with the utilities, a great number of requests for new wind installations have been submitted in certain areas of Spain. Proposals for about 5,000 MW installations have been presented to the local authorities in order to develop wind power plants until the year 2005.

2. NATIONAL STATISTICS

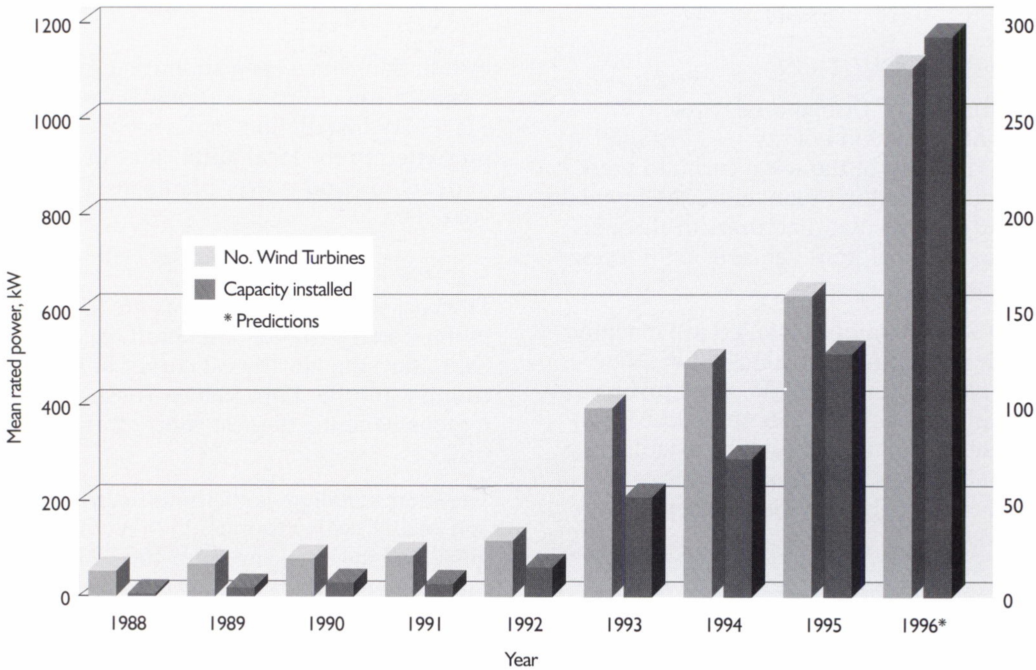
The best wind potential areas are located in the Canary Islands, the Strait of Gibraltar , the Northwest corner of the country and the Ebro Valley. These regions have the highest concentration of projects.

The total installed capacity in Spain at the end of 1995 was around 125 MW with wind turbines ranging from 100-500 kW rated power. Figure 1 shows the wind power plants' locations, and Table 1 presents the wind power evolution in Spain during the last years.

TOTAL: 126,535 MW

Figure 1. Distribution of installed wind energy capacity at the end of 1995.

Table 1. Capacity power evolution in Spain



The Tarifa area located in the South of Spain remains the area with the most wind energy installations. A new wind power plant with 300 kW Kenetech machines and a 6 MW wind power plant with 500 kW Nordtank wind turbines have been in operation since the last quarter of 1995.

In this area, a study carried out by an ornithological organization on the influence of the wind turbines on bird life was finalized. The study shows an important decrease of bird impact after a landfill of the municipality was moved out of the surroundings of the wind power plant. As a result of this study new wind power plants are approved for the area.

In the North of Spain (Navarra), an additional 10 MW have been connected to the grid with 500 kW wind turbines from GAMESA EOLICA as part of a wind power plant of 17 MW to be built during 1996. The plans for this area show a wind capacity of 220 MW in the year 2000 and 600 MW for the year 2010. The objective of this plan is to produce the total energy consumption of the region with wind energy and mini-hydro installations. The statistics of the wind power plants in this region show a capacity factor value of about 0.45 for 1995.

Wind turbine manufacturers and promoters have been very active during 1995 with a number of activities in wind resources and site selection. For instance, in the Northwest corner (Galicia region) proposals for more than 5,000 MW of wind projects have been submitted to the local authorities. In December the local government of Galicia handed out licenses for 2,550 MW for the next ten years. The regulations of these activities are defined in a "Strategic wind power plan", and the main aim of the authorities is the generation of employment and industrial activity in the region.

Another area with a great number of wind power projects is the Ebro Valley. The local authorities received requests for building permission of installations of more than 800 MW.

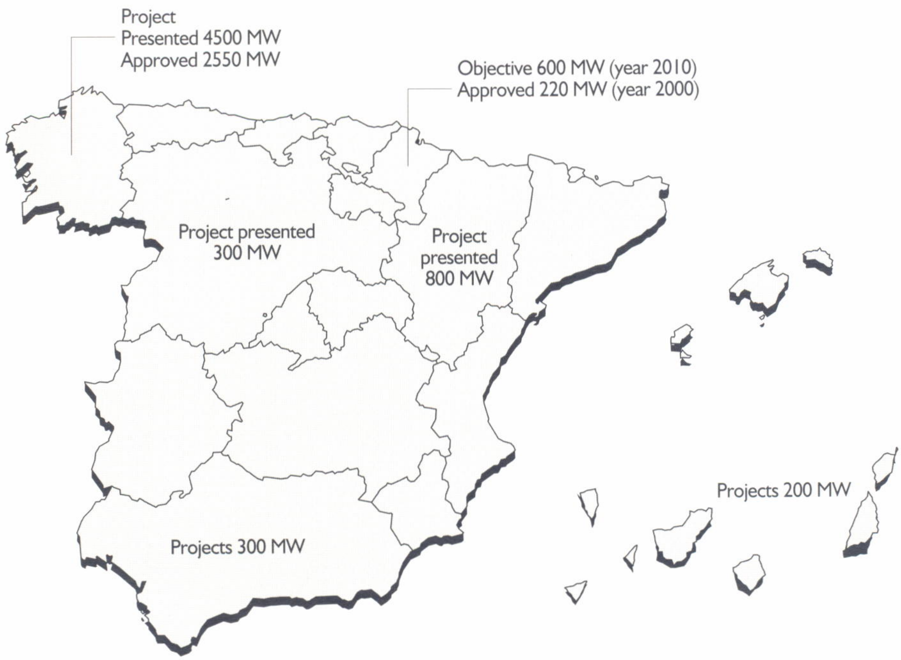


Figure 2. Future plans for wind energy.

The average performance values of wind power plants in Spain (± 70 MW total) during 1994 was:

capacity factor:	0,26
energy production:	981 kWh/m2

The 1995 figures show a high performance of machines due to better wind conditions and more economic operation of wind power plants.

3. REGULATIONS AND SUBSIDIES

The national subsidy program is regulated by the Energy Saving and Efficiency Plan which defines the subsidies for the renewable energy installations. There are two categories for wind energy:

- Wind power plants with special conditions such as difficult access, high cost in the electrical line, special wind turbines design for low wind conditions.
- Individual units for special applications such as isolated systems, special designs for extreme conditions.

Subsidies up to 30% of the eligible cost can be available.

The following Table 2 shows the projects presented to the 1995 Energy Saving and Efficiency Plan. The projects approved represent more than 140 MW of total capacity (500 new wind turbines) and an investment of ESP 21,000 million.

Regulations for electricity production

The Spanish Industry and Energy Ministry has published a new legal framework for generation of electricity for hydro power plants, cogeneration and renewable energy sources (Royal Law 2366/1994 of December 9). The main priority of the regulation is to increase the energy production from non-conventional power generation plants from 4,5% in the year 1990 to 10% in 2000, regarding two energy sources: cogeneration and renewable sources. This regulation coordinates the existing regulations and develops the basic criteria for the technical and economical relations between owners and utilities. The regulation is to be applied to wind power

Table 2. Installation of wind power plants under the PAEE program, 1995

WIND POWER PLANT	PROMOTOR	TOTAL INVESTMENT (in ESP million)	SUBSIDY (%)	POWER (MW)	UNITS	TECHNOLOGY
CAPELADA (Galicia)	ENDESA	2544	16.5	16.5	50	MADE AE/30 (330 kW)
AGAETE (Islas Canarias)	UNELCO	194	11.1	1.32	4	MADE AE/30 (330 kW)
GRANADILLA (Islas Canarias)	UNELCO	860	18.6	5.28	16	MADE AE/30 (330 kW)
SANTA LUCIA (Islas Canarias)	UNELCO	765	20.9	5.28	16	MADE AE/30 (330 kW)
LA MUELA II (Aragón)	PARQUE EOLICO ARAGON	1946	15.2	11.55	35	MADE AE/30 (330 kW)
ENIX (Andalucia)	MADE Energías Renovables	1785	18.5	10.56	32	MADE AE/30 (330 kW)
BARBANZA (Galicia)	ENDESA	3105	23.9	19.8	60	MADE AE/30 (330 kW)
LA TEIXETA (Cataluña)	Parc Eolic de la Teixeta SL	1134	17.4	14.85	66	ECOTECNIA/28 (225 kW)
TAUSTE (Aragón)	ECOTECNIA S.C.C.L.	830	19.5	5.17	23	ECOTECNIA/28 (225 kW)
ZAS (Galicia)	Desarrollos Eólicos de Galicia	2736	14.6	18.3	61	DESA 300 (300 kW)
MALPICA (Galicia)	ECOTECNIA S.C.C.L.	2203	27.2	15.0	67	ECOTECNIA/28 (225 kW)
LOS LANCES (Andalucia)	S.E.A. S.A.	1580	19.6	10.0	15 23	MADE AE/30 (330 kW) ECOTECNIA/24 (200 kW)
GAVIOTA (Islas Canarias)	ECOTECNIA S.C.C.L.	1637	21.6	10.0	45	ECOTECNIA/28 (225 kW)
	TOTAL	21,319		143.61	513	

plants up to 100 MW. The main points of the electricity price regulations are:

- special regulation for wind energy;
- at least five-year contracts for selling the energy output;
- electricity prices according to:
  - installed power;
  - energy production;
  - reactive power;
  - hours discrimination.

4. INDUSTRY

The increasing activity in the field of the wind energy is activating the development of the Spanish wind industry. As a consequence, all the manufacturers are actively working in new wind turbine developments.

MADE company, with ± 200 wind turbines of the models AE-20 (150 kW), AE-23 (180 kW) and AE-30 (330 kW) in operation, is now concentrating their manufacturing effort on the model AE-30, and for 1996, a production of ± 200 units is planned. The company has finished the construction of the MADE AE-41 prototype (500 kW). The prototype will be installed in the Monte Ahumada Wind Farm (Tarifa) in early 1996. At the same time, MADE is developing three versions of the MADE AE-41, a pitch-control version (the basic design is stall-control), a variable speed version, and a low-wind version, especially designed for sites with average wind speed around 6 m/s.

ECOTECNIA is finalizing the production of its new 500 kW wind turbine, and continues producing the 24/200 and 28/225 models. ECOTECNIA is the first Spanish company which has supplied wind turbines for the export market (ten machines for a wind power plant in India).

DESA (Desarrollos Eólicos, S.A.) is now manufacturing the new 300 kW pitch-control wind turbine, and two wind power plants of 20 MW and 18.7 MW (128 units of the DESA-300) are under construction in the Canary Islands and Galicia. A new factory was opened in

Figure 3. La Muela wind power plant (Ebro Valley) 330 kW wind turbines.

Arinaga (Canary Islands) with a production capacity of 1 DESA-300 per day.

GAMESA EOLICA is manufacturing the G-39 500 kW (with VESTAS technology), and supplying wind turbines for the next phase of the Monte del Perdón wind power plant (Navarra). At the present time, the company has a production capacity of two units of the 600 kW model per week, and the majority of the components is already manufactured by Spanish companies.

LM Spain started the manufacturing of the 14.4 m blades at the Toledo factory last September, and other companies are also active in manufacturing components for wind turbines.

Figure 4. Static strength test (blade length 41m) SFAT project.

The Spanish wind industry is now well consolidated with four manufacturers (ECOTECNIA, MADE, DESA and GAMESA) and more than 300 wind turbines in operation and with ambitious ongoing projects. In 1996, only for the Spanish market, the industry will manufacture more than 500 units ranging from 200 kW-600 kW rated power.

5. RESEARCH, DEVELOPMENT AND DEMONSTRATION

The activities in R&D projects are concentrated in two areas; i.e., the developments in relation to the activities of the Spanish wind industry, and the projects carried out by research centers and universities. However, the majority of the projects are developed under the umbrella of the R&D European programs, but Spanish organizations and companies are increasing their activities in R&D projects as well.

The main areas of activity are:

- wind resource assessment;
- blade development and testing;
- wind turbine testing;
- design and modelling of components;
- standardization;
- stand-alone applications with emphasis on desalination.

A summary of the European projects with the participation of Spanish institutions is shown at Table 3.

Table 3. Spanish participation in European R&D projects

PROGRAM	COORDINATOR	SPANISH PARTICIPANTS	PROJECT TITLE
JOULE	CRES (GR)	CIEMAT MADE	Measurement of load and power of wind turbines in complex mountainous terrain (MOUNTURB)
JOULE	ECN (NL)	CIEMAT	European wind turbine standards (EWTS)
JOULE	City University (UK)	ECOTECNIA	Optimizing the aerodynamic performance and control of wind turbines
JOULE	ECN (NL)	CIEMAT INTA	Strength and fatigue of large size wind turbine rotors (SFAT)
JOULE	RISØ (DK)	Politechnical University of Madrid	Measurement on and modelling of offshore wind power plants
VALOREN	CIEMAT (SP)	University of Las Palmas	Wind-diesel system in Fuerteventura
APAS	RISØ (DK)	CIEMAT	Feasibility studies on combined wind-diesel desalination in Greece and Spain
APAS	LAMDA TCH. (GR)	CIEMAT ECOTECNIA	Utilization of wind, solar and biomass resources in Mediterranean rural regions
APAS	ITER (SP)	University of Las Palmas	Decentralized water desalination using large-scale wind power plants
APAS	University of Athenas (GR)	University of Las Palmas	Hybrids systems for applying desalination at small villages

SWEDEN

1. GOVERNMENT PROGRAMS

Sweden has a good wind energy resource and was one of the first countries to embark on a wind energy program in 1975. Currently, about half of the electricity is generated by hydro power, which facilitates the integration of wind power, but the introduction is difficult due to the low electricity price.

At present, the government is supporting the development and installation of wind turbines in three programs managed by the Swedish National Board for Industrial and Technical Development (NUTEK):

- a fully financed research program with a three-year budget of SEK 21 million for 1994-1997;
- a development and demonstration program for wind systems, with a maximum of 50% financial support;
- a market stimulation program providing subsidies of 35% of the investment cost of installations of wind turbines with a capacity higher than 60 kW. When technology procurement is used a maximum subsidy of 50% of the investment cost can be obtained.

The utilities are engaged in studies, demonstration and evaluation projects. From 1994 onwards, the research and development activities of these utilities are coordinated in a jointly owned company, Elforsk AB, which initiates and finds sponsors for projects in the field of power generation. In addition to the activities of Elforsk AB, the largest utility, Vattenfall AB, has a substantial wind energy development program of its own.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. The electricity market

Total installed electricity capacity in Sweden is shown in Table 1. The Electricity Act which provided the framework for the Swedish electricity market for several decades dates from 1902. On January 1, 1996, a new Electricity Act came into force. The aim of the new act is to introduce competition on the electricity market, thus creating the conditions for efficient pricing and a more open trade in electricity. Competition in electricity trade makes it possible for buyers to choose freely between different vendors on the market.

The new electricity market – regulations for small-scale production

Before the reform, the holder of a regional power concession was responsible for purchasing electricity from the small power generation plants rated up to 1,500 kW located within the distributor's region.

With the aim of protecting the small power producers during the transition to the new competitive electricity market, a delivery concession for a limited period of time has been introduced in the new Act. The holder of a delivery concession is responsible for purchasing electricity from a power generation plant located within the region and capable of delivering a maximum of 1,500 kW. Thus, the delivery concession gives small power producers a guaranteed market for their output.

This responsibility applies to all holders of networks but only if the capacity of the network is sufficient to ensure that the reliability of supply of the line or network will not be jeopardized.

2.2. Installed wind energy capacity

In the early 1980's, two MW-sized prototypes and a few 50 kW units were erected in Sweden. From 1988 onwards, commercially available wind turbines were introduced at a notable rate, amounting to a total of 5 MW when the investment subsidy was introduced in July 1991. Since then the amount has increased to a total of 67 MW (December 1995), and an annual electricity production of about 105 GWh (about 150 GWh during a "normal" year).

Table 1. Total installed electricity capacity in Sweden

	1995 MW	1995 TWh
HYDRO POWER	16,500	67,0
NUCLEAR POWER	10,000	66,7
COGENERATION IN DISTRICT HEATING (AND INDUSTRY)	2,800	8,7
OIL-FIRED CONDENSING POWER	3,200	0,7
GAS TURBINES	1,900	N/A
WIND POWER	67	0,1

Historically, wind power development has been dominated by privately owned enterprises, either owned directly by individuals and private companies, mainly active in other areas than energy production, or owned as shares in companies and partnerships. Over the last years this dominance has increased even further (see Table 2). Small utilities (with some production of their own) are fairly active. The largest utility, state-owned Vattenfall AB, has invested considerable amounts in research and development of wind turbines since the end of the 1970's. Other large utilities have now started to show more interests in wind turbine produced electricity as a form of environmental friendly energy source.

3. MANUFACTURING INDUSTRY

3.1. Status/numbers/sales of manufacturers

Three manufacturers develop medium and large wind turbines in Sweden: Kvaerner Turbin AB, Nordic Windpower AB and Zephyr Energy AB.

Kvaerner Turbin AB developed and sold Näsudden I (2,000 kW) and Näsudden II (3,000 kW). Vattenfall AB is the purchaser of both turbines.

Nordic Windpower AB developed and sold Nordic 400 (400 kW at Lyse Wind Power Station) and Nordic 1000 (1,000 kW at Näsudden, Gotland). Vattenfall AB is the purchaser of both turbines.

Table 2. Owners of wind turbines (December 31, 1995)

	Number	%	MW	%
Small private companies	55	25	13,1	19
Partnerships etc.	44	20	13,1	19
Share holding companies	35	16	13,9	21
Companies with other main interests than wind energy	37	17	11,9	18
Utilities	46	21	14,6	22
Other	3	1	0,7	1
Total	220	100	67,3	100

Zephyr Energy AB has developed and sold three 250 kW turbines. The local distribution company Falkenberg Energy is the purchaser of the turbines.

4. ECONOMICS

4.1. Electricity prices

Electricity trade is pursued on different markets, which also involves a range of electricity prices. Bulk power price is the price of electricity at main grid level and serves as a basis for the prices paid by end customers and distributors. The difference consists principally of the costs of administration and transmission.

The prices on the market for high-voltage electricity paid by certain customers, industrial plants and distributors may be close to the bulk power price. On the market for low-voltage electricity, the distribution costs are considerably higher, and the price of bulk power as a proportion of the price paid by the end customer is consequently relatively low at just under one-third of the price, excluding taxes, payable by a household without electric heating (Table 3). The prices charged to various customer categories are determined by tariff systems which are made up of a mixture of variable and fixed charges. There has not been any significant change during 1995.

4.2. Turbine/project/generation costs

At good sites, current commercial wind power plants of up to 500 kW can produce electricity at a cost of SEK 0.33 - 0.40/kWh, calculated with a rate of 5% over a period of 25 years and without state subsidy. In Sweden, support is generally required for wind power to be viable.

The wind power plants that are erected today have a capacity between 150 and 600 kW; the majority are larger wind energy conversion systems. The total investment (average) cost for the different Swedish wind turbine projects are shown in Table 4. As an average, the costs for the wind turbine is about 80% of the total investment cost.

Table 3. Electricity prices at current monetary values, including taxes and VAT, for different customer categories, 1994, SE öre per kWh

	SE öre/kWh
Domestic customers, 2.2 MWh annually	
average	78.1
highest	107.7
lowest	56.6
Single-family house without electric heating, 5 MWh annually	
average	78.9
highest	98.8
lowest	55.8
Single-family house with electric heating, 20 MWh annually	
average	61.1
highest	73.8
lowest	44.2
Industrial plant, 20 MW, 140,000 MWh annually	23.8
Industrial plant, 10 MW, 50,000 MWh annually	28.8
Consumer price index, 1990 = 100	119.7

Source: Processed information from the "Tariff book" for the years 1990-1994, Association of Swedish Electric Utilities, and information from Vattenfall

4.3. Invested capital and value of generated power

The value of electricity from wind power plants connected to the grid is a reflection of the market price for electricity. The price for electricity is still fairly low; i.e., SEK 0.30 (ECU 0.033) per kWh at high voltage level; consumer price around SEK 0.45 (ECU 0.05), before taxes.

Table 4. Total average investment costs and production from wind turbines in Sweden

	SEK/kW	MWh
400-500 kW	8,600	1,100
200-250 kW	9,000	500
100-150 kW	12,400	400

The price paid for wind turbine produced electricity during 1995 was generally slightly less than SEK 0.30. The value is increased by a so-called environmental bonus, at SEK 0.09 per kWh. For 1996, this bonus will be SEK 0,097 per kWh. The environmental bonus is a government subsidy and identical to the electricity tax.

The new rules which regulate the electricity market from January 1, 1996 onwards will change the method of calculating the price for produced electricity. The wind turbine owner will get paid by two companies, the network owner and the holder of the delivery concession (see 2.1). The total invested capital for the installation of commercial wind turbines is so far about SEK 630 million (calculated from the year 1991).

5. MARKET DEVELOPMENT

5.1. Market stimulation instruments

The budget of SEK 250 million which was allocated in 1991 for the market stimulation program (35% subsidy) has since the start in 1991 been reduced with SEK 10 million with the aim of strengthening R&D. The funds were already fully spent by September 1995 except for the SEK 25 million that were allocated for technical procurement. At the end of 1995, NUTEK received another SEK 100 million which was spent immediately as the number of applications on hand by far exceeded the extra budget allocated to the program.

The technical procurement process is based on an initiative from NUTEK. Five Swedish wind turbine operating companies have decided to combine their procurement activities in an effort to raise the cost effectiveness of future energy conversion systems. The Swedish Wind Turbine Buyer Consortium (SWTBC) has been formed for that specific purpose with the following members:

- Göteborg Energi AB: a major distribution and power generating company;
- MIT Energi AB: a company specializing in the operation of wind turbines;
- Slitevind AB: one of the largest companies specialized in the operation of wind turbines;
- Vattenfall AB: Sweden's largest power generation and distribution utility;
- Sydkraft AB: Sweden's second largest power generation and distribution utility.

Following a pre-qualification phase for prospective tenders, SWTBC is now about to issue a request for tenders that focus attention on two parameters that are both considered critical for the growth of wind power utilization in Sweden: a reduced cost per kWh generated, and a lower noise level. Unlike most other requests for wind turbine tenders, SWTBC's will refrain from specifying nominal power or design concepts in order to allow manufacturers to optimize their systems.

5.2. Constraints

Environmental impact

Public attitudes to wind power, especially to its impact on the landscape, is an important factor that influences practically every wind energy project. Noise emission is also important, but rather as a "technical" problem. So far, the impact on bird life has been minimal.

Objections from the military due to the impact on the landscape have also stopped many wind projects. The military wants to avoid disturbance of military micro-wave links, radar, intelligence activities and aircraft at low altitudes.

Public attitudes

Vattenfall AB investigated the public attitudes towards two wind power plants at its test station Lyse in the municipality of Lysekil on the West Coast (north of Gothenburg). The investigation has included both inhabitants and summer residents living close to the plants and some politicians and civil servants from the municipality. A majority of the people interviewed had a positive attitude towards wind power. But in the summer residential area there were more doubts about wind power plants. All three categories pointed out how important it is to locate the wind power in areas where it does not disturb residents. Input by the residents on the location of wind power plants was considered important, and certain locations should not be exploited.

Light interference

A case of light interference caused by a wind power plant has been brought to the attention of authorities in Torekov in the municipality of Båstad in southern Sweden. The distance between the residential area and the turbine was 190 meters. The local authorities therefore stopped this wind power plant.

5.3. Institutional factors

In the spring of 1995, the Swedish Board of Housing, Building and Planning (Boverket) issued "General Guidelines 1995:1; Establishing land-based wind power, advice and information", drafted jointly by the Environmental Protection Agency and NUTEK. The publication sets out regulations on the establishment of land-based wind power plants, provides advice and supplies background information on the characteristics of wind power.

Advice is given on preparatory actions at regional and local level - in the form of physical planning, information and the setting up of administrative procedures - to facilitate the handling and establishment of wind power plants. A recommendation of particular interest is: in areas with considerable wind power potential, it is recommended that the county administrative board will develop regional reference documents on the location of wind power. The publication also describes how municipalities can handle wind power in their comprehensive plan and detailed development plans. It is recommended that when conflicts arise between other public interests and wind power they should be resolved within the framework of comprehensive planning.

A harmonious introduction of wind power - a new area demanding interest - will take time. The authorities on different levels, inhabitants, and companies need to learn, experience and work with wind turbines. There are new potential conflicts arising which need time to solve. It is important that residents can express their opinions and points of view, for example through the physical planning programs in their municipalities. These questions must be taken seriously in order to make a large-scale introduction of wind turbines accepted.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

6.1. Research and development

Scope

The overall goal for the Swedish wind energy research program is to develop the knowledge within the wind energy area in order to manufacture and develop wind turbines and utilize the wind energy efficiently in the Swedish energy system.

An applied goal is to develop methods that can be used for developing flexible and lighter machines in the future. There is a general belief that lighter machines have the potential to utilize wind energy in a more cost-effective way. This was also the common opinion of the IEA meeting on future needs for research which was held in the Netherlands in the autumn of 1995.

Financing

The wind energy research and development has a budget of SEK 7 million for the fiscal year 1995/1996 (July 1, 1995 - June 30, 1996). The work has mainly been carried out and administered by a consortium named Vindkraftkonsortiet (VKK). The consortium was formed in 1994 and comprises the following three organizations: the Aeronautical Research Institute of Sweden (FFA), and leader of the consortium, the Department of Power Electronics at Chalmers University and the Department of Meteorology at Uppsala University.

Research topics

The participants in the consortium are responsible for the following research areas:

- FFA – aerodynamics, structural mechanics, materials;
- Chalmers – electric machinery and control technology, test station at Hönö;
- Uppsala University – atmospheric research, wake effects and boundary layer phenomena.

The basic research within these topics is combined into co-operation projects with the goal of developing suitable tools for analysis and design of wind energy conversion systems. These projects will aim at developing methods for lighter and flexible wind energy conversion systems. Such machines require better understanding and prediction methods for the general behavior and structural response of the wind energy conversion systems. Improved methods for structural analysis of wind energy conversion systems are therefore considered to be essential for the success of such machines.

An area of uncertainty is within the field of aerodynamics. Blade behavior at stall and the influence of three-dimensional flow has been given extra attention lately. Methods suitable for implementation into structural codes have been developed. These calculation tools have been verified in the evaluation of Nordic 400. The evaluation has shown that the calculation tools used to design the unit and calculate the production capacity have given correct results and good estimates.

Wind resource assessments in the northern mountainous areas of Sweden as well as offshore have been studied in order to make the wind resource knowledge more complete. Special attention has been put into understanding turbulence, shear and wind direction behavior at such sites. Meteorological phenomena in wind power plants have also been studied. Results illustrate the importance of considering atmospheric conditions when describing the structure of a wind turbine wake.

The test station at Hönö on the Swedish West coast has been used to test and validate different control system algorithms. It has also been of great value for testing power electronics systems. A direct-drive generator system project has been initiated and will be tested at Hönö in order to develop effective systems.

6.2 New concepts

Zephyr

Zephyr Energy AB has developed and manufactured a 250 kW wind turbine with a two-bladed flexible design such as proprietary passive pitch control and flapping hub. This model is the first and so far the only Swedish-manufactured wind turbine that has a Swedish certificate. Zephyr is also working with the development of a larger unit, 750 kW, including variable speed control and further decrease of weights.

Nordic 400

The evaluation of the 400 kW Nordic 400 turbine was completed in June 1995 with all major goals achieved. The turbine is operated commercially by Vattenfall AB. During the winter of 1996, some minor modifications will be made. In parallel the Nordic 400 will be used for measurements with different configurations of stall-strips financed by Vindkraftskonsortiet (VKK).

6.3. MW rated turbines

Nordic 1000

The 1 MW Nordic 1000 wind turbine - described in IEA Wind Energy Annual Report 1994 - was erected on April 9, 1995. Since late June it has been in continuous operation in a commissioning program. As of December 1, 1995, the production was 0.4 GWh (see Figure 1).

Näsudden

The 3000 kW Näsudden II wind turbine has continued to have a high availability and has until December 31, 1995 produced 15,169 MWh during 13,752 hours of operation. During the calendar year 1995, it produced 5,833 MWh during 5,061 hours.

The production during February was 1,168 MWh, the highest output during one month since the start of the operation.

Development Study III

The development of the multi-MW turbines has continued during 1995 at Kvaerner Turbin AB. The company is performing the third phase of the Development Study III for the third generation of large WTS's (see Figure 2). This project has as a main goal to develop the Näsudden II/Aeolus II turbine concept into a commercially competitive machine. The goal for the project is an investment cost of SEK 3.00/kWh/year. The study is commissioned by Vattenfall AB and financed by NUTEK, Vattenfall AB and Kvaerner Turbin AB.

Radical changes in the Näsudden II design have been carried out. A few principles have characterized the design procedure:

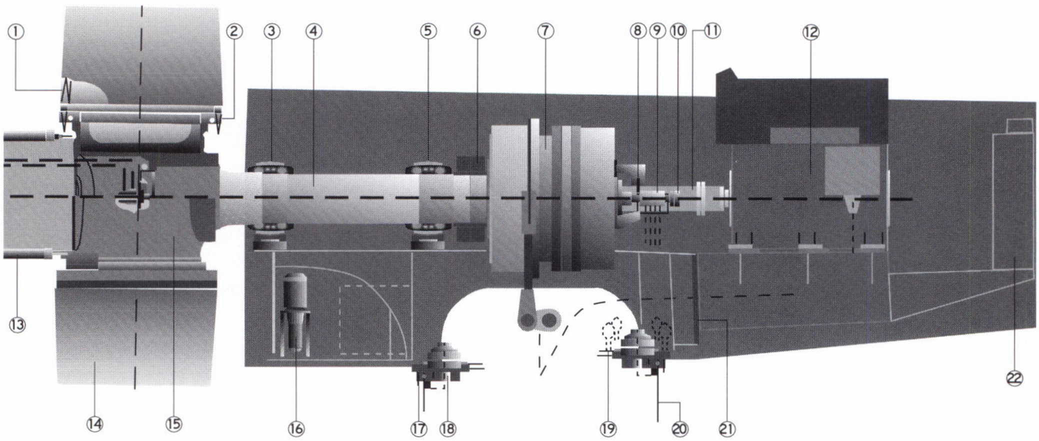
- common components should be preferred so that unnecessary development costs are avoided;
- maintenance costs should be minimized;
- size and weight should be reduced to make land transport possible;

Figure 1. Nordic 1000 Vindkraft Näsudden - Gotland.

- site erection should be carried out without extensive use of cranes.

The machine has been designed with a softer dynamic behavior compared to the Näsudden II. Alternative wooden blades have been developed. A steel tower is used instead of the former concrete tower. The rotor speed has been reduced 10% to decrease the dynamic noise. As an optional design line a concept with a direct driven generator has been recently developed together with a German company.

Kvaerner Turbin AB will, at the end of the study in May 1996, present a tender for a delivery of a new turbine. This would then be the last generation of development before a commercial introduction can be made.



1	Blade root connection	9	Swivel	16	Hydraulic system
2	Blade pitch bearing	10	Slipring unit	17	Yaw bearing
3	Front turbine shaft bearing	11	Intermediate shaft	18	Yaw motor
4	Turbine shaft	12	Generator	19	Yaw emergency brake
5	Rear turbine shaft bearing	13	Blade pitch servos	20	Tower
6	Turbine shaft coupling	14	Blade	21	Bed plate
7	Gearbox	15	Hub	22	Electric cubicles
8	Turbine maintenance brake				

Figure 2. The new 3 MW turbine concept with gearbox drive train.

6.4. Offshore siting

Nogersund

In 1991, a research program studying the impact on the environment from the 220 kW offshore wind power station at Nogersund was implemented. A report on the test program will be finalized in 1996. The migration lines are passing very near the station. The impact on bird life turned out to be non existent. The resting birds got used to the station and the migratory birds noticed the station and flew further away from the turbine. Nogersund is the biggest fishing harbor in the South of Sweden. Therefore, it was important to examine the impact on fish and fishing. The foundation of the station turned out to be a place where many fish were found. Radar in fishing boats did not register disturbances from the power station.

6.5. International collaboration

International cooperation has increased significantly during the last years. Most of the cooperation is carried out in the framework of the IEA and the European Union. Sweden participated during 1995 in 12 EU JOULE II projects. The experience from these types of projects are very positive - they give possibilities to exchange information in a structured way. The joint funding also gives the possibility to run projects which otherwise would not have been possible to carry out. Swedish researchers and companies are therefore looking forward to continuing the work in IEA R&D Wind and the next phase of the JOULE/THERMIE program.

The international cooperation between Sweden and Germany in the development of multi-MW turbines has been very successful. The work has continued during 1995/1996 with the main goal to develop the Näsudden II/Aeolus II turbine concept into a commercially competitive machine.

UNITED KINGDOM

1. NATIONAL OVERVIEW

1.1. Government aims, objectives and strategy

Policy

An Energy Paper stating government policy and summarizing the future prospects for new and renewable energy in the United Kingdom was published in March, 1994 (Reference 1). The policy is to stimulate the development of new and renewable energy sources wherever they have prospects of being economically attractive and environmentally acceptable in order to contribute to:

- diverse, secure and sustainable energy supplies;
- reduction in the emission of pollutants;
- encouragement of internationally competitive industries.

Strategy

The government has initiated a market enablement strategy to implement its policy, stimulating the development of sources and industrial and market infrastructure so that new and renewable sources are given the opportunity to compete equitably with other energy technologies in a self-sustaining market. For wind energy the strategy seeks to encourage its uptake by:

- stimulating an initial market via the Non-Fossil Fuel Obligation (see Section 1.4.);
- stimulating the development of the technology as appropriate;
- assessing when the technology will become cost effective;
- quantifying the associated environmental improvements and disbenefits;
- removing inappropriate legislative and administrative barriers;
- ensuring the market is fully informed.

The government also seeks to encourage internationally competitive industries to develop and utilize capabilities for the domestic and export markets.

1.2. Targets

Potential installed capacity

The government has no specific target for wind energy but it has been announced that it is working towards the installation of 1,500 MW DNC* of new electricity generating capacity from renewable sources for the U.K. by the year 2000.

1.3. Market stimulation

There is a requirement on the electricity supply companies in the U.K. to provide a proportion of their supply from renewable energy sources; the requirement is set out in the Government's Renewable Energy Obligations. There are separate obligations for England and Wales (the Non-Fossil Fuel Obligation - NFFO), Scotland (the Scottish Renewables Obligation - SRO) and Northern Ireland (the Northern Ireland Renewables Obligation - NIRO). The additional costs incurred by the companies in buying non-fossil fuel power to meet their obligation is passed on to the consumers. This part of the obligation is implemented through a series of tranches, set periodically by the government. The total for all the obligations is planned to be 1,500 MW DNC, to be filled competitively by the year 2000.

* DNC or Declared Net Capacity allows technologies with different availabilities to be judged on a comparable basis. Multiplying the rated capacity by the DNC factor indicates the equivalent capacity of base load plant that would produce the same annual energy output. For wind turbines this factor is 0.43.

During 1995, the following progress was made in each of the Renewables Orders:

NFFO (England and Wales)

None of the projects awarded contracts under NFFO-3 was commissioned, although several were under construction. NFFO-4 was announced in November by the government as part of its ongoing enablement program and to help maintain continuity of contracts for the industry (References 2 and 3).

Northern Ireland Renewable Energy Order (NIRO)

Under NIRO-1, three more wind power plants, each of 5 MW rated capacity, contracted were commissioned to add to the two commissioned at the end of 1994. The total installed capacity under NIRO-1 is now 25 MW. NIRO-2 was announced and proposals are being evaluated.

Scottish Renewable Energy Order (SRO)

Two wind power plants, totalling 15.6 MW, were commissioned under SRO-1. SRO-2 was announced in November and proposals were invited.

Table 1 summarizes progress to date in fulfilling the Renewable Energy Obligations, and Figure 1 shows the locations of the resulting projects.

1.4. Government support for Research, Development and Demonstration

The government (through its Department of Trade and Industry - DTI) supports a program of research, development and field trials in collaboration with suppliers and developers to assess the potential and eventual commercial prospects of wind energy. An essential adjunct is dissemination of information arising from both directly funded work and from projects in the Renewable Energy Orders. Funding for the wind program during 1995 amounted to GBP 3.1 million. As wind energy becomes more commercially attractive and industry becomes self-sustaining, this funding is expected to decrease.

Table 1. Size and timing of the Renewable Energy Obligations

Order	Effective Start Date	Contract Length (max yrs.)	Number of Projects: Contracted	Number of Projects: Built	Contracted Capacity MW DNC/ (Rated)
NFFO-1	1990	8*	9	9	12.21/(28)
NFFO-2	1992	6*	49	27	82.43/(192)
NFFO-3 (>1.6 MW)	1995	15	31	—	145.92/(339)
NFFO-3 (<1.6 MW)	1995	15	24	—	19.71/(46)
NFFO-4	1997	15	—	—	—
SRO-1	1995	15	20	2	45.60/(106)
SRO-2		not yet set			
NIRO-1	1994	15	6	5	12.66/(29)
NIRO-2	1996		not yet set		

* Limited to the end of 1998 following a European Union ruling.

Figure 1. Location of NFFO wind projects - status at September 30, 1995.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed capacity

A total of 35.1 MW of rated capacity were installed during the year. This brought the total installed capacity in the U.K. under the Renewable Energy Orders at the end of 1995 to 193 MW (518 turbines). Figure 2 shows the growth of this capacity with time.

2.2. Plant type

The capacity installed during 1995 consisted of 71 machines, all of Danish manufacture. There were 15 turbines of 300 kW rated capacity, 30 of 500 kW, and 26 of 600 kW (average 494 kW). This is to be compared to the average rated capacity of 330 kW for all 462 machines in the NFFO-1 and -2. The machines were installed in six wind power plants, one in England (15x300 kW),three in Northern Ireland each of 5 MW (10x500 kW turbines) and two in Scotland, one of 5.4 MW (9x600 kW turbines) and one of 10.2 MW (17x600 kW turbines).

2.3. Market development

Forms of ownership

The three latest wind farms in Northern Ireland are owned by major U.K. electricity generators while ownership of the Scottish ones has not been disclosed. This confirms the trend that as the reliability and performance of wind power plants becomes proven, corporate investment is increasing from, in particular, the electricity generating and distribution companies. However, during the year the U.K. government has sought to encourage small scale investors and community schemes by identifying suitable financial frameworks for such investors. As a result a wind investment fund for small investors was launched in 1995.

Operators

In many cases the operators of the wind power plants continue to be the original development companies operating under contract to the owners.

2.4. Energy output

For the year from October 1, 1994 to September 30, 1995, the total energy output from the projects in NFFO was 361 GWh bringing the cumulative total to 831 GWh. The quarter-by-quarter output from the projects is shown in Figure 3.

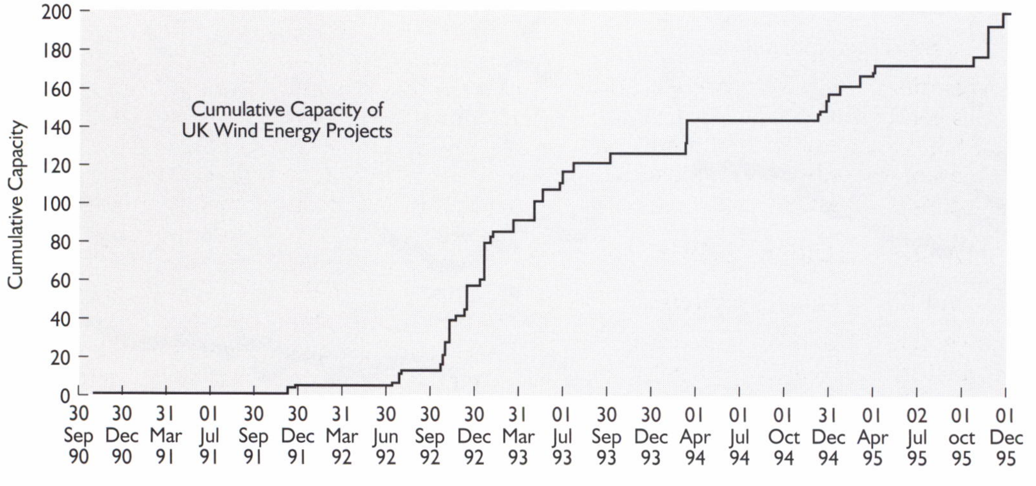


Figure 2. Cumulative installed wind energy capacity under NFFO and NIRO.

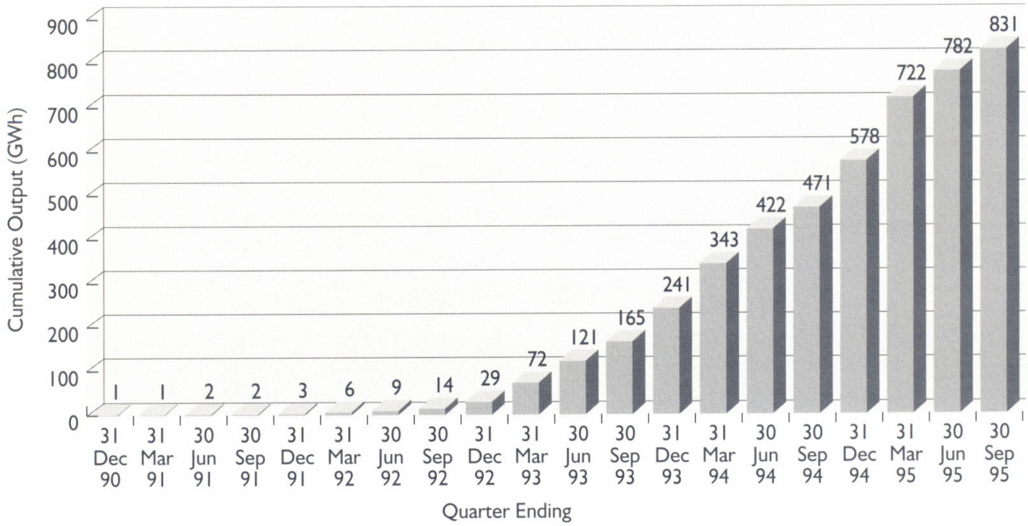


Figure 3. Quarterly and cumulative energy output of NFFO-1 and 2 projects.

Data for the SRO and NIRO projects are not yet available.

2.5. Technical performance

The technical performance of the turbines was good with high availabilities (>95%) and good load factors (>0.3) being reported from the wind power plants. The three plants using WEG MS-3 machines, which suffered a component failure in severe gales in December 1994, were all modified during 1995 and gradually returned to full operation during the year.

2.6. Operational experience

No operational difficulties were reported. Studies continued of the potential advantages and problems of increased penetration levels by renewable energy generators (Reference 4).

3. MANUFACTURING INDUSTRY

3.1. Wind turbine manufacturers

At the end of 1995, there were three U.K. manufacturers of wind turbines rated between 300 to 600 kW. These were the Wind Energy Group, Carter Technology and Markhams Engineering Ltd. The number of sales was low during 1995 (12, 5 and 0 machines, bringing the approximate total numbers sold to date by these companies to 113, 17 and 3 respectively) which was attributed to the periodic nature of the awarding of contracts for the NFFO with many of the NFFO-3 contracts not yet fulfilled. Interest is focussed on India, which is the largest growing turbine market. Both the Wind Energy Group and Carter Technology have cooperative agreements with Indian partners and are expecting orders in the near future.

3.2. Other industries

Component suppliers

The majority of wind turbines bought in the U.K. are manufactured abroad and component supplies have been limited to a few specialist companies. The Renewables Orders are seen as an opportunity for industrial expansion and there were moves by both industry and government to increase the sourcing components in the U.K. There were reports of increased sales of U.K. manufactured components to foreign manufacturers. The blade manufacturing facility set up by WEG was established as a completely separate company (Aerolam) during 1995 and supplied blades to many leading European turbine manufacturers.

Consultants

There is a continuing but uneven demand (due to the tranches in NFFO) for consultants in site exploration, performance and financial evaluation, planning applications and environmental impact statements. The announcement of NFFO-4, SRO-2 and NIRO-2 has stimulated the market recently.

4. ECONOMICS

4.1. Value

Total invested capital

On the assumption that the installed cost of the wind plant already installed was GBP 1,100/kW of rated power, the total invested capital is circa GBP 210 million. The capital invested during the past year was circa GBP 33 million.

Production

To the end of September 1995, the wind projects in the U.K. had generated 850 GWh of electricity. Assuming a conservative generation price for conventionally generated electricity (the "pool" price) of GBP 0.026/kWh this is valued at GBP 22 million. During the year of October 1, 1994 to September, 30 1995, 361 GWh of electricity were generated, valued at over GBP 9 million.

4.2. Turbine and project costs

Based on data from manufacturers, the ex-factory cost of wind turbines is in the range GBP 450-550 per kW of rated power. For NFFO-3 projects, the total project cost for wind farm developments was estimated to be about GBP 850 per installed kW.

4.3. Generation costs

The government introduced the NFFO to encourage renewable technologies to develop to the point where they can compete with conventional technologies. To show their progress, the government is looking for evidence of price convergence. For NFFO-3 contracts (up to 15 years in duration) the average bid-in price of large projects (>1.6 MW DNC) was GBP 0.0432/kWh (lowest GBP 0.0398/kWh, highest GBP 0.0480/kWh) while for SRO projects the bid-in prices averaged GBP 0.0399/kWh (lowest GBP 0.0379/kWh, highest GBP 0.0417/kWh). These prices were substantially less than the strike price for NFFO-2 which would be GBP 0.0865/kWh after allowing for the increase in contract period and for inflation. This is a very rapid price convergence. The government is looking for NFFO-4 prices to be no higher than those in NFFO-3 despite the fact that some of the best sites were bid-in to the latter. It is expected that reduced costs for less prime sites in NFFO-4 will allow price stability to be maintained.

4.4. Benefits

Employment

A study undertaken jointly by the BWEA and DTI reports that 1,300 jobs have been created in the U.K. by the wind energy industry and that this number is expected to increase by 30% over the next two years. The final report on the work will be published in 1996.

Avoided emissions

If wind power displaces electricity which otherwise would have been produced by fossil fuel, the 361 GWh generated during the past year has avoided the emission of approximately 290 million tons of CO_2, 4 million tons of SO_x and 1.8 million tons of NO_x.

5. CONSTRAINTS ON MARKET DEVELOPMENT

5.1. Environmental impact

Visual intrusion

The visual impact of turbines continues to be one of the two prime concerns in the development of U.K. wind power plants due to developers seeking the best wind speed sites on high ground which are often in areas of scenic beauty. The conflict between the environmental benefits of wind energy and loss of landscape value continues to be a major factor in obtaining planning consent for a wind power plant development. Two studies investigating the topic were published during 1995 (References 5 and 6).

Noise

The second concern is that of noise largely because of the high population density of the U.K. and dispersed settlement patterns. The noise working group (set up by the Department of Trade and Industry to review recent experience, to define a framework to measure and rate noise from wind turbines, and to provide indicative noise levels for best practice) concluded its work and its preliminary recommendations have been published (Reference 7). The full report of the Group will be published early in 1996. R&D studies of the problem continued in the governments program (Reference 8).

Ecology

Three ecological studies, including one on bird life, indicated that wind power plants have little effect on local ecology (Reference 9, 10 and 11).

Public attitudes

Public attitudes continues to be a controversial subject. Despite several earlier surveys which indicated that local support for wind power plants is high, there is still widespread adverse comment in the press from both individuals and national bodies. Well organized objectors' groups, coordinated nationally, are believed to be largely responsible for the adverse press.

Electromagnetic interference

In collaboration with British industry, the DTI have formed a working group to draw up guidelines on the siting of wind energy developments in areas where their presence may cause electromagnetic interference. The group is expected to report in 1996.

Best practice

The British Wind Energy Association's Best Practice Guidelines for developers (Reference 12), which encourages good practice in the development of wind power plants, generally received favorable comment during the year and received a European Eurosolar Award.

5.2. Institutional aspects

Planning

The government continued to encourage local authorities to establish local structure plans which include renewable energy developments. The government is now monitoring the local authority structure plans to review how national renewable energy policies are being incorporated into local plans. Several more planning studies, carried out by local authorities and electricity supply companies in collaboration with the DTI, were completed during the year. A report on the likely impact of traffic at a wind power plant site was published (Reference 13).

Certification

Standards for and certification of wind turbines received increased attention during the year. The BWEA with the support of the DTI became increasingly involved in national and international activities in these areas, especially with the work ongoing in the European Union.

Health and safety

To complement the Best Practice Guidelines for developers, the BWEA with the support of the DTI published a set of guidelines for wind power plant operators aimed at ensuring the safe operation of a wind power plant (Reference 14).

6. PROJECT REALIZATION

Type of funding available

Finance for wind power plants is obtained largely from corporate investors and banks though there is a small amount of private investment. There is no public funding available for wind power plants as the premium prices from the Renewables Energy Orders are considered sufficient incentive.

Typical financial interest rates

Interest rates asked by banks are typically 1.5% to 5% above the London Inter Bank

Offered Rate (LIBOR). Equity/debt ratios are typically 25/75, with investors requiring a post-tax return on equity of typically 15% to 25%. Clearly these figures can vary considerably from project to project.

Machine certification requirements

The only certification requirement for wind turbine installations in the U.K. is under the EU Machinery Directive. Standards and certification are currently being considered the British Standards Institute as input to possible IEC recommendations.

Insurance

Insurance of wind power plants is not mandatory (except for employer's liability) but, as far as it can be ascertained, all wind power plants take out cover for third party claims and loss of revenue.

Warranties

Machine warranties for typically a minimum of three years (and in some cases to the end of the NFFO-2 contracts) appear to be available from manufacturers subject to satisfactory operation and maintenance agreements.

7. RESEARCH & DEVELOPMENT

R&D priorities

Industrial and government R&D in the U.K. has become increasingly focussed on increasing the competitiveness of wind energy through cost reductions and improved performance, and increasing its public acceptability by seeking to decrease its environmental impact.

Government R&D funds versus invested capital

The government continues to work in a cost-shared program with industry but as the technology achieves maturity, the trend is towards decreasing contributions from the government. Reference 1 discusses the forward strategy in greater detail. To date the government has spent in excess of GBP 60 million in sponsoring R&D projects, which should be compared to the estimated GBP 210 million invested in U.K. wind power plants. As stated above, the wind program spent GBP 3.1 million during the year ending December 1995. This is to be compared to the estimated capital investment of GBP 33 million by developers (paragraph 4.1.).

New concepts under development

A major trend in machine development in the U.K. is towards light, flexible machines to reduce capital costs. Overseas markets are seen as the main outlet for these machines and consideration is being given to maintenance and simplicity of operation.

MW-size machines under development

A three-bladed, 1 MW turbine is currently being designed by Renewable Energy Systems Ltd. with support from the EU and the DTI.

Offshore

There is continued interest by some developers in the offshore siting of turbines, prompted in part by the difficulty of finding acceptable sites onshore. One developer has obtained support from the European Union to site two wind turbines offshore, while a major generator and a turbine manufacturer have erected an anemometer off the east coast of England with the expectation of building a commercial wind power plant of 25 turbines, each rated at 1.5 MW.

8. INTERNATIONAL COLLABORATION

Formal international collaboration in the DTI's wind energy program is through the IEA and the European Union (EU) programs. The DTI encourages U.K. contractors to participate in EU funded projects and the DTI and the EU programs are considered to be complementary. During 1995, there were over 40 EU projects with U.K. participation. U.K. contractors can receive supplementary funding from the DTI where the work is relevant to the DTI program, and there were 13 such collaborative projects. These had a total value GBP 6.41 million and attracted GBP 2.39 million of EU funds, complemented by GBP 1.32 million of DTI funds.

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A complete list of reports of work undertaken in the DTI's wind energy program can be obtained from the ETSU Enquiries Bureau, Building 168, ETSU, Harwell, OX11 0RA, United Kingdom.

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1. GOVERNMENT PROGRAMS

The United States supports wind energy development with a strong research and development program at the Department of Energy (DOE). The Energy Policy Act of 1992 continues to have significant impact by encouraging commercial deployment of wind and other renewable technologies. The Act provides a production incentive to public power utilities (see section 5), and a tax credit to investor-owned utilities and independent power producers. In addition, some state governments have enacted financial incentives to encourage wind and other technologies. State incentives are generally in the form of exemptions from property, sales, or corporate excise taxes or tax credits for a certain percentage of the system costs. As a result, the current level of installed capacity is expected to more than double in the next four to five years.

Wind energy development in the U.S. is driven by increasing concern for the environment, decreasing electricity reserve margins in many parts of the U.S., and expected increases in fossil-fuel costs. Recently, however the rate of new wind turbine deployment has slowed in many regions of the U.S. because of electric utility restructuring. Unsure of what the new regulatory structures will be, utilities have been reluctant to invest in new generation assets, including wind, until the many restructuring questions have been resolved. U.S. utility restructuring should bring more competition to electric markets, but may also change the vertically integrated nature of the industry. There is additional uncertainty in the California market as the wind power purchase contracts negotiated in the 1980's at higher electricity rates begin to expire in 1996. Most early contracts had ten year power purchase prices over USD 0.10/kWh whereas today prices are around USD 0.03 kWh or less.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

At the end of 1995, wind energy capacity in the United States had reached about 1,770 MW with the two latest wind power plants to come on line, both in Texas, in August and September. The first Texas project, 35 MW of generating capacity through a municipal electric agency, the Lower Colorado River Authority, came on line in two phases in August and September and employs 112 Kenetech KVS-33 turbines. The second project, under the DOE/Electric Power Research Institute (EPRI) sponsored Turbine Verification Program is a 6.6 MW wind power plant in southwest Texas. The project is owned by Central and South West Services Company and came on line in September using 12, aileron-controlled, 550 kW, Zond Z-40 turbines. A summary of future and planned installations is shown in Figure 1. The estimated energy production from the U.S.-installed wind capacity was about 3.7 Terawatt-hours during 1995.

3. MANUFACTURING INDUSTRY

The U.S. wind turbine manufacturing industry is expanding with 17 active turbine manufacturers having produced about USD 3.5 billion worth of goods and services since 1980. Many of these firms are developing new turbines for both domestic and international markets. In addition to the turbines being developed in cooperation with DOE, (see section 6.2) several larger turbines are being developed by U.S. companies.

Several U.S. turbine manufacturers are proceeding to obtain type certification of their turbines for exporting to countries with certification requirements. For turbine installation in the U.S., certification is not required because the wind turbines developed in the U.S. are designed to meet or exceed current standards for reliability and maintainability. This market approach with commercial warranties employed in the U.S. has encouraged the successful deployment of over 17,000 wind turbines domestically and overseas.

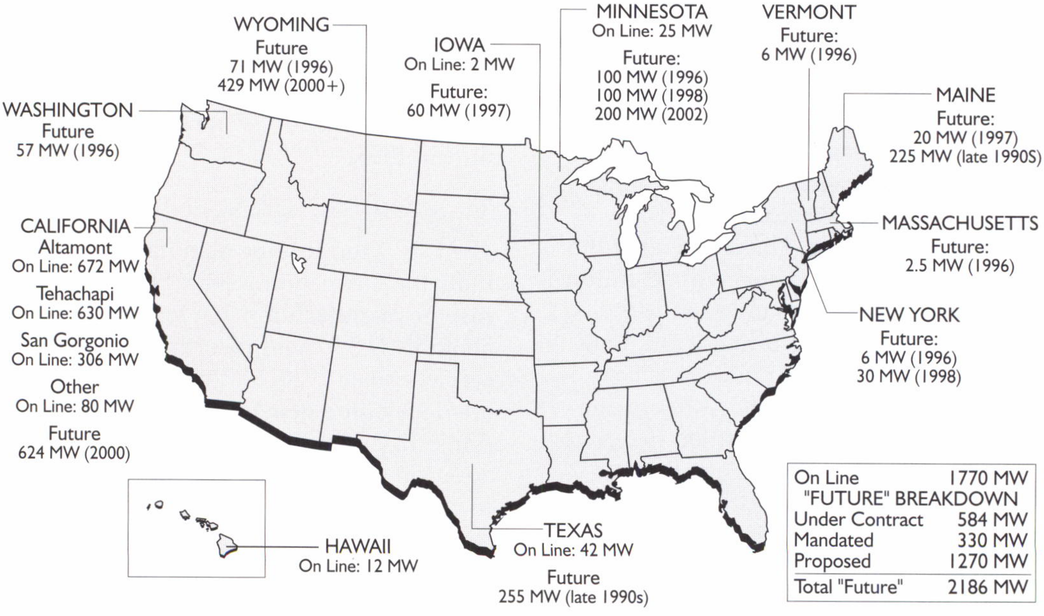
4. ECONOMICS

In order for wind energy to develop in the U.S., it has to be cost competitive with other electric generation technologies. Cost goals are also important in keeping DOE and the wind industry focused on continually improving the cost and performance characteristics of U.S.-built turbines. Wind-generated electricity is currently in the range of USD 0.04 to USD 0.07/kWh depending on the wind speed, financing and other factors. The DOE wind program's cost-of-energy goal is USD 0.025/kWh in good winds with favorable financing by the year 2000.

5. MARKET DEVELOPMENT

There are three categories of federal financial incentives available for wind power plant developers. Under a provision available to capital equipment owners, wind energy developers can use accelerated depreciation available through the Tax Reform Act of 1986. Generally, this depreciation allows for a five-year, double declining balance for wind and other types of renewable facilities because it is capital equipment.

The other two incentives that are specific to renewable technologies are contained in the Energy Policy Act of 1992 (EPAct, Public Law 102-486). Federal tax incentives were provided by Title XIX of EPAct. Section 1916 made permanent a 10% business energy credit for qualified investments in new solar, wind and geothermal properties. Lastly, Section 1914 enacted the USD 0.015/kWh production incentive for electricity sold to



On Line	1770 MW
"FUTURE" BREAKDOWN	
Under Contract	584 MW
Mandated	330 MW
Proposed	1270 MW
Total "Future"	2186 MW

Figure 1. Map of grid connected wind power plants planned, under construction and operating in the United States at the end of 1995.

an unrelated party from eligible wind and closed-loop biomass facilities. The eligibility period is January 1, 1994 through June 30, 1999. For investor-owned (tax paying) utilities, the production incentive is taken as a tax credit. For non-profit electricity generators that are tax exempt, such as municipal or cooperative electric agencies, the Renewable Energy Production Incentive (REPI) is available as an incentive payment from DOE.

In July, the Department issued the regulations to implement REPI as authorized under EPAct. The regulations contain the application procedures, qualification requirements, procedure for calculation of the incentive payments at a rate of USD 0.015/kWh, and other administrative procedures. The incentive payment rate is adjusted annually to account for inflation. For FY 1994, the first year of incentive payments, total REPI payments were USD 693,000 of which USD 93,038 was for wind.

6. DOE ENERGY PROGRAM

The goal of the DOE Wind Energy Program is to develop new technology and assist utilities and industry in its introduction into new markets and applications for wind systems. The underlying objective is to develop wind turbine technology that is economically competitive as an energy source. The DOE Wind Energy Program works with industry on the following activities:

- applied research-base program;
- wind turbine development;
- wind energy plant deployment.

The program's funding has increased from USD 30.4 million in FY 1994 to USD 49.0 million in 1995. The bulk of the increased budgets during the last several years were used for turbine development and collaborative activities with industry to assist wind turbine deployment in the U.S. The deployment program was funded at USD 13.5 million for one year in 1995. Activities in this area included resource assessment, advanced turbine field testing, and cost-sharing of larger-scale pilot plants at new sites across the U.S. This program will be discontinued in 1996 but as a result, about 60 MW of new turbines will be installed in the next several years. The overall program budget for FY 1996 is USD 32.5 million.

The wind program's R&D activities are focused at NREL's National Wind Technology Center (NWTC), located on a 280 acre site near Boulder, Colorado. The NWTC will conduct a wide range of wind energy research, component development, and testing to complete system verification. The NWTC now includes a 20 KW combined-experiment test bed, a structural test facility, and a main research building. Construction has started on a 10,000 square foot Industrial User Facility to be used for industry research and to support wind turbine certification program testing. In addition, a 600 kW advanced research turbine, designed for use in testing and evaluating a wide range of turbine components, will be operational in 1996. When completed, the NWTC will be one of the most advanced wind research facilities in the world.

6.1. Applied research base

Industry-driven, applied research continues at about USD 10 million per year ensuring that fundamental analysis and design tools are available for industry to perform detailed designs of future advanced wind turbines. Research includes computer models for aerodynamic performance, structural dynamics, and yaw dynamics. Key research activities support the wind industry's needs for turbines, components, and subsystems with more innovative and risky designs but which could yield major improvements in turbine performance, reliability, and cost. These activities are difficult for industry to support because of the long-term payback on research investments. Projects include the 10 m blade research test bed, wind characterization, aerodynamics, structural dynamics and fatigue, and power subsystems.

6.2. Wind turbine development

The development of technologically advanced wind turbines is one of DOE's and industry's highest priorities. The overall goal of the wind program is to develop systems that can compete with conventional electric generation in moderate wind speeds of 5 m/s (13 m/h) annual average. This goal will be achieved through a number of coordinated turbine development and product improvement efforts with the U.S. wind industry.

The Turbine Development Program (TDP) uses a dual-path technology development approach, addressing both near-term and next-generation issues. Near-term efforts support the development, fabrication, and field testing of several new turbines (see Table 1). The near-term cost-of-energy goal of USD 0.05/kWh at 5.8 m/s sites by the mid-1990's has been met. These machines help bridge the gap between current technology and the next-generation of utility-grade wind turbines. Another near-term project is the Value Engineered Turbine (VET). VET focuses on re-engineering and/or improving current conventional wind turbine configurations. The activity supports, on a cost-shared basis, value analyses of current technology.

Next-generation TDP machines will employ advanced technology and innovative designs to reach the target levelized costs of electricity of USD 0.025/kWh by the year 2000. These machines will compete directly for bulk electric power markets without the need for subsidies.

Under an open competition for this program in 1995, seven companies were

Table 1. Characteristics and status of advanced wind turbines developed under the U.S. Department of Energy wind energy program

COMPANY NAME	MACHINE NAME	ROTOR DIAMETER	POWER	INSTALLED OR PLANNED
Advanced Wind Turbines, Inc. (Figure 2)	AWT-26	26 m	275 kW	25 MW planned, U.S. 80 MW planned, India
Atlantic Orient Wind Systems, Inc. (Figure 3)	AOC 15/50	15 m	50 kW	4 turbines installed, U.S. 1 turbine installed, Canada 6 turbines planned, Alaska Up to 20 turbines planned, Morocco
New World Power Technologies Co.*	North Wind 250	25 m	250 kW	Prototype
Zond Systems, Inc.*	Z-40	40 m	550 kW	7 MW installed, U.S. 30 MW planned, China 60 MW planned, India
FloWind Corporation*	EHD-17	17 m	300 kW	Prototype

* Shown in 1994 IEA Wind Agreement Annual Report

Figure 2. AWT-26 prototype, 275 kW, 26 m rotor diameter advanced turbine operating at the National Wind Technology Center near Golden, Colorado.

selected to prepare conceptual design reports. Subsequently, several of the best concepts will be supported for cost-shared full scale development. The companies selected to prepare designs were: Certek, FloWind, Kenetech Windpower, New World Power Technologies, The Wind Turbine Co./Dow Chemical/United Technologies, UltraWind and Zond Systems. An innovative subsystems activity, currently underway, also supports the next-generation path by developing advanced generators, rotors, and control systems.

Figure 3. AOC 15/50, 50 kW turbine with 15 m rotor diameter being tested in wind/diesel applications at the National Wind Technology Center near Golden, Colorado.

7. WIND POWER PLANT DEPLOYMENT

DOE has initiated a series of activities addressing issues regarding the integration of wind systems into electric utility operations. One of the most important activities is the National Wind Coordinating Committee. Members of the industry-led collaborative include electric utilities, independent power producers, regulators, wind power equipment manufacturers, service providers, and consumer and environmental groups. The group's aim is to ensure responsible and self-sustaining commercial use of wind power. This organization coordinates wind resource assessment, research on avian and other environmental issues, and disseminates technical and program information. Some activities involve DOE wind program funding, while other activities, such as removing state regulatory barriers, involve DOE in a supporting role.

Another activity is the Utility Wind Turbine Performance Verification Program (TVP). Co-sponsored with EPRI, this cost-shared program is deploying 6 MW or larger wind power plants to evaluate commercial/prototype wind turbines in typical utility operating environments in diverse regions of the country. The first three host utilities under this program have been selected. The first one, Central and Southwest Public Service Corporation (Texas), began operations in September, 1995 as discussed earlier. The other two, Green Mountain Power Corporation (Vermont) and Niagara Mohawk Power Company (New York) should come on line in 1996 and 1997, respectively. The host utilities will provide a range of operating data on advanced turbines from utility-scale wind installations in different parts of the U.S.

Another parallel deployment program assists the states by familiarizing them with wind resources and applications. This program, called Sustainable Technology Energy Partnerships (STEP) received USD 1.5 million in DOE subcontract and cooperative funding, leveraged by cost-sharing of 50% or more by the states. STEP focuses on the latter stages of research and development and the early stages of commercialization. Projects involve wind resource assessment, avian population studies, and the testing of wind turbines in cold climates. DOE, through NREL, has selected a total of ten cost-shared pilot projects under this pilot program. Environmental research in the DOE wind program is focused on avian issues. Several meetings have been held with industry, utilities and environmental groups to develop a comprehensive research program. One of the first studies, which analyzed golden eagles in Altamont Pass in California, was published in May 1995. Under this program, the birds were tagged with transmitters. Of the ten birds that died since the study began in early 1994, two collided with turbines while the other eight perished from a variety of causes including accidental poisoning, being shot, or getting hit by a car. The study results also add support to the thesis that lattice-type towers with horizontal cross bars for perching may be associated with higher avian mortality rates.

8. INTERNATIONAL PROGRAMS

The DOE wind program provides technical assistance to governments and utilities in countries planning wind projects in Central and South America, Asia, Africa and elsewhere. An example is a bilateral agreement signed with China that will allow the exchange of scientists and assistance in planning large scale grid-connected and village power wind projects.

DOE is leading the Committee on Renewable Energy Commerce and Trade (CORECT), a working group of U.S. government agencies whose objective is to promote increased international use of renewable energy technologies. CORECT activities include assessing opportunities for renewables use overseas, supporting renewable energy pilot project and feasibility studies, increasing access to project financing and supporting renewable energy education efforts.

Recent CORECT accomplishments have included implementation of financing mechanisms that bundle loans for small scale renewable energy projects with larger development bank loans with emphasis on support for renewable energy projects in the western hemisphere. Ongoing activities include support of several wind hybrid power system and water pumping installations in Mexico, Brazil, Chile, Argentina and other countries. Under the related U.S./Brazilian Rural Electrification Pilot Project, the National Renewable Energy Laboratory (NREL) will expand on the previous photovoltaics installations to the demonstration at two sites of hybrid wind-photovoltaic systems. Similar rural electrification projects are operating in Mexico.

In cooperation with the U.S. Agency for International Development, DOE and its laboratories are involved in the support of wind resource assessment and renewable project evaluation and implementation in Mexico. Several wind-hybrid systems are being deployed there. In a related project in Indonesia, wind and wind-hybrid projects for electricity supply and irrigation water pumping are being installed through local Indonesian communities and non-governmental organizations (see Figure 4).

Other international activities include such work as aiding wind assessment efforts in eastern Europe and the former Soviet Union. DOE, working with the government of Ukraine, developed a plan to replace the output of the Chernobyl nuclear plant with energy conservation measures and a variety of new generating facilities, including a 1,000 MW wind power plant. Under a private commercial venture, the U.S. company Kenetech Windpower has begun manufacturing 100 kW turbines in the Ukraine. Initial turbines have been installed and are operating on the Crimean peninsula as the first step toward the installation of a 500 MW wind plant on that site.

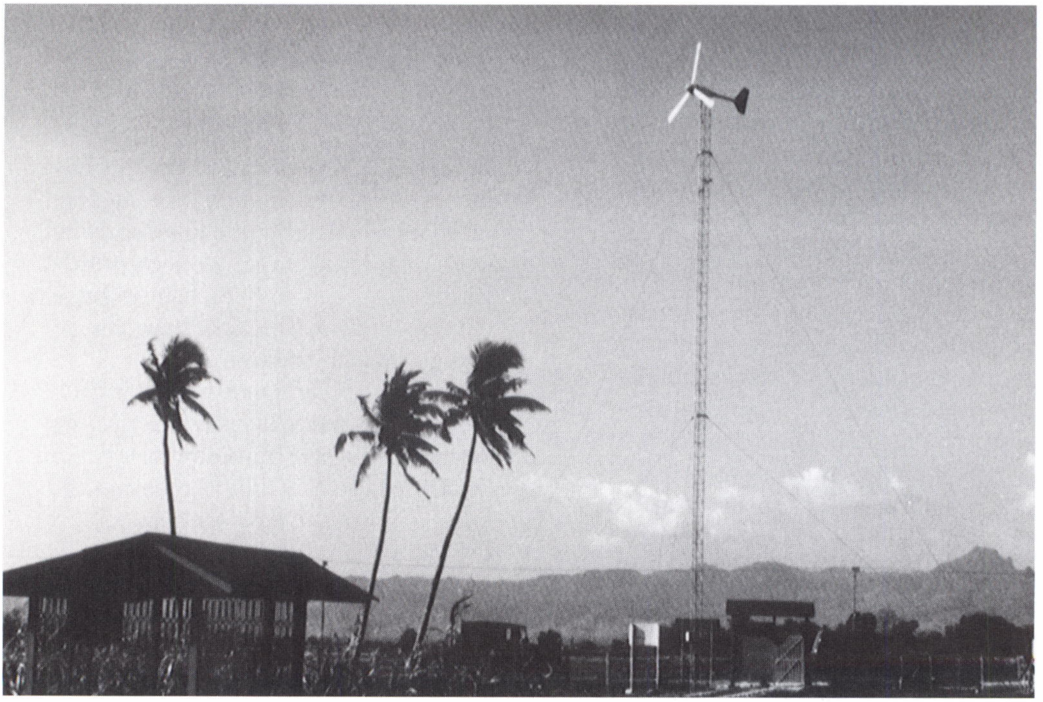


Figure 4. BWC 1500-PD, 1.5 kW, 3 m rotor diameter, Bergey Windpower turbine in the Indonesian village of Oesao, used for wind-electric water pumping that irrigates four hectares of vegetable farms.

APPENDIX I – Currency Conversion Table

Currency conversion as of the end of December 1995

		SDR	AUD	CAD	DKK	ECU	FIM	DEM	GDR	ITL	JPY	NLG	NOK	ESP	SEK	GBP	USD
IMF SDR	SDR	--	0.500	0.493	0.121	0.856	0.155	0.467	0.003	0.00042	0.007	0.417	0.106	0.005	0.102	1.042	0.671
Australian Dollar	AUD	2.000	--	0.985	0.241	1.712	0.311	0.935	0.006	0.001	0.013	0.833	0.212	0.011	0.203	2.083	1.342
Canadian Dollar	CAD	2.030	1.015	--	0.245	1.738	0.315	0.949	0.006	0.001	0.013	0.846	0.215	0.011	0.206	2.115	1.362
Danish Krone	DKK	8.290	4.145	4.084	--	7.096	1.287	3.874	0.023	0.004	0.055	3.454	0.879	0.046	0.842	8.635	5.564
European Currency Unit	*ECU	1.168	0.584	0.575	0.141	--	0.181	0.546	0.003	0.000	0.008	0.487	0.124	0.006	0.119	1.217	0.784
Finnish Markka	FIM	6.440	3.220	3.172	0.777	5.513	--	3.009	0.018	0.003	0.043	2.683	0.683	0.035	0.654	6.708	4.322
German Mark	DEM	2.140	1.070	1.054	0.258	1.832	0.332	--	0.006	0.001	0.014	0.892	0.227	0.012	0.217	2.229	1.436
Greek Drachma	GDR	353.36	176.68	174.1	42.625	302.48	54.870	165.1	--	0.1492	2.3367	147.23	37.472	1.9415	35.874	368.08	237.15
Italian Lire	ITL	2,368.3	1,184.2	1,166.7	285.68	2,027.3	367.75	1,106.7	6.7	--	15.661	986.80	251.15	13.013	240.44	2,467.0	1,589.5
Japanese Yen	JPY	151.22	75.610	74.493	18.241	129.45	23.481	70.664	70.664	0.0639	--	63.008	16.036	0.831	15.352	157.52	101.49
Netherlands Guilder	NLG	2.400	1.200	1.182	0.290	2.054	0.373	1.121	1.121	0.0010	0.016	--	0.255	0.013	0.244	2.500	1.611
Norwegian Krone	NOK	9.430	4.715	4.645	1.138	8.072	1.464	4.407	4.407	0.0040	0.062	.929	--	0.052	0.957	9.823	6.329
Spanish Peseta	ESP	182.00	91.000	89.655	21.954	155.80	28.261	85.047	85.047	0.0768	1.204	75.833	19.300	--	18.477	189.58	122.15
Swedish Krone	SEK	9.850	4.925	4.852	1.188	8.432	1.530	4.603	4.603	0.0042	0.065	4.104	1.045	0.054	--	10.260	6.611
U.K. British Pound	GBP	0.960	0.480	0.473	0.116	0.822	0.149	0.449	0.44	0.0004	0.006	0.400	0.102	0.005	0.097	--	0.644
U.S. Dollar	USD	1.490	0.745	0.734	0.180	1.275	0.231	0.696	0.696	0.0006	0.010	0.621	0.158	0.008	0.151	1.552	--

Source: International Monetary Fund Internet Web site, average of daily rates in December 1995.
Original IMF rates are all reported in national currency units per SDR.

*ECU December average rate from the Federal Reserve Bank of New York.

APPENDIX II

The 35th Executive Committee meeting in Vouliagmeni, Greece, on October 11/12, 1995.

APPENDIX III

IEA R&D EXECUTIVE COMMITTEE 1995
M = Member   A = Alternate Member

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National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393

A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute under contract No. DE-AC36-83H10093

For orders call +1 303 275-4363
Printing paid for by IEA
SP-440-20860

Printed on recycled paper.

IEA WIND ENERGY ANNUAL REPORT 1995

Wind energy stands out as one of the most promising renewable energy sources in the near term. The deployment of wind energy is promoted by national programs for advanced technology research and market incentives in many countries.

Parties from 16 countries collaborate in wind energy research and development under the auspices of the International Energy Agency. The program includes joint research projects and information exchange on wind systems development and deployment.

The report reviews the progress of the joint projects during 1995 and highlights the national wind energy activities in the member countries.

By the end of the report period more than 27,000 grid-connected wind turbines were operational in the member countries, representing a rated power of around 4,300 MW, bringing the world-wide total to about 4,900 MW. Collectively, these turbines produced about 8 TWh during the year.

There has been a trend towards larger commercial turbines (now up to 500-750 kW, corresponding to rotor diameters of up to 40-45 m). Prototype megawatt-sized turbines (up to 3 MW) are in operation in nine member countries.