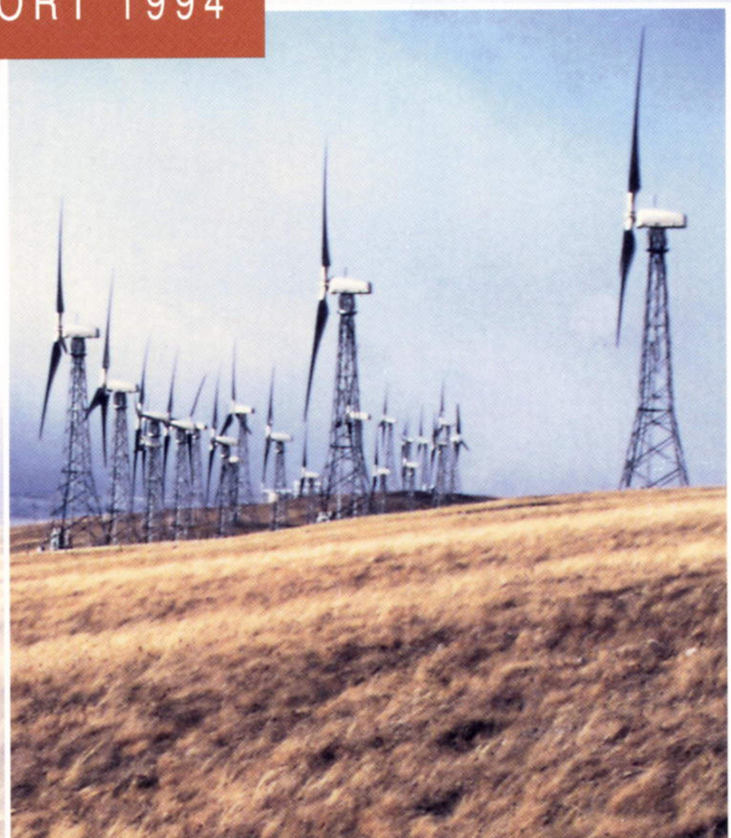
IEA WIND ENERGY

ANNUAL REPORT 1994



R&D
WIND

INTERNATIONAL
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AGENCY

IEA WIND ENERGY

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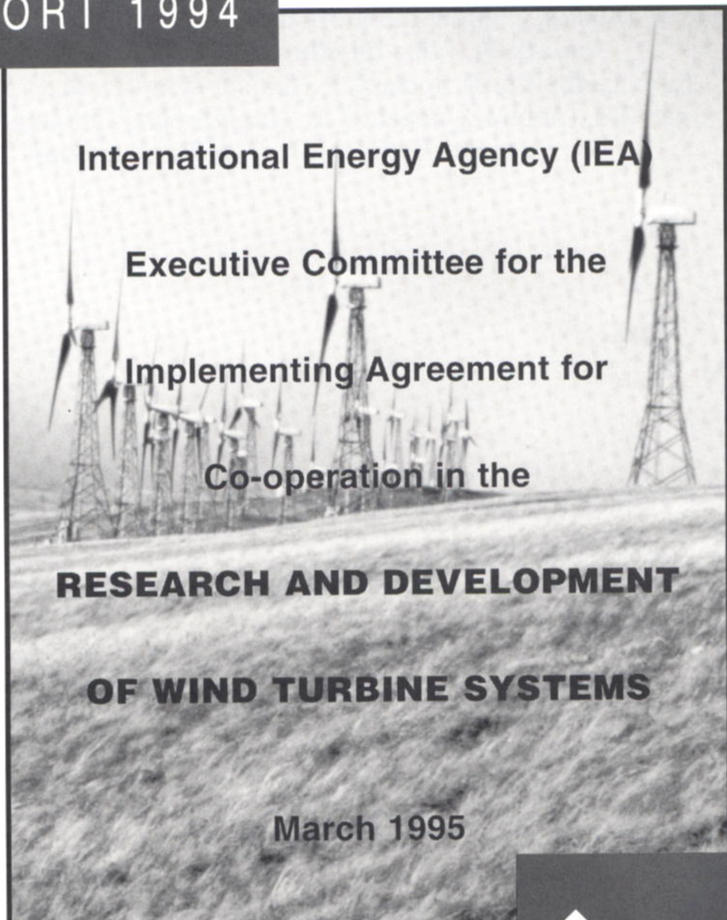

International Energy Agency (IEA)

Executive Committee for the

Implementing Agreement for

Co-operation in the

RESEARCH AND DEVELOPMENT

OF WIND TURBINE SYSTEMS

March 1995

NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado
80401-3393
United States

Cover photo of Cowley Ridge Wind Plant, Alberta, Canada; Kenetech Windpower turbines in 18.9 MW wind powered electric generating facility.

Photo by H.J.M. Beurskens.

FOREWORD

This is the seventeenth Annual Report 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. The Agreement and its program, which is known as IEA R&D Wind, is a collaborative venture among parties from 14 IEA 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-Diederen with contributions from R.S. Rangi (Canada), P. Nielsen (Denmark), E. Peltola (Finland), R. Windheim and K.A. Braun (Germany), L. Barra (Italy), H. Matsumiya (Japan), J. 't Hooft (the Netherlands), E. Solberg (Norway), F. Avia and C. Lago (Spain), H. Ohlsson (Sweden), D.I. Page (United Kingdom), and D.F. Ancona and P.W. Carlin (United States).

Milan, January 1995

Dr. E. Sesto
Chairman of the
Executive Committee

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EXECUTIVE SUMMARY

INTRODUCTION

Wind energy stands out as one of the most promising renewable energy sources in the near and medium term. Small and medium-sized wind turbines (up 500 kW rated capacity) are commercially available; their technology is maturing and, under suitable conditions, is becoming economically competitive with conventional means of electricity generation. Most of the plants are owned by private investors or cooperatives, but utilities are taking an increasing interest in the deployment of wind power plants on a large scale. Further cost reductions and improvement in performance are needed, and the development of large-scale wind turbines is likely to be essential if large-scale generation of wind energy is to be achieved.

The purpose of the IEA Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems (IEA R&D Wind) is to carry out cooperative research, development, and demonstration projects in wind energy. Since 1991, the activity also includes the exchange of information on the planning and execution of national programs for the design, construction, operation and evaluation of large-scale wind systems having a rated power of approximately 1 MW or more.

IEA R&D Wind has 16 signatories from 14 countries: Austria, Canada, Denmark, Finland, Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, the United Kingdom, and the United States.

The IEA R&D Wind Agreement 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.

The report reviews the progress during 1994 in the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems, set up in 1977 under the auspices of the International Energy Agency (IEA).

NATIONAL PROGRAMS

The national wind energy programs are the basis for the IEA R&D Wind collaboration. These national programs are continuing to expand in the member countries. Total government funding in the member countries is about USD 190 million for 1995, an increase of over USD 10 million compared to 1994. The programs are mainly directed to the development and deployment of advanced wind turbines. Reviews of progress in each national program are given in the chapter *National Activities*. The main points of note from the national programs include:

Canada In Canada, there is surplus installed conventional capacity producing low cost energy. With local subsidies, commercial wind energy development is beginning. The main focus of the Canadian National Program continues to be on R&D and field trails.

Denmark During 1994, wind energy capacity in Denmark increased by 52 MW to a total of 540 MW. The new 1 MW, 50 m diameter, stall controlled turbine at Avedøre in the ELKRAFT area was inaugurated in September. The first of three new near MW-size turbines (Bonus 750 kW) to be installed in the ELSAM area was erected in the same month. Planning permission for the second Danish off-shore wind farm was received late in the year and construction is under way.

Finland Despite the 100 MW program announced in 1993, there were no new wind installations in 1994, although a number are planned. The national program is active in the areas of wind resource, arctic wind technology, integration studies, and component development. The latter is in support of the export activities of the component supply industry because there is no manufacturer of turbines in Finland.

Germany Wind energy development grew rapidly during 1994 due to good pay back prices and the stimulation of the "250 MW" program. During the year, the installed rated capacity almost doubled from 334 MW to 643 MW and is composed of 2,617 turbines in total. Late in the year, turbine selling prices of around DEM 2,000/kW (USD 1,315/kW) started to decrease, portending a good market for 1995. Commercial machines of 500-600 kW showed availabilities over 98%, while the development of several MW-rated turbines made good progress.

Italy As at the end of 1994, Italy's grid connected wind generating capacity totalled almost 22 MW, consisting of 87 machines installed in 22 plants. Most of these plants had been set up or connected recently. In addition, construction of ENEL's 11 MW wind farm at Monte Arci was under way. In 1993-1994, projects totalling over 50 MW were submitted by autonomous producers to authorities for financial support. The prototype 1.5 MW GAMMA-60 turbine reached its target of 1,000 MWh, thus completing the commissioning phase.

Japan An experimental wind farm consisting of machines from various manufacturers with a total capacity of 1 MW is under construction on Miyako Island in Okinawa. In December 1994, the Japanese government announced a target of 150 MW capacity to be installed by the year 2010.

The Netherlands During 1994, wind energy capacity in the Netherlands increased by 22 MW (93 turbines) to a total of 153 MW and is composed of 729 machines. Annual production of electricity was 247 GWh. At the start of the year, average project costs were NLG 2,425/kW (USD 1,397/kW) - NLG 1,000/m^2 (USD 576/m^2), with turbine costs accounting for 70% of the project costs, or NLG 700/m^2 (USD 403/m^2). By the end of the year, a 500 kW, 41.3 m diameter turbine was priced at NLG 850,000 (USD 489,913) - NLG 635/m^2 (USD 365/m^2).

The government is an advocate of ecological taxes and recently announced that if the European Union does not introduce such a tax in the short term, the Netherlands will do so at a national level by January 1, 1996.

Norway In January 1994, the wind energy R&D program was combined with those for biomass, solar, and wave energy into a single program on new and renewable sources of energy. The wind energy budget for 1994 was small - NOK 0.6 million (USD 0.08 million) - and is sufficient to support ongoing R&D activities. A second generation wind/diesel installation with a newly developed control system was put into operation at the test station at Frøya in 1994. A program for testing the new wind/diesel system against consumer load is in progress and is proceeding satisfactorily.

Sweden Wind energy in Sweden received a big stimulus from the introduction of an "environmental bonus" on wind produced energy of SEK 0.09/kWh (USD 0.012/kWh). The development of new turbines has also progressed. During 1994, the prototype 3 MW turbine at Näsudden produced 6.7 GWh, with an availability of 93%. Energy cost analyses for such turbines have indicated a likely cost of ECU 0.035-0.04/kWh with series production. There is increased involvement with R&D activities in the European Union following an agreement and the fact that Sweden joins the European Union in 1995.

United Kingdom Installed wind energy capacity increased to 145 MW with the completion of the remaining projects in the second tranche of the NFFO. The three wind farms using Wind Energy Group MS3 turbines (damaged in a storm in December 1993) all resumed operation, and high availability and output were reported generally. In December, contracts were announced for the third tranche; there are 55 projects totalling 385 MW rated capacity, 31 of the projects having a capacity exceeding 3.7 MW rated. In March, the government issued an Energy Paper (No. 62) which was a statement of policy, strategy, and forward program on the Future Prospects for New and Renewable Energy in the United Kingdom.

United States During 1994, the number of wind energy projects continued to grow, particularly in the Midwest where a 73 turbine, 25 MW plant was completed in Minnesota. Other large plants, totaling several hundred megawatts, are under construction. DOE wind program funding levels increased substantially to USD 30.4 million for 1994 and USD 49 million for 1995. The 500 kW Z-40 (Zond), the 275 kW AWT-26 (Lynette and Associates), and the 50 kW AOC 15/50 (Atlantic Orient Corporation), developed under the DOE program, are now operational. The Turbine Development Program is beginning its next phase, with the goal of producing turbines capable of generating electricity at less than USD 0.04/kWh by the year 2000. Initial deployment of new turbines in wind farms is being cost-shared by DOE with utilities and industry.

COLLABORATIVE ACTIVITIES

Tasks

Eleven projects, called 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 Tasks are given in the chapter IEA R&D Wind Program. In brief, the status of current Tasks is:

TASK VIII was completed with the publication of the book Wind-Diesel Systems in February 1994 by Cambridge University Press.

TASK XI—BASIC TECHNOLOGY INFORMATION EXCHANGE. Task XI has participants from 12 countries. The main activities include the preparation of documents in the series of 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. During 1994, revised editions of "Estimation of Cost of Energy from Wind Energy Conversion Systems" and "Acoustics Measurement of Noise Emission from Wind Turbines" were published. An Expert Group has been formed in order to prepare a Recommendation for Noise Emission Measurements. The Group had its first meeting in September 1994.

TASK XII—UNIVERSAL WIND TURBINE FOR EXPERIMENTS (UNIWEX) is to be completed by January 1995. This Task has 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, completed in 1994, with a final report to be published by January 1995, consisted of co-operative action and exchange of information on the planning and execution of national R&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 is a relatively new joint research project involving five laboratories in four countries (Denmark, the Netherlands, the 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. Activities are ahead of schedule and are expected to be finished by July 1995, with a final report to be published in the second half of 1995.

TASK XV—REVIEW OF PROGRESS IN THE IMPLEMENTATION OF WIND ENERGY. Arising from a review of the strategic plan, a new Task, "Annual Review of Progress in the Implementation of Wind Energy by the Member Countries of the IEA," was proposed to be coordinated by the UK Atomic Energy Authority on behalf of the United Kingdom. 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. The review is to be 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.

Expert meetings
These are a subtask of Annex XI. The 26th Topical Expert Meeting was held in March 1994 on "Lightning Protection of Wind Turbine Generator Systems and EMC Problems in the Associated Control Systems."

Joint Actions
These are also subtasks of Annex XI. The 3rd symposium on "Wind Turbine Fatigue" was held in April 1994. A symposium on "Wind Conditions for Wind Turbine Design" took place in June 1994.

EXECUTIVE COMMITTEE ACTIVITIES

Officers
Dr E. Sesto (Italy) and Mr. D. Ancona (United States) served as Chairman and Vice-Chairman during the year. At the fall meeting, Dr. Sesto and Mr. Ancona were re-elected Chairman and Vice-Chairman for 1995.

Transfer of the EC Secretariat from Mr. B. Pershagen (Sweden) took place following his retirement after 15 years of service as Secretary to Mrs. K. Steer-Diederen (United States) who was contracted to serve as the new Secretary as of January 1, 1994.

Participants
At the end of 1994, Scottish Hydro-Electric plc withdrew from the Agreement. The Greek Ministry for Energy announced its interest in joining the Agreement, and it was accepted unanimously as a new member by the Executive Committee

at its fall meeting. The Norwegian Water Resources and Energy Administration (NVE), in co-operation with the Norwegian Research Council, renewed its obligation as the contracting party to the Agreement. Australia, Mexico and Poland have shown interest in joining the Agreement.

Several changes in Executive Committee membership were announced during the year. See Appendix II for an updated list of Members and Alternate Members.

Spring 1994 meeting

The 33rd meeting of the Executive Committee was held on April 18 and 19, 1994, in Rotterdam, the Netherlands. The meeting was attended by 24 participants, including representatives from 10 of 14 member states, Operating Agents, and representatives from the IEA in Paris and the European Union (DG XII). Observers from Greece, Poland, and Lithuania attended the meeting.

During the meeting, progress of the ongoing Tasks was reviewed and the necessary administrative decisions were taken. Proposals for new cooperative actions were discussed. Information was exchanged on the national wind energy R&D programs and the large-scale wind system activities in the member countries. Strategic Plan priorities were prepared for discussion.

On April 20, the Committee visited a new wind park of twelve 500 kW NedWind 40 wind turbines under construction in "Van Pallandt Polder."

Fall 1994 meeting

The 34th meeting took place on October 26 and 27, 1994, in Banff, Alberta, Canada. The attendance was 21 participants, representing 12 of the 14 member states and Operating Agents. During the meeting, again highlights of national programs were presented, progress on the ongoing Tasks was reviewed, and proposals for new cooperative actions were discussed.

The Executive Committee approved a new task (Annex XV), "Annual Review of Progress in the Implementation of Wind Energy by the Member Countries of the IEA." Dr. D.I. Page was nominated by the United Kingdom as Operating Agent; this was accepted by the Executive Committee. The objective of this new Task is to produce an annual review giving an overview of the progress in the commercial development of wind turbine systems in the member countries of the IEA R&D Wind IA. The review is to be in a form suitable for presentation to decision makers in government, industry, financial and planning institutions, and the public. It was proposed that the Annex would become operative on January 1, 1995, and remain in force for three years.

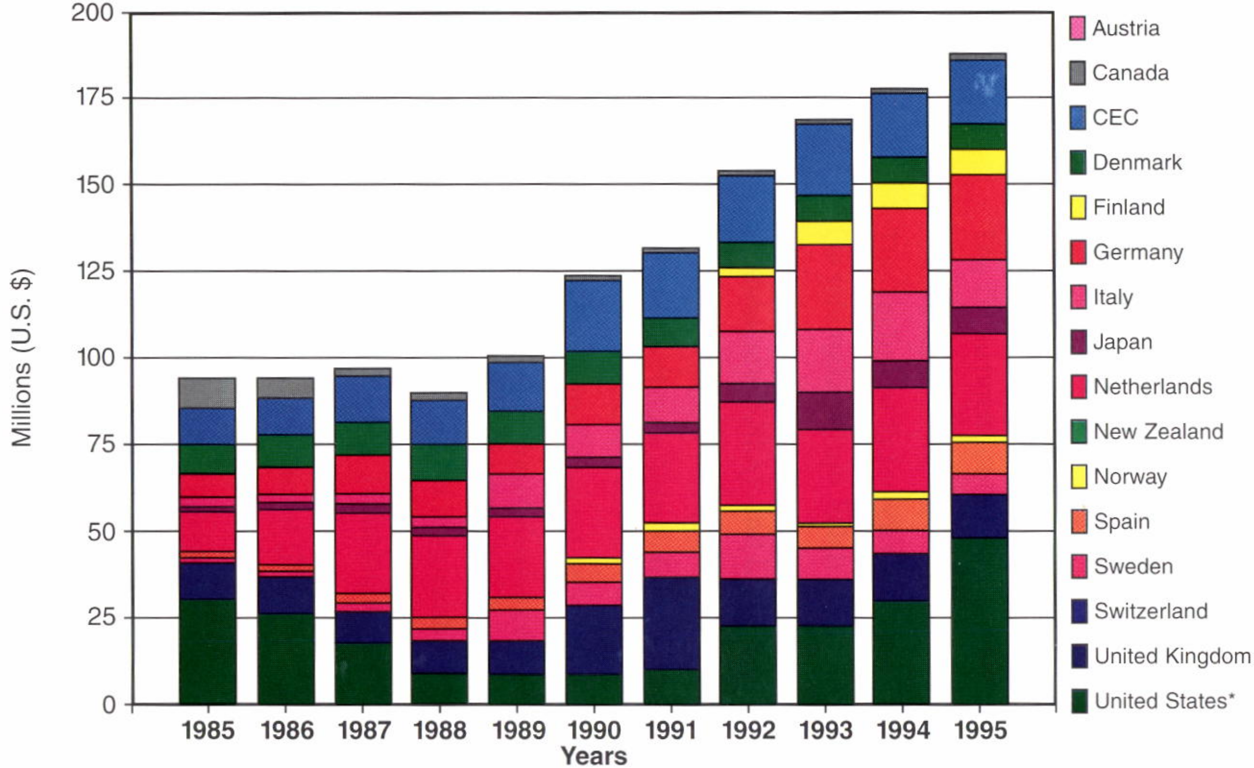
A status report on the IEA R&D Wind activities was prepared and presented at the IEA Working Party on Renewable Energy Technology (REWP) November meeting in Paris.

A visit to the Cowley Ridge Wind Plant in Pincher Creek, Alberta, took place on October 28, 1994.

Planning Committee meeting

The Planning Committee met on February 3 and 4 in Petten, the Netherlands.

WIND ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION GOVERNMENT FUNDING



Source: International Energy Agency
Wind Energy Systems Agreement
Executive Committee 10/94

*Includes investment
or Operating Subsidies

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THE IEA R&D WIND PROGRAM

THE IMPLEMENTING AGREEMENT

The IEA cooperation in wind energy started in 1977. Presently 16 parties, designated by the governments of 14 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:

Austria	The Republic of Austria
Canada	The Department of National Resources Canada
Denmark	The Ministry of Energy
Finland	The Technical Research Centre of Finland (VTT)
Germany	Forschungszentrum Jülich GmbH
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, 13 Tasks have been initiated. Eight Tasks have been successfully completed. Three Tasks are technically completed but the final reports are pending.

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: U.S. 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 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 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 1995
Task XII	Universal wind turbine for experiments (UNIWEX) Operating Agent: Institute for Computer Applications, University of Stuttgart, Germany Completed in 1994. Final report pending

Task XIII Cooperation in the development of large-scale wind systems
Operating Agent: National Renewable Energy Laboratory (USA)
Completed in 1994. Final report pending

Task XIV Field rotor aerodynamics
Operating Agent: Stichting Energieonderzoek Centrum Nederland (ECN)
To be completed in 1995

Task XV Review of progress in the implementation of wind energy
Operating Agent: UK Atomic Energy Authority
To begin in 1995

In Task XI, the participants contribute manpower and work, usually in their home countries, to a joint program coordinated by the Operating Agent. 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. Tasks XII, XIII and XIV are mixed cost- and task-shared. The participation in current Tasks is shown in the following table.

Table 1. Participation per Country in Current Tasks (OA Indicates Operating Agent)

Country	**Task**				
	XI	**XII**	**XIII**	**XIV**	**XV**
Canada	x		x		To
Denmark	OA		x	x	be
Finland	x				determined
Germany	x	OA	x		
Italy	x		x		
Japan			x		
Netherlands	x	x	x	OA	
New Zealand	x				
Norway	x		x		
Spain	x		x		
Sweden	x	x	x		
United Kingdom	x		x	x	OA
United States	x		OA	x	

TASK VIII—DECENTRALIZED APPLICATIONS FOR WIND ENERGY

This Task was set up in 1985 and has involved 10 countries in a task-sharing arrangement, coordinated by the UK National Engineering Laboratory as Operating Agent. The overall objectives were to:

- Define cost-effective models and techniques suitable for obtaining wind and load data necessary for planning and specifying decentralized wind energy conversion installations.
- Apply and further develop models suitable for analyzing the performance of wind-diesel systems.

In 1994, the final report of Task VIII, Wind-Diesel Systems, was published by the Cambridge University Press (ISBN 0 521 43440 8 hardback). Edited by Messrs. Ray Hunter and George Elliot, this book provides for the first time in a single volume the collective knowledge of many leading researchers on state-of-the-art wind-diesel technology. It contains the results and advice of numerous experts from many different countries.

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

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.

A Standing Committee (SC) has been reviewing the needs for revising existing recommendations or for preparing new recommendations. At their fall meeting, it was decided by the Executive Committee to dissolve the Standing Committee, and that Expert Meetings should be held whenever the need would arise to study a particular subject.

During 1994, revised editions of "Estimation of Cost of Energy from Wind Energy Conversion Systems" and "Acoustics Measurement of Noise Emission from Wind Turbines" were published.

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.

A symposium within the Joint Action on "Fatigue of Wind Turbine Blades" took place on April 21-22, 1994, in Petten, the Netherlands. Within the Joint Action "Wind Conditions for Wind Turbine Design," a symposium was held on June 27-28, 1994, in Hamburg, Germany. The 8th symposium within the Joint Action on "Aerodynamics" was held on November 21-22, 1994, at the Technical University of Denmark.

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

Table 2. Documents in the Series of Recommended Practices for Wind Turbine Testing and Evaluation

Vol	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 the 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

Table 2. Documents in the Series of Recommended Practices for Wind Turbine Testing and Evaluation (Continued)

Vol	Title	1st Ed	2nd Ed	3rd Ed
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, along with their proper definitions.	1987	1993	
9	POINT WIND SPEED MEASUREMENTS	In preparation		

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 26th Expert Meeting was held in Milan on March 8-9, 1994, on Lightning Protection of Wind Turbine Generator Systems and EMC Problems in the Associated Control Systems.

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 National Resources Canada
Denmark	Department of Fluid Mechanics, Technical University of Denmark
Germany	KFA Jülich
Finland	VTT

Italy	ENEA
Norway	NVE
Netherlands	ECN
New Zealand	ECNZ
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 78	Munich, Germany
2	Control of LS WECS and Adaptation of Wind Electricity to the Network	4 Apr 79	Copenhagen, Denmark
3	Data Acquisition and Analysis for LS WECS	26-27 Sep 79	Blowing Rock, USA
4	Rotor Blade Technology with Special Respect to Fatigue Design	21-22 Apr 80	Stockholm, Sweden
5	Environmental and Safety Aspects of the Present LS WECS	25-26 Sep 80	Munich, Germany
6	Reliability and Maintenance Problems of LS WECS	29-30 Apr 81	Aalborg, Denmark
7	Costing of Wind Turbines	8-19 Nov 81	Copenhagen
8	Safety Assurance and Quality Control of LS WECS during Assembly, Erection and Acceptance Testing	26-27 May 82	Stockholm
9	Structural Design Criteria for LS WECS	7-8 Mar 83	Greenford, UK
10	Utility and Operational Experience from Major Wind Installations	12-14 Oct 83	Palo Alto, California
11	General Environmental Aspects	7-9 May 84	Munich, Germany
12	Aerodynamic Calculation Methods for WECS	29-30 Oct 84	Copenhagen
13	Economic Aspects of Wind Turbines	30-31 May 85	Petten, Netherlands

Table 3. IEA Wind Energy Expert Meetings (Continued)

14	Modelling of Atmospheric Turbulence for Use in WECS Rotor Loading Calculations	4-5 Dec 85	Stockholm, Sweden
15	General Planning and Environmental Issues of LS WECS Installations	2 Dec 87	Hamburg, Germany
16	Requirements for Safety Systems for LS WECS	17-18 Oct 88	Rome, Italy
17	Integrating Wind Turbines into Utility Power Systems	11-12 Apr 89	Herndon, USA
18	Noise Generating Mechanisms for Wind Turbines	27-28 Nov 89	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 March 1994	Milan, Italy

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.

Representatives of the participants met on the following occasions:

- Two Executive Committee meetings of IEA R&D Wind (April 18-19, 1994, in Rotterdam, the Netherlands and October 26-27, 1994, in Banff, Canada)
- DEWEK 94, Deutsche Windenergie-Konferenz 1994 (June 21-24, 1994, in Wilhelmshaven, Germany)
- Wind Energy R&D Contractor Meeting, CEC DG XII, Program JOULE (May 4-5, 1994, in Harwell, Great Britain)
- EWEC 94, European Wind Energy Association Conference and Exhibition (October 10-14, 1994, in Thessaloniki, Greece).

The project was technically completed in 1992. A short summary report of 52 pages on the German contribution was submitted in 1993. An extended and more detailed version of this report, including also the contributions of the Netherlands and Sweden, is almost completed.

Since the project results were reported already at former Executive Committee meetings, in annual reports, and in technical reports, only a short survey is given here on the outcome of the project, including the spin-off and the diversification into new (EU) projects.

The direct results can be summarized under the headlines hard- and software, validation of numerical codes (PHATAS II, FLEXLAST, DUWECS, ARLIS), simulation, and comparison of concepts and experimental investigations.

As a spin-off, several industrial projects were conducted and further research triggered:

- Inflow turbulence
- Induced velocities for instationary inflow and yawed operation
- Parameter studies for different turbine configurations with special interest in:
  - Hub configurations
  - Mass distribution in the blades
  - Cyclically controlled blade-root stiffness.

The aim was for an improvement of the ARLIS software.

Diversification into new projects took place in the form of an investigation of aero-acoustics of blade tips and measurements of dynamic inflow effects. In the framework of the first project, both acoustic measurement methods and blade tips were developed and used in free-field measurement campaigns. For the second project, experiments with pitch steps, stationary yaw, and aerodynamic emergency braking were conducted. The results obtained so far with the UNIWEX turbine in the mentioned projects look promising.

In 1994, the Dutch participants continued to analyze the data acquired over the last years to validate various computer design codes and to compare (pitch-) controllers. Results from 280 experiments have also been placed on a CD-ROM for wider dissemination and further evaluation.

Publications in 1993/1994:

1. J. Argyris, K.A. Braun, M. Müller: "UNIWEX - An International Research Project - History - Results - Spin-off - Future," European Community Wind Energy Conference and Exhibition, Lübeck-Travemünde, 8-12 March 1993.
2. A.J. Brand, H. Snel, N.O.T. Hansen, G.A.M. van Kuik, G.E. van Baars, P.M.M. Bongers: "Validating Wind Turbine Design Codes by Analyzing Teeter, "Free" Flap and "Free" Lead/Lag Motions," ibid.
3. J. Argyris, K.A. Braun, M. Müller: "UNIWEX - A Universal Wind Turbine for Experiments, Short Summary Report on the German Contribution," ICA-Report No. 43, University of Stuttgart, 1993.
4. A. Fischer: "Induzierter Abwind bei Schräganblasung einer Windturbine mit horizontaler Achse," Studienarbeit, Universität Stuttgart, 1994.
5. A. Heim: "Numerische Simulation des aeroelastischen Verhaltens der Versuchs-turbine UNIWEX für unterschiedliche Pendelsteifigkeiten, Pendeldämpfer und Blattwinkelrücksteuerungsfaktoren," Studienarbeit, Universität Stuttgart, 1994.
6. M. Bühler: "Einfluss der Massenverteilung im Rotorblatt der UNIWEX Windturbine auf deren aeroelastisches Verhalten," Studienarbeit, Universität Stuttgart, 1994.
7. 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, Sept. 1994.
8. K.A. Braun, B. Dressler: "Einfache Beschreibung des Zustroms bei einer Windturbine mit Rohrturm," ICA-Bericht Nr. 45, Universität Stuttgart, 1994 (t.b.p.).
9. A. Gordner: "Lastreduktion bei einer Horizontalachsen-Windturbine mittels zyklischer Blatteinspannsteifigkeiten," Studienarbeit, Univertsität Stuttgart, 1995 (t.b.p.).

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 single wind machine of one megawatt rating, or a wind farm whose rated output power exceeds one megawatt, provided that the wind machines forming the farm exceed 25 meters in diameter. Large wind machines were usually prototypes, while machines constituting wind farms 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 farm 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, the United Kingdom, and the 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 for that country. The Operating Agent for this Annex was the National Renewable Energy Laboratory in the United States.

Since the Annex was established for a three year lifetime, formal annex activity ended on 31 December 1993; data analysis continued during 1994, and the final report will be published in 1995. The original purpose of Annex XIII will now largely be subsumed into the new and broader Annex XV. The latter will gather wind energy information on economics, financing, and constraints on wind energy market development, as well as information about accidents and incidents, operational experience, national wind energy use, and R&D innovation. This Annex will synthesize this information from a broad spectrum of sources and regularly publish an analysis in the Wind R&D Annual Report.

TASK XIV—FIELD ROTOR AERODYNAMICS

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

The objective of the task is to exchange measured data to develop a database for the verification of profile codes and for use as a design basis for stall-controlled rotor blades.

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
   Status: operational

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
     Status: operational
   - Measurements on a rotating test rig.
     Status: under construction

   (b) Delft University of Technology
   Rotor diameter 10 m
   Pressure tap measurements at four stations
   Status: operational

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

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

Since the start of the project in November 1992, three meetings have taken place between the participating laboratories. At the first meeting, a work plan was defined. At the second meeting, a first round of data exchange was completed.

The third meeting of March 1994 had the following results:
- Zero yaw campaigns were selected from the statistical overviews. The campaigns cover the whole power curve.
- Six methods were defined for the measurement of the angle of attack. These methods will be compared.
- Agreement was reached on the conventions to be used.
- All parties will complete the questionnaire which describes their turbine.
- Measurements will be transferred by “ftp” (file transfer protocol) e-mail.

Conclusions:

- Work is underway to come to a base which consists of data from aerodynamic full-scale experiments. This will give a unique chance to build accurate aerodynamic models.
- The first part of the test matrix was finished in October 1994.
- The Annex serves as a platform where ideas are exchanged between parties which are involved in doing aerodynamic experiments (i.e., ideas about the measurement of the angle of attack).

A Dynamic Stall meeting was held in November as part of the related JOULE program supported by the European Union.

The status of the database is:

- The format for data exchange has been established.
- Data are exchanged via anonymous ftp to ECN.
- The test data sets have been exchanged.
- Periodic status reports are sent via e-mail.

Activities are ahead of schedule and are expected to be finished in July 1995. The report is to be published in the second half of 1995.

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

INTRODUCTION

Since the energy crisis of 1973, about 3,500 MW of wind energy capacity for electricity production have been installed throughout the world, largely in the IEA Member countries. This is largely the result of market stimulation by the individual governments backed up by national research, development, and demonstration programs.

Wind energy technology is still young but is maturing rapidly. It has become reliable and is becoming competitive with conventional ways of electricity generation under suitable conditions. However, commercial implementation is being limited by a number of technical, economic, and environmental issues.

One of the ways to strengthen confidence in the technology and to help to tackle the issues is to provide reliable information on the commercial development of wind energy to decision makers in industry, financial institutions and planning, and to the public. To do so, it is proposed to publish on an annual basis a review of the progress of the implementation of the technology in IEA member countries participating in this Agreement.

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. Key topics would include government initiatives, market growth, progress towards national targets, economic trends, technical advances, commercial developments, progress in addressing environmental issues, and public reaction.

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. The form is to be suitable for presentation to decision makers in government, planning authorities, the electricity supply industry, financial institutions, and the wind industry.

MEANS

The annual review will be based on the annual national reports submitted to the Executive Committee. It will be included as an executive summary in the annual report of the Agreement but should be suitable for printing as a stand alone document with references to the annual review for those seeking more detailed information. A final report will be prepared after three years upon completion of the Annex.

The suggested list of contents includes the following:

a. National Programs

   Summary of status of wind energy, including government objectives, strategy, targets, market stimulation instruments, and level of direct government support for R&D/promotion.

b. Commercial Implementation of Wind Power

   Summary of progress in installing wind-driven generating plants, including existing capacity and rate of growth; number and size of installed machines during past year; performance in terms of total output and annual production; and operational experience, including electricity network effects.

c. Industry

   Summary of how the market is developing in each country, including types of owners/operators, new developers, marketing concepts/forms of ownership; and status of manufacturing industry in each country, including total production/sales/exports, new products/technical developments, and interesting business developments.

d. Constraints on Market Development

   Experience of the effect of non-technical constraints on the commercial market, including environmental impact and the effect of institutional regulations on development.

e. Economics

   Summary of the trends in costs and benefits of wind energy generation per country, including broad brush estimates of invested capital, value of generated electricity, and level of subsidy for production; machine and project costs and cost of generated power; and benefits, including broad brush estimates of employment, avoided emissions, and replaced fuels.

f. Financing

Experience of financing developments, including types of funding available, typical financial interest rates, certification requirements, insurance, and warranties.

g. Research and Development (R&D)

Advances and innovations arising from R&D work, including R&D priorities, new concepts under development (including MW-rated turbines), direct government R&D funding, and advances in offshore siting.

h. International Collaboration

National involvement in collaborative programs (for example, European Union, bilateral) in terms of number of projects/funding.

It is appreciated that some information may not be available or easily accessible for every participating country. It is suggested that, where possible, the annual national reports should include reference to, and summaries of, reports, studies and analyses from both government and credible industrial and academic sources for each country. Accuracy and quality of the data quoted in the national reports is important. Therefore, questionable data will be excluded.

The Operating Agent of the Annex will be responsible for writing the draft and final versions of the review, and a Working Group will be nominated by the Executive Committee to comment on the draft review. The final review based on the national reports will be presented at the spring meeting of the Executive Committee for discussion and approval.

It will be necessary to measure whether or not the review achieves its aim. It is proposed that this evaluation is done through feedback from the intended audience (including the IEA Renewable Energy Working Party) as to whether the Annex presents useful information in a compact and understandable form. Their views will be taken into account in subsequent years.

The results of the Annex will be an annual review describing progress and trends in the commercial development of wind energy in the IEA member countries. The style of the review will be appropriate to the needs of decision makers in governments, electricity supply industries, financial institutions, and industry. A final report will be prepared after three years upon completion of the Annex.

The Annex has entered into force on January 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, taking into account any recommendations of the Agency's Committee on Energy Research and Technology concerning the Annex, and thereafter apply only to those Participants.

All costs incurred by the Operating Agent in his duties related to this Annex and relevant Tasks will be borne by the participants, each of which will be charged with an equal share of these costs.

The Operating Agent will be the UKAEA on behalf of the United Kingdom. It is suggested that all signatories to the Implementing Agreement are participants in this Task.

NATIONAL ACTIVITIES

This chapter reviews the wind energy R&D programs and the status and prospects of wind energy in the member countries with emphasis on large-scale applications. The review is based on contributions by members of the Executive Committee as indicated in the Foreword.

CANADA

1. NATIONAL PROGRAM

The focus of the Canadian National Program continues to be in R&D and field trials. The elements of the R&D program are: resource assessment, test facilities, and technology development 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 was expanded to include a larger area on the east shore of Lake Huron, Ontario. This will provide farmers in agri-business better wind data to assess the economics of wind energy.

Resource assessment in southern Saskatchewan has been completed. It has confirmed large potential (about 2,000 MW) for this region.

Wind turbine test sites

The program also 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

- The Lagerwey 80 kW wind turbine is undergoing testing at Atlantic Wind Test Site (AWTS).
- The tower of the 80 kW Lagerwey at Kincardine fell to the ground. The turbine was a total loss. At the time of the failure, the wind speed was in the 60-65 km/hr range and the turbine was producing rated power. The cause of the tower failure is under investigation.
- The Atlantic Orient 15/50 kW has been fitted with a new control system and is performing very well. It will be going through its first winter at AWTS.
- The High-Penetration-No-Storage (HPNS) wind/diesel system by Hydro-Quebec and AWTS is being developed.

A series of tests for final validation of the control system are to be performed in early November 1994. The test-bed will be operated continuously as a small community HPNS system for about three months.

- TACKE 600 kW HAWT

  NRCan has signed an agreement with TACKE Windpower, Inc., of London, Ontario, to construct and evaluate the 600 kW turbine manufactured by TACKE Windtechnik of Germany. TACKE Windpower plans to redesign the 600 kW wind turbine to suit the environmental conditions of North America. The turbine will be installed in 1995 near Kincardine, Ontario, and tested for one year.

- 150 kW Bonus at Haeckel Hill

  The turbine installed on Haeckel Hill (1,450 m height) near White Horse in Yukon was commissioned in August 1993. The turbine performance up to the end of September 1994 was:

Energy output	=	261,346 kWh
Generation	=	5,300 hours
Turbine Availability	=	95.5% (ignoring grid outages)

  The power line outages due to icing resulted in loss of 766 hours of generating time for the turbine. 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 two winters.

  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 (mid-September to October) migrating periods of 1993 and 1994. No dead birds were found. Bird monitoring will continue for another three years.

- Project Eole

  As reported earlier, the project was shut down in April 1993 because of the failure of the lower rotor bearing. York Research and Mr. Lam Tho (owner of Project Eole) have signed an agreement with Hydro Quebec to install eight 500 kW Vestas wind turbines in the vicinity of Eole, and to repair Eole and operate it up to a rated power of 2 MW. The buy-back rate for the 6 MW wind farm will be 5.5 cents per kWh.

- Christopher Point, British Columbia

  Since March 1981, the Indal 50 kW VAWT (installed at Christopher Point on Vancouver Island, British Columbia) has produced about 542 MWh of electricity in 31,909 hours.

- 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 (approximately long. 81 W, lat. 69.5 N) and are being monitored for cold weather performance.

  The turbines generated about 5,000 kWh from August 1993 to February 1994. The turbines were down during the summer months. After repairs last month, they have generated about 1,100 kWh.

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity
Pincher Creek, Alberta

- ADECON 1.5 MW

  The turbines are being commissioned and are expected to be operational in 1995.

- 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 of the turbines are not available as yet.

2.4. Operational experience
No details available as yet.

3. CONSTRAINTS ON MARKET DEVELOPMENT

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

4. ECONOMICS

4.1. Economics and financing
The budget for the Wind Energy R&D (WERD) program of Natural Resources Canada is about CAD 700 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 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
- CWT Power International Ltd., Calgary. Adecon 150 kW is the only turbine designed and manufactured in Canada.

6. INTERNATIONAL COLLABORATION

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

DENMARK

1. NATIONAL PROGRAM

In 1973, Denmark's need for primary energy was almost totally covered by imported fuel. The first reaction to the oil crisis, therefore, 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.

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.

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

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, has recommended a number of suitable sites. Despite this, the implementation of the 1990 agreement has been delayed at least two years due to local opposition to wind turbines. Various planning measures to overcome this obstacle have been initiated.

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 promotion of the small-scale technology.

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, which supplied 10% of the annual Danish electricity consumption.

2. IMPLEMENTATION

2.1. Installed capacity

Installation of modern grid-connected wind turbines in Denmark began in 1976, but no significant progress was seen until 10 years later. Cumulated data for number and power capacity by the end of 1986 was about 1,250 turbines and 80 MW.

As of 31 December 1994, the total number of grid-connected wind turbines in Denmark, privately as well as utility owned, was 3,700 units with a total electrical output capacity of 540 MW.

Data on privately owned turbines were 3,190 units, totalling 402 MW installed power. The corresponding numbers for utility owned machines were 510 turbines, totalling 138 MW of capacity.

The total increase in 1994 was 142 turbines with an output capacity of 52 MW. The utilities installed 54 new turbines with an output capacity of 25 MW. Private individuals installed 88 turbines with a total capacity of 27 MW. This was higher than in 1993, in which year the total increase was 36 MW.

As of 31 December 1993, the maximum continuous net capacity of the Danish power generation system was 9,952 MW (including wind turbines). Installed wind power capacity at that time related to total national capacity was thus 4.9%.

2.2. Machine details

All wind turbines installed in Denmark are of Danish origin.

The average capacity of all new installations in 1994 was 366 kW: 463 kW for utility turbines and 306 for private machines. For many reasons, utilities prefer large units.

2.3. Electricity production

Cumulated electricity generation by wind turbines in Denmark during the years 1976-1986 was about 300 GWh. By the end of 1993, the total output over all years increased to about 4,400 GWh.

In 1994, the total electricity production by wind turbines was 1,083 GWh, which supplied about 3.5% of the annual Danish electricity consumption. Related to privately and utility owned turbines, the numbers were 842 GWh and 241 GWh.

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.

2.4. Grid connection

Over the years, much work has been spent on assessments of power quality. No final rules regarding number of turbines per feeder line have yet been established. Hopefully, ongoing research will lead to general guidelines.

According to a new statutory order, 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.

3. INDUSTRY

3.1. Market development

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 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.

3.2. Manufacturing industry

A Danish home market for wind turbines and a wind turbine industry was established during the years 1979-1981, strongly stimulated by an installation subsidy of 30% (see Section 5.2).

Later, the Californian 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.

Cumulated figures for number of turbines and capacity are approximately 10,000 turbines with a capacity of 1,150 MW. Total value of this export cumulates to about DKK 8.5 billion, and, assuming 30% of this amount being the value of imported components (gearboxes, generators, etc.), the net value is about DKK 6 billion. The turbines are sold to about 30 countries all over the world.

The export in 1993 accounted for 572 wind turbines with a total capacity of 181 MW. This represents an increase of 50% in relation to 1992. The same pattern was seen for 1994 in relation to 1993.

The latest development trend shows that the well known "Danish design" is unchanged: 3-bladed, upwind rotors, active yawing and induction generators connected to the low voltage level at 380 Volt. 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 are designing and installing one 55 m, 750 kW and two 60 m, 1.5 MW prototype machines at Tjæreborg in Jutland. These prototypes are ordered by the Elsam utility in order to promote the technological development of wind turbines.

As earlier mentioned, 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 power.

3.3. Support industries

Currently no industry is independent of sub-suppliers and external expertise (consulting). Furthermore, Denmark, being a small country, has to import many components incorporated in wind turbines, such as steel parts, gearboxes, generators, etc.

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

LM Glasfiber A/S also exports turbine blades to many parts of the world, and subsidiaries abroad are also established.

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. CONSTRAINTS

4.1. Environmental impact

Visual intrusion, public attitudes

The public attitude in Denmark is, in general, in favor of wind energy, but the "not in my back yard" syndrome is becoming more widespread. This means that the planning procedure for both turbines and wind farms 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 Denmark, a statutory order was issued by the Ministry of the Environment in 1991 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.

Up to now, only one wind farm has given cause for complaints about acoustic noise, and altogether, the authorities have received complaints about noise from less than 2% of the country's total number of wind turbines.

Birds

The impact of wind turbines on bird life has been studied in relation to both the Nibe turbines (1984) and the Tjæreborg wind turbine (1986-90). In the first study, it was concluded that no birds were found whose death were 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.

The general conclusion from the latest study is that, compared to other 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 being installed at Tunø Knob (see Section 7).

Ecology

In some parts of the world, installation of wind turbines have 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.

4.2. Institutional aspects

Planning policies

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 will be published by July 1, 1995. 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.

Approval and certification systems

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, installing, 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 secretary at Risø. Lately, "Norske Veritas" and "Germanischer Lloyds" have also been authorized to certify wind turbines in Denmark.

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.

In case of accidents or incidents, full information must be given to the Test Station for Wind Turbines at Risø.

5. ECONOMICS

5.1. Value

It is difficult to calculate exactly the total invested capital over the years, but figures for government subsidies give an indication. In the 10-year period 1979-1989, cumulated installation subsidies for about 2,550 private wind turbines were DKK 275 million.

Invested capital in Denmark for 1994, assuming a total cost of DKK 7,500 per kW, amounts to DKK 390 million (see Section 2.1).

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.

5.2. Subsidies

Development of private, small scale wind turbines was for a period of 10 years promoted by government installation subsidies. In August 1979, the level was set at 30%, and over the following years, it gradually decreased until it finally faded out in August 1989.

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 0.60 per kWh delivered to the grid. This amount is calculated as follows: 85% of the pre-tax selling price to private consumers, DKK 0.33, 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 utilities get a production subsidy of DKK 0.10 per kWh of electricity produced in utility wind farms as reimbursement for the general carbon dioxide tax.

For utility production, the level of subsidy for 1994 was DKK 0.10 per kWh, with a total of DKK 24 million paid out.

For private production, the subsidy for 1994 was DKK 0.27 per kWh, with a total of DKK 227 million paid out.

5.3. Estimates in development costs

Recent cost data are available from the ELSAM utility operating in Jutland. The total installation costs for 500 kW wind turbines installed in wind farms are today 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 about 70% of the total cost.

5.4. Benefits of wind power

As of December 1993, about 2,500 people were employed by the Danish wind turbine industry: 1,100 by manufacturers and 1,400 by subsuppliers, consultants, and service companies. Due to the increase in export volume, the total number of employed people was about 3,000 by the end of 1994.

Production of electricity by wind turbines saves the environment from harmful emissions from coal-fired power stations. Exact figures depend on age and efficiency of power stations, but roughly, 1 GWh of wind-generated electricity in 1994 had the following effect:

Reduction of CO_2:	1 million tons
Reduction of NO_x:	5,000 tons
Reduction of SO_x:	7,000 tons
Reduction of flyash:	5,500 tons

Emissions from power stations fueled by oil and natural gas are less harmful but still add to the emissions.

6. FINANCING

Over the years, financing of new wind turbine projects at the commercial stage has not raised major problems. Utility wind farms 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.

7. RESEARCH, DEVELOPMENT, AND DEMONSTRATION

Total government funding of R&D work during the years 1976-1994 was about DKK 290 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 1994 was DKK 37.5 million. Of this amount, DKK 9.5 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% to 100% of the total cost). DKK 10 million went to support the test station at Risø and miscellaneous minor projects.

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.

The 3-bladed Danish wind turbine concept is still predominant, but in view of the fact that the 2-bladed concept is in widespread use all over the world, the test station of Risø has, during recent years, made experiments with a small 2-bladed machine. A final conclusion has not been drawn—and will not be drawn—until planned work on rotor optimization is finished. It can, however, be added that it is a very flexible, downwind test machine with free yawing.

7.1. Large-scale developments

The status of the development of MW-sized machines was mentioned in section 3.2, and the status of the older LS-projects at Nibe, Masnedø and Tjæreborg has been reported in previous annual reports. The new 50 m diameter, 1 MW stall regulated turbine at Avedøre south of Copenhagen was inaugurated in September 1994 and is still in the commissioning stage.

7.2. Offshore wind farms

The first Danish offshore wind farm was commissioned in 1991. The site is at Vindeby, Northwest of Lolland in the Baltic Sea. The wind farm consists of 11 turbines in two rows. Each turbine is rated at 450 kW, and hub height and rotor diameter are respectively 37.5 m and 35 m.

Although the specific energy output is expected to be about 60% higher than for average onshore sites, the cost of energy produced by this prototype windfarm (DKK 0.60 per kWh) is estimated to be about 50% higher than for average inland sites. The total cost of the project, including a two-year measurement program, was about DKK 80 million. The reported availability exceeds 96%.

A second Danish offshore wind farm being built by ELSAM is in the construction phase. The selected site is at Tunø Knob in the area between Jutland and Samsø. Installed capacity will be 5 MW (10 Vestas V39 turbines). The total cost is about DKK 87 million, and the projected cost of energy is about DKK 0.67 per kWh.

8. 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). Information on total numbers and total funding are presently not available.

FINLAND

1. NATIONAL PROGRAMS

1.1. Research and development

NEMO2 (Advanced Energy Systems and Technologies National Research Program) is one of eight major national energy research programs in Finland. It is primarily funded by the Ministry of Trade and Industry. The total budget of the NEMO2 program is about FIM 120 million (equivalent to about 20 million ECU) for 1993-1998. The share of direct government 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 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.

Wind resources, modeling and measurements

- Complex terrain
- Offshore.

Arctic wind technology

- Test turbine in Pyhätunturi
- Monitoring of icing events
- Heating systems: control and design
- Load measurements and modelling.

Integration

- Local network integration
- Optimal planning
- Reserve power.

Components

- Direct-drive generators
- Power transmission systems
- Blades.

International cooperation

- EU/JOULE
- IEA.

2. NATIONAL STATISTICS ON WIND POWER

The locations of the operational wind power plants are shown in Figure 1. There were no new installations during 1994 after the installed capacity tripled from 1.5 MW to 4.7 MW in 1993.

There are two typical locations of wind turbines in Finland, which are shown in Figures 2 and 3.

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

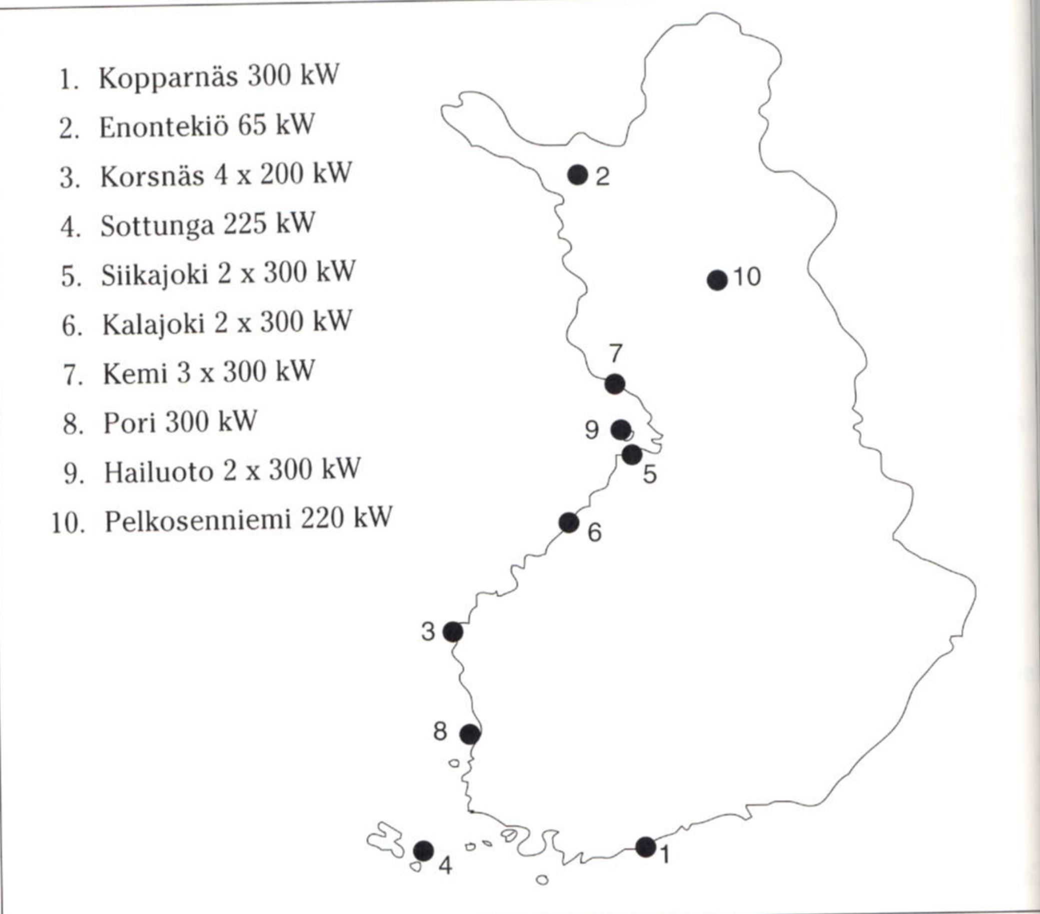


Figure 1. Locations of the operational wind power plants

Figure 2. Nordtank 300 kW turbine in Siikajoki, Finland, close to a small fishing harbor (Foto Revon Sähkö Oy)

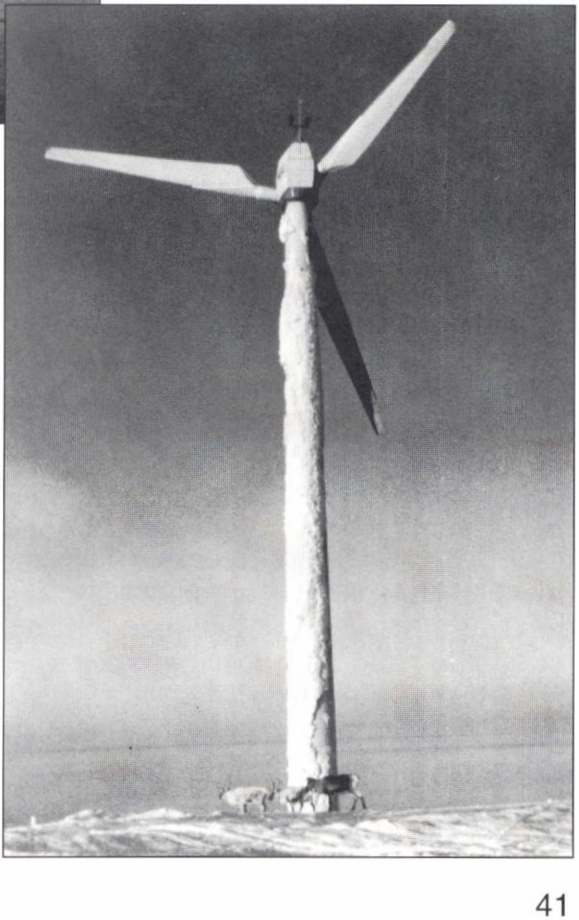


Figure 3. The arctic test turbine in Pyhätunturi

Table 1. The Operational Wind Turbines in Finland

Project	Operator (Type)	Manufacturer	Machine Details P(kW)/D(m)/H (m)
Kopparnäs (1) 1 x 300 kW	Utility	Danish Wind Technology	300/31/31
Enontekiö (0) 1 x 65 kW	Utility	Nordtank	65/20/26
Korsnäs (3) 4 x 200 kW	Private Company	Nordtank	200/25/32
Sottunga (4) 1 x 225 kW	Local Technology Centre	Vestas	225/25/31
Siikajoki (5) 2 x 300 kW	Distribution Utility	Nordtank	300/31/31
Kalajoki (6) 2 x 300 kW	Distribution Utility	Nordtank	300/31/31
Kemi (7) 3 x 300 kW	Private Company	Nordtank	300/31/35
Pori (8) 1 x 300 kW	Distribution Utility	Nordtank	300/31/31
Hailuoto (9) 2 x 300 kW	Distribution Utility	Nordtank	300/31/31
Pyhätunturi (10) 1 x 220 kW	Research Centre and Utility	Wind World	220/25/31

The production statistics (Figure 4) are collected by VTT Energy. The total production in 1994 amounted to 7,251 MWh, giving a mean capacity factor of only 18%. The low capacity factor was mainly due to a low wind year. There were also some difficulties related to cold weather with some of the turbines. The research turbine at Pyhätunturi suffered from severe icing during the winter of 1993-1994.

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 by 2005
- To support product development by domestic industry.

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

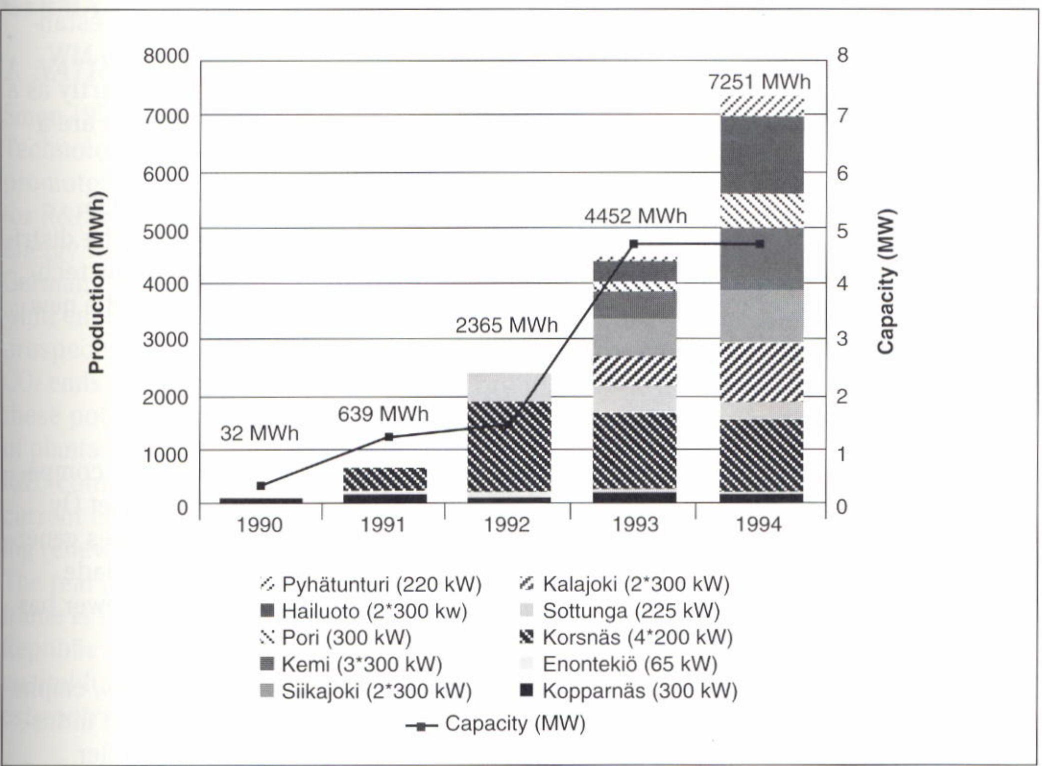


Figure 4. Wind energy production and installed wind power capacity in Finland

The amount of investment subsidy to a project depends 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. Wind energy associations play an important role in information dissemination.

4. CONSTRAINTS ON MARKET DEVELOPMENT

Despite the 100 MW program, there were no new installations in 1994, although a number of projects were planned. The main reasons for this are probably the novelty of the technology to most potential users and the distribution utilities, and the lack of any agreements on buy-back rates for private developers. The utilities are, however, carefully following the operational experience gained from the present turbines. Positive experience has now encouraged other utilities to look at the possibility of using wind energy.

During the first half of the 1990s, wind technology has become more familiar to users in Finland. The first 4.7 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 wind energy component industry and its need for an established home market have also been recognized. This means that the 100 MW program launched by the Ministry of Trade and Industry can be seen partly as a test bed for new domestic products. Cold and icing climate applications are a specialty, which could offer a small market niche in the future.

Electricity deregulation, which is due to take place in the summer of 1995, means 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.

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), the turbine tower has been supplied by Finnish industry.

Since wind technology is presently developing new sizes of components, emphasis has been placed in the R&D program on the needs of the component industry. Some new developments, including a direct-drive generator, are under development in cooperation between the government research program and industry.

6. INTERNATIONAL COLLABORATION

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.

The Finnish Meteorological Institute (FMI) is currently taking part in the following JOULE II-projects:

- Icing of wind turbines (coordinator DEWI, FMI)
- Wind resources in the Baltic Sea (coordinator Risø, FMI)
- Measurements and modeling of offshore wind power plants (coordinator Risø, FMI).

In 1993, Finland, represented by VTT Energy, joined the IEA Implementing Agreement for Cooperation in the Research & Development of Wind Turbine Systems. The Finnish participation is so far limited to Task XI Base Technology Information Exchange. Discussions about a new IEA Annex related to cold climate and icing issues have started.

GERMANY

1. NATIONAL PROGRAMS

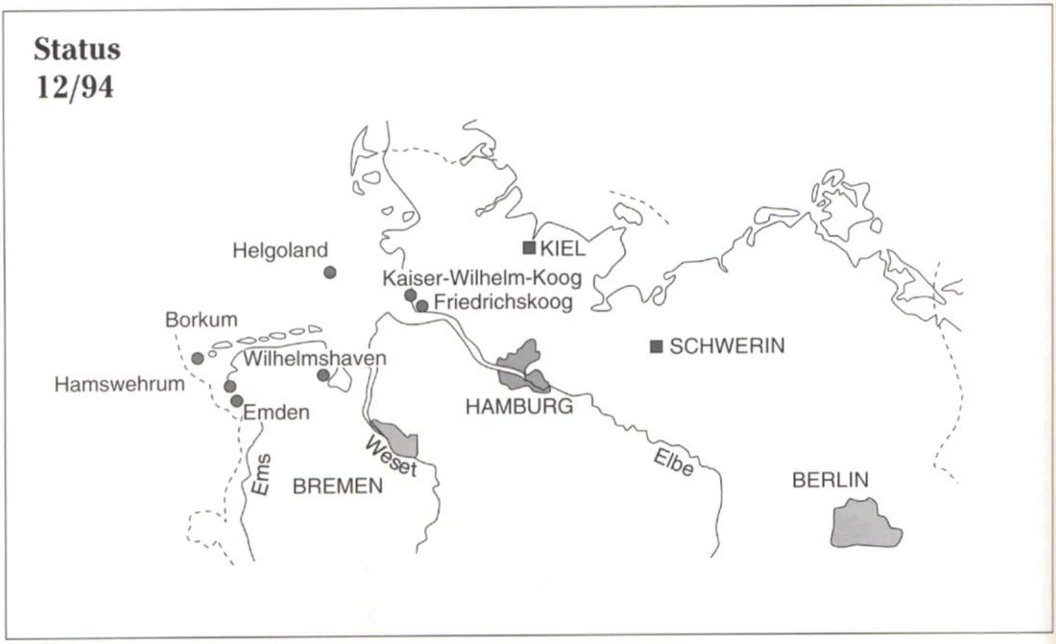
Since 1974, the Federal Ministry for Education, Science, Research and Technology (BMBF, formerly the Ministry for Research and Technology) has promoted wind energy in Germany by providing approximately DEM 330 million for R&D and demonstrations. The framework has been a series of "Programs for Energy 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 energy sources at acceptable costs in the long term, field tests of plants for the use of alternative energy sources 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 projects, including four wind farms. From 1983 to 1992, a total of 214 WECs were supported, having a total rated power of 14.5 MW. These demonstration projects formed an adequate basis for the "250 MW Wind" program offered since 1989 (see Section 1.2).

Today BMBF's support for R&D reflects the trend towards WECs of increasing rated power. It should be pointed out that all studies and predictions indicate that the existing wind potential in a densely populated country such as Germany can be best exploited by large WECs. Experts from an 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 1980s, 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



Power	Type	Site	Project By	Realization
3 à 640 kW	MON 50	Wilhelmshaven	GEW	Summer 89
1.2 MW	WKA 60	Heligoland	Town Helig.	Autumn 90
1.2 MW	AWEC 60	Cabo Villano (Spain)	U. Fenosa	Summer 89
3 MW	AEOLUS II	Wilhelmshaven	P.E. Windk.	Spring 93
1.2 MW	WKA 60 II	Kaiser Wilhelm-Koog	P.E. Windk.	Autumn 91
750 kW	HSW 750	Kaiser Wilhelm-Koog	Hus.Schiffs w.	Autumn 91
400 kW	E-36	Hamswehrum	EWE	Spring 92
500 kW	TW 500	Borkum	St.Bork./Mün.	Summer 92
500 kW	E-40/PV	Geesthacht	HEW	94
500 kW	V-12	Wilhelmshaven	DEWI	94
1.0 MW	E-55	Northern Germany	Enercon	95
1.0 MW	TW1000	Emden	Tacke Windt.	95
1.0 MW	A1000	Friedrichskoog	Autoflug	95

Plus two 800 kW prototypes funded > 94 by E.U. in Eastern Germany (BOEHM, NORDEX), as well as a German/French/British MW Class type WEGA turbine (Tacke Windtechnik) in Dunkerque, E.U.

Figure 1. German prototypes with a rated power more than 400 kW

on one of the rotor blades, the owner of the Heligoland turbine decided to dismantle this turbine.

This second generation of large-scale (LS) WECs also includes AEOLUS II with 3 MW rated power, put into operation by PreussenElektra Windkraft Niedersachsen GmbH in December 1993 (see Figure 3). During the first year of operation, this machine has produced more than 5 million kWh. The availability was 93% (experimental standstill not considered). A second turbine of this type has been installed by Vattenfall in Gotland as a cooperation project 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. None of these second-generation type machines has so far been operated other than as a prototype.

Several German wind turbine manufacturers started constructing 1 MW WECs using a different approach in order to obtain the economy of commercial medium-sized WECs on a relatively short term basis (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 24 R&D projects by BMBF in 1994/1995 (see Table 1 and References 2 and 3).

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 functions to collect various statistical data and to prepare technical improvements (Reference 4).

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

By November 30, 1994, the number of operating turbines in the "250 MW Wind" program was 1,255, which corresponds to a

Figure 2. HSW 750. Prototype at the test site Kaiser-Wilhelm-Koog. HSW 1000, summer 1995. Rated power: 1 MW. Rotor Ø: 54 m, pitch. Hub high: 55 m. Steel tower. Nacelle with rotor: 73.000 kg

Figure 3. AEOLUS II, near Wilhelmshaven. Mean annual wind speed at hub height is around 7.5 m/s.

rated power of 233 MW (see Figure 4). This means that today about half of the total wind energy capacity in Germany has been installed through this BMBF program (see Section 2.1).

Table 1. Wind Energy R&D Projects, 1994 ff

Subject	Participants	Period	Costs (MDM)	BMBF (%)
Wind Powered Desalination Plant, Rügen	Rügenwasser GmbH	06.93-05.97	3,401.8	70
Aeolus II, 3 MW Wind Program	Preussenelektra Windkraft	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 NDS	02.89-09.95	10,0	40

Table 1. Wind Energy R&D Projects, 1994 ff (Continued)

Subject	Participants	Period	Costs (MDM)	BMBF (%)
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	312.0	50.0
Evaluation of Energy Economics of Aeolus II	Preussenelektra Windkraft NDS	10.91-05.95	577.4	50.0
Evaluation of Energy Economics of WKA 60	Preussenelektra Windkraft SH	10.91-05.95	556.7	50.0
An Analysis of the Operating and Grid Behaviour of Various Wind Turbine Concepts	Windenergiepark Westküste	01.93-09.95	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	607.0	100.0
Construction and Installation of a Quiet and Economic 1 MW WEC	Enercon	01.93-09.95	7,745.0	14.20
Measuring Program HSW 750	Husumer Schiffswerft	06.93-06.95	604.7	50.0
Special Wind Data and Program for Complex Terrain	Deutscher Wetterdienst	07.93-06.97	1,641.9	100.0
Phase II of 250 MW Wind Measurement and Evaluation Program WMEP	ISET	07.92-06.96	13,386.9	100.0
Operation of MW Scale Wind Turbines	Germanischer Lloyd	04.92-12.94	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
Promotion and Further Development of Wind Turbines in Germany and Europe	Fördergesellschaft Windenergie	03.94-02.95	129.9	50.0

Table 1. Wind Energy R&D Projects, 1994 ff (Continued)

Subject	Participants	Period	Costs (MDM)	BMBF (%)
Development and Construction of a 1 MW Two-bladed Turbine	Autoflug	04.94-03.97	6,047.7	23.7
Installation and Measurement Program Ventis V 12	Deutsche Windenergie Institut DEWI	04.94-03.99	1,085.0	36.9
Development and Construction TW 1000 with 1 MW Rated Power	Tacke-Windtechnik	06.94-12.95	5,813.5	25.0
Special Grid Measurements and Simulation	NATI GmbH	09.94-08.95	374.2	63.3
Detailed Investigation WT Flicker	Windtest Kaiser-Wilhelm-Koog	01.95-12.96	416.8	50.0
Technical and economical investigations of offshore WECs	Siemens AG	01.95-06.95	266.1	50.0
	Vulkan Engineering GmbH	01.95-06.95	730.0	50.0

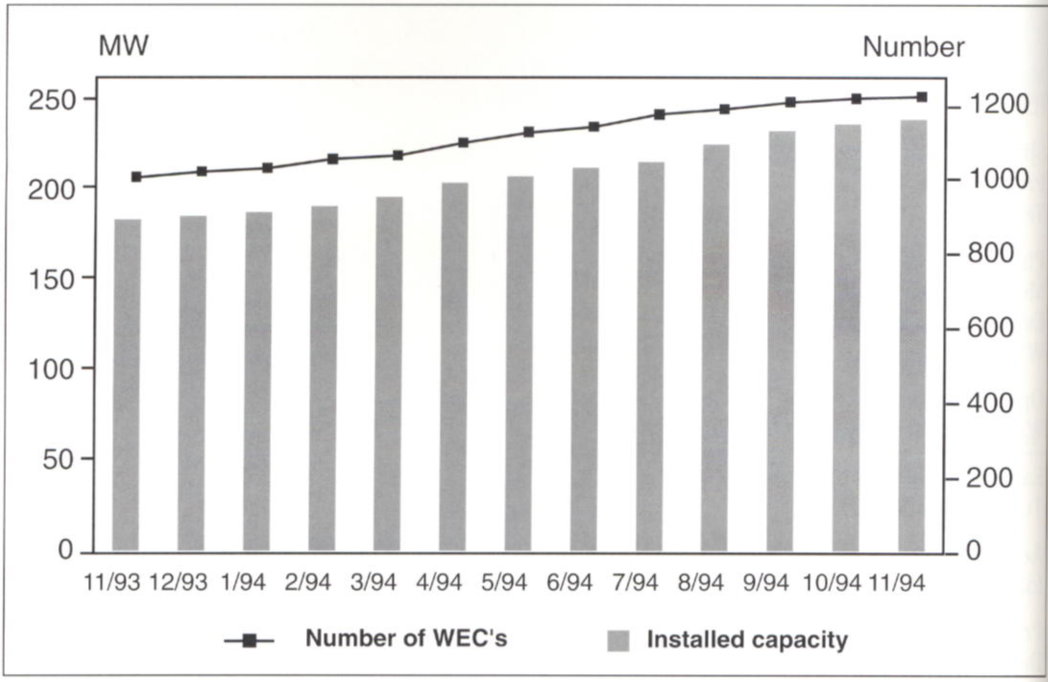


Figure 4. Scientific measurement and evaluation programme WMEP. Total installed rated power and number of WECs by November 1994 [4]

Interest in participating in the "250 MW Wind" program has been high up to now. Therefore, only a fraction of the proposals could be approved. By November 30, 1994, 1,146 proposals corresponding to 1,517 turbines were approved. This means that in addition to the already operating turbines (1,255—see above), an additional 262 turbines are in the building or planning phase. Today, three-fourths of the available power of the "250 MW Wind" program has been approved (the "250 MW" is not related to the rated power but to power at the reference wind velocity of 10 m/s). Further applications may be submitted until December 31, 1995. Figure 5 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 coastal states having wind speeds between 5 and 7 m/s. Now more and more applications are received from central regions with less favorable wind conditions. The regional distribution of the total wind power for several power classes is shown in Figure 6.

The analysis furthermore shows a tendency towards larger WECs. The average rated output of WECs was about 160 kW around 1990 and has risen to about 200 kW since then. Figure 7 shows examples of wind farms.

A further demonstration program was offered in 1994 by the Federal Ministry of Economic Affairs for single wind turbines with capacities of between 450 kW and 1 MW, at sites with wind speeds up to 5.5 m/s at a 10 m height. About 10 machines were approved, with a total support of DEM 1 million. The continuation of this program is planned, along with a similar program for renewable energies by the Ministry of Economic Affairs.

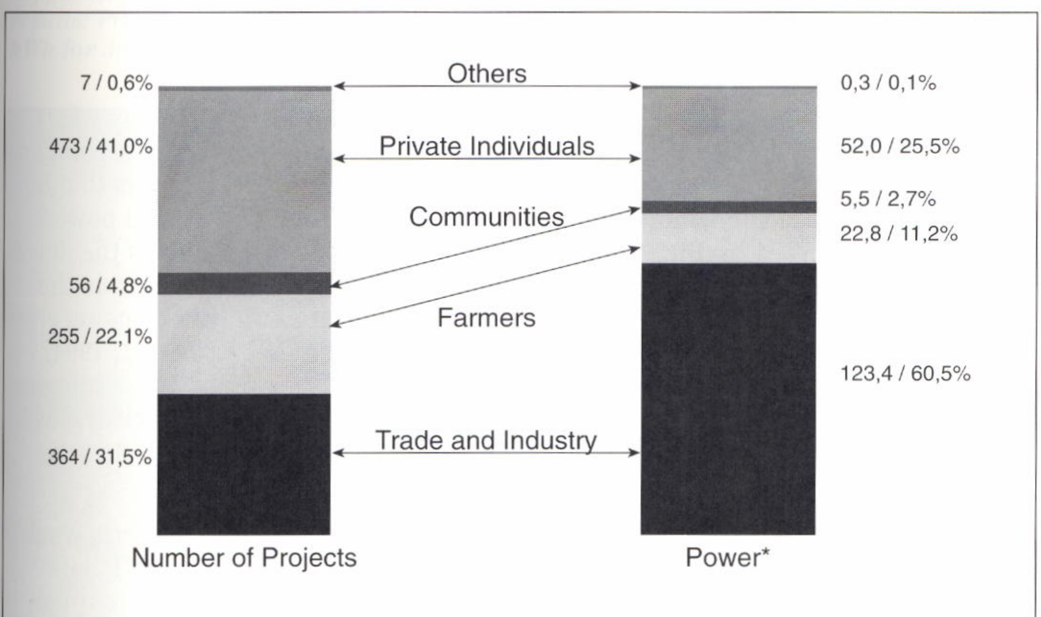


Figure 5. "250 MW Wind" programme. Distribution of number of projects and power (in kW*, measured at 10 m/s wind velocity) for different operators. Status December 20, 1994, with 1155 projects and 1527 WECs

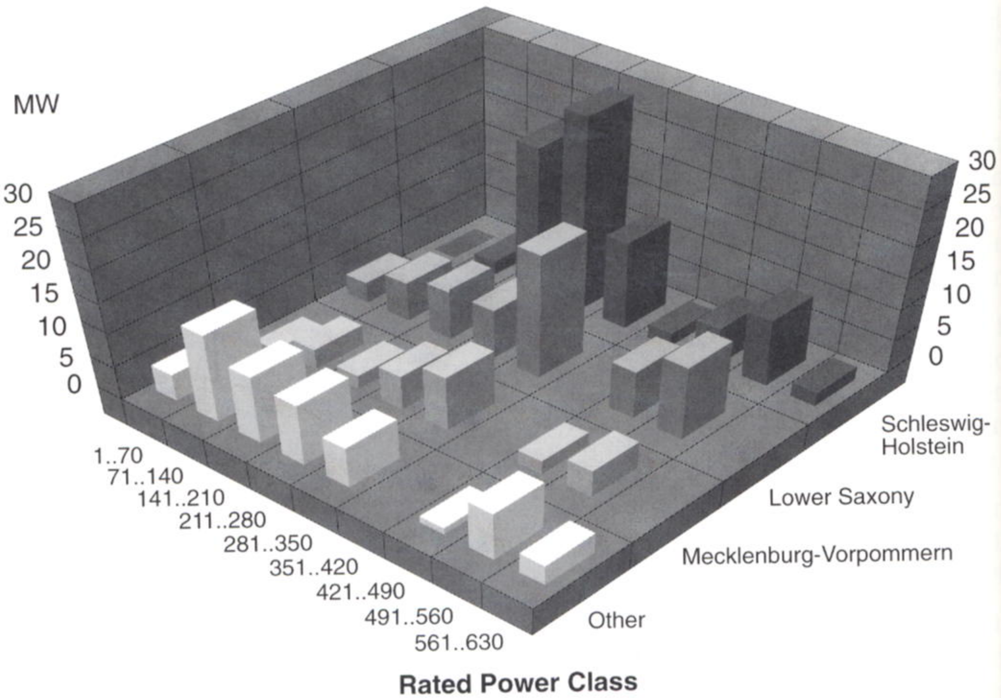


Figure 6. WMEP. Regional distribution of installed rated capacity/rated power class by November 30, 1994 [4]

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity

By June 30, 1994, the number of wind turbines in operation in Germany was 2,079, which corresponds to a rated power of 429 MW (Reference 7). A comparison with WMEP data (1,143 turbines, 197 MW) by June 30, 1994, shows that up to that time, 55% of the wind turbines and 46% of the total rated wind power have been supported by the "250 MW Wind" program. Figure 8 shows the development of wind power in Germany. With the increase of wind power from the "250 MW Wind" program from June 30, 1994, to November 30, 1994, one receives a first estimate of the total wind power in Germany as of December 31, 1994, with around 2,300 turbines and around 520 MW total rated power. According to DEWI (Reference 7), the total rated power in Germany as of December 31, 1994, was 643 MW, corresponding to 2,617 wind turbines. This count again demonstrates the rapid expansion of wind power in Germany.

Wind farms are included in the statistics above. Because BMBF supports wind turbines in these farms, too (but in general not the whole farm), WMEP data are available for these supported parts of the farms. In 1993, WMEP recorded 19 major wind farms with more than 1.2 MW rated power. This corresponded to a total rated power of 56 MW for 180 WECs.

Figure 7. "250 MW Wind" programme. Examples of wind farms

***Above:** 12.5 MW "Nordfriesland Windpark" of 50 HSW 250 WT (45 WT BMBF-supported), erected 1991/92. Electricity was 29 mill kWh in 1992, 26.6 mill kWh in 1993, and 26.4 mill kWh until November 30, 1994.*

***Below:** Two new wind farms of 17 MW total rated power at the island of Fehmarn, Baltic Sea. WT-type is the 500 kW E-40. Wind farm Presen: 18 WT (4 WT BMBF-supported). Wind farm Klingenberg West: 16 WT (4 WT BMBF-supported). First results: Presen—5 mill kWh for October/November 1994; Klingenberg—9.1 mill kWh for June until November 1994*

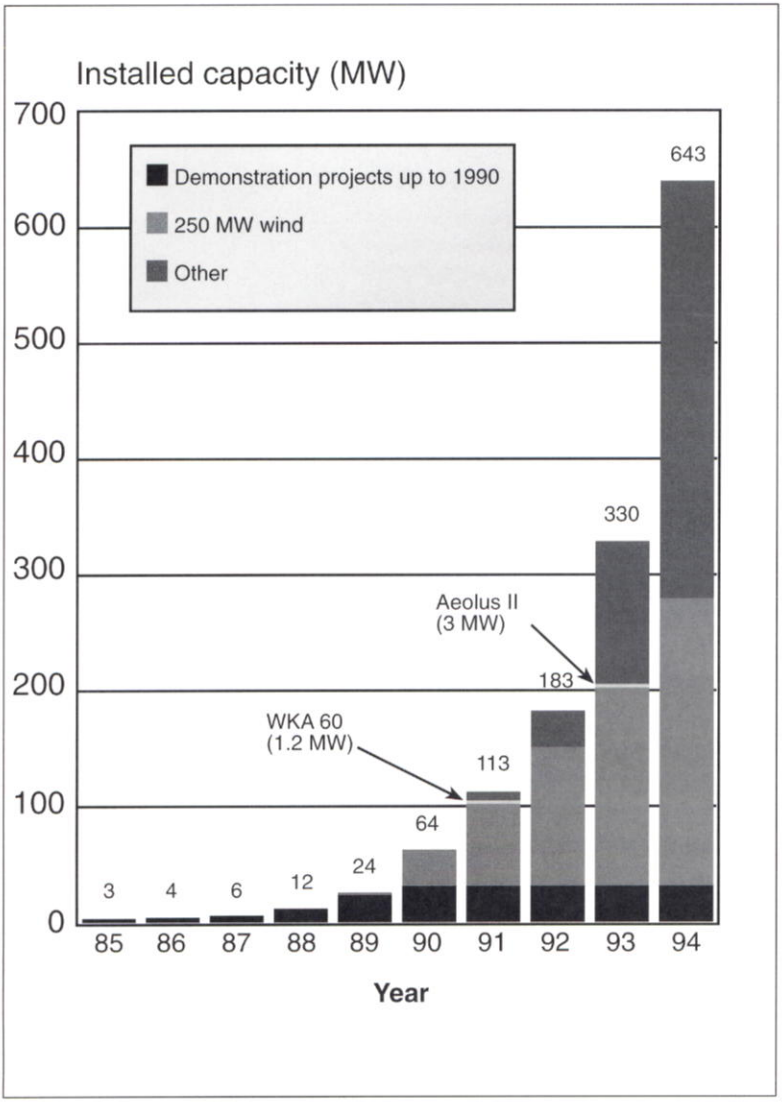


Figure 8. Wind energy development in Germany (1994 estimated)

2.2. Machine details

The determining factor for the increased installation rate in 1994, compared with 1993, is the new 500-600 kW class which now dominates the market. These are highly developed turbines with maximized energy production and minimized noise emissions. Detailed technical descriptions of these commercial WECs are given in Reference 8.

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 this IEA agreement.

2.3. Performance

The performance of the wind turbines in the "250 MW Wind" program is measured in detail by ISET (Reference 4). For example, we mention the technical availability which was 98% in 1993. This means that the average medium stand-still time was 138 h per WEC per year. So far, even after operation periods of several years, no increase in the stand-still time of WECs was observed. The turbines in the "250 MW Wind" program produced 303 million kWh in 1993. Around 98% of this energy was produced in the three German coastal states of Schleswig-Holstein, Lower Saxony and Mecklenburg-Vorpommern. Ninety point three percent of the produced wind electricity was fed into the public grids, and 9.7% was self-consumed by the operators. The total electricity produced by WECs in 1993 in Germany was around 500 million kWh. For 1994, the total wind energy production is estimated to be 850 million kWh, with the "250 MW Wind" program's contribution being 500 million kWh. ISET will publish the corresponding WMEP results in a new Annual Report, Part I, in March 1995 (see also Reference 4).

2.4. Operational experience

Monthly and yearly reports of the turbines in the "250 MW Wind" program are published by ISET (Reference 4). Figure 9 shows examples of failure statistics.

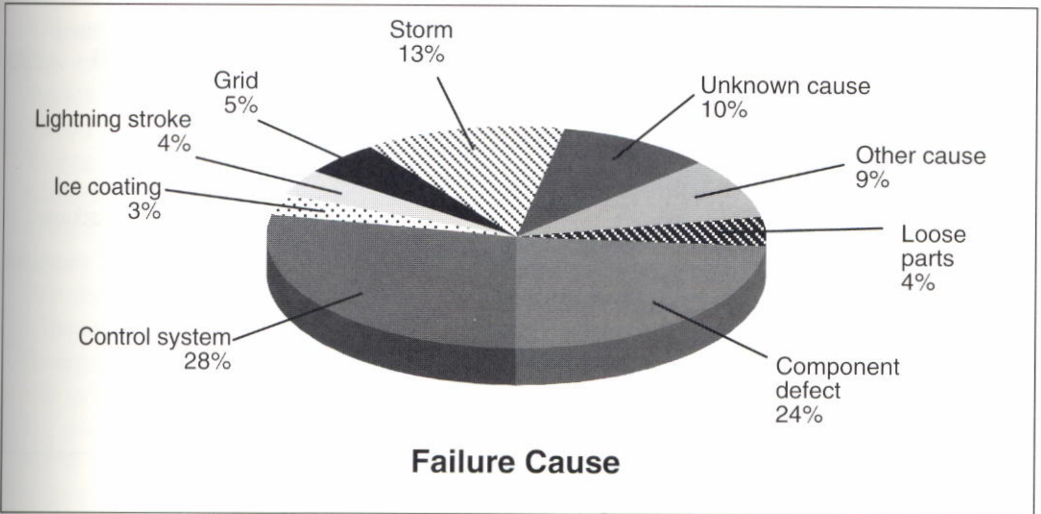
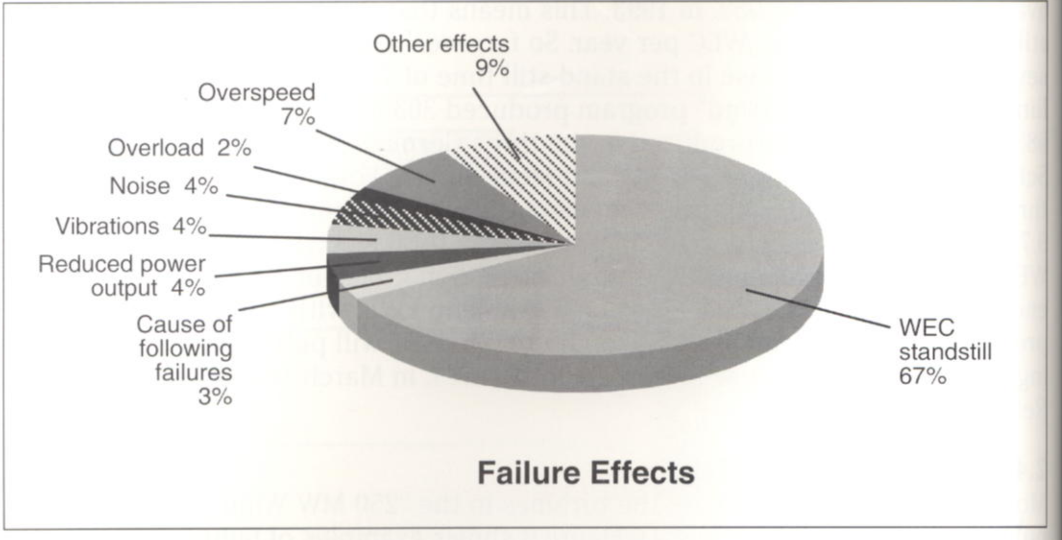


Figure 9. WMEP. Examples of failure statistics [4]



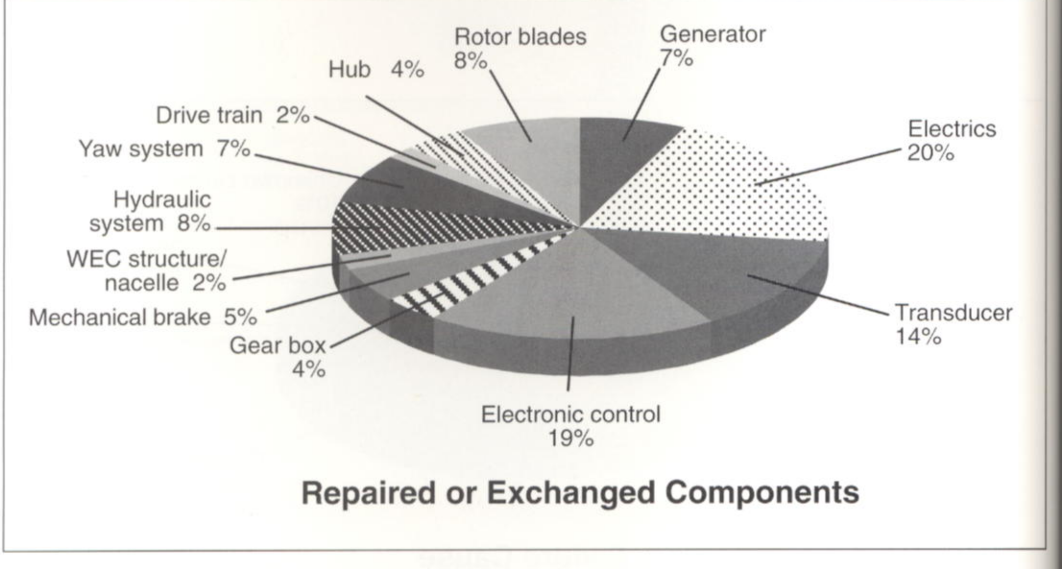


Figure 9. WMEP. Examples of failure statistics [4] (continued)

Figure 9. WMEP. Examples of failure statistics [4] (continued)

Repaired or exchanged parts,
Until December 1, 1994, received and calculated reports
(Not all reports have been evaluated yet.)

Hub	**91**
Hub body	11
Blade adjustment	59
Blade bearings	11
Others	10
Rotor blades	**155**
Blade joints	6
Blade body	54
Tip brakes	54
Others	41
Generator	**137**
Winding	12
Collector/brushes	37
Bearings	29
Others	59
Other electrical	**464**
Inverter	90
Fuses	155
Contactors/switches	109
Cables	61
Others	49
Sensors	**243**
Windspeed and wind direction	113
Vibration	17
Temperature	25
Oil pressure	18
El. power	5
RPM	43
Others	22
Other Control & Supervision	**392**
Microprocessor	305
Relays	32
Wiring/contacts	26
Others	29
Gear Box	**56**
Bearings	14
Gearwheels	2
Gear shafts	5
Sealings	11
Others	24
Mechanical Brake	**136**
Brake dick	12
Brake lining	61
Bremssattel	18
Others	45
Other (Drive Train)	**46**
Rotor bearings	12
Shafts	3
Couplings	25
Others	6
Hydraulic System	**214**
Hydraulic pump	47
Pumpdrive	11
Valves	48
Hydraulic pipes	33
Others	75
Yaw System	**174**
Azimut bearing	27
Motor	31
Gear	25
Others	91
WEC Structure	**106**
Foundation	3
Tower/bolts	55
Nacelle structure	13
Nacelle cover	22
Others	13

3. CONSTRAINTS ON MARKET DEVELOPMENT

Because BMBF focuses on R&D and demonstration of wind power, investigations of constraints on market development are made mainly by other institutions, without governmental support. Constraints certainly exist, despite the rapid increase of wind power in Germany during 1994, with about 500 new turbines installed, which corresponds to about 200 MW, and despite the fact that the German companies (60% of 200 MW) may reach certain limits of production with 500 kW wind power per working day. This is indicated, for instance, by the number of applications for the "250 MW Wind" program. Only about a tenth of these applications could be approved. Another example is the utility Schleswag AG, in the Federal State Schleswig-Holstein. As of December 1994, they have 255 MW of wind power connected to the grid, and applications for another 1,800 MW of wind power have been submitted. Bottlenecks in the 110 kV grid are under consideration today.

The licensing procedure in Germany should be mentioned. Building permission for a WEC or a wind farm is given by the local building supervisory board. This board checks that this installation follows 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, every area is used for a certain purpose or is restricted, like the two Wattenmeer National Parks. Regional wind power development plans must be taken into account in many areas (Reference 9). The increasing concerns about wind power siting and building permission are major problems to be solved by wind turbine operators or customers (Reference 10). This is especially true in the coastal sites with the best conditions where room for new development is becoming limited. On the west coast of Schleswig-Holstein, for instance, many people are fighting against a further expansion of wind power. This indicates that working for public acceptance becomes more and more important.

A special project with the title "Promotion and Further Development of Wind Turbines in Germany and Europe" is supported by BMBF (see also Table 1). Here trade constraints are considered, too.

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. This is the time required to regain the investment expense 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.

Consider a specific example: a 200 kW machine producing about 490,000 kWh/year, which required an equity capital investment of about DEM 420,000, and which also received about DEM 100,000 in initial subsidies and financial contributions (see Section 4.2). Such a turbine might have about DEM 5,500/year in operational costs. The total investment was DEM 520,000 (420,000 plus 100,000).

The BMBF's operating subsidy at the beginning of the program was DEM 0.08 per kWh. The calculations predict that after four years, DEM 340,000 was accumulated, and after five years, DEM 430,000. This means that the amortization time for the equity capital is between four and five years. After 10 years, the accumulated result is DEM 970,000. This means that the surplus is DEM 550,000 (970,000-420,000).

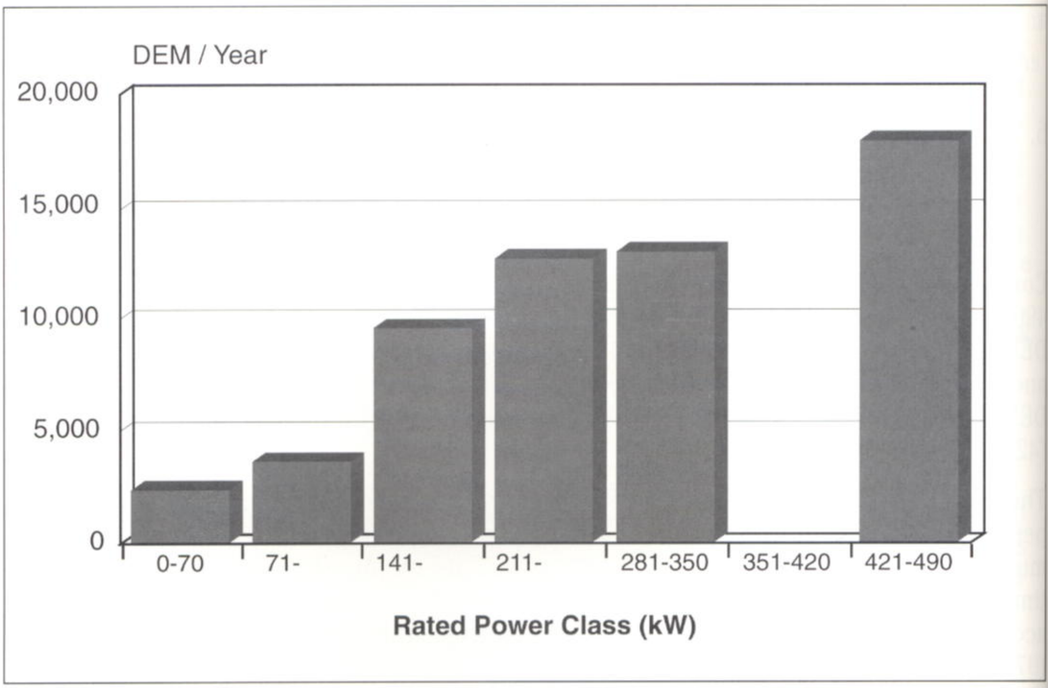
A major financial contribution for all economic calculations is given by the Law on Payment for Electricity from Renewable Energy Sources. This is connected with the obligation for utilities to purchase the wind power at a price of DEM 0.1693 per kWh.

Recently, important parameters for economic calculations were investigated in more detail, especially within the framework of the "250 MW Wind" program (Reference 4). An example is given in Figure 10, showing average annual operating costs with respect to wind-power class. Figure 10 shows a further example, which is the average 50% drop of energy yields from coastal to inland and low mountain-range WEC sites.

Recently, the German Windenergie-Institut (DEWI) published an article on the costs of electricity generation of wind in Germany, included in Reference 7. They came to the following conclusions:

> "The costs of electric energy generation from wind in Germany have been reduced considerably during the last years. Depending on infrastructure costs, legal tariff structure, and based on ten years' operation time, which guarantees at the moment DEM 0.1693/kWh (about USD 0.10/kWh), it is possible to benefit without any subsidies from a 500 kW wind turbine at sites with wind speeds above 5.8 m/s, measured at 10 m height. Including subsidies of 17% of the total project investment, the necessary site wind speed may be reduced to 5.4 m/s. In the present situation, 500 and 600 kW turbines are the most economic, compared to smaller sizes from 100 kW to about 300 kW."

Although the tax yield as another cost factor may be quite considerable, it is mostly neglected in general discussions. For example, at sites with energy



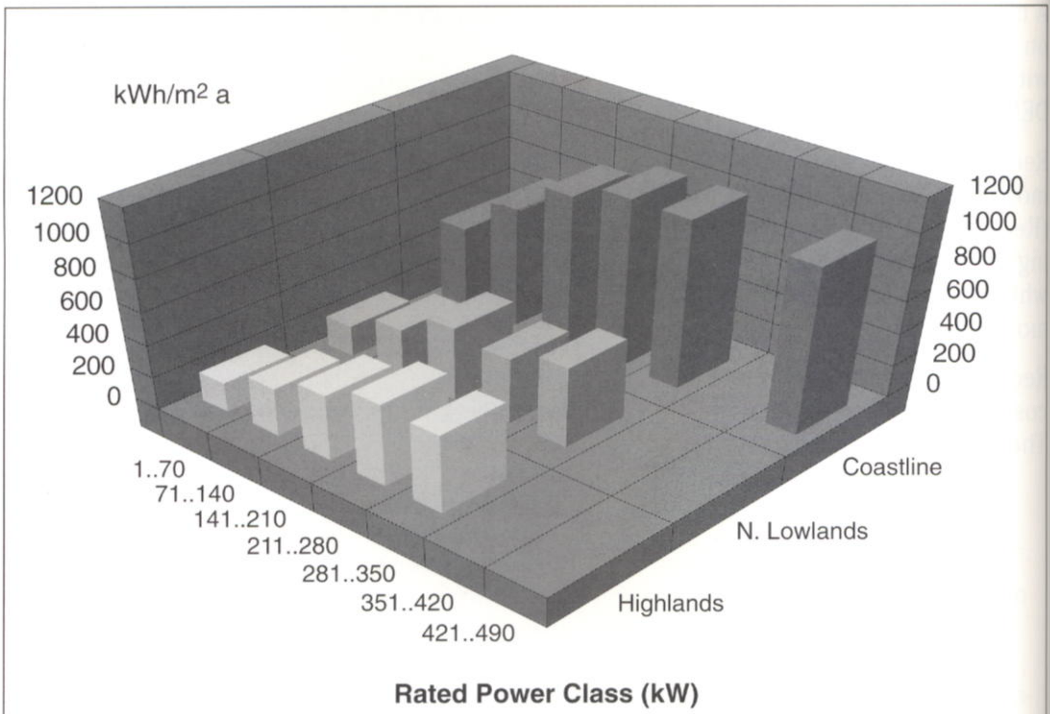


Figure 10. Economical calculation. Examples of WMEP for trends. Above: Annual total O&M costs (insurance, O&M, site rents). Below: Mean annual energy output [4]

production of 1.0-1.1 million kWh per turbine, the average yearly trade tax is DEM 120,000 for a farm of 10 units with 20 years utilization. In 20 years, the taxes sum up to DEM 2.4 million (Reference 11). Taxes are considered in the example calculation shown earlier in this section.

4.2. Subsidies

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

1. Federal Ministry for Education, Science, Research and Technology (BMBF)
   - R&D (see Section 1.1 and Table 1)
   - "250 MW Wind" demonstration program (see Section 1.2)
   - Applications in other climatic zones and "ELDORADO Wind" (see Section 6.0).
2. Federal Ministry for Economic Affairs
   - Demonstration program (see Section 1.2).
3. German Federal States
   - R&D
   - "250 MW Wind" demonstration program.
4. EU
   - R&D
   - Demonstration.

The current subsidy for operators in the "250 MW Wind" program is either DEM 0.06 or DEM 0.08 per kWh, depending on whether the energy is fed into the grid (≈ 90%, [see Section 2.1]) or if it is being used by the owner of the WEC (≈ 10%). The latter applies, for instance, on a farm, in a factory or in a private household, and also in the case of 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, today limited to DEM 90,000, is possible. The owner of the example discussed in Section 4.1 received a 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%, granted to a WEC manufacturer.

The BMBF subsidies in 1994 will be about:

- DEM 11 million for R&D
- DEM 27 million for "250 MW Wind"
- DEM 6 million for the ELDORADO program.

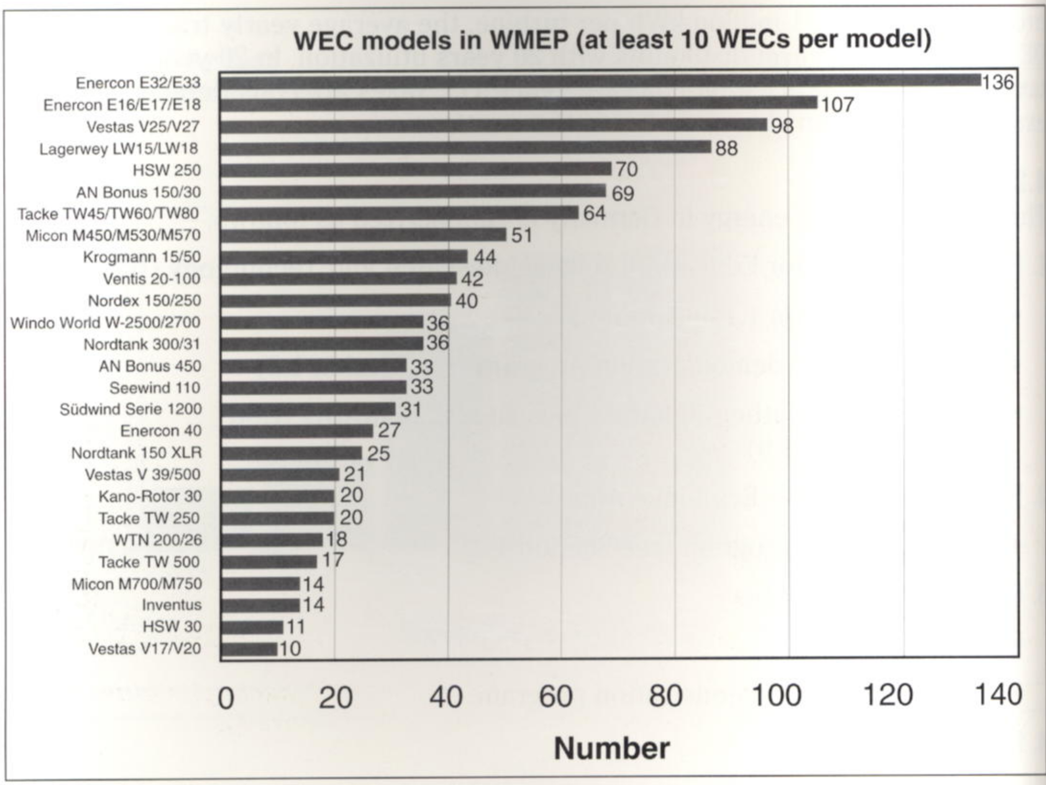


Figure 11. WMEP: WEC models (at last 10 WECs per model), Status November 30, 1994 [4]

Furthermore, governmental credit institutions provide favorable interest rates for wind turbines (Deutsche Ausgleichsbank DtA, Kreditanstalt für Wiederaufbau KfW). The loan rates are 0.5 to 1.3% below the customary interest rates, with the possibility of pay-off-free years.

5. INDUSTRY

Fifty-five percent of the operating WECs in Germany are investigated by the WMEP. The actual distribution of WEC models is shown in Figure 11. The gross domestic sales of the German manufacturers may roughly be estimated at DEM 240 million, based on average selling prices of around DEM 2,000/kW and a total annual wind-power plant production in 1994 (see Section 2.1) of 120 MW (60% market share of 200 MW). These figures do not include exports, which are discussed below. Other industries participate with installation services like foundations and electric grid connections. The situation for the whole wind energy market is considered by DEWI (Reference 7) as follows:

> "As a consequence of the growing wind energy market in Germany, the importance of the industry in this business area has grown. In 1994, gross sales will go beyond DEM 500 million, and the number of employees will reach 2,900. The sales and the number of employees are increasing in spite

Figure 12. Example of industrial trade. 4 Tacke TW 600 at Tehachapi, California, 1994. The 500 kW prototype was supported by BMBF (see Figure 1)

> of higher manufacturing efficiency. In 1994, only five employees were needed by a manufacturer to install 1 MW rated power instead of 15 in 1989, and the ratio of installed power to manufacturer's gross sales has risen from 0.25 W/DEM in 1988 to 0.455 W/DEM in 1994."

International trade increased remarkably. German manufacturers sold turbines to European countries and North America. For example *Windpower Monthly* reported that Enercon is going to sell 80 WECs (40 MW) to Texas. For details, see Task XIII of this IEA agreement. An example may illustrate this trade (see Figure 12).

6. INTERNATIONAL COLLABORATION

The German/Swedish R&D cooperation was already mentioned (see Section 1.2). Many contacts between European partners exist in the framework of projects of the EU. BMBF's interest also includes the use 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 may be assisted by decentralized concepts, and renewable energies are considered to be one option for decentralized energy supply.

Against this background, BMBF launched the ELDORADO wind program (Reference 12) in 1991, which is being jointly carried out with several partner countries. The type of support selected by the BMBF is intended to motivate a larger number of users in southern climatic zones to construct and operate

WECs in cooperation with German partners. The aim is to achieve an installed total power of 20 MW in these countries within the next five years on the basis of findings derived from domestic measures.

Response to the ELDORADO program was very favorable. Several projects have already been started (see Table 2 and Figure 13), and others are in preparation.

Table 2. Projects Approved within the ELDORADO Programme

Country	Project	Technology
Egypt	Wind Farm	10 x 100 kW Ventis
Brazil	Wind Farm	4 x 250 kW Tacke
Brazil	Wind Farm	5 x 100 kW Ventis
China	Wind Farm	4 x 250 kW HSW
China	Wind Farm	4 x 250 kW HSW
China	Wind/Diesel	5 x 30 kW Jacobs Energy
Russia	Wind/Diesel	10 x 30 kW HSW
China	Wind Farm	10 x 250 kW HSW
Russia	Single Turbine	1 x 37 kW Südwind
Argentina	Wind Farm	10 x 100 kW Ventis
Latvia	Wind Farm	2 x 600 kW Tacke

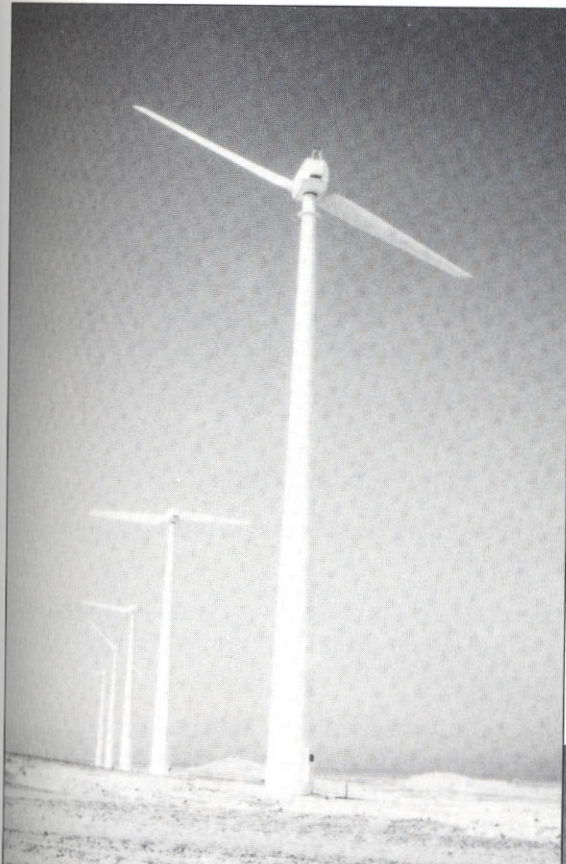


Figure 13. Examples of the ELDORADO Programme

Left: 1 MW-wind farm in Hurgada/Egypt: 10 Ventis 20-100/WT

Bottom Right: Erection of a HSW 250 for a 1 MW wind farm in Zhurihe/China

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ITALY

1. NATIONAL PROGRAMS

Italy's national programs in the wind energy sector have seen the commitment of ENEA, ENEL S.p.A. and industrial companies, under the supervision of the Ministry of Industry and Commerce (MICA).

ENEA is the Italian Agency for Energy, New Technology and the Environment. So far, the efforts of this state-owned organization have been aimed at developing wind turbine technology, promoting the domestic wind energy market by technically supporting private installers and local authorities, and providing Italy's wind energy industry with both technical and financial assistance.

ENEL S.p.A. is the main electricity utility company in Italy. In order to diversify and supplement its primary energy resources, ENEL has been interested in exploring any renewable energy forms likely to approach competitiveness with imported fossil fuels, upon which electricity production still depends very heavily in Italy.

As for the Italian wind energy industry, two companies have undertaken the manufacture of machines of significant size intended for grid-connected operation: WEST (of the Alenia Group) and Riva Calzoni.

Up to now, the work carried out in Italy has consisted mainly of wind surveys (over 200 wind measuring stations have been set up) and designing and testing of wind turbines. More recently, to comply with the 1988 National Energy Plan (PEN), ENEL and ENEA have also undertaken actions aimed at setting up Italy's first demonstration wind farms. Meanwhile, Italian manufacturers have also embarked on other installation projects within the framework of cooperation with local authorities and ENEA.

Wind data gathered so far show that pretty good wind resources exist in some areas of southern Italy and the islands. But careful micrositing studies of candidate locations are generally required, as most of them feature a complex terrain which makes wind measurements at a single station inadequate for evaluating the actual potential and optimal machine layout on the surrounding area.

More details of the R & D and demonstration activities currently carried out or planned by ENEA and ENEL, either separately or within the framework of cooperations involving industry as well, are provided hereunder.

1.1. Research and development

ENEA's programs

ENEA has been involved in the assessment of usable wind potential and the development of Italy's own wind turbine technology. Wind turbine activities have led to the development of two families of medium-sized machines in cooperation with industry. The first is the Medit family, which started from a 225 kW two-bladed prototype made by Aeritalia (now Alenia/WEST) with ENEA's assistance; the second is the single-bladed M30 family developed by Riva Calzoni from a 200 kW prototype made in cooperation with ENEA (see Section 5 on

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity

As of the end of 1994, available statistics put Italy's installed wind capacity at nearly 22 MW, considering only grid-connected plants of significant size. Reliable data cannot be given as far as small, dispersed grid-connected installations or stand-alone plants are concerned; however, no appreciable contribution to overall capacity is expected from these kinds of plants, the use of which has so far been very limited in Italy. The 22 MW grid-connected capacity mentioned above is installed in 21 plants totalling 87 machines; machine rated powers range from 30 kW to 1500 kW, although medium-sized units rated between 200 and 400 kW prevail.

It is worth pointing out that these plants comprise two wind turbine test sites owned and run by the utility ENEL, namely the Alta Nurra site in Sardinia, at present with 5 units totalling 2.77 MW, and the newly-built Acqua Spruzza site in Molise, with 8 units totalling 2.44 MW.

The remaining 19 plants have been set up for production purposes by as many local investors, such as Regional governments, small town municipalities, industrial and reclamation consortia, wind turbine manufacturers, etc., often with some financial support from the European Commission or ENEA. Unit plant capacities are therefore generally rather small, with few machines per plant. The wind farms over 1 MW capacity are at present:

- The 2.4 MW wind farm set up and operated by the WEST company near Bisaccia in the Campania Region under concession from the Regional government, with six Medit 320 machines plus sixteen 30 kW AIT-03 small units (all made by the Alenia Group)
- The 4.5 MW wind farm built in the area of Bassa Nurra (northern Sardinia) for "Consorzio di Bonifica di Nurra" by WEST and Riva Calzoni; it consists of four clusters located, respectively, at Monte Uccari (5 Medit 320, 1.6 MW) (Figure 3), Brunestica (3 Medit 320, 0.96 MW), Campanedda (4 M30-A, 1 MW) and Ottava (4 M30-A, 1 MW)
- The 1.3 MW wind farm near Palena in the Abruzzo Region, with 3 Medit 320 and 2 Vestas machines, operated by "Consorzio di Bonifica del Sangro"
- The 3.5 MW wind farm (Figure 4) that has just been set up by Riva Calzoni at Casone Romano near Castelnuovo della Daunia in the Puglia Region, with 10 units of the M30 series.

ENEL's Monte Arci wind farm (11 MW) is still under construction in Sardinia and cannot be included in these statistics yet.

Installed capacity can be expected to grow at a more significant rate in the next couple of years, taking into account both the 20 MW capacity that is being set up by the utility ENEL, and the interest in wind plant installation recorded among autonomous producers, especially in southern Italy, where the country's best resources seem to be. In 1993-1994, projects totalling over 50 MW were submitted to concerned authorities for financial support (see also Section 4 on

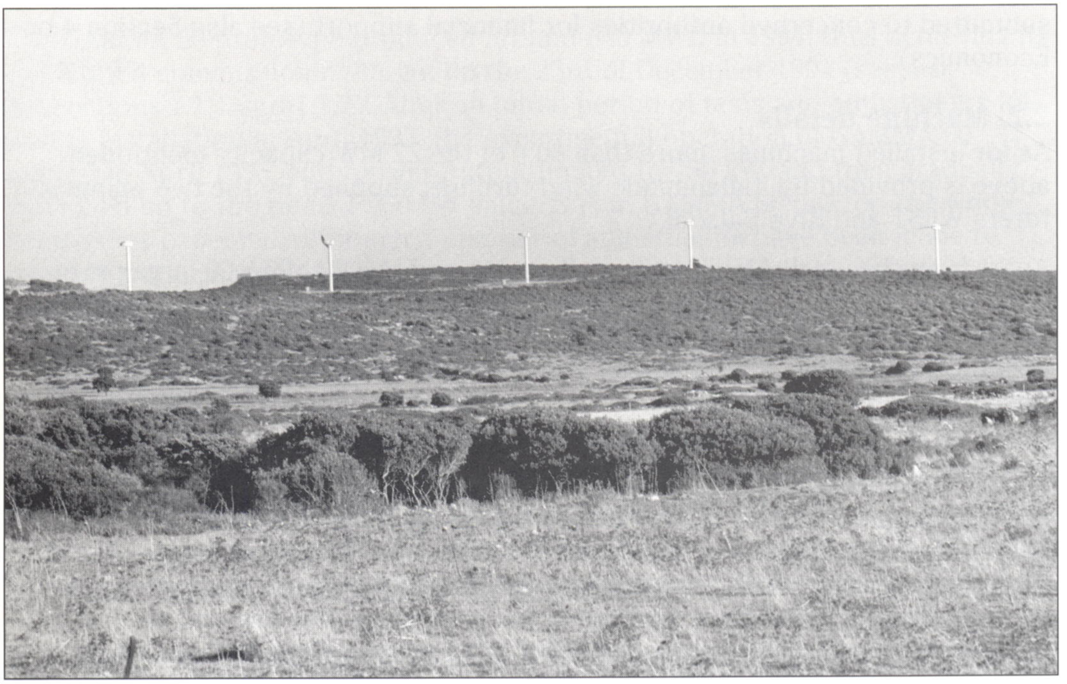

Figure 3. The wind turbine cluster at Monte Uccari (northern Sardinia) with five WEST Medit 320 units totalling 1.6 MW. This cluster is a part of the 4.5 MW wind farm built for Consorzio di Bonifica di Nurra.

Figure 4. The 3.5 MW wind farm recently set up by Riva Calzoni at Casone Romano near Castelnuovo della Daunia (Puglia), with 10 units of the M30 series

submitted to concerned authorities for financial support (see also Section 4 on Economics).

2.2. Machine details

As for installed machines, more than 80% of the 22 MW capacity mentioned above is provided by Italian-made wind turbines supplied by the two manufacturers WEST and Riva Calzoni.

Apart from the small AIT-03 units at Bisaccia, and the GAMMA 60 large prototype, all of the WEST machines currently installed at wind farms and test sites are of the Medit 320 model, featuring the following main characteristics: upwind, two-bladed, 33 m diameter rotor with rigid hub and fixed speed; power regulation through blade pitch control; one induction generator; and rated power of 320 kW at 11.5 m/s wind speed (10 m height).

All the Riva Calzoni units belong to the M30 series, although with different ratings. The most common, typical industrialized machine of this family is the M30-A, the main features of which are the following: downwind, single-bladed, 33 m diameter rotor with teetering hub and dual fixed speed; power regulation through blade pitch control; two induction generators (for low and high winds, respectively); and rated power of 250 kW at 12 m/s wind speed (hub height).

It is also worth recalling here, for the convenience of the reader, the main characteristics of the GAMMA 60 prototype: upwind, two-bladed, 60 m diameter rotor with fixed blade pitch and teetering hub; operation at broad-range (15-44 rpm) variable rotor speed; power regulation through yaw control instead of blade pitch control; one synchronous generator with a.c./d.c./a.c. power convertor; and rated power of 1,500 kW at 13.5 m/s (hub height).

Additional information on the development of Italian wind turbine models can be found in Sections 1 (Programs) and 5 (Industry).

As to foreign-made machines, various units rated between 100 and 400 kW have been installed in Italy so far; most of them have been supplied by Vestas (Denmark), HMZ-Windmaster (Belgium/Netherlands), and WEG (United Kingdom).

2.3. Performance and operational experience

Gathering comprehensive information on energy production from wind in Italy is not simple, given the number of rather small and dispersed plants operated by many different bodies. In addition, it should be borne in mind that some of the larger plants, e.g., the Bassa Nurra, Palena, and Casone Romano wind farms, or the Acqua Spruzza test site, have been connected to the grid, or set up, only recently, and no significant production data are as yet available from them. Some data can, however, be given for some plants.

At ENEL's Alta Nurra test site, overall 1994 production from the medium-sized machines (only three units over most of the year) has been around 700 MWh, thus bringing the total energy generated by medium-sized units to around 3,200 MWh.

The GAMMA 60 prototype produced around 640 MWh in 1994, thus achieving its 1,000 MWh commissioning target on the 23rd of December 1994 (see also Subsections 1.1.1 and 1.1.2). After an initial period of tests and adjustments following installation in April 1992, the experimental operation of GAMMA 60 started in April 1993, with power output limited to 750 kW, and then gradually increased up to the rated 1,500 kW value. So far, GAMMA 60 has, on the whole, behaved as expected, although a number of adjustments have been made to improve performance and enhance safety, as is customary on prototypes.

The 1994 production of the Bisaccia wind farm has been reported to be around 1,200 MWh; the plant's total production has been around 3,500 MWh since the connection of the first units in 1992.

The earliest plant set up with Riva Calzoni machines (the 400 kW plant of Tocco da Casauria in Abruzzo, consisting of two 200 kW M30 units) has had a 1994 production of 850 MWh with 88% average availability over the year.

3. CONSTRAINTS ON MARKET DEVELOPMENT

3.1. Environmental impact

As already said in the foregoing, wind data gathered up to now show that pretty good wind resources exist in some areas of Italy. Nevertheless, most of these sites are found in coastal areas or in the mountains, mainly in the Apennines at 800-1,000 m or even higher altitudes. The use of both types of location is often subject to special constraints ensuing from laws protecting the landscape. Moreover, most seaside areas are densely populated and sites available for plant installation are consequently very limited in number and size; mountain areas, on their part, often have harsh weather conditions during the winter and may require the construction of long dedicated lines for connecting to existing power networks.

In addition, the fear that natural environment might be somehow damaged, or existing human activities be seriously hampered, has often led local people and authorities to be rather mistrustful towards proposed wind energy projects. These attitudes, along with the lengthy permitting procedures (see below), have already brought about severe delays in developing projects, with ensuing financial losses. The diffusion of correct knowledge about wind energy, especially among local authorities, should therefore be deemed a high priority action.

In Italy, wind power plants are explicitly left out by the law governing the Assessment of Environmental Impact (VIA). The Regional governments only require a visual impact study for wind farms. Some plant developers, such as ENEL, have however undertaken complete environmental compatibility studies with a view to gaining correct knowledge of all aspects of the matter; this information could give both developers and local authorities a better insight into the problem, thus helping to speed up permitting procedures.

Another major factor that can bias the public's attitude is noise pollution. There are laws in Italy which impose limits on acoustic emissions, especially the change of noise levels ensuing from new installations in an area, but regulations for applying these laws are lacking; in the specific case of wind plants, there are no reference conditions to check compliance with the law. Noise evaluations are complicated further by the fact that most Italian sites are on complex terrain.

In default of more definite regulations, some developers have, for the moment, taken their own precautions. For example, ENEL has fixed its provisional noise emission limits for wind turbines (65 dB(A) measured as specified in the IEA Recommended Practices), as well as minimum distances (at least 100 m) between wind turbines and main public roads.

3.2. Institutional aspects

In Italy, the setting-up of wind turbines requires a building permit as for any other kind of building. This permit is issued by the Commune concerned with the area where the plant is to be installed, upon application by the plant developer. However, no local planning regulations make reference to wind turbines, and the granting of permits has so far been based on subjective criteria, which may vary remarkably from one place to another.

Before issuing a building permit, however, the Commune is also obliged to obtain the agreement of a number of other public bodies, depending on the specific case in hand. Among these, mention should be made of the Regional government, especially the Councilors for Industry, National Heritage and Environment, and Agriculture and Forests. The Air Force and Civil Aviation Authorities must also be asked for permit in case of possible hazard to low-altitude flight. Moreover, the Ministry of Industry and Commerce, the Technical Office of Manufacturing Taxation (UTIF), and the ENEL company must be informed of the intention to set up a generating plant of whatever kind.

Another act required by the Commune is to demonstrate the availability of the land obtained by purchasing or leasing; this may prove very difficult, especially if the land (as often happens in Italy's countryside) is divided among a large number of private owners.

The overall procedure described above takes a period of at least one to two years, with ensuing delays and additional unexpected costs. Hence the need, deeply felt by all those involved in the sector, for the establishment of more streamlined procedures that are somehow trimmed to the particular case of wind and other small renewable energy plants.

In this connection, the need has also recently been recognized to set up a national wind turbine certification system in Italy as well. As noted above (see Section 1.1), ENEA has been entrusted with the task of developing this system.

4. ECONOMICS

4.1. Economics and financing

Since the development of wind energy applications in Italy has not yet become so mature as in other countries, it is not possible, for the time being, to provide reliable and meaningful figures on such parameters as the invested capital per kilowatt installed, the value of total wind generated energy, unit energy cost, subsidies per unit energy produced, etcetera.

However, as noted in Section 1, efforts have been made to boost the diffusion of wind energy and prime the domestic wind turbine market through R&D, certification, and demonstration activities, as well as suitable legislation.

Activities under the 1994-1996 MICA-ENEA agreement have been allocated an overall funding of US$ 15 million (US$ 1 = ITL 1,600) over their full three years period. Table 1 below gives more details on resources devoted to activities provided for in the 1994 plan (the cost of a man-year is about US$ 75,000; "other expenses" include travels, current expenses, and external assistance).

Table 1. Resources (Million U.S. $) Allocated to the 1994 Plan under the ENEA-MICA Wind Energy Agreement

Line of Activity	Personnel	Investment Expenses	Other	Total
Certification	0.70	0.51	0.58	1.79
Siting	0.63	0.46	0.94	2.03
Technology	0.18	0.14	0.04	0.36
Total	1.51	1.11	1.56	4.18

As regards the utility ENEL (engaged in both R&D and demonstration activities), total expenditure has been around US$ 18 million (ITL 29 billion) in 1994. ENEL's wind energy budget for 1995 is around US$ 25 million (ITL 40 billion).

The manufacturers Alenia/WEST and Riva Calzoni have financed their own internal R&D activities with a 1994 commitment totalling about U.S. $ 1.9 million (ITL 3 billion) for each of them.

4.2. Subsidies

Law No. 9 of January 9, 1991, allowed autonomous electricity producers to set up generating plants from renewable sources and sell the energy to ENEL. In addition, Law No. 10 of the same date stated that the use of renewable sources is to be considered in the public interest, and, among others, also provided for subsidies from state or local authorities covering a percentage of the capital cost of the plant (for wind energy plants, 30% to 65% of total capital cost). It must be noted, however, that up to now, funds for Law No. 10 have not yet been made available, due to financial restrictions.

A more effective incentive so far has been given by Directive No. 6 issued by CIP (Interministerial Committee for Prices) on 29th of April 1992. This provision allowed a price of ITL 150 per kilowatt-hour of wind-generated electricity fed into the ENEL system over the first eight years of plant operation, and ITL 72/kWh for the remaining lifetime. These prices are periodically revised depending on inflation. According to CIP 15/93, updated tariffs are: ITL 155.4/kWh for the first eight years (about ITL 120 if the plant has also been granted subsidies to capital cost) and ITL 73.3 for the remaining lifetime. For the first time in Italy, the concept of "avoided costs" was taken into account in fixing the above-mentioned tariffs. The share of grid-connection cost an autonomous producer has to bear mainly depends on the energy supplied to the utility. The lowest share allowed is one-third of the cost (two-thirds borne by the utility).

5. INDUSTRY

5.1. Manufacturing

Italy's main industrial companies involved in the manufacture of wind turbines are WEST of the Alenia Group (formerly Aeritalia) and Riva Calzoni. Both these manufacturers entered the wind energy field in the 1980s, developing their own wind turbine models in cooperation with ENEA (see Section 1.1.1). They have since continued cooperating with ENEA and ENEL for testing and diffusing their products.

The WEST Company

WEST was constituted within the Alenia Group in 1989 with the scope of designing, building, and commercializing blades, wind turbines, and wind farms. At present, WEST owns a factory in Taranto and employs about 100 people, half of whom are engaged in research, development, and design. WEST has produced three wind turbine lines: the Medit 320, the GAMMA 60 and, more recently, the TAW 636.

As already stated (see Section 2.2), the Medit 320 machine (320 kW) is currently the main industrial product of WEST. About 70 Medit 320 units have been manufactured; of these, 34 were ordered by ENEL for the Monte Arci wind farm (see Section 1.2).

Commitment to large-sized wind turbines has also been very significant: the development of the innovative 1.5 MW GAMMA 60 prototype started in the mid-1980s through an agreement between the former Aeritalia company, ENEA and ENEL. As previously stated, GAMMA 60 is now going to be upgraded to 2 MW rated power at 14.9 m/s wind speed, corresponding to an operating speed of 55 pm, and then commercialized.

WEST is also developing the 620 kW TAW 636 machine, a wind turbine positioned half-way between medium and large sizes, which is believed to be suitable for the near-term wind farm market. The TAW 636 design has been based on the same GAMMA 60 concepts, in particular variable speed, yaw control, and teetered hub.

The Riva Calzoni Company

All the Riva Calzoni wind turbines feature a single-bladed rotor. This option was preferred because it allows for lower weight, increased safety, flexible structure, and suitability for turbulent wind regimes.

Riva Calzoni's products include the small-sized (5 kW) M7-S wind turbine, designed for stand-alone applications, and the medium-sized M30 family. In this series, most of the units produced so far have been of the 250 kW M30-A model.

Several plants using the various versions of M30 machines (about 7 MW installed so far) have been set up in Italy. An additional 36 M30-A wind turbines are being manufactured under an ENEL order for the 9 MW wind farm planned at Collarmele (see Section 1.2).

The more recent evolution of the M30 series has led Riva Calzoni to manufacture the M30-S1 prototype featuring a new rotor, with an innovative blade and hub (currently installed at ENEL's Alta Nurra test site). Based on this machine, the 350 kW M30-S2 version has been developed. Besides the new rotor, the M30-S2 features other substantial innovations in the energy conversion system, which operates at semi-variable speed. The machine is intended as the final issue of the M30 series.

Riva Calzoni's current policy foresees commitment as both a wind turbine manufacturer and a wind farm developer. Significant penetration into the market is deemed a basic condition for improvement of machines and their evolution toward larger sizes. To this end, Riva Calzoni has also started designing the 500 kW M55 turbine.

5.2. Other industries

A number of Italian firms have been involved in the wind energy sector by the aforementioned manufacturers as suppliers of wind turbine sub-systems and components. Among them, special mention should be made of the following:

- De Pretto (hub, drive-train shafts, actuators, etc.)
- Elli and OTO Trasm (gearbox)
- Ansaldo (electrical sub-system)
- Gavazzi and Termokimik (control sub-system)
- Siderpali, Simi and Stanisci (tower)
- Stoma (nacelle frame and transport facilities).

6. INTERNATIONAL COLLABORATION

In the last few years, ENEA, ENEL, and wind turbine manufacturers have been involved in a number of international collaborations with utilities, universities, and research institutes, mainly as far as R&D projects are concerned. Most of these projects have been carried out within the framework of programs sponsored by the European Commission, such as JOULE, etcetera.

JAPAN

1. NATIONAL PROGRAM

1.1. Research & development

Since 1978, the Japanese wind energy R&D program 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 Energy and Industrial Technology Development Organization (NEDO) plays the main role in the construction and operation of the large-scale test plants in the project. The Mechanical Engineering Laboratory (MEL) and the National Institute for Resources and Environment (NIRE) are carrying out basic research in wind energy and are supporting the New Sunshine Project through technology evaluation of the program. The national program also includes standardization activities.

Table 1. Wind Energy Activities in Japan

National Activities	
R&D LS-WTGS	NSS-H.Q.
(1) 500 kW WTGS	NEDO/MHI
(2) Basic Research	
WINDMEL-I, Wind/Diesel,	
WINDMEL-II, etc.	MEL
Wind Analysis	NIRE
(3) Wind Observation	NEDO
Demonstration	NSS-H.Q.
1 MW Wind Farm	NEDO/Okinawa EPC/
Standard (IEC, ISO, JIS)	
MIT/MEL/Manufacturers	
	Utilities/Universities
Industrial Activities	Utilities/Local Authorities/ Manufacturers/School

The budget for wind energy in the New Sunshine Project is shown in Table 2.

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

Development of Large-Scale Wind-Turbine Generating Systems (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 3.

In FY 1993, some components of the 500 kW wind turbine were tested by Mitsubishi Heavy Industry Ltd. (MHI). Full scale fatigue testing of the rotor blades was carried out to verify the blade design. Load testing and noise measurement of the gearbox and modal analysis of the nacelle cover by FEM were undertaken. The field test of the machine will start in 1996.

Basic research

MEL has been carrying out research of basic aspects of rotor aerodynamics, structural dynamics, vibration, wind/diesel system, and acoustic noise, etc. since 1978. MEL had developed and has been operating a two-bladed variable-speed soft designed 15 kW experimental wind turbine (WINDMEL-I) for basic research purposes. Based on the experience of this machine, a new experimental machine, WINDMEL-II, has been developed and was installed in March 1994 in order to compare performance and strength between advanced concepts and traditional concepts. This machine has a variety of options, such as a teetered/rigid hub, constant/variable speed, etc.

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

Wind observation

As a complement to the nationwide network for local meteorological observations, NEDO has measured wind characteristics at selected sites since 1983. In 1993, a wind map data base, which includes restricting factors for a wind farm construction, was developed based on the combination of the network data and new wind observation data obtained. The final data report was completed in FY 1994.

1.2. Demonstration

An experimental wind farm of approximately 1 MW rated power is still under construction on Miyako Island in Okinawa. Okinawa is located at the southernmost prefecture of Japan. Two 250 kW wind turbines are now under operation, and the operational results of these two WTGS in FY 1993 are shown in Table 4.

Table 3. 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 deg
	Corn Angle	0 deg
	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

Table 4. Operation Data of Miyako Wind Farm (Two Units of 250 kW Machine)

Month	Wind Speed (m/s)	Generation (MWh)	Capacity Factor (%)
1993, April	7.6	95.5	26.5
May	5.8	51.5	13.8
June	7.4	93.8	26.1
July	5.7	39.6	10.6
August	6.0	68.5	18.4
September	6.4	45.8	12.7
October	9.0	112.1	30.1
November	8.6	126.0	35.0
December	10.3	198.0	53.2
1994, January	8.1	118.2	31.8
February	8.3	124.2	37.0
March	8.4	131.6	35.4
Total	7.6	1204.7	27.5

It is remarkable that the wind farm made the highest monthly record of a capacity factor of 53.2% in December 1994.

The government decided on guidelines for a new energy policy in December 1994, in which wind energy will be promoted up to 150 MW capacity by 2010.

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity

Installed capacity/number of machines over recent years is shown in Table 5.

Table 5. Installation of WTGS in Japan

Year	Installed Capacity kW	Total Capacity kW	Number of Installed Units	Total Number of Units
Before 1990	147.5	147.5	9	9
1990	633.0	780.5	5	14
1991	1625.0	2405.5	7	21
1992	533.0	2938.5	2	23
1993	1800.0	4738.5	9	32
1994	891.0	5629.5	7	39

2.2. Machine details

A list of WTGS in Japan is shown in Table 6 with machine data.

Table 6. List of Wind Turbine Generator Systems in Japan

Operation	Owner	Location	Machine	Rated Power kW	Rotor Dia. m	No. of Units	Purpose
1980-1985	MHI	Nagasaki	MHI	40	18.9	1	R&D
1982-1990	Kyushu EPC	Okinoerabu	MHI	300	33	1	R&D
1983-1986	SS/NEDO/ Tokyo EPC	Miyake Isl.	IHI	100	29	1	R&D (SS Project)
1985-1989	Tokyo EPC	Miyake Isl.	HMZ	80	25	1	R&D
1985-	MHI	Nagasaki	MHI	250	25	1	R&D
1987-	SS/MEL	Tsukuba	WINDMEL -I(Yamaha)	15	15	1	R&D (SS Project)
1988-1991	Tohoku EPC	Shiriyasaki	Yamaha	16.5	15	1	R&D
1989-	Suttsu-machi	Suttsu	Yamaha	16.5	15	5	Power Supply
1989-	Kansai EPC	Oeyama Miyazu	Sumitomo Seimitsu, etc.	10	7.5	2	R&D
1990-	Kyushu EPC	Koshiki Isl.	MHI	250	28	1	Demo

Table 6. List of Wind Turbine Generator Systems in Japan (Continued)

Operation	Owner	Location	Machine	Rated Power kW	Rotor Dia. m	No. of Units	Purpose
1990-	MHI	Nagasaki	MHI	250	28	1	R&D
1990-1991	Yamaha	Okinawa Isl.	Yamaha	100	30	1	R&D
1990-	NEDO/Kansai EPC	Rokkou Isl.	Yamaha	16.5	15	2	R&D
1990-	Seto-cho	Seto-cho	MHI	100	28	1	Demo
1991-	NSS/NEDO/ Okinawa EPC	Miyako Isl.	MHI	250	28	2	R&D (NSS Project)
1991-	Tohoku EPC	Tappi	MHI	275	28	5	Demo
(1991-)	NSS/NEDO	Tappi	MHI	500	28	1	R&D (NSS Project)
1991-	Chubu EPC	Hekinan	MHI	250	28	1	Demo
1992-	Izumo-shi	Izumo-shi	Yamaha	16.5	15	2	Power Supply
1993-	Tachikawa-machi	Tachikawa-machi	USW	100	18	3	Power Supply
1993-	Tokyo EPC	Futtsu	IHI	300	30	1	Demo
1993-	Matto-shi	Matto-shi	Micon	100	20	1	Demo
1993-	Hokkaido EPC	Tomari-mura	MHI	275	28	2	Demo
			IHI	300	30	1	Demo
			R.C.	250	33	1	Demo
1994-	Tohoku EPC	Onagawa	Yamaha	16.5	15	1	Demo
1994-	Hokuriko EPC	Mikuni-shi	Yamaha	16.5	15	1	Demo
		Shiga-machi	MHI	275	28	1	Demo
1994-	Shikoku EPC	Murotomisaki	MHI	300	29	1	Demo
1994-	Mikamo-mura	Mikamo	Yamaha	16.5	15	1	Demo
1994-	NSS/MEL	Tsukuba	WINDMEL -II(Yamaha)	16.5	15	1	R&D (NSS Project)
1994-	Kantoukoku-sai School	Katasuura	Micon	250/50	27.6	1	Power Supply

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

2.3. Performance

In Table 7, performance and operation data of active WTGS, excluding Research machines, are shown. The data in 1994 are incomplete (with symbol *). Total capacity is now 5.6 MW, and the wind generation in 1993 was 1988 MWh with 4.7 MW total capacity.

Table 7. Operation Data of WTG in Japan

Operation	Owner	Location	Capacity kW	Generation in FY 1993 MWH	Capacity Factor %	Avg. Wind Speed m/s
1989-	Suttsu-machi	Suttsu	82.5	91.2	12.6	3.4
1990-	Kyushu EPC	Koshiki Isl.	250	474.6	21.7	6.6
1991-	NSS/NEDO/	Miyako Isl.	500	1204.7	27.5	7.6
1991-	Tohoku EPC	Tappi	1375	2884.2	24.0	—
1991-	Chubu EPC	Hekinan	250	122.9	20.1	—
1992-	Izumo-shi	Izumo-shi	33	45.7	15.8	—
1993-	Tachikawa-machi	Tachikawa	300	240.7	9.2	5.2
1993-	Tokyo EPC	Futtsu	300	80.8	9.4	—
1993-	Matto-shi	Matto-shi	100	176.8	20.2	4.6
1993-	Hokkaido EPC	Tomari-mura	1100	1489.7	15.5	—
1994-	Hokuriku EPC	Mijuni-shi	16.5	9.3*	9.7	4.2
		Shiga-machi	275	43.2*	4.3	4.4
1994-	Kantoukokusai Schl.	Katsuura	250	26.9*	5.0	—
	Other R&D WTGS		797.5	—	—	—
Total			5629.5	6811.3		

2.4. Operational experience

There are not enough data to discuss the operational experience; however, it must be pointed out that siting is very important. If the performance, such as rated wind speed, is not fit for the wind characteristics, the operation data cannot be good.

3. CONSTRAINTS ON MARKET DEVELOPMENT

3.1. Environmental impact

Due to the fact that the history of wind farm development is very young so far, no significant environmental problems have occurred. At the Tappi wind farm, a complaint was heard, but it was solved by a sound-proof construction. At Hekinan, the WTGS stops its operation during the night.

At Tappi, no birds have been killed by the WTGS. The behavior of migratory birds was observed by Tohoku EPC to find that they are clever enough to recognize the rotating blades.

3.2. Institutional aspects

The most important changes in electricity regulations were made in 1992. Reverse current was permitted for the first time, which created the way of actual utilization of grid connected WTGS. The price of wind electricity is decided by negotiation between owner and electric power companies. On average, the price is approximately JPY 15-20/kWh.

4. ECONOMICS

4.1. Economics, financing and subsidies

Quantitative evaluation of the economics of wind generation in Japan is in an early stage, since only a few wind farms can provide available information. However, the list of economics and financing is shown in Table 8.

Table 8. List of Economics and Financing

Project	Total Invested Capital (MJPY)	Percentage of WTGS (%)	Cost per kW (MJPY/kW)	National Project/ Subsidy (MJPY)
Tappi Wind Park	1225.6	60.0	0.639	83.5
Miyako Wind Farm	443.8	81.7	0.825	485.2
Tachikawa Wind Farm	241.7	37.8	0.806	6.9
Izumo-shi Wind Farm	104.335	50.1	1.043	—

5. INDUSTRY

5.1. Market development

With the target of 150 MW capacity by 2010, MITI/NEDO, electric power companies, etc. continue to observe wind characteristics at many potential sites. A wind atlas is considered to be of great help in market development.

5.2. Manufacturing

The main information can be obtained from Tables 6 and 7.

6. INTERNATIONAL COLLABORATION

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

THE NETHERLANDS

1. NATIONAL PROGRAM

1.1. Statement of governmental aims and objectives for renewables/wind

Dutch energy policy is integrated with environmental policy and has been laid down by the Dutch government in the Environmental Policy Plan (Reference 1). Reducing CO_2 emissions is one of the key objectives. By the year 2000, emissions should have been reduced to the 1985 level. The Ministry of Economic Affairs has adopted a policy, laid down in the "Follow-up Policy Document on Energy Conservation" (Reference 2), which stimulates more efficient use of energy and the application of renewable energy. Eventually this should result in an overall efficiency improvement by 17% of the total national energy consumption.

Table 1. Objectives and Results for Renewable Energy-Avoided Emissions (Reference 3)

Renewable Energy	**Annual Savings on Fossil Fuels**			**Avoided Emissions**	
	Aimed Contribution		**Avoided Fuel**	**CO_2**	**NO_x/SO_2**
	[PJ]	[PJ]	[PJ]	[kton]	[10^6ae*]
	2000	2010	1992	1992	1992
Wind Energy	16	33	1,60	113	8,4
Solar Energy PV	1	2	0,01	1	0,1
Solar Energy Thermal	2	5	0,12	7	0,2
Hydro Power	1	3	1,08	76	5,6
Biomass (Incl. Waste)	54	60	20,05	1.187	0,5
Total	74	103	22,86	1.384	14,8

* Acid Equivalents

1.2. Strategy

Various approaches are being used in order to meet these objectives. The most important ones are:

- Introduction into the market of renewable energy technologies
- Agreement with the Electricity Boards, which have adopted their own environmental action schemes, financed by a special levy on energy rates
- Long-term agreements with sectors of industry on reducing the intensity of energy use
- Development of new technologies.

Within the European Union, the Dutch government is a keen advocate of an "eco tax." Recently, the government has announced that if the European Union does not introduce such a tax in the short term, the Netherlands will do so on a national level by January 1, 1996.

1.3. National target for wind energy

The national target for wind energy aims at an annual saving on fossil fuel of 17 PJ in the year 2000 and 33 PJ in the year 2010. To achieve this, an estimated 1,000 MW of wind power is needed by the year 2000, and 2,000 MW by the year 2010.

1.4. National market stimulation instruments

In order to meet the wind energy objectives, the Netherlands Agency for Energy and the Environment (NOVEM), commissioned by the Ministry of Economic Affairs, is carrying out a national program known as "Application of Wind Energy in the Netherlands" (TWIN). The program focuses on the development of technologies, product development, and the installation of wind turbines.

To stimulate the installation of wind turbines, NOVEM has carried out an investment subsidy program since 1986. Levels of subsidies have varied through the years. The basis for the subsidies has ranged from capacity (kW) to physical size, type of investor, etc. In 1995, the subsidy will be equal to NLG 260 per m^2 swept rotor area up to a maximum of 35% of the investment costs.

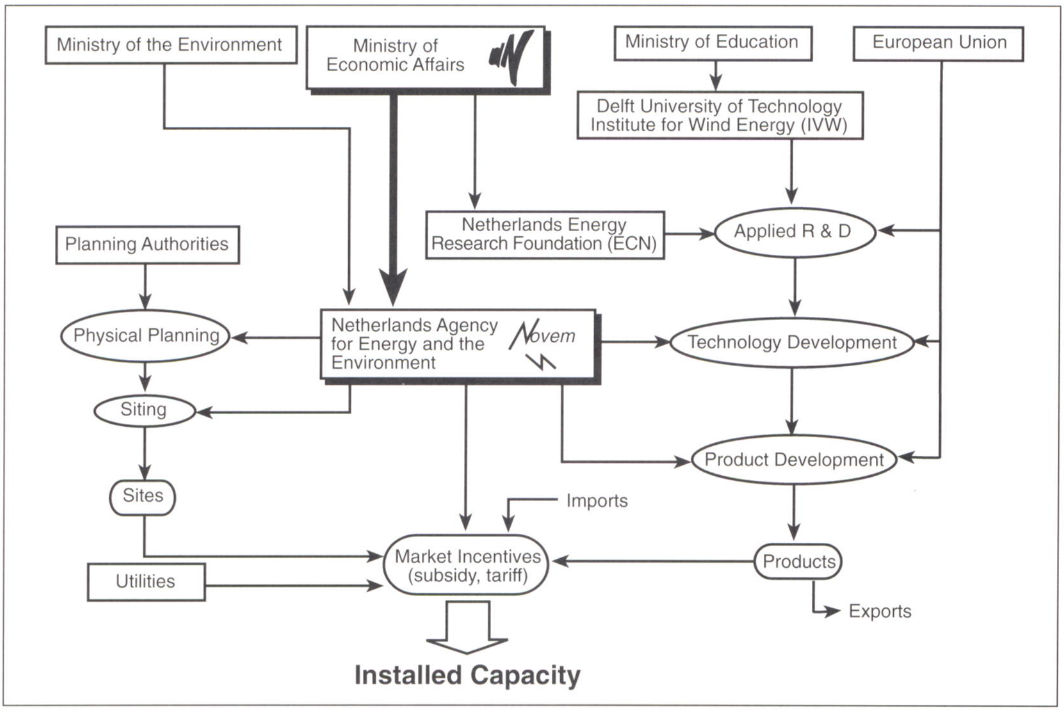

Figure 1. Structure of the national program for wind energy

Table 2. Average Annual Government Budgets for Wind Energy Development During the Period 1991-1995 (5 years) in NLG Million

	1991	1992	1993	1994	1995	Total
Investment Subsidies	40,0	42,0	45,5	35,0	35,0	197,5
Market Development	1,5	1,7	1,1	1,1	0,7	6,1
Product Development	4,0	3,6	3,5	3,5	3,3	17,8
Technological Development	3,0	3,4	3,0	3,0	2,4	14,8
Long Term Market Development	0,1	0,2	0,4	0,3	0,2	1,2
Dissemination of Know How	0,4	0,5	0,3	0,3	0,5	2,0
Total TWIN Programme	49,0	51,4	53,8	43,1	42,0	239,3
Applied R&D (ECN)	2,5	2,5	3,0	3,0	3,0	14,0
R&D Universities (est.)	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	2,2
Total	54,1	56,5	59,4	48,5	47,0	265,5

1.5. Level of direct support for R&D and promotion

Apart from the National program implemented by NOVEM, the Ministry of Economic Affairs directly finances applied research at some of the large technological institutions, of which the Netherlands Energy Research Centre (ECN) is the most important. The Ministry of Education is financing more specialized degree courses at universities, in particular the Institute for Wind Energy (IVW) at the Technical University of Delft (TUD). The TUD is carrying out basic research in wind energy. The basic and applied research is coordinated with the TWIN program, so that the results are most effectively linked up with the technology development.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed capacity

- The total installed capacity of wind turbines per December 31, 1994, was 153,947 kW, consisting of 729 machines.
- The installed capacity in 1994 was 22 MW, consisting of 93 machines.
- National capacity in 1994 was about 13,000 MW. Total installed capacity of wind turbines is 153 MW, which is 1.2% of the national capacity.

2.2. Machine details

Data on size and power of turbine installed in 1994 are not yet available.

With regard to the numbers of machines installed during all years as function of size and power, in October 1994, this involved approximately 700 turbines, of which 63% (120 MW) is installed in wind farms. The classification of the turbines is shown in Tables 3, 4, and 5.

Data on country of origin turbines installed in 1994 is not yet available.

2.3. Performance

- Total output over all years is given in Table 3. The grand total for 1986 to 1994 is 759 GWh.
- Annual production during in 1994 was 247 GWh.
- Annual production of national electricity usage in 1993 was 70,740 GWh.
- Availability during 1994 was more than 95%.

2.4. Operational experience

A study has been carried out in order to take an inventory of the weak grid structure in the province of Friesland and the effects on future installed capacity. Final results are not yet available.

There are no problems concerning grid effects.

Table 3. Installed Capacity, Swept Area, Number of Turbines, and Electricity Production for 1986-1994 (Reference 4)

Wind Energy	Installed Capacity		Swept Area		No. of Turbines		Electricity Production	
Year per 31-12	**Total [MW]**	**Increase [MW]**	**Total [m²]**	**Increase [m²]**	**Total [-]**	**Increase [-]**	**Total [GWh]**	**Increase [GWh]**
1986	7	0			138	0	7	0
1987	16	9			168	30	16	9
1988	22	6			223	55	26	10
1989	33	11			255	32	26	0
1990	49	16			318	63	55	29
1991	82	33			426	108	72	17
1992	105	23			510	84	145	73
1993	132	27			636	126	165	20
1994	154	22	298.784		729	93	247	82

Table 4. Wind Turbine Classification (Reference 5)

Power Classes (kW)	Rotor Diameter (m)	Total Number	Total Capacity (kW)	Total Rotor Area (m^2)
≤ 100	≤ 18	267	20,825	60,984
100 - 200	20	34	5,455	10,681
200 - 300	20 - 30	170	42,375	85,567
300 - 400	25 - 35	87	26,130	43,335
400 - 500	33	12	4,800	10,264
≥ 500	35 - 50	90	45,750	94,667

Table 5. Windex, Specific Production, and Capacity Factors for 1988-1994 (Reference 6)

Year	Windex	Specific Production	Working Time Maximum	Capacity Factor
per 31-12	[%]	[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	n.a.	n.a.

3. INDUSTRY

3.1. Market development

Types of owners/operators of wind turbines:

- Utilities
- Public private partnerships, e.g., limited company or incorporation with utility, developer, and bank
- Industries, e.g., industry in windy areas with a large electricity consumption
- Farmers who join forces in limited companies or partnerships to operate wind turbines on their land
- Cooperatives in which individuals, farmers, local city councils, and building societies take a share in one or more wind turbines
- Associations.

In 1993 and 1994, the following new developers were entering the market:

- Limited companies of developers with wind turbine manufacturer
- Limited companies of foreign wind turbine manufacturers together with distribution utilities.

3.2. Manufacturing

Status of manufacturing industry:

- Annual production/sales/exports per country: no data are available and/or are confidential.
- New products/development:
  - Lagerwey has certified its 27 m/250 kW turbine.
  - NedWind has certified its 55 m/1000 kW turbine.
  - WindMaster has erected its 43 m/750 kW turbine and started certification. Engineering is almost finished on the Lagerwey 43 m/750 kW turbine with variable speed, direct drive, and three blades; the prototype will be built in 1995.
  - NedWind plans to build a prototype of the NedWind 30 m/250 kW and the Nedwind 43 m/500 kW.

3.3. Other industries

Development in support industries:

- Aerpac as a supplier of blades is expanding rapidly and produces blades for Enercon, Micon. The development of a new blade for a MW machine is started. In 1995 they will move to new facilities.
- KEMA, the research institute of the utilities, has started consultancy work to develop wind farms for a foreign utility.

4. CONSTRAINTS ON MARKET DEVELOPMENT

4.1. Environmental impact

In a recent hearing, plans were presented to integrate 200 MW of wind energy in the province of Friesland. Groups concerned about the conservation of the landscape were opposing the presented plan on grounds of visual intrusion. Environmentalists in general were in favor.

In a study on the effect on bird life concluded in 1991, it was shown that wind turbines have less effect on birds than major motor ways and high tension lines. Nevertheless, in 1995, new studies will be carried out, with radar observation, at locations were new wind turbines will be erected in bird migratory areas.

4.2. Institutional aspects

Local plans/planning policies

In the province of Friesland, a MER (Environmental Effect Report) was made by the provincial authorities to establish the effect of accommodating 200 MW of wind energy. Two or three alternatives were selected. These are now being discussed in hearings on a local level.

Public attitudes

The public attitude towards wind energy in the Netherlands in general is still positive.

Certification

To be eligible for subsidy in 1995, wind turbines need to be certified according to NEN 6996/2.

5. ECONOMICS

5.1. Value

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.

Invested capital during 1994, assuming the same per kW, and an installed capacity of 22 MW, is NLG 53 million.

The value of total wind generated electricity during 1986-1994 at 759 GWh and an average pay back rate of NLG 0.12 was NLG 91.1 million.

The value of wind generated electricity during 1994 at 247 GWh and an average pay back rate of NLG 0.12 was NLG 29.6 million.

5.2. Subsidies

Total subsidy for the period 1986-1993 was NLG 126 million for 132 MW.

5.3. Trends/estimates in development costs

At the end of 1993, the average project cost was NLG 2,425 per installed kW, or about NLG 1,000 per m^2. Turbine costs were about 70% of project costs.

At the end of 1994, the cost of a machine of 500 kW and a rotor diameter of 41.3m was NLG 850,000, which amounts to NLG 1,700 per kW or NLG 635 per m^2.

Development of generating costs during past years is given in Table 6. These costs are calculated according to a uniform method based on collected data from the Dutch wind turbine database. All costs are based on averages and consist of machine costs and yearly expenditure for maintenance and insurance. Depreciation period is 15 years, availability is 98%, inflation 2.5%, and interest rate corrected for inflation is 5%. The energy output is corrected to the long year average.

Table 6. Development of kWh Price 1987-1993 (Reference 7)

Year	Solitary [NLG/kWh]	Farm [NLG/kWh]
1987	0,166	0,250
1988	0,162	0,225
1989	0,157	0,207
1990	0,152	0,194
1991	0,148	0,184
1992	0,145	0,174
1993	0,142	0,167
1994	n.a.	n.a.

Solitary at Vhub = 6 m/s

Farm at Vhub = 7 m/s

The decrease in generating costs is due to a decrease in investment costs, improved production methods, and the effects of the "economy of scale." 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.

5.4. Benefits

Employment per sector:

- Manufacturing, maintenance, sales ≈ 300
- Civil and electrotechnical infrastructure ≈ 100
- R&D and engineering consultants ≈ 50
- Project development and financing ≈ 30
- Government policy and program ≈ 20.

Avoided emissions, replaced fuels

In 1993, wind energy produced 165 GWh, thereby saving 171 Mm^3 of natural gas and avoiding the emission of 109k tons of CO_2, 155 tons of NO_x, 30 tons of SO_2, and 4 tons of dust.

The estimated production for 1994 of 247 GWh thus saved an estimate of 256 Mm^3 of natural gas and avoided the emission of 160k tons of CO_2, 232 tons of NO_x, 44 tons of SO_2, and 6 tons of dust.

6. FINANCING

6.1. Type of funding available

Generally two types of funding can be discerned. The first is funding in which the turbine is considered part of the normal management of a company. The willingness of the financier does not depend on the project with the wind turbine, but on the liquidity and reputation of the builder. This type of funding is found with utilities and companies that operate one turbine for their own supply of energy.

Secondly, there is project funding in which the financier primarily establishes the rentability and the risk profile of a project. This type of funding is used by private developers and Public-Private Partnerships (PPPs).

Utilities primarily use public funds. Farmers, small companies, developers, and PPPs use a mixture of private and bank funds. Sometimes two banks are involved: one that finances the first part of the investment and one that takes the risky top of the investment (this is usually a "green" bank).

6.2. Typical financial interest rates

Interest rates depend on the way capital is secured. Farmers increase their mortgage with banks, with security as the farm, the equipment, etc. Interest rates of 7%-9% are typical. In the case where the wind turbine or wind farm is the security, e.g., in the case of private developers, interest rates of around 10% are normal. Utilities usually use public funds and long depreciation times (20-30 years), and calculate with interest rates of 5%.

A new feature is the establishment of so called "green funds." Such funds, when recognized by the Ministry of Finance, can invest in green projects. At least 70% of the investment portfolio must consist of green projects. Profits from these funds are exempted from income tax. The estimated effect is a reduction of interest rates of 2%.

6.3. Certification requirements

These are covered under the subsidy scheme and are usually acceptable for banks. Sometimes additional requirements are asked for special customers or projects.

6.4. Operating costs

These consist mainly of the capital costs of a project. On top of that there are costs for maintenance, operation, and insurance. On the average, they are 1.5% of the investment.

6.5. Warranties

Warranties can be required in several ways. Sometimes a warranty is asked on the PV curve. In other cases, a warranty is asked for the amount of electricity delivered to the grid. Also, some investors demand warranties on specific components, e.g., blades, gearbox, and generator.

7. RESEARCH AND DEVELOPMENT

7.1. R&D priorities, focal points of R&D programs

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

- Reduction in noise emission, through design and testing of silent rotor blades with serrated trailing edges
- Rotor aerodynamics, especially dynamic and 3D-effects
- Inventory of extreme wind conditions from existing wind data
- Safety and reliability analyses
- Standards and certification
- Materials and construction
- Components, whereby flexible components take up a special place.

7.2. Direct government R&D funds versus invested capital (total and past year)

From Table 2 it can be derived that allocated funds for all RD&D during 1991-1994 was NLG 56 million. Total invested capital during 1991-1994 was NLG 373 million.

7.3. New concepts under development

As a follow-up of the Flexhat research, design and testing continued in 1994. In 1995, design will be concluded and a prototype will be built.

All Dutch wind turbine manufacturers are investigating the direct-drive concept. Lagerwey plans to build a prototype in 1995.

7.4. MW-size turbines under development

In 1995, the second NedWind 55 m, 1 MW wind turbine will be built.

7.5. Offshore

It is not yet clear how much wind capacity in the Netherlands can be realized at what are now regarded as traditional sites, but there is a saturation point. Possibilities for non-traditional sites (e.g., offshore) are being surveyed in order to meet further demand for wind capacity in the longer term.

In a first project at a non-traditional site, four NedWind 40 m, 500 kW turbines have recently been installed in the IJsselmeer (an inland lake).

8. INTERNATIONAL COLLABORATION

With regard to involvement in collaborative programs in terms of projects/funding, NOVEM and ECN are co-financing numerous research projects of the European Union. The Netherlands are participating in IEA Annex XIV, Field Rotor Aerodynamics.

9. REFERENCES

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NORWAY

1. NATIONAL PROGRAMS

In January 1994, the separate R&D programs on wind, bio, solar, and wave energy were merged together into one R&D program on new and renewable sources of energy. The new program is managed by the Research Council of Norway (NFR). The Norwegian Water Resources and Energy Administration (NVE), which formerly managed the wind energy RD&D program, participates in the Executive Committee of the new program. NVE is, in addition, responsible for an introduction program on energy effective technologies, which includes technologies for new and renewable sources of energy.

The new R&D program is divided into two main areas:

- Product development in the renewable energy sectors
- Research as a basis for industrial undertakings in these sectors.

The program will mainly focus on product development for the market. It is the trade and manufacturing industries that are responsible for submitting applications and running the 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 frame for the program in 1994 was NOK 30 million (about USD 4.2 million), with a government support of NOK 20 million (USD 2.8 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%. A government subsidy of up to 50% is also available from NVE for running activities under the market introduction program in order to promote the implementation of new and energy effective technologies.

Only a minor part of the R&D budget, about NOK 600,000, has been assigned to the wind energy sector in 1994. On the other hand, the completion of some wind energy development projects under the former RD&D program have maintained some R&D activities during the past year.

2. COMMERCIAL IMPLEMENTATION OF 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.

Table 1. Wind Turbines and Output

Wind Turbines, Power Rating (kW)		Year of Commissioning	Production 1994 (GWh)	Total Output Over All Years (GWh)
Frøya	1x 55	1986	0.108	1.059
"	1 x 400	1989	0.848	3.673
Valler-sund	1 x 75	1987	0.169	1.387
Kleppe	1 x 55	1988	0.048	0.218
Smøla	1 x 300	1989	0.587	2.884
Andøya	1 x 400	1991	0.989	3.338
Vester-ålen	1 x 400	1991	1.156	3.755
Vikna	(3 x 400	1991		
"	2 x 500)	1993	6.256	16.133
SUM 3,885 kW			10.2	32.4

The wind turbines are installed as single units, except for five units installed in a wind farm (2.2 MW) at Vikna, northwest of Trondheim. They are all connected to the grid system.

Ten of the wind turbines are owned by power companies. These have been installed with the help of about a 50% investment subsidy from the former wind energy program. The two others are privately financed and owned. No new wind turbines have been installed during the past year.

Hydro power is the dominating form of energy production in Norway and provides more than 99% of the energy for electricity supply in a normal year, with an installed capacity of about 27,200 MW. The installed wind turbine capacity accordingly represents only a minor part of the total capacity demand.

The wind turbines have yielded an output of about 32.4 GWh over the operating years. The production during 1994 (about 9.1 GWh) represents only a minor part of the average national electricity consumption of 112 TWh/year.

The wind farm at Vikna (2.2MW) (see Figure 1) yielded during the past year an energy output of about 6.3 GWh, corresponding to 1,195 kWh/m^2 rotor area. This output was attained at an average wind speed of 7.2 m/sec, a capacity factor of 0.325, and an average technical availability at the wind farm of 96.6%.

The wind turbines at Vikna are situated on a mountain ridge, which towers 80-90 m above sea level. The energy produced is delivered for local supply.

Most of the failures and troubles that have occurred with the wind turbines are due to the control system, damage by lightning, or component defects.

Figure 1. View of the wind farm at Vikna

The lightning activities in the areas along the Norwegian west coast may be quite high. An analysis of the lightning problems in connection with the operation of wind turbines was carried out in 1994, resulting in recommendations on how to protect the wind turbines against damage by lightning. The analysis, carried out by TransiNor Technology A/S, gives a description of the problem together with recommendations and proposals for improvements.

Studies of the integration of wind energy into the existing supply system show that wind energy may be economically acceptable in certain coastal areas with favorable wind conditions and high power values. It is also quite obvious that the Norwegian hydropower system can integrate a substantial amount of wind energy without particular problems.

Extended and often weak distribution grids along the West coast may give considerable marginal losses in heavy load periods if power is supplied from the central production system. In such cases it may be possible to save energy losses if wind turbines are installed at the end of the grid system.

3. 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. In this situation, only a few industrial companies are deeply involved in R&D projects on wind energy, except for the wind/diesel system.

A second generation wind/diesel system was installed at the test station at Frøya in 1993. The new system (55 kW wind turbine and a 50 kW diesel engine from the former plant) has a forced commutated converter with a battery storage. It has a control system developed in cooperation between the Norwegian Electric Power Research Institute (EFI) and ABB Energi A/S as the industrial partner. The Sør-Trøndelag Kraftselskap (S-TK) power company is the operating manager of the plant.

Preliminary testing of the new wind/diesel system in 1993 disclosed some voltage problems (flickering). The problems are, however, solved and the whole system is now operating very satisfactorily. A program for testing the new wind/diesel system against consumer load is in progress. The plant is serving an autonomous grid with approximately 10 domestic consumers. The testing period is supposed to be finished in March 1995. After this test period, the concept will be available on the market.

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. It was concluded that there is a potential to design blades which are structurally improved compared to the blades currently in use.

4. CONSTRAINTS ON MARKET DEVELOPMENT

The home market for exploitation of wind energy will be quite limited as long as new hydropower plants, on an average, are able to generate electricity at about half the cost of wind energy in places with favorable wind conditions. The main challenge in the R&D program will therefore be to lower the production cost of wind energy and make it a cost-effective source of energy contribution.

The prevailing transmission tariff system represents another barrier which has to be overcome. This system does not take into account the difference in geographical localization of the power production systems. As wind turbines usually are located close to the consumers, they should be credited with a lower transmission cost. If a wind energy market is to be developed, it may be necessary to establish separate transmission tariffs for the small and local energy production systems. This is looked upon by NVE.

5. ECONOMICS

The total invested capital in the Norwegian wind turbine systems may be estimated at about NOK 42 million. No capital investment has been made during the past year. The value of the total wind-generated electricity may be estimated at about NOK 6.5 million. The value of the wind-generated electricity during the past year may be estimated at about NOK 1.8 million. The average generating cost in the hydropower system has been used as a reference for this calculation.

The cost of electricity from the Norwegian wind turbine systems may be estimated at NOK 0.35-0.45/kWh, dependent on the wind regime and the local conditions. In addition to these costs come the grid transmission cost, taxes, and levies.

It may be difficult to indicate savings in pollution or other environmental advantages with the use of wind energy in a hydropower-dominated energy system. Nevertheless, fuel oil is also used for heating purposes in the Norwegian energy system. If the energy output from the wind turbines is used to substitute fuel oil for room heating (energy efficiency 0.80), it may be estimated to save approximately 950 TOE/year (0.105 kg fuel oil/kWh utilized).

6. FINANCING

The former RD&D program offered a 50% subsidy on the investment cost to stimulate the interest in the exploitation of wind energy. The intention in the new R&D program is to offer subsidies only to stimulate the development of new and energy-effective technologies, and under certain conditions, to stimulate the market introduction processes.

No general financial support scheme is, for the moment, 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.

7. RESEARCH AND DEVELOPMENT

The new R&D program for wind energy tries to influence industrial companies to take an interest in wind energy in order to make commercial wind turbines more reliable and safe in a harsh climate. In particular, industry is 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.

The approved development projects will be run by the manufacturing industries. Research as a basis for industrial undertakings are run by universities and institutes in collaboration with industry.

The total governmental budget for R&D on new renewable sources of energy is around NOK 10 million (US$ 1.4 million) in 1995.

8. 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 EU and IEA R&D projects).

The Norwegian Institute for Energy Technology (IFE) has since autumn 1993 been involved in the Joule II program, "Wind Measurements and Modeling in Complex Terrain."

SPAIN

1. NATIONAL PROGRAM

The technological development and progressive utilization of renewable energy sources in Spain have been supported by the Spanish government through the preparation of National Plans with specific targets laid down in each area.

In 1991, the Spanish government approved a new National Energy Plan (PEN), which included the 1991-2000 Energy Saving and Efficiency Plan (P.A.E.E.). In the wind energy area, emphasis is being placed on projects in the areas of Spain with considerable potential through the installation of wind farms connected to the electricity grid. Priority is also being given to the technological development and manufacturing of Spanish wind turbines. The targets for wind energy were set at 168 MW for the year 2000, with an energy production of 403 GWh/year, which implies a total investment of 180 millions ECU and Public Funds of 78 million ECU. This goal of 168 MW for the year 2000 is going to be widely exceeded and will reach that amount already in 1995, according to the already confirmed projects to be built during this year. This gives an idea of the current high level of wind energy market activity in Spain. Information regarding new installations is continuously provided by national and international manufacturers and promoters.

1.1. Research and development projects

The main R&D organization in the field of wind energy in Spain is the Instituto de Energías Renovables of CIEMAT. They are involved in several projects:

BLADE DEVELOPMENT AND TESTING

- Design and manufacturing of blades for a wind turbine of medium size.

  Design and manufacturing of the blades for a new prototype of MADE, model AE-41, with 500 kW of rated power and 41 m diameter. This prototype, developed by ENDESA with the support of OCIDE, foresees the mass production of blades and plans to incorporate a company.

- SFAT Project.

  SFAT is a JOULE project of the EU, in collaboration with other European institutes, with the purpose of elaborating recommendations for blade testing of wind turbines to establish criteria for testing proceedings.

- Blades Static Testing of 300 kW wind turbines.

  The Wind Division has carried out static testing of the first 15 m blade prototype to be installed in a new machine of 300 kW rated power. This turbine, called "DESA 300," is being developed by Desarrollos Eólicos Company. The testing was carried out with the application of preplanned load cases ending with the breakage of the tested blade. Studies on fatigue testing of similar blades are planned.

WIND TURBINE TESTING

- AWEC-60 project.

  CIEMAT is the subcontractor to Unión Fenosa in the following JOULE projects:

  - WEGA Follow-up
  - WEGA Design Review.

  Two Spanish manufacturers (MADE and ECOTECNIA) are participating in the second project to incorporate their design criteria in the MW range wind turbines.

- Power curve verification in the Cabo Villano wind park.

  At the request of MADE and according to the international recommendations, measurements of the power curve in the Cabo Villano wind park and in one machine of 150 kW (MADE AE-20) have been carried out.

- Measurement of the MADE AE-23 wind turbine.

  The 300 kW prototype, made by MADE and installed in Granadilla (Tenerife), was monitored. In this first prototype, measurements of power, loads on the machine, noise, and quality of the energy generated have been analyzed in accordance with the recommendations of the International Energy Agency. A complete evaluation and modifications of the machine needed for commercial development were carried out.

- Study of vibrations in wind turbines for failure prediction.

  A study of wind turbines (150 and 300 kW) in order to predict failures in their components is planned.

- MONTURB Project.

  This project is integrated in the JOULE II program. The objective is to carry out measurements and an evaluation of loads on wind turbines operating in mountainous areas. Two MADE-300 kW wind turbines located in Tarifa (complex terrain) and Fuerteventura (flat terrain) will be analyzed in this project.

DESIGN AND MODELING OF COMPONENTS

- Refstress Project.

  The objective of this JOULE project of the EU is to obtain a fatigue model for wind turbines. The project has been carried out through comparison of programs used in different European institutes and the quantification of effects that can have influence on the fatigue life of the components in the wind turbines.

- DESA-300 wind turbine performance analysis.

  Performance analysis and extreme loads, along with theoretical power curve valuation, pitch variation, aerodynamic design verification, and initial valuation of loads, have been studied.

- MADE 300 modeling.

  Using a MADE design, a complete modeling of the aerogenerator with the components fatigue study has been carried out.

HARMONIZATION OF STANDARDS

- EWTS project.

  This is a JOULE program. The objective is to make a revision of the different standards and recommendations (nationals, IEA, IEC, certification institutes) to prepare a European common standard to apply to wind energy.

EUROPEAN DATABASE

- Eurowin project.

  The Wind Division participating in this database collected the information on Spanish wind farms.

WIND RESOURCE ASSESSMENT

- Wind measurement and modeling in complex terrain, in order to estimate the site climatology and the model performances.
- Site selection for wind farms.

  Several projects have been contracted by utilities, wind farm promoters, and regional authorities. Sites with a capacity of installing several hundreds of megawatts have been evaluated.
- Inventory of wind farm sites and elaboration of wind resource maps.

1.2. Demonstration projects

Inside the framework of the THERMIE program, several projects have been developed in Spain:

- Installation of 3.9 MW wind farm in the district of Baix Ebre, in the Cataluña region
- Installation of a 6 MW wind farm at Cortijo de la Joya
- Development of a ECOTECNIA 500 kW wind turbine.

Since 1989, CIEMAT has been working together with the Universidad Politecnica de las Palmas on the Wind-Diesel plant at Pájara (Fuerteventura - Canary Islands). This autonomous system, with a 225 kW wind turbine and two 60 HP diesel engines, is financed by EU through the VALOREN program.

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity

The best wind potential areas are located in the Canary Islands, the Strait of Gibraltar, and Galicia, with the highest concentration of projects. Other regions

(Arágon, Cataluña, Navarra) are also making a good use of their interesting wind conditions and have carried out several projects.

The power range of wind farms installed in Spain usually exceeds 1 MW, with a machine range from 100 to 500 kW unit nominal power. The regional distribution presents 4.86 MW installed in Galicia, 0.59 MW in Cataluña, 3 MW in Navarra, 3.85 MW in Aragón, 24.48 MW in the Canary Islands, and 33.09 MW in the Strait of Gibraltar. The Strait of Gibraltar continues to have the highest concentration of wind turbines in Spain, with 266 machines, followed by the Canary Islands with 130 wind turbines. Galicia, with 35 turbines installed, is the most dynamic area at this moment; it is the Spanish region with the largest number of projects in the planning state for the year 1995.

The total power installed in 1994 was 72.5 MW. It is foreseen for the end of 1995 that a total power of 194 MW will be installed.

The following graph (Figure 1) presents the wind power evolution in Spain during the last years.

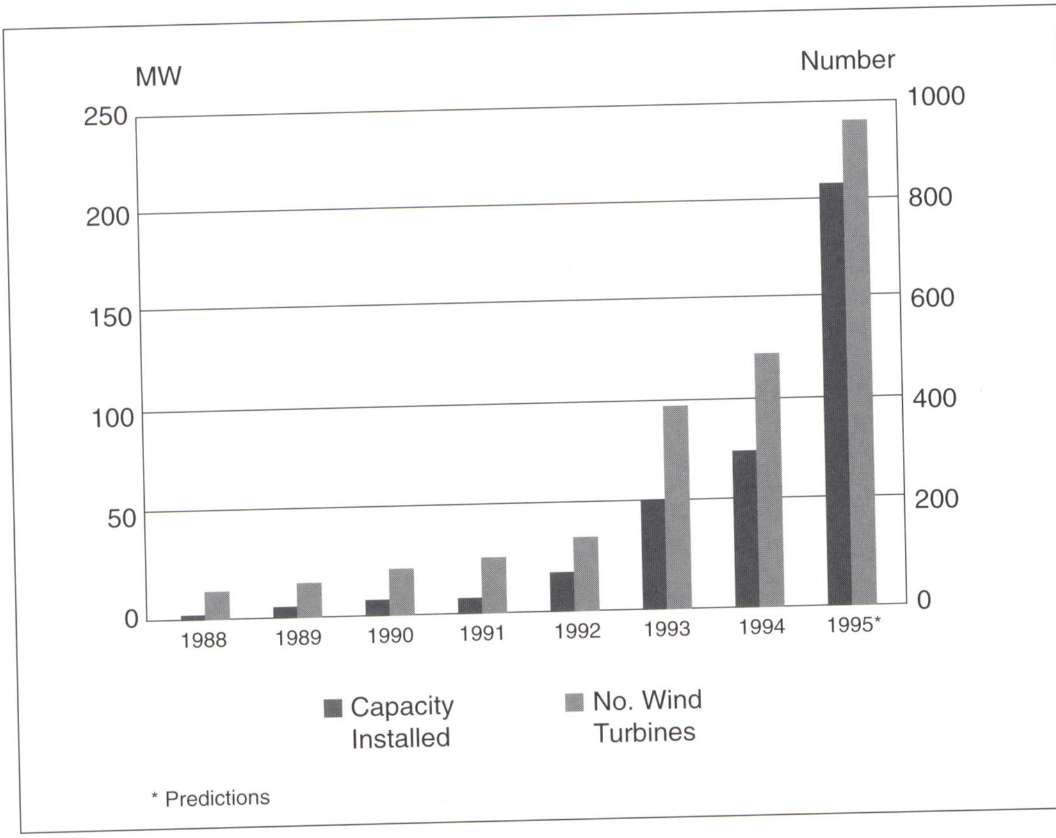
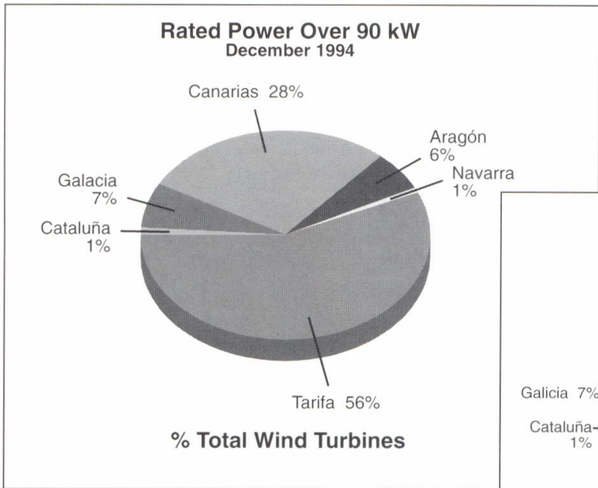


Figure 1. Capacity power evolution in Spain

2.2 Machine details

The following graphs (Figures 2 and 3) show the regional and manufacturers' distribution.



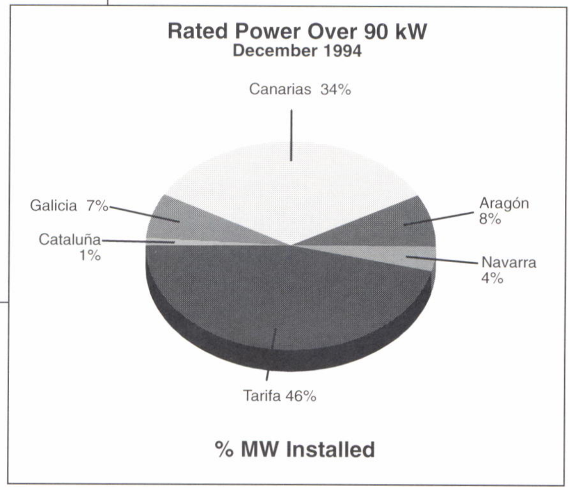
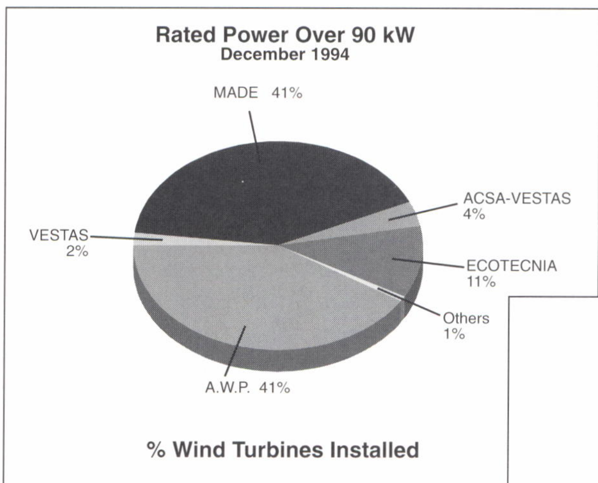


Figure 2. Areas of wind power installation



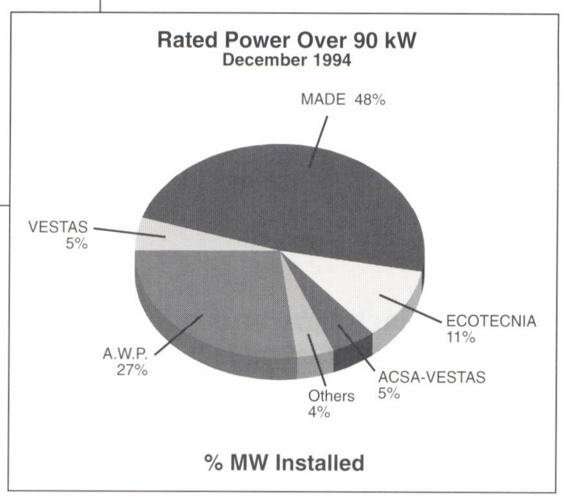


Figure 3. Wind turbines installed in Spain

The power of wind turbines to be installed in Spain in the next years ranges from 200 to 500 kW (VESTAS V27-225 kW, DESA 300 kW, MADE AE-30 300 kW, VESTAS V39 500 kW, and ECOTECNIA 24/200 kW).

A brief description of the wind turbines installed in Spain is shown in the following table (Table 1).

2.3. Performance and operational experience

The progressive increase of the total power installed, together with the maturity reached in Spain, is reflected in the wind energy produced in the past years. During 1992, 4,908 MWh were generated, an amount exceeded in 1993 with 35,000 MWh, and with 116,800 MWh produced from January to October 1994.

The excellent results obtained in wind farms in Spain during 1993 are shown in the following table (Table 2).

More than the 70% of the total wind turbines installed in Spain have been operating with a capacity factor above 0.25, and 13% of the machines have been operating with a capacity factor higher than 0.35.

The experience of operating during the last year shows the monthly variation of the capacity factor in the different wind areas in Spain. The Canary Islands graphic (Figure 4) shows clearly a higher energy production, exceeding a 0.6 capacity factor in July, during summer due to the increased action of "trade winds" which blow in the islands during this period, Galicia and Tarifa shows more uniform seasonal distribution. Tarifa (Figure 5) performed exceptionally well during February 1993 with a capacity factor of 0.5. Galicia (Figure 6) shows lower monthly values.

3. SUBSIDIES

In 1994, the Spanish government approved a new Energy Saving and Efficiency Plan regulating the subsidies for the renewable energy installations. For wind projects, three different categories are defined: innovative projects, demonstration projects and commercial projects. The maximum subsidy varies from 26% of the eligible cost for commercial projects up to 49% of the eligible cost for innovative projects, and a maximum of 35% of the eligible cost for demonstration projects.

The average value of the kWh paid by the utilities during 1994 was ESP 10.47 (USD 0.08/kWh).

4. INDUSTRY

4.1. Manufacturing and other industries

There are several manufacturers of wind turbines in Spain.

The public utility ENDESA is engaged in major wind energy projects through its subsidiary manufacturing company MADE. MADE has developed several models of wind turbines, the MADE AE-20 (150 kW), the MADE AE-23 (180 kW), and the

Table 1. Wind Turbines Installed in Spain

Manufacturer	Desarrollos Eolicos		ECOTECNIA		MADE			VESTAS	
Model	AWP 56	DESA 300	20/150	24/200	AE-20	AE-23	AE-30	V 27 (1)	V 39 (2)
Rated Power (kW)	100	300	150	200	150	180	330	225	500
Diameter (m)	18	30	20	24	20	23	30	27	39
Blades	3	3	3	3	3	3	3	3	3
Power Control	Pitch Down Wind	Pitch	Stall	Stall	Stall	Stall	Stall	Pitch	Pitch
V Cut-in (m/s)	5	5	4	4	4	4	5	3.5	4
Rated Wind Speed (m/s)	12	12	14.5	15	14	14	14	13.5	15
V Cut-off (m/s)	20	15	25	25	25	28	25	25	25
Hub Height (m)	19	30	25	29	29	29	30	30	40
No. Turbines Installed	197	1	52	1	63	62	37	15	6

(1) Supply by Aerogeneradores Canarios

(2) Installed by Gamesa Eólica

Table 2. 1993 Production in Wind Energy

Wind Farm	Rated Power (kw)	kWh/m^2 1993 Average Wind Stats	kWh/m^2 1993 Average Wind Farm	Capacity Factor 1993 Average Wind Stats	Capacity Factor 1993 Average Wind Farm
ARINAGA	90	736.75	927.90	0.26	0.33
CABO VILLANO	100	692.91	857.84	0.25	0.31
	200	791.24	1066.26	0.23	0.30
	180	855.46	842.52	0.23	0.20
GRANADILLA	150 MADE	776.28	981.28	0.27	0.23
	150 ECOTEC.	776.28	1037.53	0.27	0.27
	200	791.24	1220.88	0.22	0.34
	330	n.a.	1097.68	n.a.	0.32
	300 MADE	815.71	896.73	0.24	0.18
MONTAÑA MINA	225	1036.37	1419.0	0.30	0.41
PUNTA TENEFE	225	1036.37	1546.71	0.30	0.44
CAÑADA DE LA BARCA	225	1036.37	982.31	0.30	0.28
EEE	150	776.28	1436.6	0.27	0.34

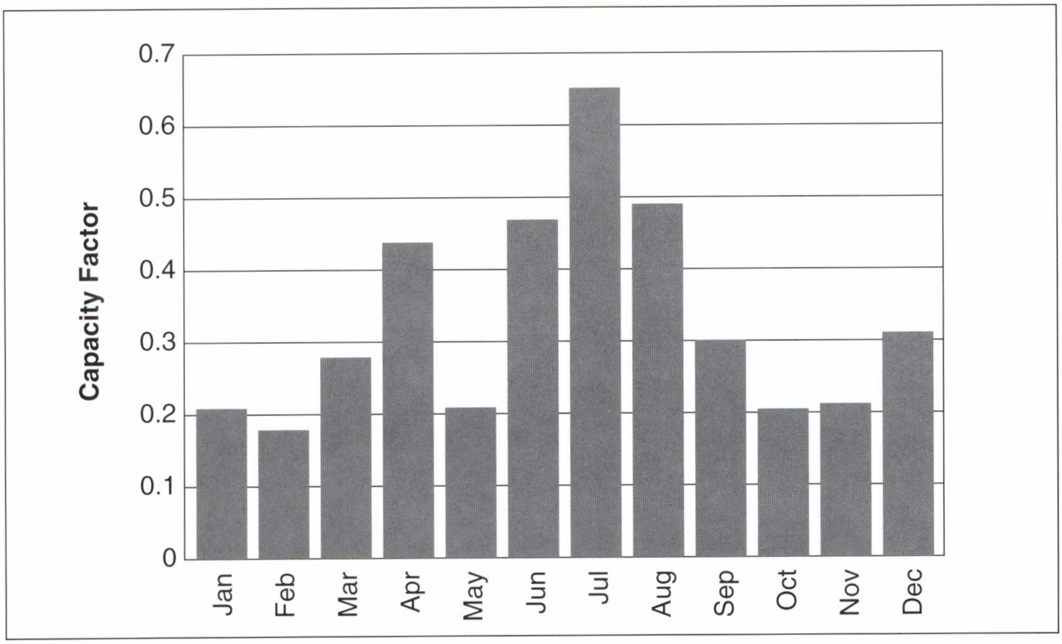


Figure 4. Canarias monthly capacity factor for wind regions

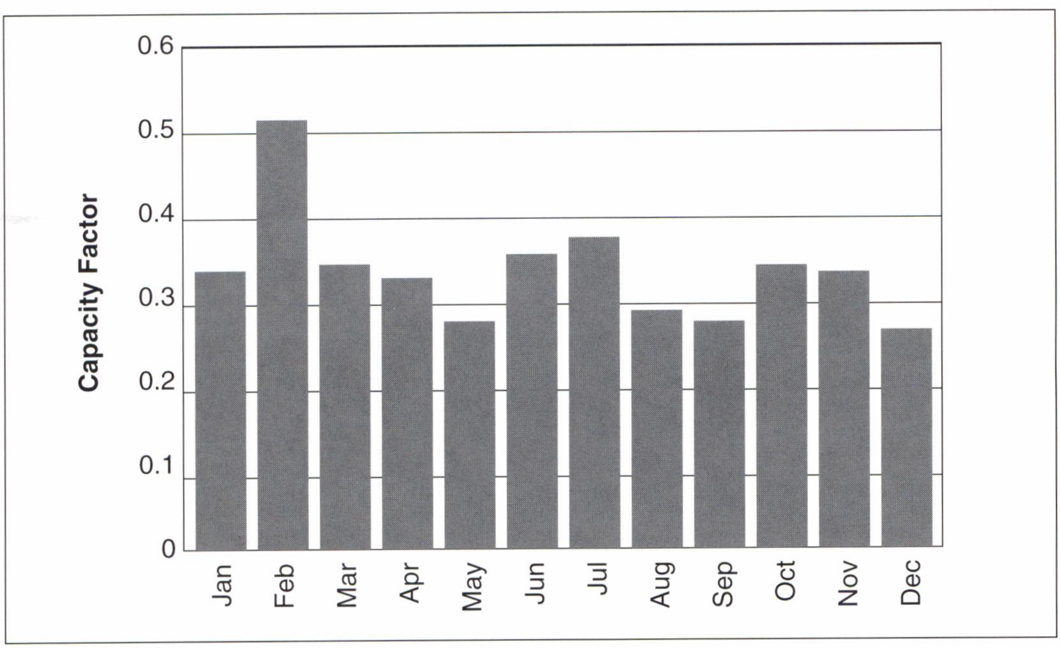


Figure 5. Tarifa monthly capacity factor for wind regions

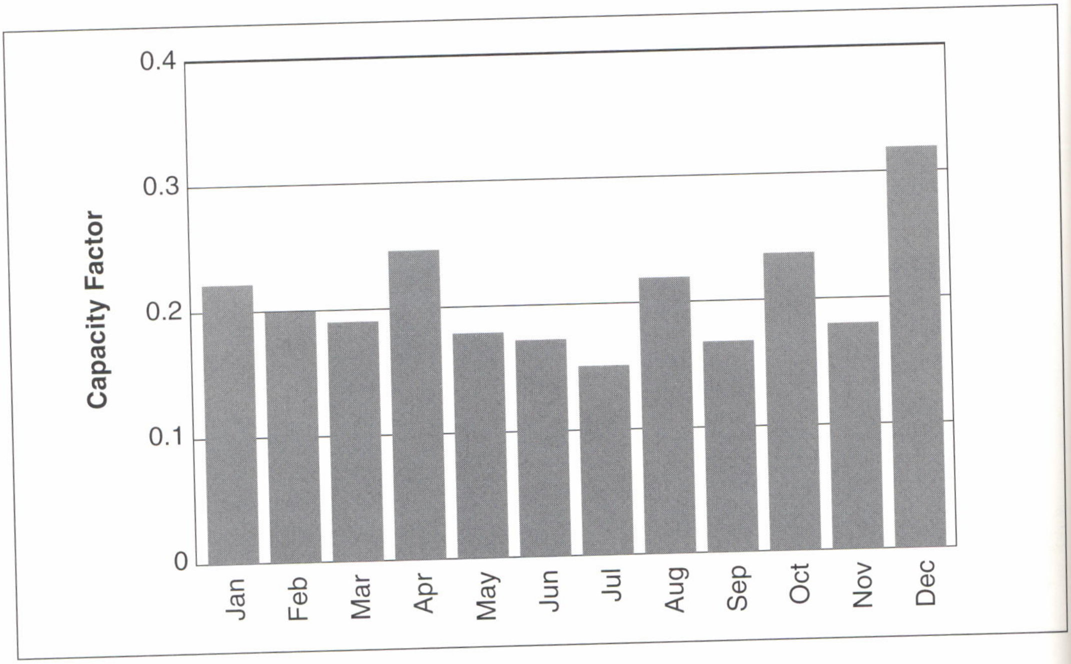


Figure 6. Galicia monthly capacity for wind regions

MADE AE-30 (330 kW). At present, MADE is working on the development of two prototypes in the range of 500 kW (Made AE-41). One of them is stall power regulated and will start operation in June 1995; the other is pitch regulated with variable speed, and it is planned to be in operation in November 1995.

ECOTECNIA, a cooperative of specialists in renewable energy, has installed 7.8 MW with the model 20/150. The prototype 24/200 has been installed in June 1993 at Tarifa, and a wind farm in Malpica (Galicia) with 27 Ecotecnia 24/200 wind turbines is planned during 1996. A new 200 kW wind turbine of 28 m diameter will be used in areas with lower wind speed.

ECOTECNIA is developing a new prototype of 500 kW machines (under the framework of the Thermie program) to be in operation at the end of 1995.

Desarrollos Eólicos S.A. (DESA), the former partner of Kenetech with more than 19 MW in operation, is developing a new prototype of a 300 kW pitch controlled wind turbine (Figure 8), which started operation in November 1994 and is now in the experimental phase. The prototype has been fully developed by the company, including the blades and the control systems.

A new interesting region for wind energy is located in the north of the country, in Navarra. A wind farm of 6 MW total capacity has been operating since December 1994, with VESTAS V39 500 kW wind turbines assembled in Spain by GAMESA. The target of the company for the next years is to install about 100 MW in this area.

In blade manufacturing, an agreement between a Spanish company with experience in the aerospace field, International of Composites S.A., and the Danish

Figure 7. Canada del Rio Wind Farm 10.8 MW

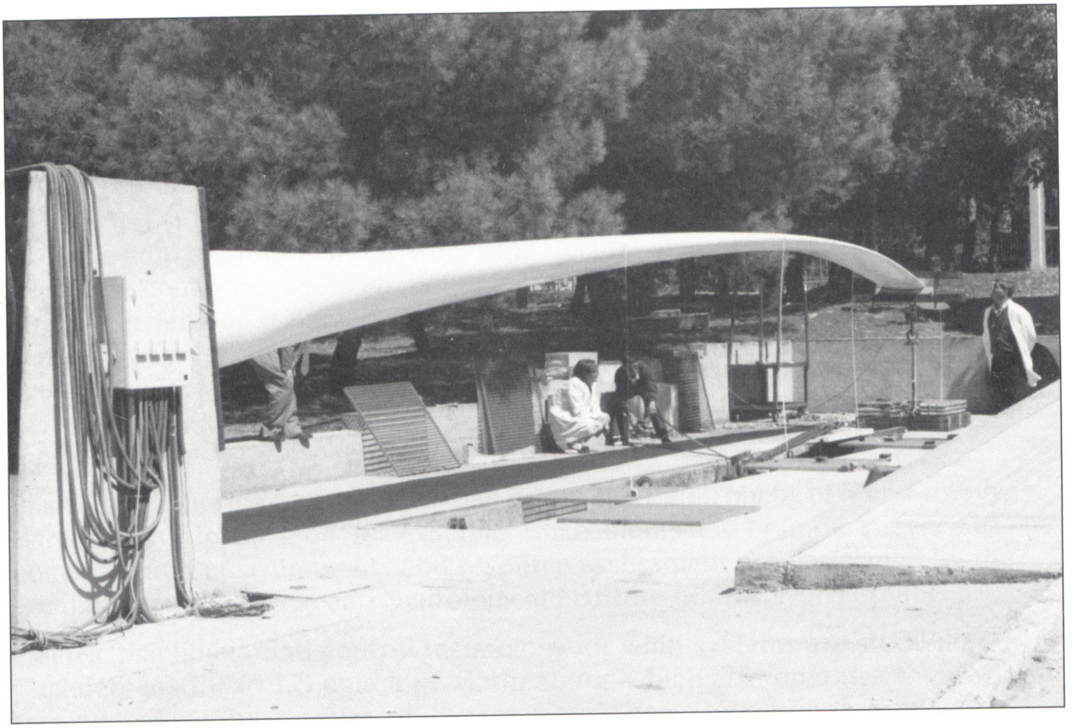


Figure 8. Wind turbine performance analysis (Blade of DESA-300)

company LM has been signed to transfer technology to build the LM-series blades in Spain. A new factory installed in Toledo will start soon with blade production.

In the small wind turbine field, BORNAY developed a new series of small machines from 250 watts to 2,500 watts for isolated applications. It has more than 500 units in operation for a wide range of applications, such as power for civil radio telecommunications transmitters or supplying electricity for houses.

SWEDEN

1. NATIONAL PROGRAMS

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% support
- A market stimulation program where the installation of wind turbines with a capacity larger than 60 kW is subsidized at 35% of the investment cost. If technology procurement is used, there is a possibility to have a maximum of 50% of the investment cost subsidized.

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

1.1. Research and development

The allocation for wind energy research in fiscal year 1995 (July 1, 1994-June 30, 1995) is SEK 7 million.

An agreement with the European Union, and the fact that, as of 1995, Sweden will be a member of the European Union, have increased the involvement in the wind energy activities within the European Union.

From July 1, 1994, a newly started Wind Power Consortium (VKK) has taken over the administration and the decision making over proposed research projects. The consortium gets all its funds from NUTEK and continues the research mainly carried out at universities and national research institutes. Studies in aerodynamics, structural mechanics, materials, advanced design methods, acoustic noise, control technology, and safety standards are performed at the Aeronautical Research Institute (FFA), which also coordinates the work within the consortium.

Basic atmospheric research is carried out at the Department of Meteorology, University of Uppsala, on, for example, wake effects and boundary layer phenomena. Wind measurements and resource assessment are performed by the Swedish Meteorological and Hydrological Institute (SMHI), Norrköping.

Electric machinery and control technology for wind systems are studied at the Chalmers Institute of Technology, Gothenburg, which also operates the wind turbine test station at Hönö, off the west coast near Gothenburg. A small wind turbine is operated at Hönö mainly for testing power electronics.

Integration of wind power into electric grids is studied at the Department of Electrical Energy Systems, Royal Institute of Technology, Stockholm.

1.2. Demonstration

Näsudden II

The 3000 kW turbine was connected to the grid in March 1993, and the delivery was completed in April 1994 by Kvaerner Turbine AB; the ownership was taken over by the operator Vattenfall AB. The official inauguration of the Näsudden II turbine was held on May 20.

The large wind turbine has continued to have a very high availability, with many months over 99%. Until December 31, 1994, Näsudden II has produced 9,335 MWh during 8,691 hours of operation. During the calendar year 1994, it produced 6,740 MWh during 5,994 hours.

Figure 1 shows the power production and availability during 1994. January and March were very windy on Gotland, while February had a stable high pressure weather with low winds. The production during March was 1,016 MWh, which is close to Maglarp's best monthly production from October 1983, which was about 1,040 MWh.

The two-year evaluation program includes comparisons with the performance of the sister turbine Aeolus II in Germany. Both 3 MW turbines will also be evaluated within the EU JOULE II/WEGA-II project until spring 1997.

Nogesund

In early November 1993, an accident occurred at the 200 kW offshore demonstration turbine. A new turbine has now replaced the old machine. In 1995 there will be a report on the test program.

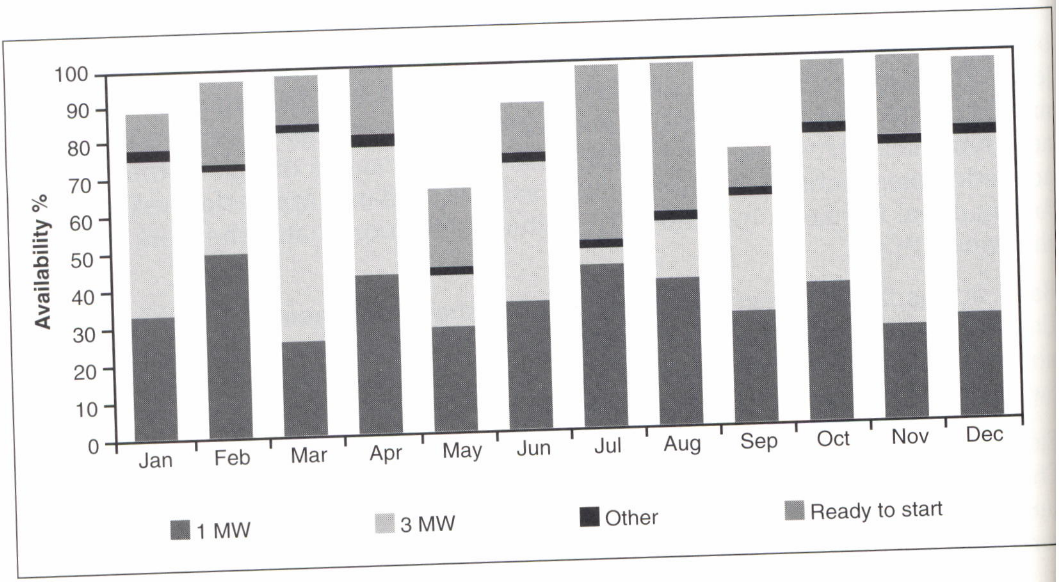


Figure 1. Availability data from Näsudden II (percent)

1.3. Advanced wind turbines

Zephyr

The three 250 kW Zephyr wind turbines at Falkenberg on the west coast are two-bladed, passively pitch controlled with individually flapping blades. The machines have been functioning well, and a study of how to make a larger machine has started (Figure 2).

Nordic 400 at Lyse Wind Power Station

The Nordic Windpower 400 kW wind turbine has a 35 m diameter, two-bladed, fixed pitch rotor that combines stall control with a variable speed electrical system and a teetering hub (data for Nordic 400 and Nordic 1000 are shown in Table 1). The soft steel shell tower reaches a hub height of 40 m. Emergency braking is performed by the rotatable blade tips, backed up by a mechanical brake on the secondary shaft. During the commissioning period, the unit passed a 500-hour acceptance test and was handed over to Vattenfall AB on April 8, 1994. The turbine is currently operated remotely by Vattenfall Västsverige from their 70 km distant district office in Trollhättan.

The design is certified by Det Norske Veritas. The technical and operational evaluation program has started and will be completed before summer 1995.

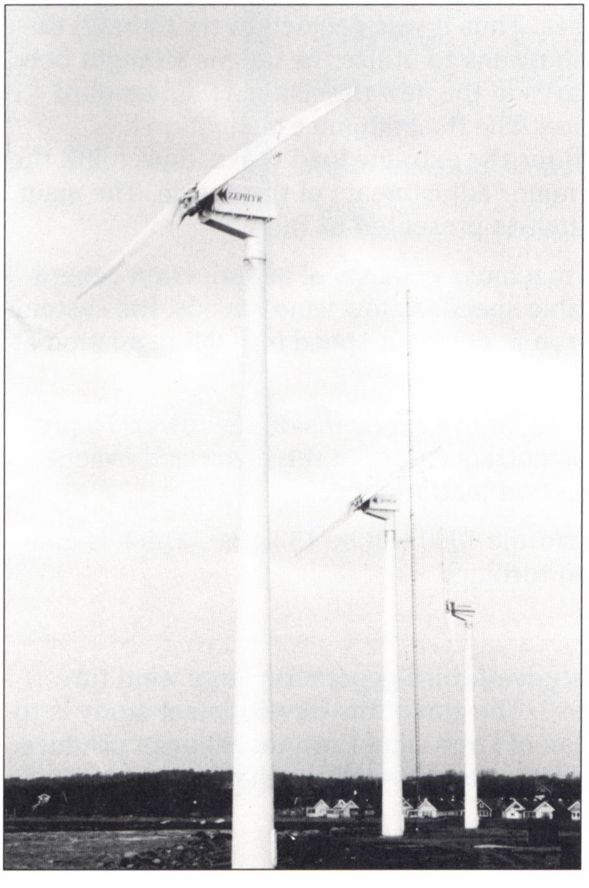


Figure 2. The three 250 kW Zephyr wind turbines at Falkenberg

Until December 31, 1994, the turbine has produced 805 MWh during 7,000 hours of operation. The production is somewhat limited by shut-offs due to large teeter angles, created by a combination of high wind speeds and sharp wind gradients, which exist in certain wind directions. Such strange wind situations may be created by the complex terrain at the site.

The experience from the very rough terrain with measured high wind turbulences will be of special value for future projects in complex terrain.

Nordic 1000

Nordic 1000 is one of the wind turbines sponsored by the EU JOULE II program. The main design work of the Nordic 1000 kW turbine was performed between January 1993 and February 1994. In January 1995, the tower will be completed and the nacelle is in its final stage of construction. The prototype turbine will be erected in March 1995 at Vattenfall's wind power station at Näsudden on the island of Gotland in the Baltic Sea, close to Vattenfall's 3000 kW Näsudden II turbine.

After commissioning, a two-year evaluation will be performed by Vattenfall. The evaluation is made according to the standards of the other JOULE II/WEGA II projects.

The emphasis has been to use the Nordic 400 (Figure 3) design solutions as far as possible and practical. However, the Nordic 400 prototype is almost entirely dimensioned by the extreme load cases. Thus it was decided to try to build the Nordic 1000 a little less flexible, which means to utilize the fatigue strength better. The addition of some new load cases in the new provisional IEC standard also pushed the design in this direction. The final fatigue examination has revealed that the unit, when designed for the extreme load cases, does fulfill the 30-year fatigue life requirement with minor adjustments of the design. The main differences between Nordic 400 and 1000 is presented in Table 1.

The electrical system in Nordic 1000 machines consists of an induction generator and an AC-DC-AC system for variable speed. At low wind speeds, the system is run at variable RPM, whereas it is run at constant speed for stall regulation at high wind speeds.

The whole AC-DC-AC system is mounted on five levels inside the tower. To provide cooling, air is entered around the entrance door in the tower and evacuated through openings over the inspection platform level.

The specific tower head mass of the Nordic 1000 will be 19 kg/m^2, which is considerably lighter than traditional wind turbines.

Näsudden III

Phase 1 of Vattenfall's development study of third generation large wind turbines was completed in December 1992. The aim of the development study is to create a design for the third generation of large wind turbines that can produce electricity at a cost competitive to today's commercially available turbines (SEK 3/kWh/year).

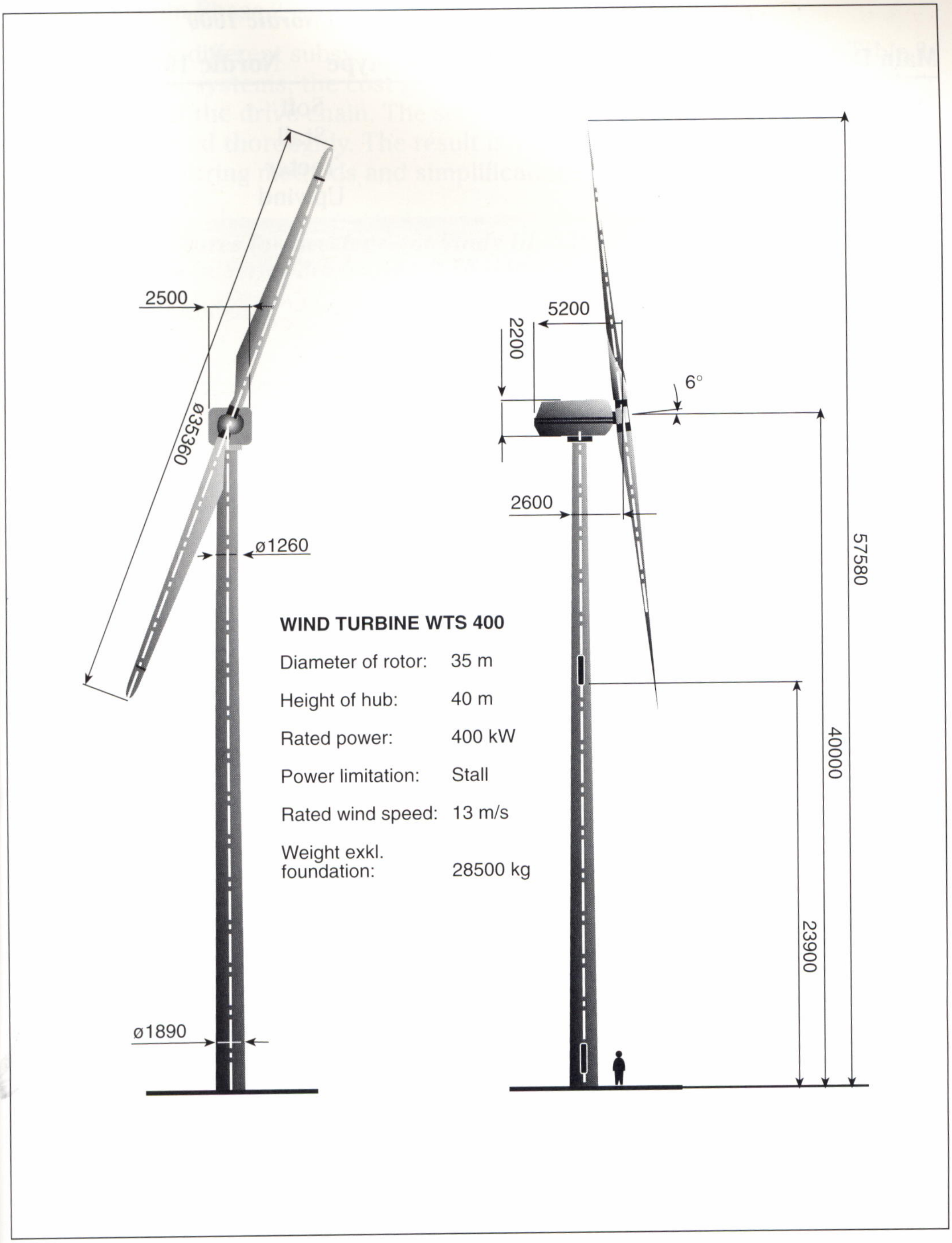


Figure 3. Drawing of Nordic 400

Table 1. Main Data for Nordic 400 and Nordic 1000

Main Data	Nordic 400 Prototype	Nordic 1000 Prototype
Type of Design	Soft	Soft
Control Principle	Stall	Stall
Hub	Teeter	Teeter
Orientation	Upwind	Upwind
Rotor		
Turbine Diameter (m)	35,4	53,0
Rotational Speed (r/min)	20-39	15-25
Tip Speed (m/s)	37-72	42-69
Airfoil	NACA 63.2xx FFA-W3	LM2 NACA 63.4xx FFA-W3
Tower		
Type	Steel Shell	Steel Shell
Hub Height (m)	40,0	58,0
Diameter Top/Base	1,3/1,9	1,9/2,6
Machinery		
Gear Box	2-Stage Planetary with Integral Turbine Shaft Bearings	2-Stage Planetary with Integral Turbine Shaft Bearings
Ratio	1:40	1:51,7
Generator	Induction	Induction
Conversion System	AC-DC-AC Grid Commutated	AC-DC-AC Grid Commutated
Power (kW)	400	1000
Weights		
Machinery and Turbine (ton)	14	41
Total Excl. Foundation (ton)	28 Incl. Power Conv.	92 Incl. Power Conv.
Electrical Production, Prel (Wind Class 1, MWh/yr)	880	2300

General technical specifications, safety requirements, and target costs were established. The target cost was derived from the cost of a comparable group of medium-sized turbines. It ended up at one-third of the cost of the present Näsudden II machine, at the same location. Blades and machinery were in the study and identified as critical parts for cost reduction, for which a 50%-75% lower cost was needed.

Phase 2 of the development study included a conceptual design study based on Phase 1 and the experience of Näsudden II and Aeolus II. In Phase 2, a detailed design study on three main subsystems was also done on blades, hub, and machinery.

The result from Phase 2 is the turbine layout shown in Figure 4.

The cost of the different subsystems and a complete machine is shown in Table 2. For the studied systems, the cost goals from Phase 1 are reached for all subsystems except the drive chain. The serial effects on bearings and gearbox have to be investigated thoroughly. The result is very much a combination of changes of the manufacturing methods and simplifications in the system design.

Table 2. Cost Figures for Development Study III: Näsudden II, Target and Result from a Machine in Serial Production (SEK/kWh/year)

	Näsudden II	Development Study III Target	Development Study III Min.	Development Study III Prob.	Development Study III Max.
Blades	1.8	0.42	0.25	0.26	0.28
Hub	0.25	0.11	0.08	0.09	0.10
Machinery	1.55	0.73	0.71	0.84	1.06
Total WTS	9.00	3.00		<3.0	

The experiences and results from the Development Study III are so far very positive. A large step has been taken in simplifying the turbine concept to be able to meet both cost requirements and adequate technical maturity.

The steps that are now under discussion are to study a complete machine, and in the end, to build a new machine.

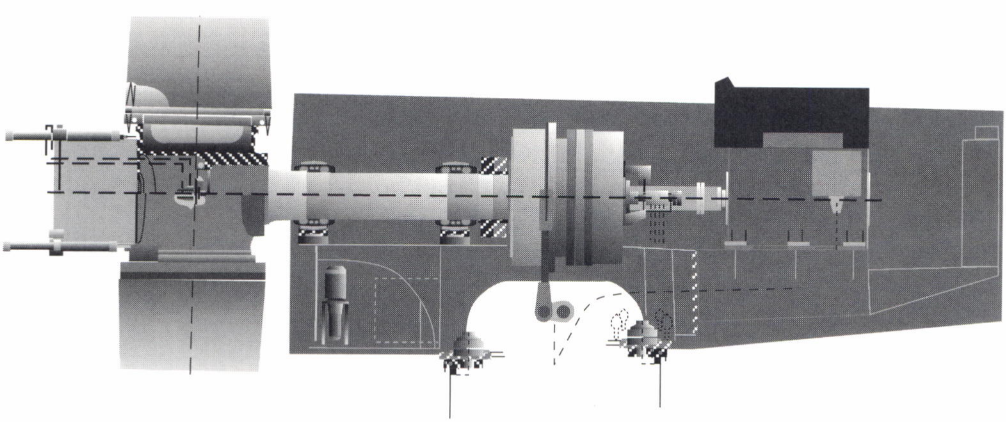


Figure 4. Turbine layout, new development study III concept

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed capacity

During 1994, the number of wind turbines above 50 kW increased from 129 to 157. The electricity produced by wind turbines increased by 44%, from 52 to 75 GWh (Figure 5). The installed capacity on December 31, 1994, was 38.4 MW, including Näsudden II.

2.2. Machine details

The most common types of the new wind turbines during 1994 were Vestas 225 kW (14 units), Vestas 500 kW (5 units), and WindWorld 490 kW (5 units). A high percentage (15%) of the wind turbines in Sweden are now above 400 kW. They produced 32% of the total wind electricity during 1994.

2.3. Performance

The average availability during 1993 for the standard turbines in Sweden was 95.3%. The average capacity factor was 0.243 and average energy per swept area was 745 kWh/m². The peak energy per swept area was around 1,180 kWh/m².

2.4. Operational experience

The most common disturbances in the standard wind turbines during 1993 was caused by problems with gearboxes (34% of the total hindrance time), control systems (16%), electrical systems (6%) and other technical problems (20%). Most of the turbines that had a gearbox breakdown during 1993 had been in operation between 6 and 10 years. Lightning caused around 3,000 hours of hindrance time (8%).

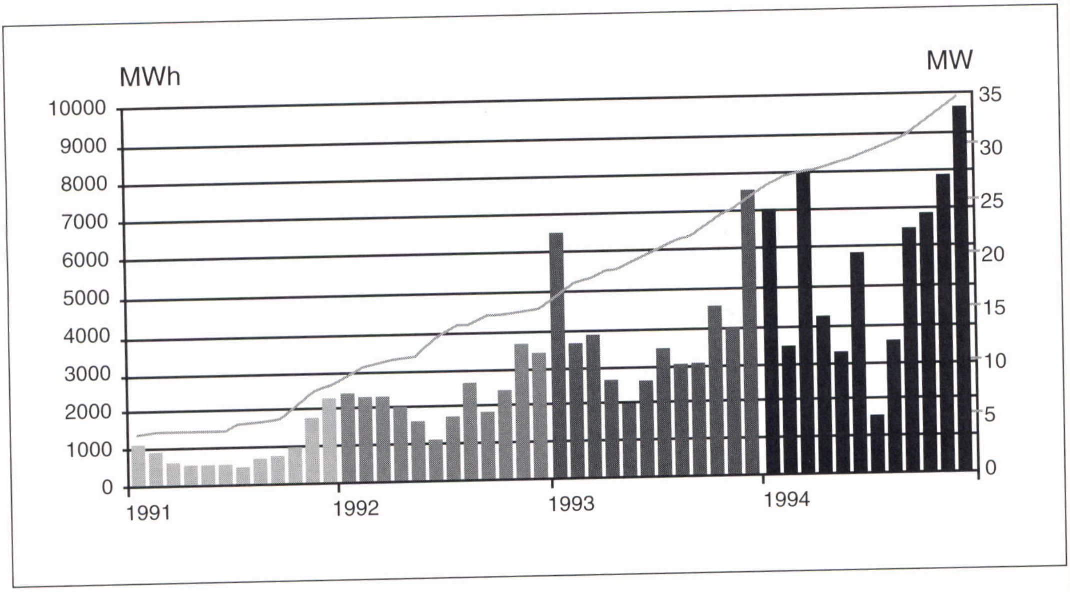


Figure 5. Wind turbine capacity and electricity produced in Sweden in 1994

3. CONSTRAINTS ON MARKET DEVELOPMENT

3.1. Environmental impact

The technical potential for wind energy on land in Sweden is 70 TWh ("Läge för vindkraft," SOU 1988:32). The useable potential on land is, with consideration of different environmental aspects (mainly noise and institutional aspects), on short term reduced to 3-7 TWh. The useable potential offshore is larger and has been estimated to be about 20 TWh.

The expansion of wind energy in Sweden has put focus on the environmental impact of wind turbines. Public attitudes to wind power, especially to its impact on the landscape, is a most important factor that influences practically every wind project. Noise emission is also important, but rather as a "technical" problem. Nevertheless, it is very important that the noise impact is minimized.

The impact on bird life so far has been minimal. Objections from the public regarding this subject mask a general negative attitude.

Objections from the military have stopped many wind projects due to disturbance of military micro-wave links, radar, intelligence activities, and aircraft at low altitudes.

3.2. Institutional aspects

The major hindrance to wind power is that, whereas the landscape is full of established and recognized interests from all parts of society (farming, transportation, nature conservation, recreation, and military), wind power is still a new source of power and not yet fully accepted as something that is beneficial for the society and thus has a "right" to utilize the landscape. The solution has to involve some means of increasing the public interest in wind power. Sweden has established areas of "national interest of wind power" ("riksintresse för vindkraft"), i.e., areas with especially good wind resources. When applying for building permits in such an area, the intent is that the authorities shall rate the wind power interest higher, and thus the likelihood to succeed will be better than in other areas.

NUTEK is involved in several projects in order to make it easier to find sites for wind turbines. A project in cooperation with local authorities is a first step for finding criteria that can be used in the local planing process on how to find and evaluate an area suitable for wind energy. Another project financed by NUTEK is a research program on how to measure and evaluate the impact of noise from wind turbines.

Wind turbines have to be certified according to acceptable standards, and safety regulations have to be applied. Access to the grid is no problem.

4. ECONOMICS

4.1. Economics and financing

Investments in wind energy plants are financed in the same way as buildings and other power plants.

Power distribution in Sweden is obliged to allow connection to the grid for power plants with a maximum capacity of 1,500 kW. This is regulated by law.

The value of the electricity produced in small and medium-sized power plants is valued as the avoided cost of the distributor, i.e., what he saves by not having to buy that amount of electricity (kW and kWh) from his prime producer. The benefit to have a local production unit (lower losses on the grid, etc.) is also taken into account when settling the value of the electricity production.

In general, the value of the electricity differs during the year. The price of electricity is highest during the winter and differs with the time of year, day, night, and with the marginal cost of producing power plants connected to the grid. On an average over the year, a small producer gets paid about SEK 0.25-0.26/kWh.

The payment is increased by an "environmental fee," which is a subsidy from the government and is identical to the tax on electricity. It amounts currently to SEK 0.09/kWh.

When the electricity market will be deregulated, there will be a similar law concerning payment for wind generated electricity, according to an earlier government bill, at least for an interim period. It is, however, not clear today if there will be such a law, and if there is, what level the payment may reach.

4.2. Subsidies

The government has allocated SEK 250 million over a five year period from July 1, 1991, for supporting the installation of wind power plants larger than 60 kW rated power. The main interest in the program has been by private investors who can use the produced electricity for their own consumption. This is usually done either by holding stock in private wind energy companies or by forming co-operatives. Local distributors have also shown interest in investing in wind turbines.

By January 1, 1993, the subsidy was increased from 25% to 35% of the total investment cost. From July 1, 1994, there is also a possibility, if technology procurement is used, to have a maximum of 50% of the investment cost subsidized.

Changes have been made to further stimulate the wind energy market in Sweden. Installation has so far been slower than expected, mostly due to low demand for new capacity and the low cost of electricity in Sweden.

5. INDUSTRY

5.1. Manufacturing

In Sweden there are three manufacturers of wind turbines with a capacity larger than 60 kW: Zephyr Energy AB, Nordic Windpower AB, and Kvaerner Turbin AB. Zephyr Energy AB is the only Swedish manufacturing company, so far, which has a Swedish certificate and fulfills similar demands as commercial turbines from Denmark.

6. INTERNATIONAL COLLABORATION

The EU cooperation has a strategic importance for the further development of wind power in Sweden. Without it, the current market development of commercial MW-scale units would be delayed. Since it requires international cooperation, it has directed the development towards more internationalism.

As wind power becomes a more fully developed technology and the market expands, it is likely that it will follow the general trends towards fewer and larger producers. Who will be the winners of the future is impossible to foresee today.

The IEA cooperation on recommended practices, information exchange, etc. is well established and will hopefully continue.

UNITED KINGDOM

1. OVERVIEW

1.1. Government aims, objectives, and strategy

Policy

An Energy Paper (Reference 1) stating government policy and summarizing the future prospects for new and renewable energy in the U.K. was published in March 1994. 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 United Kingdom by the year 2000.

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* 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.

1.3. Market stimulation

There is a requirement on the twelve Regional Electricity Companies (RECs) in England and Wales to provide a proportion of their supply from generating plants which does not use fossil fuel—the Non-Fossil Fuel Obligation (NFFO). The additional costs incurred by the companies in buying non-fossil fuel power to meet their obligation is passed on to the consumers. The bulk of the Obligation is met by nuclear power, but part of the NFFO is exclusively for renewable energy sources. This part of the obligation is implemented through a series of tranches, set periodically by the government.

Similar obligations have also been placed on the Scottish and Northern Ireland electricity supply industry who are responsible to different government Departments. The total for all the obligations is planned to be 1,500 MW DNC, to be filled competitively by the year 2000.

During 1994, the first NFFO for Northern Ireland (NI-NFFO 1) was announced in March, and the first Scottish Renewable Energy Order (SRO 1) was announced in December. NFFO 3 was also announced in December. The latter distinguishes between wind farms (capacity > 1.6 MW DNC) and single turbines or small clusters to encourage small-scale development. It is expected that only 20 wind farms will be commissioned. Table 1 summaries progress to date in fulfilling the renewable energy obligations.

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 its potential and eventual commercial prospects. Funding for the wind program in the financial year 1993/94 amounted to GBP 7.8 million. An essential adjunct is dissemination of information arising from both directly funded work and from projects in the NFFO.

Table 1. Size and Timing of the Renewable Energy Obligations

Order	Effective Start Date	Contract Length (Max. Years)	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)
SRO 1	1995	15	20	-	45.60/(106)
NI-NFFO 1	1994	15	6	-	12.66/(29)

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

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed capacity

The installation of plants contracted under NFFO 1 and NFFO 2 finished in 1994 due to the short time remaining to complete any further contracts. It is estimated that 20.3 MW of rated capacity were installed in England and Wales in the year ending 30 September 1994. This consisted of 59 machines of average rated capacity 440 kW (1 x 225 kW, 12 x 400 kW, 46 x 450 kW) compared to the average rated capacity of 330 kW for all 462 machines in the NFFO. This brings the total installed capacity under NFFO to 133.5 MW. Figure 1 shows the growth of this capacity with time.

2.3. Performance

For the year from October 1, 1993, to September 30, 1994, the total energy output from the projects in NFFO was 306,000 MWh. The cumulative output from the projects is shown in Figure 2. The technical performance of the turbines was good. Figure 3 shows the energy output per square meter of rotor swept area for the projects for which data are available, separated into wind farms (19 projects) and single machines (9 projects).

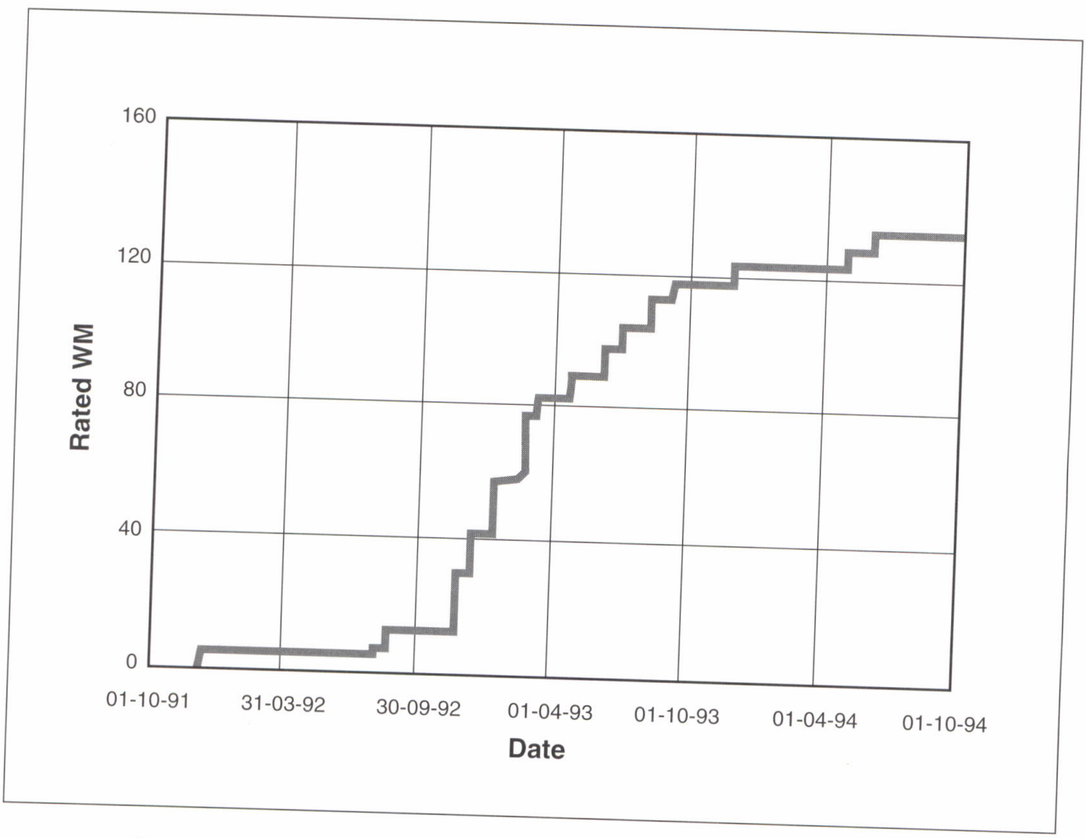

Figure 1. NFFO 1 & 2 wind projects—rate of installing capacity

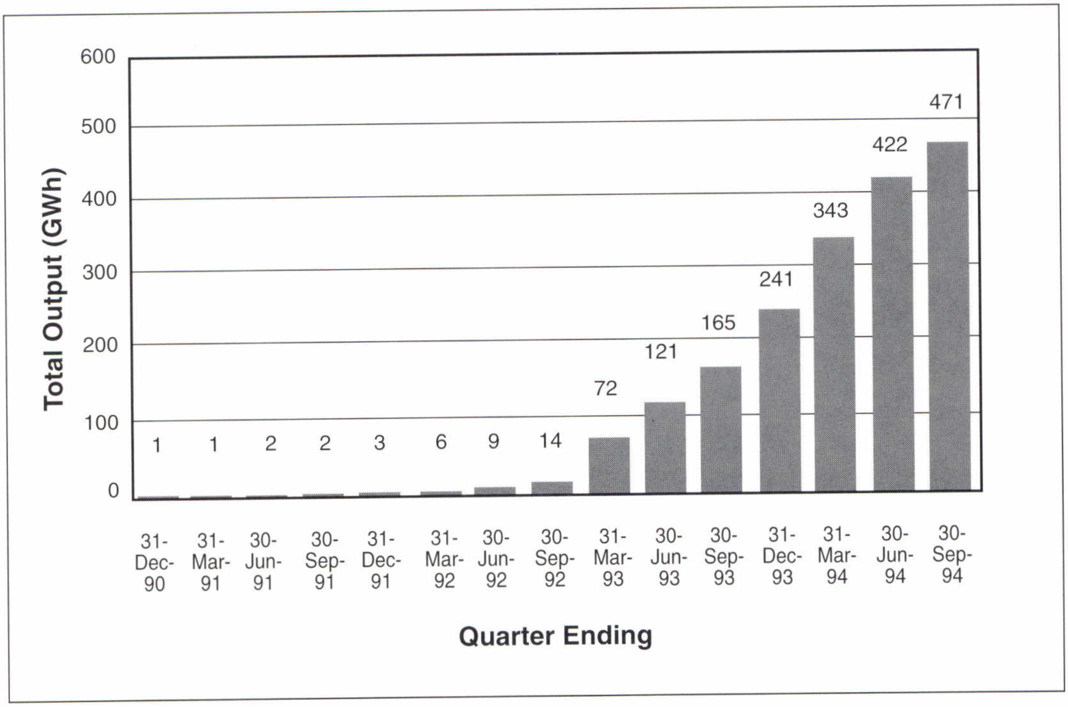

Figure 2. NFFO 1 & 2 wind projects—cumulative energy output

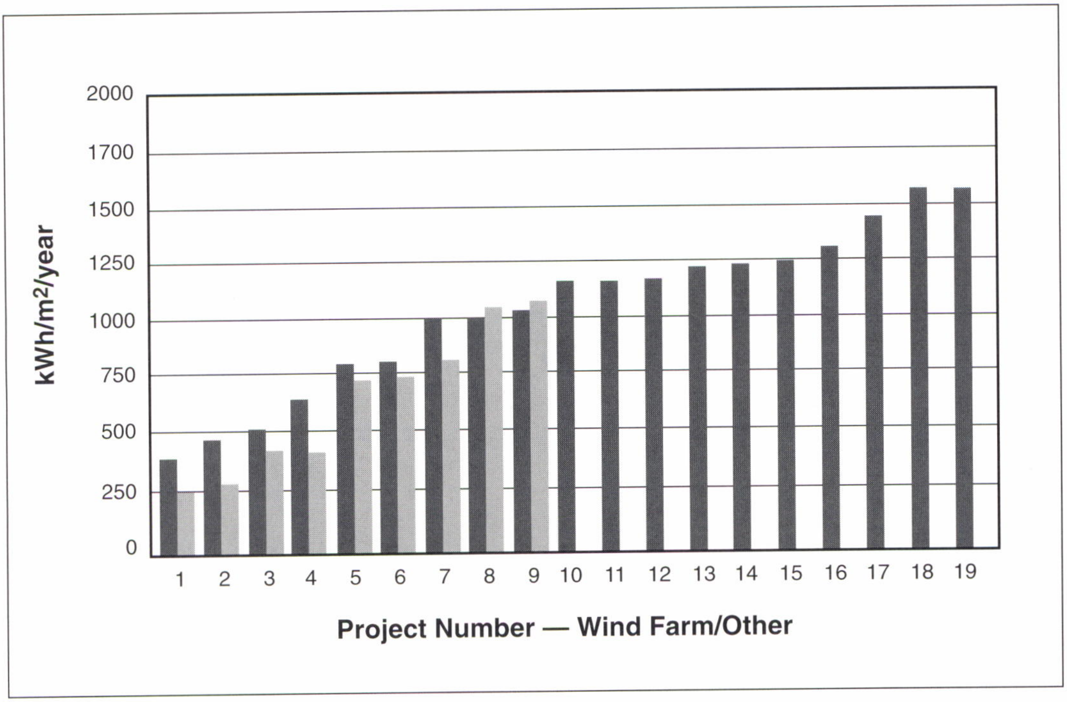

Figure 3. NFFO 1 & 2 wind projects—mean annual energy output in kW/m² separated into wind farms and others (data exclude 1st quarter of operation)

2.4. Operational experience

With one exception, operational experience has been good with high availabilities and good load factors being reported from the wind farms. The exception is the three farms using WEG MS-3 machines which were modified during the first half of the year following a component failure in severe gales in December 1994. All three farms resumed full operation in October.

3. *THE WIND INDUSTRY*

3.1. Market development

Owners

Initially many of the wind projects were developed by a number of small U.K. companies who sought to attract investment. Wind technology was seen as a high risk investment and the developers having to raise capital at premium interest rates from banks and finance houses. As the performance of wind farms confirmed the reliability and performance of the turbines, corporate investment increased from, in particular, the generating companies and RECs. During the year, the U.S.-based New World Power entered the market by developing three wind farms for which planning consent was available.

Operators

In most cases the operators of the wind farms are the original development companies operating under contract to the owners.

Marketing concepts/forms of ownership

Most of the schemes are corporately or project financed, but 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 is due to be launched in 1995.

3.2. Manufacturing industry

In the United Kingdom, there are currently three manufacturers of wind turbines rated at between 300 and 600 kW. These are the Wind Energy Group, Carter Wind Turbines, and Markhams Engineering Ltd. The approximate total numbers of machines sold to date by these companies are 101, 12, and 3 respectively. Due to the periodic nature of the awarding of contracts for the NFFO, few machines were sold in the United Kingdom during 1994. Orders are expected to pick up as the NFFO three contracts are fulfilled.

During 1994, Windharvester, a potential manufacturer who sought to improve and market the technology originally marketed by James Howden, ceased trading.

3.3. Other industries

Component suppliers

The majority of wind turbines in the United Kingdom are manufactured abroad and component suppliers have been limited to a few specialist companies. However WEG are now supplying blades to other manufacturers and sold 35 in 1994, bringing the total sold to 272. NFFO is seen as an opportunity for industrial expansion, and there are moves by both industry and government to source components in the United Kingdom.

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 3, SRO, and NIRO has stimulated the market recently.

4. CONSTRAINTS ON MARKET DEVELOPMENT

4.1. 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 farms due to developers seeking the best wind speed sites on high ground which are often in areas of scenic beauty. This is reflected in the success rate of projects in NFFO 2, which is 55% compared to 100% for NFFO 1. The conflict between the environmental benefits of wind energy and loss of landscape value is subject to intense debate in places as august as the House of Commons where a Welsh Affairs Select Committee published a report on the future developments of wind farms in Wales (Reference 2).

Noise

The second concern is that of noise because of the high population density of the United Kingdom. A noise working group has been 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. The Group will also consider how to encourage the adoption of the recommendations.

Ecology

Several ecological studies, including two on bird life, have been reported which indicate that wind farms have little effect on local ecology.

Public attitudes

Several surveys have been carried out by a number of organizations, including the BBC (Reference 3), and indicate that local support for wind farms is high; usually around 80% of the local inhabitants are supportive of their neighboring wind farm.

On the other hand, there is widespread adverse comment in the Press from both individuals and some national bodies (e.g., Council for the Preservation of Rural England) and pressure groups (e.g., Country Guardians). Other national bodies (e.g., Friends of the Earth), while advising caution in development, see the need for the environmental benefits offered by wind energy and have issued policy documents.

To encourage good practice in the development of wind farms, the British Wind Energy Association have issued Best Practice Guidelines for developers (Reference 4).

4.2. Institutional aspects

National

In August, the Scottish Office issued a National Planning Policy Guideline for Renewable Energy (Reference 5). This focusses on those renewables likely to attract support in the SRO and defines the factors the Secretary of State will have in mind when considering renewable energy developments. A Planning Advice Note was also issued (Reference 6).

Local plans/planning policies

Several planning studies, carried by local authorities and RECs in collaboration with the DTI, were completed during the year, including a major study of the potential of renewable energy projects in Scotland.

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. Lloyds Register produced a conformity assessment system for certification purposes.

5. ECONOMICS

5.1. Value

Total invested capital

On the assumption that the installed cost of the wind farms already installed was GBP 1000/kW of rated power, the total invested capital is circa GBP 133 million. The capital invested during past year is circa GBP 20 million.

Production

To the end of September 1994, the NFFO wind projects had generated 471 GWh of electricity. Assuming a conservative generation price for conventionally generated electricity (the "pool" price) of GBP 0.026/kWh (Reference 7), this is valued at GBP 12.2 million. During the year 1 October 1993 to 30 September 1994, 306 GWh of electricity were generated, valued at GBP 8.0 million.

5.2. Cost of support

The wind energy market is supported by the payment of premium prices for the energy produced. This premium price is index linked to the Retail Price Index. This means the NFFO 2 strike price of GBP 0.11/kWh is currently circa GBP 0.12/kWh. Assuming all the generated electricity attracts this price, the amount paid to the wind farm developers has been circa GBP 56 million. The corresponding amount for the last year is circa GBP 37 million.

Consequently, the premium on the production amounts to circa GBP 44 million in total and circa GBP 29 million for the year to 30 September 1994. It should be noted, however, that the premium ceases for NFFO 1 and 2 contracts at the end of 1998, after which wind farm operators will sell the power at market price on a purely commercial basis.

5.3. Trends in 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. The premium price of GBP 0.11/kWh for NFFO 2 electricity is acknowledged to be artificially high for two reasons. Firstly, it was a "strike price," i.e., it was the highest accepted bid in the Order, and most developers would have bid-in below this price. Secondly, European Commission regulations at that time prevented payment of the premium price beyond 1998, and the short contract period of 6 years resulted in higher prices.

For NFFO 3, the government has allowed contracts of up to 15 years and this, together with the experience gained by the developers and reductions in the market price of equipment, means the average bid-in price of large projects (>1.6 MW DNC) for offered contracts has dropped to GBP 0.0432/kWh (lowest GBP 0.0398/kWh, highest GBP 0.0480/kWh). This is to be compared with 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.

5.4. Benefits

Employment

No data are yet available, but the BWEA and DTI have initiated a study in this area.

Avoided emissions

If wind power displaces electricity which otherwise would have been produced by fossil fuel, the 306 GWh generated during the past year has avoided the emission of approximately 250 million tons of CO_2, 3.5 million tons of SO_x and 1.5 million tons of NO_x.

6. *FINANCING*

6.1. Type of funding available

Finance for wind farms 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 farms under NFFO as the premium price is considered sufficient incentive.

6.2. 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%.

6.3. Certification requirements

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

6.4. Insurance

Insurance of wind farms is not mandatory (except for employer's liability), but all, as far as it can be ascertained, wind farms have taken out coverage for third party claims and loss of revenue.

6.5. Warranties

Machine warranties for a minimum of 5 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 AND DEVELOPMENT*

7.1. R&D priorities

Industrial and government R&D in the United Kingdom has become more and more focussed on increasing the competitiveness of wind generation, through cost reductions and improved performance, and its acceptability by seeking to decrease its environmental impact.

7.2. Government R&D funds versus invested capital

The government continues to work with industry in a collaborative program but as the technology achieves maturity, the trend is towards decreasing contributions. Energy Paper 62 (Reference 1) discusses the forward strategy in greater detail.

To date the government has spent in excess of GBP 50M in sponsoring R&D work, which should be compared to the estimated GBP 133 million invested in U.K. wind farms. As stated above, the government's wind program expenditure was GBP 7.8M during the last financial year (to April 1994), while an estimated GBP 30 million was invested by the industry in wind farms.

7.3. New concepts under development

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

7.4. 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.

7.5. Offshore

There is continued interest by one or two developers in the United Kingdom in the offshore siting of turbines, which is prompted by the difficulty of finding acceptable sites onshore. However, work commissioned by the DTI indicates that the associated costs will be about twice those on land, and at present, the DTI is maintaining a watching brief on developments.

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 encourage U.K. contractors to participate in EU funded projects, and the DTI and the EU programs are considered to be complementary. Currently, there are approximately 40 EU projects with U.K. participation. These contractors receive supplementary funding from the DTI where the work is relevant to the DTI program.

During 1994, there were 10 active, collaborative projects involving DTI funding. These attracted GBP 880,000 of EU funds, complemented by GBP 370,000 of DTI funds.

REFERENCES

A list of reports of work undertaken in the DTI's wind energy program can be obtained from the ETSU Enquiries Bureau, Building 153, ETSU, Harwell, OX11 0RA.

The references quoted in this paper not obtainable from ETSU include:

(1) Energy Paper No. 62, New and Renewable Energy: Future Prospects in the United Kingdom (HMSO, 1994).

(2) Second Report from the Welsh Affairs Committee, Session 1993-94 (HMSO, 1994).

(3) BBC Research Report, Public Attitudes to Wind Farms in Wales (University of Wales, Cardiff, 1994).

(4) Best Practice Guidelines for Wind Energy Development (BWEA, London, 1994).

(5) National Planning Policy Guideline NPPG 6, Scottish Office (HMSO, 1994).

(6) Planning Advice Note PAN 45, Scottish Office (HMSO, 1994).

(7) Third Renewables Order for England and Wales (OFFER, 1994).

UNITED STATES

1. NATIONAL PROGRAMS

The U.S. Department of Energy (DOE) Wind Energy Program is continuing broad based research and technology development with increasing emphasis on turbine development activities and commercialization. Activities under the DOE wind energy program are expanding in response to the growing interest in the significant progress on both technology and business development for domestic and international applications.

The Turbine Development Program has moved to its next phase, Next-Generation Turbine Development, exploring designs for commercialization in the 1998-2000 time frame. At the same time, DOE is participating in a new commercialization task undertaken in close collaboration with the utilities, the wind industry, and other key parties, which will accelerate the commercialization of wind technology. Key elements of these programs are described below.

DOE wind program funding levels have increased substantially since 1991. Program funding increased from USD 11.1 million in Fiscal Year (FY) 1991 to USD 21.4 in FY 1992, then to USD 24.0 million in FY 1993 and to USD 30.4 million in FY 1994. The FY 1995 program is USD 49.0 million, with increased funding for development of next-generation turbines and a collaborative with industry to promote the use of wind power throughout the United States.

1.1. Turbine development

The development of technologically advanced, higher efficiency wind turbines is one of DOE's highest priority activities. The overall goal of the wind program is to develop systems that can compete with conventional electric generation for USD 0.05/kWh at 13 mph (5.8 m/s) sites by the mid-1990s, and by less than USD 0.04/kWh by 2000; both targets are expressed in levelized constant 1993 dollars. These goals will be achieved through a number of carefully coordinated turbine development and product improvement efforts with the U.S. wind industry that include the following components:

1.2. Turbine Development Program (TDP)

The TDP uses a dual-path technology development approach, addressing both near-term and next-generation issues. Near-term efforts are supporting the development, fabrication, and field testing of several new turbines. These include: the Atlantic Orient AOC 15/50, a three-bladed downwind turbine with a 15 meter diameter rotor and a 50 kW rated capacity; the Advanced Wind Turbine AWT-26, a two-bladed downwind turbine with a 26 meter diameter rotor and a 275 kW rated capacity (see IEA Wind Energy Annual Report 1993); and the New World Power Technology (Northern Power Systems) NPS 250 with a two-bladed 25 meter diameter upwind rotor and a rated capacity of 250 kW (see Figure 1). These machines are intended to 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, manufacturing studies, and commercialization of existing machines. Several projects are expected to be completed in the 1994-1995 time-frame. Turbines being developed are the Zond Z-40 500 kW (see Figure 2), the FloWind EHD 300 kW vertical axis turbine (see Figure 3), and the 500-XST, 500 kW machine being developed by New World Power Grid Co.

Next-generation TDP machines will employ advanced technology and innovative designs to reach the target levelized costs of electricity at less than USD 0.04/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 1994, seven companies were 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 do designs are: Certek, FloWind, Kenetech Windpower, New World Power Technology (Northern Power Systems)/Westinghouse, The Wind Turbine Co./Dow Chemical/United Technologies, Ultra Wind and Zond Systems. An innovative subsystems activity, currently underway, also supports the next-generation path by developing advanced generators, rotors, and control systems.

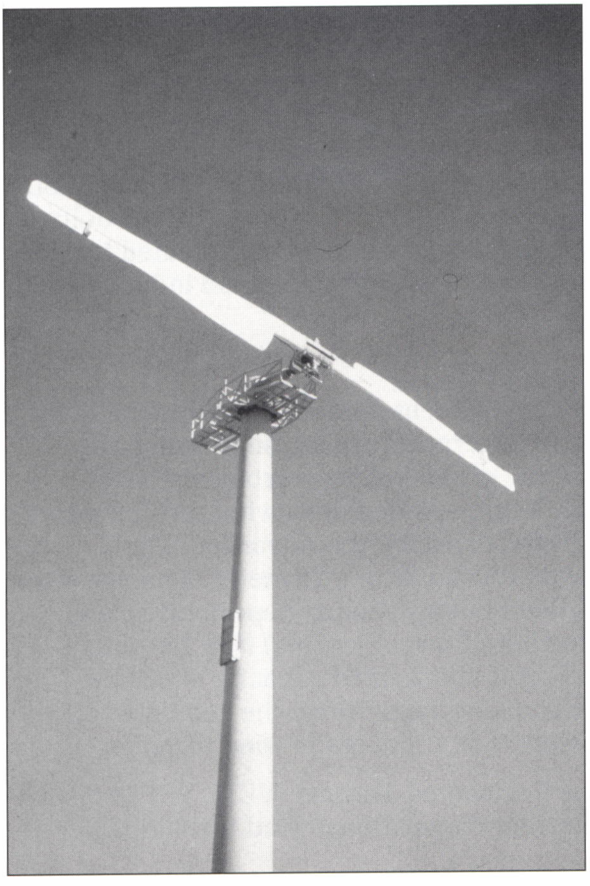

Figure 1. Northwind 250 by New World Power Technology (Northern Power Systems)

Figure 2. Zond Z-40 500 kW

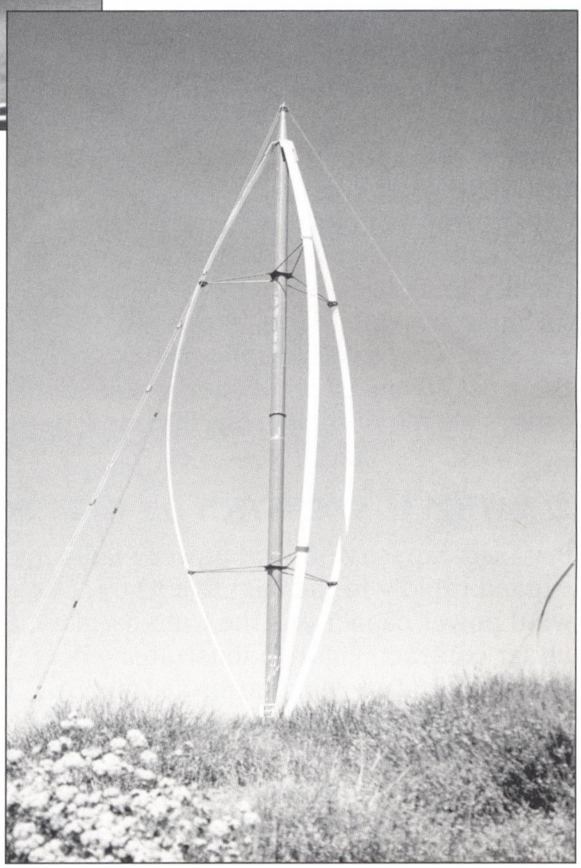

Figure 3. FloWind EHD 300 kW

1.3. Utility integration program

The U.S. DOE has initiated a series of activities addressing issues regarding the integration of wind systems into typical electric utility operations. An important mechanism is the Utility Wind Turbine Performance Verification Program (TVP). Co-sponsored with the Electric Power Research Institute (EPRI), this program will deploy 6 MW or larger windpower 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 activity have been selected: Green Mountain Power Corporation (Vermont), Central and Southwest Public Service Corporation (Texas), and Niagara Mohawk Power Co. (New York). The host utilities will provide a range of operating data.

A new group called the National Wind Coordinating Committee has been formed. 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 development of wind power. Activities of this organization will involve cost sharing of wind installations, cost-shared acquisition of site specific wind resource data, and research on avian issues. Some activities will involve DOE Wind Program funding, while other activities, such as removing state regulatory barriers, involve DOE in a supporting role.

1.4. The National Wind Technology Center

In October of 1994, The National Renewable Energy Laboratory (NREL) dedicated a new wind research facility, located on a 280 acre site near Boulder, Colorado. The National Wind Technology Center (NWTC) will facilitate a wide range of wind energy research from state-of-the-art component development and testing to complete system verification. The NWTC now includes a combined-experiment test bed, a structural test facility, and a main research building. Eventually the NWTC will also include a 10,000 square foot Industrial User Facility to be used for industry research. In addition, several advanced research turbines, 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 energy research facilities in the world. Figure 4 is an artist's sketch of the new facility, now partially in operation.

2. NATIONAL STATISTICS ON WIND POWER

Installed capacity of wind power plants in the United States is expected to expand rapidly in the next five years. Currently, there are a total of 1,630 MW of wind power capacity in the United States, and 370 MW of additional capacity is under contract. Figure 5 illustrates where the current wind farms are located and where future wind farms are planned. The majority of wind farm installations are in California, but as the map indicates, there is considerable activity all over the country. The northern plains area of the United States has extraordinary wind potential. Minnesota, Iowa, and Wyoming power producers and utilities plan to add significant amounts of wind power capacity in the near future.

Figure 4. Artist's sketch of the new NREL facility

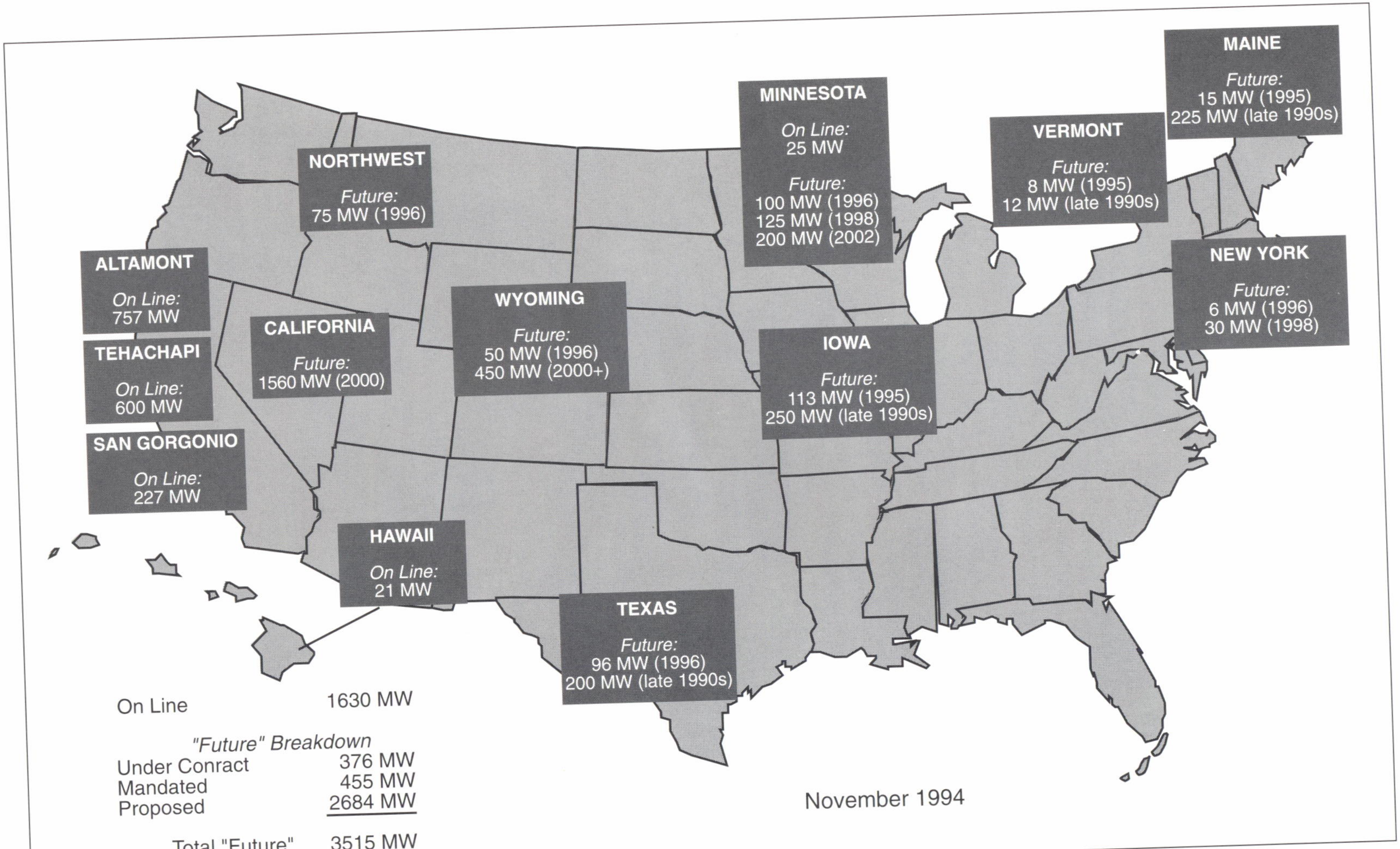

Figure 5. Current and future wind farm locations

Texas power producers and utilities have been very active with several projects in various stages of planning, including two contracts totalling 46 MW expected on line by the end of 1995. Collectively, the wind plants are producing approximately 3 billion kilowatt-hours (TWh) annually.

3. MARKET DEVELOPMENT ISSUES

Environmental benefits are generally a major contributing factor to the deployment of wind systems. One area of concern, however, is that of the effects of wind plant development on birds and their habitats. Avian issues are the topic of a substantial new research effort by DOE and the wind industry. Concern over bird deaths in northern California, particularly any loss in a few protected species, has resulted in expanded research to define the magnitude of the problem and find ways to prevent bird collisions. Efforts are already underway, with notable success in reducing electrocution deaths. However, further research into collisions will be pursued, with attention to regions outside of California.

Another potential constraint on the growth of the wind market is current electric industry restructuring. The U.S. electric industry is in a major transitional period. Federal energy policy has helped create an environment of increased competition, which is having both beneficial and negative effects on the wind market. While some aspects of the increased freedom of independent power producers or utilities to "wheel" power across another utility's transmission lines can potentially be a boon to the wind industry, other changes are having an adverse effect. The reevaluation of the implementation of integrated resource planning (IRP), for instance, is resulting in some utilities pulling back somewhat from the integration of wind and other renewables on the basis of their environmental benefits.

4. ECONOMICS

The economics of wind power plants is continuing to improve. Several years ago typical wind projects were selling energy produced from wind turbines at a cost of USD 0.07-0.09/kWh. Today, some projects at sites with the best winds (estimated to be 6 to 9 m/s) are signing power purchase contracts at USD 0.05/kWh or less.

Federal and state incentives have been a factor stimulating development and dropping prices. Individual states employ a wide variety of financial incentives, ranging from reduced property and other taxes to mandated wind power capacity additions.

The primary Federal subsidy is the USD 0.015/kWh Renewable Energy Production Incentive (REPI), a provision of the Energy Policy Act of 1992 (EPAct), which took effect for wind facilities installed beginning January of 1994 through July 1, 1999. The REPI, effective for the first 10 years of the plant's life, takes the form of a federal tax credit for investor-owned utilities (IOUs) and independent developers. As such, the actual percentage of the USD 0.015/kWh that can be recovered will vary depending on the tax situation of the individual developer/owner. In spite of this, the REPI has clearly had an impact on the timing and extent of wind plant development in the United States. The incentive's importance was enhanced by a recent ruling by the Internal Revenue Service that will allow new wind turbines within an existing wind farm to qualify for the credit. Additionally, a facility (even composed of a single turbine) with used parts may qualify for the credit if the value of its used components is not more than 20% of its total value.

5. INTERNATIONAL COLLABORATION

The U.S. Department of Energy and its national laboratories have a number of ongoing activities to promote the use of wind and wind-hybrid generating technologies throughout the developing world, with a particular emphasis on Latin America and the Pacific Rim regions.

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, and creation of the America's 21st Century program. This program supports renewable energy projects in Latin America and the Caribbean. Ongoing activities include support of wind resource assessments for potential wind farm development in Central America and wind hybrid power system 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 several national laboratories are involved in the support of wind resource assessment and renewable project evaluation and implementation in that country. Several wind-hybrid systems are being deployed. In Indonesia, wind resource assessment is ongoing in the country's southeastern islands, and potential wind and wind-hybrid projects for electricity supply and water pumping are being evaluated in coordination with local Indonesian communities and non-governmental organizations.

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 1,000 MW of wind power plants. 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.

APPENDIX I: CURRENCY CONVERSION TABLE

Currency Conversions as of the End of December, 1994
Shown as Row Currency per Column Currency

		SDR	CAD	DKK	FIM	DEM	ITL	JPY	NLG	NOK	ESP	SEK	GBP	USD
IMF SDR	SDR	—	0.488	0.113	0.144	0.442	0.00042	0.007	0.395	0.101	0.005	0.092	1.070	0.685
Canadian Dollar	CAD	2.048	—	0.231	0.296	0.906	0.0009	0.014	0.808	0.207	0.011	0.188	2.192	1.403
Danish Krone	DKK	8.880	4.336	—	1.282	3.927	0.0037	0.061	3.506	0.900	0.046	0.815	9.504	6.083
Finnish Markka	FIM	6.924	3.381	0.780	—	3.063	0.0029	0.048	2.734	0.701	0.036	0.636	7.411	4.743
German Mark	DEM	2.261	1.104	0.255	0.327	—	0.0010	0.016	0.893	0.229	0.012	0.208	2.420	1.549
Italian Lire	ITL	2,379.2	1,161.8	267.928	343.597	1,052 .3	—	16.340	939.281	241.017	12.371	218.422	2,546.5	1,629.8
Japanese Yen	JPY	145.610	71.102	16.398	21.029	64.401	0.0612	—	57.485	14.751	0.757	13.368	155.849	99.743
Netherlands Guilder	NLG	2.533	1.237	0.285	0.366	1.120	0.0011	0.017	—	0.257	0.013	0.233	2.711	1.735
Norwegian Krone	NOK	9.872	4.820	1.112	1.426	4.366	0.0041	0.068	3.897	—	0.051	0.906	10.566	6.762
Spanish Peseta	ESP	192.320	93.911	21.658	27.774	85.060	0.0808	1.321	75.926	19.482	—	17.656	205.844	131.740
Swedish Krona	SEK	10.893	5.319	1.227	1.573	4.818	0.0046	0.075	4.300	1.103	0.057	—	11.659	7.462
(U.K.) British Pound	GBP	0.934	0.456	0.105	0.135	0.413	0.0004	0.006	0.369	0.095	0.005	0.086	—	0.640
U.S. Dollar	USD	1.460	0.713	0.164	0.211	0.646	0.0006	0.010	0.576	0.148	0.008	0.134	1.563	—

Source: "International Financial Statistics," International Monetary Fund, February 1995.

APPENDIX II

The 34th Executive Committee meeting in Banff, Canada, on October 26-27, 1994

IEA R & D Wind Executive Committee 1994

M = Member A = Alternate Member

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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 14 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 deployment.

The report reviews the progress of the joint projects during 1994 and highlights the national wind energy activities in the member countries.

By the end of the report period, more than 25,000 grid-connected wind turbines were operational in the member countries, representing a rated power of around 3,500 MW. The rate of increase is presently about 600 MW per year. Collectively, these turbines are producing more than 6 TWh annually.

The average rated power is more than 300 kW in new units. Commercial machines in the 500 kW range are marketed. Prototype megawatt-sized wind turbines are in operation in nine member countries.