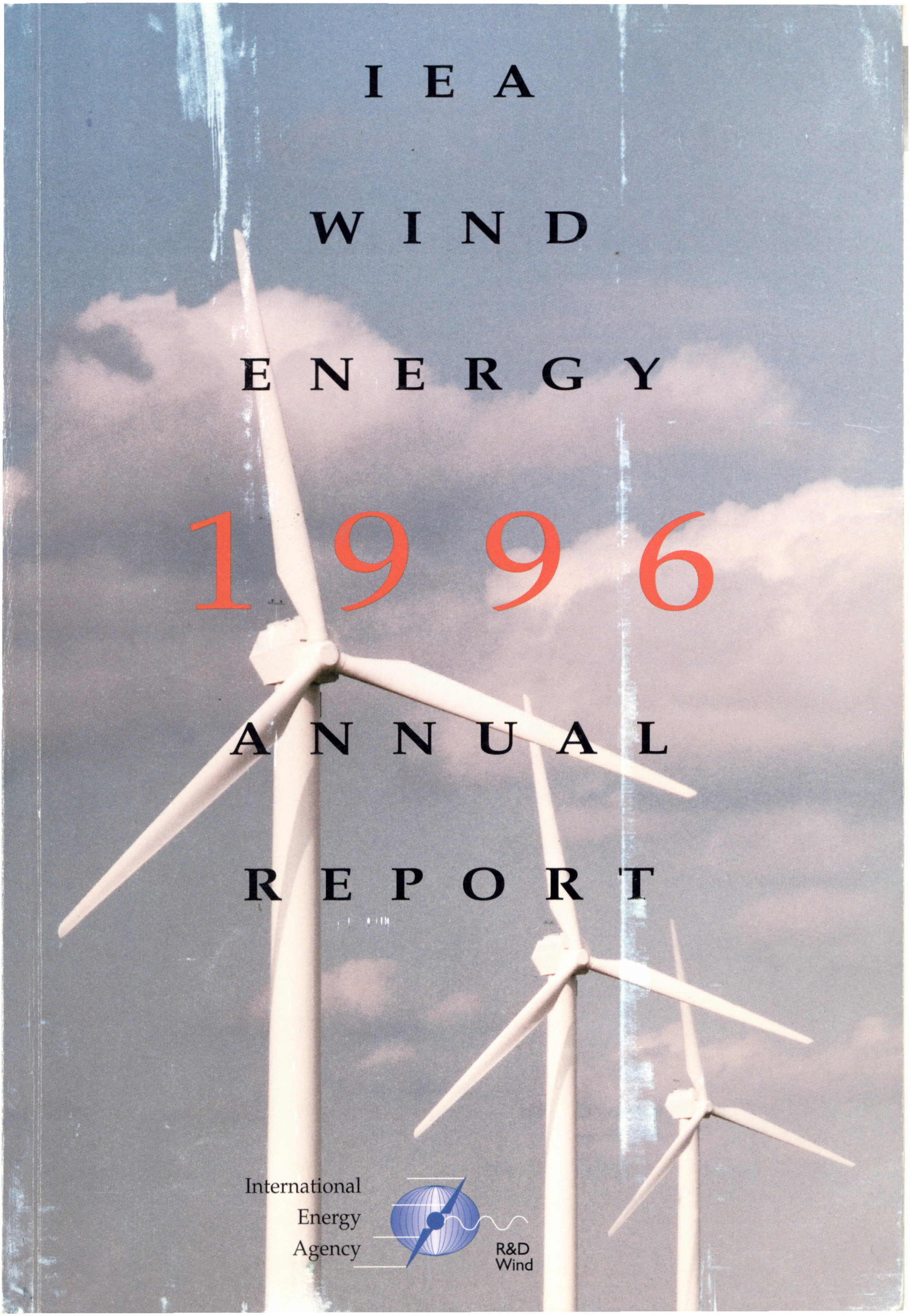
IEA WIND ENERGY 1996 ANNUAL REPORT



International Energy Agency

R&D Wind

The nineteenth Annual Report reviews the progress during 1996 of the activities in the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems under the auspices of the International Energy Agency (IEA). The Agreement and its program, which is known as IEA R&D Wind, is a collaborative venture between parties from 16 IEA member countries and the European Commission.

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

The report is published by the National Renewable Energy Laboratory (NREL) in Colorado, United States, on behalf of the IEA R&D Wind Executive Committee. It is edited by K. Tromly (NREL) with contributions from A. Chegwidden (Australia), R. Rangi (Canada), P. Nielsen (Denmark), E. Peltola (Finland), R. Windheim (Germany), P. Vionis (Greece), C. Casale and L. Pirazzi (Italy), H. Matsumiya (Japan), J. 't Hooft (the Netherlands), D. Chand (New Zealand), E. Solberg (Norway), F. Avia (Spain), H. Ohlsson (Sweden), M. Legerton (United Kingdom), D. Ancona (United States) and K. Steer-Diederen (United States).

Daniel F. ANCONA
Chairman of the Executive Committee

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INTRODUCTION

Wind energy is now being deployed worldwide at a rapidly increasing rate and the International Energy Agency (IEA) has a changing role in its growth. Recently there has been increasing interest in IEA participation from both Organization for Economic Cooperation and Development (OECD) and non-OECD countries. Because of its diverse international makeup, the IEA is viewed as a source of reliable technical and economic information. The World Bank has approached the IEA R&D Wind Executive Committee to assist in the expansion of wind deployment. In addition, IEA is expanding from R,D&D programs to include tracking of implementation incentives offered by its member countries.

Interest in the Agreement has also been expanded to include countries that are beginning to develop and deploy wind systems. The overall question of expanding participation in the Wind Energy Agreement activities has broad and far-reaching consideration, both to the operation of the Agreement and in encouraging the large scale deployment of wind turbines. To consider these questions an Ad Hoc Task Force has been formed in 1996.

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

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

To date, the IEA R&D Wind Agreement has been signed by 19 parties from 16 countries and the European Commission: Australia, Austria, Canada, Denmark, Finland, Germany, Greece, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, the United Kingdom and the United States. In addition, several other countries are in the process of joining.

Since 1990, wind power has risen over 200%, representing an annual growth rate of 33%. The European wind industry has grown at an explosive pace during 1995/96. Europe's leadership stems from the financial incentives and high purchase prices established for renewable energy in response to concern about atmospheric pollution. Several manufacturers in Europe are now building and shipping new turbines at the rate of one megawatt per day. Countries around the world are starting new grid-connected wind power plants and off-grid power projects. The IEA estimates wind power installations worldwide will grow from 2 GW in 1990 to 6.2 in 1996 to over 12 GW by the end of 2000.

Just as wind energy development has taken off in Europe, it has stalled in the United States, the main reasons being uncertainty about the future structure of the electricity industry. The restructured utility industry should provide new opportunities for wind energy development. Meanwhile, in developing nations wind power development is picking up pace. The leader so far is India. It has been estimated that these developing countries could generate 50% of the world's electricity by 2030.

NATIONAL PROGRAMS

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

COLLABORATIVE ACTIVITIES

Tasks

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

TASK XI - BASE TECHNOLOGY INFORMATION EXCHANGE

Operating Agent: Department of Fluid Mechanics of the Technical University of Denmark.

During 1996, the European Commission joined Task XI. There are now 14 participants The main activities include the preparation of documents in the series "Recommended practices for wind turbine testing and evaluation," the undertaking of Joint Actions in specific research areas where a periodic exchange of information is considered necessary, and the organization of Topical Expert Meetings.

Recommended Practices

The Expert Group preparing a recommendation on "Noise emmission measurements" met twice, and a final document has been completed. A recommendation on "Point wind speed measurements" is in preparation and the first draft of the document has been prepared. The Expert Groups on "Lightning protection and related issues" had its first meeting and a first draft document has been prepared. Both should be completed in 1997.

Joint Actions

Within this subtask the fourth symposium on "Wind turbine fatigue" was held on February 1/2, 1996, in Stuttgart, Germany. Proceedings have been printed and distributed.

Topical Expert meetings

The 28th Topical Expert Meeting was held on April 11/12, 1996, in Lyngby, Denmark on "State of the art of aeroelastic codes for wind turbine calculations."

TASK XIV - FIELD ROTOR AERODYNAMICS

Operating Agent: Netherlands Energy Research Foundation - ECN, the Netherlands.

A joint research project involving five laboratories in four countries (Denmark, the Netherlands, United Kingdom, and 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.

The work of this Task is almost completed and has resulted in a unique documented database of aerodynamic measurements on different wind turbines.

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

Operating Agent: Energy Technology Support Unit (ETSU), United Kingdom.

Arising from a review of the strategic plan, this Task was initiated in 1995. The objective is to produce an annual review giving an overview of the progress in the commercial deployment of wind turbine systems in the IEA member countries participating in this Agreement. The review will 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.

Two annual reviews have been completed.

TASK XVI - WIND TURBINE ROUND ROBIN TEST PROGRAM

Operating Agent: National Renewable Energy Laboratory - NREL, United States.

This Task was initiated in 1995. The objective of this project is to validate wind turbine testing procedures, analyze and resolve sources of discrepancies, and to improve the testing methods and procedures. A series of round robin comparison tests at participating national laboratories and other interested test stations will be the means of validating test procedures and establishing reciprocity between different certification testing laboratories. All participating laboratories will test identical machines at their own facilities, using comparable test instrumentation and data acquisition equipment. Discrepancies in the test data will be resolved and form the basis for improvements in testing procedures and calibration methods. This will also serve as justification for mutual recognition of foreign certifications. A joint report on the results of noise tests, power performance and load tests will be published. Due to technical problems the completion of the Task is delayed until June 1998.

EXECUTIVE COMMITTEE ACTIVITIES

Officers

D.F. Ancona (United States) and R. Rangi (Canada) served as Chairman and Vice-Chairman during 1996. At the fall meeting, R. Rangi (Canada) and F. Avia (Spain) were elected Chairman and Vice-Chairman for 1997.

Participants

In 1996, the European Commission signed the R&D Wind Agreement, thereby increasing the membership to 18 participants. During the year, the Executive Committee invited Brazil and Mexico to join the Agreement. Israel and Poland have shown interest in membership.

Several changes on the Executive Committee were announced: the United Kingdom requested to change its Contracting Party from the United Kingdom Atomic Energy Agency to AEA Technology plc. See Appendix II for an updated list of Members and Alternate Members.

Meetings

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

The 37th meeting took place on May 28 and 29, 1996 in Helsinki, Finland.

The attendance was 19 participants, representing 9 of the 17 member countries and Operating Agents, and including observers from Brazil and Mexico.

The Executive Committee established a Task Force to study ways the IEA can assist non-member countries considering the use of wind power. Some of the largest markets for wind power are in countries that are not members of the OECD. The Task Force has completed a Wind Theme Note for the World Bank presenting the fundamentals and the current status of wind energy technology development. Two additional papers will focus on grid-connected and off-grid wind power applications drawing on the broad experience in the IEA member countries.

The 1995 status report of Annex XV - Review of progress in the implementation of wind energy by the member countries of the IEA - was presented.

Annex XVI - Wind turbine round robin test program - started its program with a first kickoff meeting at NREL, United States. The attendees agreed to the overall program objectives to

- determine how closely wind turbine test results compare when tests are conducted according to methods specified by IEC standards
- identify the likely causes of differences in cases where test results differ.

Discussion of a new Annex was initiated to compile detailed wind characteristics at typical sites in the participating countries. High resolution, time series wind speed measurements will be stored in a data base that will be used by the participants in the design of new turbines for operation in a variety of environments.

On May 30, 1996, the Committee visited the Kemijoki Oy arctic wind turbine test station in Lapland.

The 38th meeting was held on October 29 and 30, 1996 in Emden, Germany, and was attended by 21 participants, representing 14 of the 17 member countries and including an observer from the World Bank.

The Executive Committee approved the 1997 budget and decided to print an updated version of the IEA R&D Wind brochure, aimed at informing the general public about the IEA's and member countries' commitment to wind energy.

Annex XIV - Field rotor aerodynamics - is almost completed and has resulted in a unique documented data base of aerodynamic measurements on different wind turbines. A draft version of the final report is complete.

Annex XV was expanded to include the collection of wind power plant performance data at six or more sites in member countries and possibly other locations in non-member countries. These data will be compiled in cooperation with the World Bank and the World Energy Council.

The Executive Committee discussed plans on organizing international wind energy business symposiums in an effort to disseminate information on the wind energy technology and deployment. The first of these regional meetings will be held in conjunction with an Executive Committee meeting being planned for late 1997 or in 1998 in New Zealand. Senior officials from governments, utilities, financial institutions and other key organizations will be invited to briefings and open discussion on a full range of technology diffusion topics.

A decision was made to review and update the August 1993 *Strategic Plan 1994-1998*. This revision will take into account the further expansion of the wind industry and the changing role of the IEA.

On October 30, the Executive Committee visited the Stadtwerke Emden, the prototype 1.5 MW Tacke TW 1500 and the Enercon manufacturing plant where the prototype E-66 1.5 MW was inspected.

Planning Committee

The Planning Committee met on October 28, 1996 in Emden, Germany.

IEA Wind Energy Newsletter

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

THE IMPLEMENTING AGREEMENT

The IEA cooperation in wind energy started in 1977. Presently 19 parties, designated by the governments of 16 countries and the European Commission are participating. The cooperation is governed by "The Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems," or IEA R&D Wind for short. The Contracting Parties are

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

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

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

Task I	Environmental and meteorological aspects of wind energy conversion systems Operating Agent: The National Swedish Board for Energy

Source Development
Completed in 1981.

Task II — Evaluation of wind models for wind energy siting
Operating Agent: 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, Germany
Completed in 1983.

Task IV — Investigation of rotor stressing and smoothness of operation of large-scale wind energy conversion systems
Operating Agent: Kernforschungsanlage Jülich GmbH, Germany
Completed in 1980.

Task V — Study of wake effects behind single turbines and in wind turbine parks
Operating Agent: Netherlands Energy Research Foundation
Completed in 1984.

Task VI — Study of local flow at potential WECS hill sites
Operating Agent: National Research Council of Canada
Completed in 1985.

Task VII — Study of offshore WECS
Operating Agent: UK Central Electricity Generating Board
Completed in 1988.

Task VIII — Study of decentralized applications for wind energy
Operating Agent: UK National Engineering Laboratory
Technically completed in 1989.
Final report published in 1994.

Task IX — Intensified study of wind turbine wake effects
Operating Agent: UK National Power plc
Completed in 1992.

Task X — Systems interaction
Deferred indefinitely.

Task XI — Base technology information exchange
Operating Agent: Department of Fluid Mechanics, Technical University of Denmark
Continuing through 1996 and 1997.

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

Task XIII — Cooperation in the development of large-scale wind systems
Operating Agent: National Renewable Energy Laboratory (NREL), USA
Completed in 1994.
Final report published in 1995.

Task XIV — Field rotor aerodynamics
Operating Agent: Stichting Energieonderzoek Centrum Nederland (ECN), the Netherlands
Continuing through 1996.

Task XV — Annual review of progress in the implementation of wind energy by the member countries of the IEA
Operating Agent: ETSU, on behalf of the United Kingdom
To be completed in 1998.

Task XVI — Wind turbine round robin test program

Operating Agent: the National Renewable Energy Laboratory (NREL), United States
To be completed in 1998.

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 of work for several years. Several Tasks 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 Technology information	XIV Field rotor aerodynamics	XV Annual wind energy review	XVI Round robin test program
Australia	x		x	
Canada	x			x
Denmark	OA	x	x	x
European Union	x			
Finland	x			
Germany	x		x	
Greece	x		x	x
Italy	x		x	x
Japan			x	
Netherlands	x	OA	x	
New Zealand	x			
Norway	x		x	
Spain	x		x	
Sweden	x		x	
United Kingdom	x	x	OA	
United States	x	x	x	OA

TASK XI BASE TECHNOLOGY INFORMATION EXCHANGE

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

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

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

VOLUME	TITLE	1ST ED.	2ND ED.	3RD ED.
1	POWER PERFORMANCE TESTING Describes in detail in what way measurements shall be performed in order to get correct power curve for a wind turbine.	1982	1990	
2	ESTIMATION OF COST OF ENERGY FROM WIND ENERGY CONVERSION SYSTEMS States all the various elements and assumptions that enter a cost calculation.	1983	1994	
3	FATIGUE LOAD CHARACTERISTICS The correct procedure is described for getting a valid estimate of the fatigue life for the components of a wind turbine.	1984	1989	
4	MEASUREMENT OF NOISE EMISSION Noise being one of the potential nuisances caused by a wind turbine, the correct measurement of noise output is vital.	1984	1988	1994
5	ELECTROMAGNETIC INTERFERENCE This other possible source of disturbance caused by a wind turbine must be evaluated carefully and accurately.	1986		
6	STRUCTURAL SAFETY Outlines a rational procedure for setting up standards of safety.	1988		
7	QUALITY OF POWER The quality of the power output from a wind turbine needs to be described unambiguously.	1984		
8	GLOSSARY OF TERMS A comprehensive collection is compiled of the special terms used in the trade, with their proper definitions.	1987	1993	
9	POINT WIND SPEED MEASUREMENTS	1997		
10	NOISE EMISSION MEASUREMENTS	in preparation		
11	LIGHTNING PROTECTION OF WIND TURBINE GENERATOR SYSTEMS	in preparation		

b. Joint Actions

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

A. Recommended Practices for Wind Turbine Testing and Evaluation

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

The Experts Group preparing a recommendation on "Noise emmission measurements" held three meetings during 1996 (on March 25/26 at NWTC in Boulder, Colorado, on August 5/6, at ETSU, United Kingdom, and on November 25/28 at ENEL, Milan, Italy). The final document will be printed in 1997.

The Experts Group which will prepare a recommendation on "Point wind speed measurements" met at NEL, Glasgow, United Kingdom on February 22/23, 1996. The first draft of the final document will be published at the end of the year.

The Experts Group on "Lightning protection of wind turbine generator systems" had their first meeting at AEA, LTT, Culham, United Kingdom on February 7, 1996. A final document will be printed in 1997.

B. Joint Actions

Joint Actions are set up by the Executive Committee in a specific research area of current interest, in which 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, three Joint Actions have been initiated:

- Aerodynamics of wind turbines
- Fatigue of wind turbine blades
- Offshore wind systems.

The fourth symposium within the Joint Action on "Fatigue of wind turbine blades" was held on February 1/2, 1996 at DLR, Stuttgart, Germany.

The tenth symposium with the Joint Action on "Aerodynamics of wind turbines" took place on December 15/17, 1996 in Edinburgh, United Kingdom.

IEA supported a conference on off-shore wind energy systems in Mediterranean and European seas organized by ENEA and planned for April 10/11, 1997 in Maddalena, Italy.

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

Topical Expert Meetings

Topical Expert meetings are arranged once or twice a year, as decided by the Executive Committee. Attendance is by invitation through the national Executive Committee member, and the number of participants is limited to a few per country. The 28th Expert Meeting was held in Denmark on April 11/12, 1996, on "State of the art of aeroelastic codes for wind turbine calculations."

Proceedings are published by the Operating Agent.

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

Participating Organizations

Australia	The Energy Research and Development Corporation (ERDC)
Canada	Department of Natural Resources Canada

Table 3. IEA Wind Energy Expert Meetings.

1	Seminar on structural dynamics	12 Oct 1978	Munich, Germany
2	Control of LS WECS and adaptation of wind electricity to the network	4 Apr 1979	Copenhagen, Denmark
3	Data acquisition and analysis for LS WECS	26-27 Sept 1979	Blowing Rock, USA
4	Rotor blade technology with special respect to fatigue design	21-22 Apr 1980	Stockholm, Sweden
5	Environmental and safety aspects of the present LS WECS	25-26 Sept 1980	Munich, Germany
6	Reliability and maintenance problems of LS WECS	29-30 Apr 1981	Aalborg, Denmark
7	Costing of wind turbines	8-19 Nov 1981	Copenhagen, Denmark
8	Safety assurance and quality control of LS WECS during assembly, erection and acceptance testing	26-27 May 1982	Stockholm, Sweden
9	Structural design criteria for LS WECS	7-8 Mar 1983	Greenford, UK
10	Utility and operational experience from major wind installations	12-14 Oct 1983	Palo Alto, California
11	General environmental aspects	7-9 May 1984	Munich, Germany
12	Aerodynamic calculation methods for WECS	29-30 Oct 1984	Copenhagen, Denmark
13	Economic aspects of wind turbines	30-31 May 1985	Petten, Netherlands
14	Modelling of atmospheric turbulence for use in WECS rotor loading calculations	4-5 Dec 1985	Stockholm, Sweden
15	General planning and environmental issues of LS WECS installations	2 Dec 1987	Hamburg, Germany
16	Requirements for safety systems for LS WECS	17-18 Oct 1988	Rome, Italy
17	Integrating wind turbines into utility power systems	11-12 Apr 1989	Herndon, USA
18	Noise generating mechanisms for wind turbines	27-28 Nov 1989	Petten, Netherlands
19	Wind turbine control systems–strategy and problems	3-4 May 1990	London, England
20	Wind characteristics of relevance for wind turbine design	7-8 Mar 1991	Stockholm, Sweden
21	Electrical systems for wind turbines with constant or variable speed	7-8 Oct 1991	Gothenburg,Sweden
22	Effects of environment on wind turbine safety and performance	16-17 June 1992	Wilhelmshaven, Germany
23	Fatigue of wind turbines, full-scale blade testing and non-destructive testing	15-16 Oct 1992	Golden, Colorado, USA
24	Wind conditions for wind turbine design	29-30 Apr 1993	Risø, Denmark
25	Increased loads in wind power stations (wind farms)	3-4 May 1993	Gothenburg, Sweden
26	Lightning protection of wind turbine generator systems and EMC problems in the associated control systems	8-9 Mar 1994	Milan, Italy
27	Current R&D needs in wind energy technology	11-12 Sept 1995	Utrecht, Netherlands
28	State of the art of aeroelastic codes for wind turbines	11-12 Apr 1996	Lyngby, Denmark

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

Operating Agent

Department of Fluid Mechanics of the Technical University of Denmark

TASK XIV - FIELD ROTOR AERODYNAMICS

A joint research project involving five laboratories in four countries (Denmark, the Netherlands, United Kingdom, and 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 develop and verify aerodynamic models.

The work of this Task is completed. The final report was published in 1997. (1) The Task has resulted in a unique documented data base of aerodynamic measurements on different wind turbines. A total of about 125 time series of aerodynamic field measurements is available.

The measurements are obtained on five different wind turbines. The diameter of these turbines ranges from 10 to 27 m. Very different blades have been considered:

- blades without twist and taper
- a blade with twist but without taper
- blades with twist and taper.

Measurements have been supplied for very different conditions, including yaw misalignment. The angles of attack range between negative values and deep stall. The angle of attack has been varied by means of a variation in wind speed or eventually pitch angle or rotor speed.

All parties have provided:

- an aeroelastic model description to aid in the interpretation of the measurements
- measurements of ambient conditions
- measurements of operational conditions;
- measurements of global blade and rotor data (i.e. blade loads);
- measurements of local aerodynamic forces and inflow conditions.

The supply of local aerodynamic data is a major step forward in understanding the aerodynamic behavior of a wind turbine. In conventional experimental programs only integrated blade (or rotor) quantities are measured from which the local aerodynamic properties can be derived only indirectly.

The access to the data base is made as easy as possible. Therefore the files are stored in a uniform format. In addition, the conventions that have been applied in the data base are uniform and the file names are prescribed. Furthermore, statistical overviews are supplied for every file, which will assist the user to select relevant data.

The data base can serve as a validation base for the development and validation of aerodynamic models.

In interpreting the measurements and when comparing field data with wind tunnel experiments, it should be borne in mind that the definition of angle of attack, dynamic pressure and aerodynamic coefficients is less straightforward than in the wind tunnel case. Several methods are applied by the IEA Annex XIV participants for the determination of these quantities. A number of investigations were performed on behalf of Annex XIV or by the participants independently that addressed the problem of angle of attack, dynamic pressure and aerodynamic coefficients:

- In general, no conclusion could be drawn about the accuracy of the methods because no values for the "real" angles of attack and dynamic pressure were available to compare with.
- A mutual comparison of results and a

comparison with non-rotating wind tunnel data (from DUT and NREL) has led to the following indications:

- The mutual agreement between the mean angles of attack from the different methods was reasonable, at pre-stalled conditions often excellent.
- The mutual agreement between the dynamic pressure from the different methods was good.
- Although the unknown reference pressure can introduce uncertainties in the aerodynamic coefficients, the introduction of a method that did not suffer from this problem indicated that this uncertainty is limited.

It must be noted that the above mentioned indications are still premature and only based on measurements of turbines with untwisted untapered blade. More investigation is required in order to draw more thorough conclusions.

- The project served as a platform where very specific knowledge associated with aerodynamic measurements could be exchanged. This has been very instructive for all participants and enabled the acceleration of the experimental programs.

(1) J.G. Schepers, A.J. Brand, A. Bruining, J.M.R. Graham, M.M. Hand, D.G. Infield, H.A. Madsen, R.J.H. Paynter, D.A. Simms: "Final report of IEA Annex XIV, Field Rotor Aerodynamics." ECN-C-97-027, June 1997.

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

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

Objective

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

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

Means

The annual review will be based on the annual national reports submitted to the Executive Committee. A summary of progress in the implementation of wind energy during 1996 is included in this Annual Report (see page 19), and a full review will be published shortly afterwards as a stand-alone document, with references to the annual report, for those seeking more detailed information. A final report will be prepared after three years on completion of the Annex.

Participants

Australia	The Energy Research and Development Corporation (ERDC)
Denmark	The Ministry of Energy
Germany	Forschungszentrum Jülich GmbH
Greece	The Ministry of Industry/Energy and Technology
Italy	Ente per le Nuove Tecnologie, l'Energia el'Ambiente (ENEA); and ENEL, Società per Azione
Japan	The Government of Japan
Netherlands	The Netherlands Agency for Energy and the Environment (NOVEM)
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	AEA Technology plc
United States	The Department of Energy

TASK XVI - WIND TURBINE ROUND ROBIN TEST PROGRAM

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

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

Objective

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

Task Descriptions

- Development of test and analysis plan
- Procurement and installation of test turbines
- Preparation of test sites
- Testing of standard turbines and data analysis.

The Operating Agent is the National Renewable Energy Laboratory (NREL) in the United States.

Participants

Danish National Laboratory (Risø, Denmark)
ENEA (Italian National Agency for New Technology, Energy, and the Environment, Italy)
CRES (Center for Renewable Energy Sources, Greece)
Atlantic Wind Test Center (Canada)
National Renewable Energy Laboratory (USA)–Operating Agent

Status

After the program kick-off meeting, in April 1996, participants began detailed preparations for testing. These included drafting of test plans, initiation of anemometer wind tunnel calibrations, and initiation of site calibration measurements. Wind tunnel calibrations are being conducted in cooperation with a European Wind Turbine Standards program, MEASNET, in which anemometers from eight countries are being calibrated in ten wind tunnels.

Site calibration measurements (which quantify wind speed difference between the anemometer tower and the wind turbine) are being conducted by Risø and NREL. Tests at other test sites are expected to be conducted late in 1998.

The key element of the Annex is the Standard Turbine, an AOC 15/50. It was initially proposed by NREL and subsequently accepted by participants at the April 1996 kickoff meeting. The turbine is a 50-kW free-yaw configuration that is relatively easy to transport and install. However, the manufacturer, Atlantic Orient Corporation, initially had difficulties with suppliers and financing. As a result, the Annex has been delayed by one year. The turbine has now been delivered, checked by NREL and sent to Risø for installation. A second turbine has been installed and tests are being conducted at NREL. Power performance and noise tests are expected to be complete by spring of 1998 at both NREL and Risø. After tests are complete at Risø and the data is reviewed, the turbine will sent to Italy for testing by ENEA and CRES.

SUMMARY

The National Reports in this volume describe in some detail the wind energy activities and developments in the individual countries. This overview collates the information given in the National Reports on the status of the industry. When information relates to a specific country, its two letter national identification code is included in parentheses.

A full review comparing all aspects of national approaches to promoting the technology will be published in 1997 as a stand-alone document for those seeking a more detailed overview.

1. MARKET STIMULATION INSTRUMENTS

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

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

2. MAIN CONSTRAINTS ON MARKET DEVELOPMENT

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

3. COMMERCIAL IMPLEMENTATION OF WIND POWER

3.1. Installed Capacity

The annual installed capacity in the IEA member countries rose in 1996 by 913 MW compared to 863 MW in 1995 and 519 MW in 1994. This brought the total installed capacity in the member countries to 5152 MW. The number of new turbines actually fell slightly to 1849 (compared to 1951 in 1995 and 1518 in 1994) as the trend to replace smaller and older machines with larger ones of higher rated capacity continued. The average rating of the turbines installed during 1996 was around 500 kW.

The annual installed capacities and numbers of turbines for IEA member countries from 1994 to 1996 are shown on the following page. The increase in average rated capacity over the three years is apparent.

Worldwide the growth in wind system installations is continuing. During 1996, the total capacity increased approximately 1267 MW to 6172 MW. This includes wind systems in countries that are not members of the IEA Wind Agreement, e.g., India with 820 MW; Costa Rica, 20 MW; and China, 57 MW. The regional expansion in wind power plant capacity is shown in Figure 1. Growth was fastest in Europe and India and expansion is expected to

Table 1. Annual Installed Capacities and Numbers of Turbines for IEA Member Countries, 1994–1996.

COUNTRY	ANNUAL INSTALLED CAPACITY (MW)			ANNUAL NUMBER OF MACHINES INSTALLED		
	1994	1995	1996	1994	1995	1996
Australia		3.0	0		18.0	0
Canada	18.9	0.6	0.2	54.0	1.0	2.0
Denmark	52.0	98.0	169.0	142.0	199.0	343.0
Finland	0	2.0		0	4.0	
Germany	309.0	505.0	428.0	834.0	1070.0	808.0
Greece	0.7	0.7	0	3.0	2.0	0
Italy	10.2	0.6	48.4	36.0	1.0	105.0
Japan	0.9	3.7	4.4	8.0	13.0	16.0
Netherlands	22.0	100.0	47.0	93.0	255.0	129.0
New Zealand	0	0	3.5	0	0	7.0
Norway	0	0	0	0	0	0
Spain	23.4	47.0	96.5	86.0	149.0	220.0
Sweden	7.0	28.8	38.0	28.0	62.0	84.0
United Kingdom	33.0	35.1	70.4	74.0	71.0	122.0
United States	42.0	41.6	7.2	160.0	124.0	13.0
Totals	519.0	866.0	914.0	1518.0	1969.0	1849.0
Average (MW)				.34	.44	.49

increase in China and the United States in 1997 and 1998.

3.2. Performance of Installed Plant

Electricity Generation

The aggregate numbers for generation for the participating countries was 8,500 GWh during 1996 compared to 7,100 GWh during 1995 and 6,250 GWh in 1994. This increase could have been larger except several northern European countries reported an exceptionally low wind year.

Availability and Load Factors

Information on performance of installed plant continues to be sparse as few countries have a reporting system in operation and outside of these the information is regarded as commercially sensitive. Most commercial plants are reported to be operating with availabilities in excess of 95% and capacity factors as high as 0.4. Wind plant energy production depends on the wind speeds at the sites, with the best sites over 0.5 capacity factor. Spain reported the national average for all sites during 1995 was 0.28.

3.3. Operational Experience

In general the installed turbines performed well with few operational difficulties. Lightning strikes and icing resulting from extreme weather conditions at a few sites were the main operational problems.

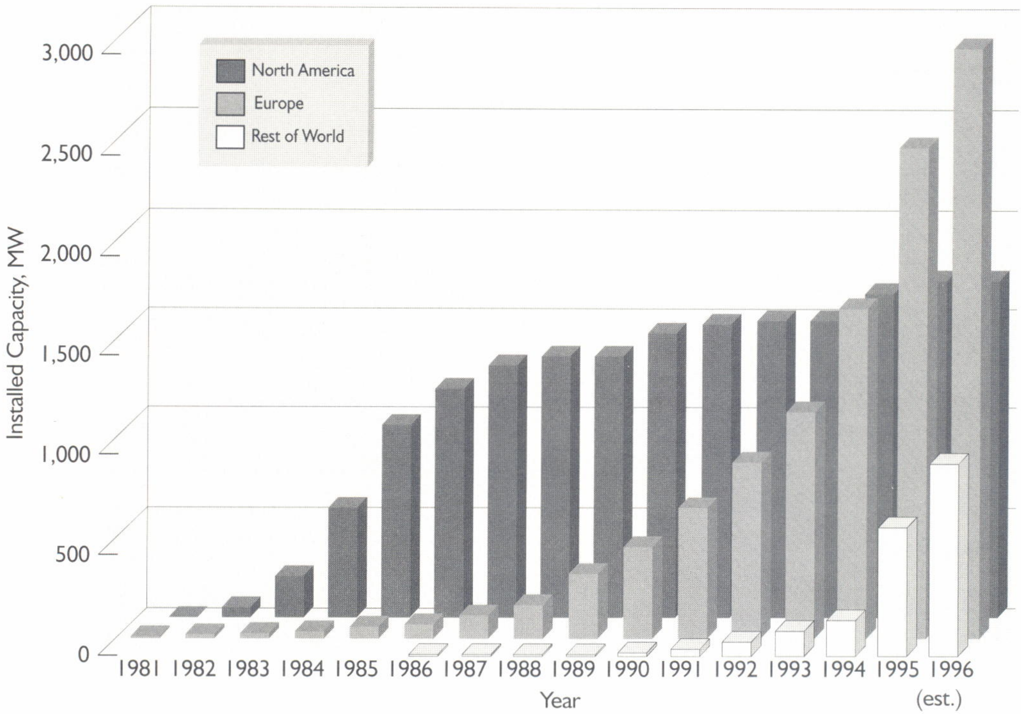


Figure 1. Wind energy capacity worldwide.

No major problem was reported on the integration of output into the electrical distribution systems. Large-scale integration was identified by several countries as a potential constraint on development in sparsely populated areas although the benefits of embedded (often called distributed) generation were also stressed.

4. ECONOMICS

4.1. Turbine Manufacturing and Project Costs

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

During 1996, the ex-factory costs of turbines fell slightly from the 1995 levels probably due to increased demand and reduced production costs per rated kW as the size of turbines increased. In 1996 the reported prices ranged from USD 635–1000 per rated/kW with a median of around USD 900/kW.

Total project costs also decreased in 1996 compared to 1995, with average reported costs varying in the range USD 940–1440/installed kW with an overall average of around USD 1200/installed kW. One would expect the variation in these costs to arise from the difficulty of working in the terrain in which the wind farm is installed and the ease of access to the electricity network

4.2. Invested Capital

The capital investment in commercial wind power can be calculated from the installed capacity and estimated total project costs per installed kilowatt. On the assumption that a plant installed during 1996 is costed at an average figure of USD 1200 per installed kW, and plants over all other years are costed at USD 1350 per installed kW (which is recognized as being only indicative), the aggregate investments in wind energy generation by the reporting countries are very approximately USD 1100M during 1996 and USD 6900M in total. Assuming that higher shipping costs overseas are offset by lower labor costs, the worldwide investment was more than USD 1500 million during 1996 alone.

5. MANUFACTURING INDUSTRY

5.1. Status of Manufacturing Industry.

The status of the wind turbine manufacturing industry in the individual countries depends strongly on the internal program of installation of capacity as most countries see wind power as an opportunity to develop an industrial manufacturing capability and use a high proportion of nationally produced machines. Thus the manufacturing industry flourishes most strongly in DE, IT, NL, ES, SW and US. The industry is even stronger in DK, which as well as having an internal installation program, exports turbines to many countries, both in the IEA regions and elsewhere. Two exceptions to the general trend are JP, which is maintaining a manufacturing potential mainly aimed at exports, and the UK where only one manufacturer survives due to the competitive nature of the support for installations which has resulted in developers importing cheaper turbines from overseas.

5.2. Technical and Business Developments

The trend toward turbines with increased rated capacity for the commercial market continued during 1996. Several 600/750 kW machines were available and manufacturers began producing commercial prototypes rated at or over 1 MW. Smaller machines, less than 50 kW, continued to be developed, usually through value engineering to make them lighter and more cost competitive.

5.3. Supporting Industries

As the sales of wind turbines grows, the market has become more buoyant for component manufacturers, especially as local sourcing of components is regarded favourably in several countries.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

6.1. R,D&D Funding

There are government-sponsored programs in all the countries either funded by the central government through government departments or agencies, or funded and managed by government-owned companies. The reported 1996 annual budgets for direct R&D work, excluding support for large scale demonstration, range from less than MUSD 1 (AU, CN, SF, NZ, NO, SW), through MUSD 1.0 to 7.5 (DK, DE, GR, IT, JP, NL, ES, UK) to MUSD 31 for the USA.

In Europe, overall R&D funding levels are higher than indicated as additional funding is available through the European Union which, of course, originates from the contributions of the individual national governments. The 1996 national funding levels show only small changes compared to those of 1995.

6.2. Priorities

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

National issues

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

Technology development

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

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

6.3. New R,D&D Developments

The main trends in turbine development during 1996 continued to be towards lighter, more flexible turbines, the use of direct-drive generators and variable-speed operation. The development of turbines of increased rated capacity for the commercial market also continued. New concepts under development are described in the individual national reports.

6.4. Offshore Siting

Interest in the offshore siting of turbines is, in the main, limited to those countries where there is a shortage of suitable sites on land (IT, SW) or where population density precludes extensive on-land development because of environmental intrusion (DK, NL, UK). By the end of 1996, Denmark had two offshore wind farms of 5 MW each in operation. The Netherlands (4 x 500 kW) and Sweden (1 x 220 kW, 5 x 500 kW planned) had mounted demonstration projects and Italy had a small R&D program. In the UK, some developers have begun to formulate plans for the siting of turbines in near-shore waters.

6.5. International Collaboration

There is strong multi-national collaboration from Europe through numerous JOULE and THERMIE projects which are partially funded by the European Union. The US has bilateral technical assistance agreements with several countries. In seeking to establish overseas trade, most countries are actively seeking collaboration with countries and regions with large potential markets (e.g., India, China and South America).

AUSTRALIA

The end of 1996 saw some uncertainty as to the future of wind energy in the newly deregulated electricity market in Australia, though substantial new commercial wind projects have been announced, which should see the installed capacity rise by 250% to 10 MW by the end of 1997. Some of these announcements have followed a new interest by utilities in the "green energy" market, typically in which the utility offers the customer a renewable energy tariff or the opportunity to install their own renewable energy equipment. Customer response so far is positive. These announcements have also formed part of the electricity community's contribution to greenhouse gas abatement in Australia.

In New South Wales (NSW), a continuing wind monitoring program by Pacific Power has seen them announce the development of the first wind farm in NSW at Crookwell, in the state's southern highlands. The farm, with a nominal 5–MW rating, is still to pass the planning and environmental approval process but is expected to be operating by the end of 1997, at which time it will be the largest wind farm in Australia. Pacific Power has also recently refurbished its 150–kW Windmaster turbine at Malabar in Sydney, and has an ongoing study to identify the types of turbines best suited to the wind regimes in NSW. Another wind energy development is being undertaken by energyAustralia at Kooragang Island in Newcastle, where a single 500–600 kW turbine has gone to tender and should be operating by June 1997. This single machine is to supply some of the energy for energyAustralia's renewable energy tariff, which was launched in August 1996 to a trial area. This tariff will be eventually offered to all of energyAustralia's three million customers, and more turbines are expected to be installed to meet the future tariff demand.

In Tasmania, The Hydro-Electric Corporation announced the development of an AUD 2.5 million wind farm at Huxley Hill, on King Island, which lies in Bass Strait between the Australian mainland and Tasmania. The average wind speed at the site is better than 9 m/s at a 30-meter height, making it ideal for wind energy. The farm will initially consist of between two and five turbines feeding into the existing diesel powered grid, with a maximum expected penetration of about 18%. Presently four 1200-kW diesel generators power this grid. A similar off-grid wind/diesel turbine installation was announced for Queensland by the Far North Queensland Electricity Board for a two turbine installation on Thursday Island, just off Cape York in Torres Strait between the Australian mainland and New Guinea. The tendering process has already been completed for this installation with two Vestas 225-kW turbines being selected.

In mid-1996, the ETSA Corporation of South Australia announced an AUD 0.5 million commitment to conduct a study to determine the commercial viability of a 5–MW wind farm in that state. A site in the Fleurieu Peninsula has been selected, with a 40-meter wind monitoring mast installed to supplement the two years of wind monitoring already completed at 10 meters and provide for a more accurate prediction of the wind energy potential. The overall study is expected to be completed by the end of June 1997.

In Western Australia, the two wind power plants owned and operated by Western Power at Esperance in the state's south continued successful operation with a combined output in 1996 of 7 GWh, saving about two million liters of fuel oil in the area's 14-MW diesel powered grid. Western Power also continued assessments for more wind turbine installations at both remote area grids and for their large interconnected southwestern grid, where the inclusion of a large wind power plant is being investigated. At the end of 1996, the diesel-powered grid at Denham is the most likely next turbine installation, with a variable speed Lagerwey 30/250 expected to be installed in 1997. An option being pursued for the Denham site is the inclusion of a large zinc bromide battery set for grid regulation.

During 1996, the federal government formed the Australian Co-operative Research Centre for Renewable Energy (ACRE), aimed at assisting the development of a world competitive renewable energy industry in Australia through research and innovation. ACRE manages a partnership between government research institutions, universities, and private companies, and will in time have eight separate but interconnected programs involving a wide range of renewable energy technologies and issues. One of these programs, the Power Generation Program, involves the development of small independent wind turbines up to 50 kW. This should result in a range of turbines designed and operating in various locations in Australia within the next few years, with the wind program expected to run for a total of seven years with total funding, including private commitments, of around AUD 4.5 million. Total ACRE funding for all programs for the same period is in excess of AUD 50 million.

CANADA

1. GOVERNMENT PROGRAMS

1.1. Aims and Objectives

The focus of the Canadian National Program continues to be in R&D support and field trials.

1.2. Strategy

The main elements of the Wind Energy R&D program are Technology Development, Resource Assessment, Test Facilities, and Information/Technology Transfer. Field trial projects are selected to evaluate the performance of the equipment under special environmental conditions or for specific applications.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed Wind Capacity

- CWT Power 1.2 MW
  The Adecon turbines were inspected thoroughly and some modifications, e.g., strengthening blade root, have been carried out. The turbines have been put into service. All of the machines will be fitted with a new control system that has been designed and tested.
- Canadian Niagara Power Co.
  18.9 MW
  9 MW - Kenetech 350-kW turbines in operation since January 1, 1994

  9.9 MW - Kenetech 350-kW turbines in operation since September 1, 1994
- Various other small installations with a total capacity of 2.5 MW

2.2. Installed Conventional Capacity

The total conventional installed capacity in Canada at the end of 1995 (the most recent year for which statistics are available) was 114,470 MW, which includes coal, oil, natural gas, nuclear and hydro power plants.

2.3. Numbers/Type, Make of Turbines

100-kW and 150-kW VAWT Adecon turbines with external support frame constant speed, stall controlled.

33 M-VS, 350-kW Kenetech turbines with variable speed, variable pitch blades and lattice tower.

2.4. Performance

The total wind energy production in 1996 was 61 GWh.

2.5. Operational Experience

Operating experience with the two main wind power plants (CWT Power and Canadian Niagara Power), is limited to energy output figures.

An 80-kW Lagerwey turbine was installed at Cambridge Bay, Northwest Territories (NWT) in October 1994. The turbine is performing very well. The oil in the yaw mechanism became thick during very cold weather in January 1995. This slowed the rate of yaw considerably. The oil was changed to a grade more suitable for cold weather and it cured the problem. This lead to two additional Lagerway turbines being installed at Coppermine, NWT.

Tacke Windpower Inc. (TWP) of Huron Park, Ontario, as per an agreement with NRCan, has installed a 600-kW turbine near Kincardine, Ontario. The turbine, modified for cold weather conditions, has been undergoing evaluation since the beginning of October 1995. The turbine has been performing trouble free. It was producing more power than the generator rating due to higher density. This was fixed by changing the blade pitch. TWP has started to manufacture and export blades for the Tacke 600 wind turbine.

The 150-kW Bonus turbine installed on the Haeckel Hill (1450 m height) near Whitehorse in Yukon was commissioned in August 1993. The turbine's energy output in 1996 was 453,875 kWh.

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

3. MANUFACTURING INDUSTRY

3.1. Status/Number/Sales of Manufacturers

- Dutch Industries (water pumps), Regina, Saskatchewan
- Koenders, (water pumpers) Englefield, Saskatchewan
- CWT 150 kW is the only turbine designed and manufactured in Canada by CWT Power International Ltd. of Calgary.
- Tacke Windpower Inc, Huron Park, Ontario is manufacturing sets of blades for Tacke 600-kW wind turbines.
- Some components for the Atlantic Orient 50 kW and for Lagerway 80 kW are also manufactured in Canada.

3.2. Support Industries

- Control system, inverter, tower manufacturers

4. ECONOMICS

4.1. Electricity Prices

Electricity prices varied depending on the province and sometimes even within the same province. The price range in January 1996 was

- for residential customers: from CAD 0.066/kWh to CAD 0.141/kWh
- for commercial customers: from CAD 0.067/kWh to CAD 0.142/kWh (based on 100 kW billing demand)
- for industrial customers: from CAD 0.048/kWh to CAD 0.085/kWh (based on 1,000 kW billing demand)

4.2 Invested Capital

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

5. MARKET DEVELOPMENT

5.1. Market Stimulation Instruments

Curently, Class 43.1 of the federal Income Tax Act provides an accelerated capital cost allowance (30% capital cost allowance rate computed on a declining balance basis) for certain types of renewable energies—essentially equipment used to generate electricity or to produce thermal energy for direct use in an industrial process.

As well, the government is considering now the extension of the use of flow-through share financing currently available for non-renewable energy and mining projects to include intangible expenses in certain renewable projects, by creating a new Canadian Renewable and Conservation Expense category in the income tax system.

5.2. Constraints

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

5.3. Environmental Impact

There have been no bird kills reported from Haeckel Hill installation and the five wind turbines at the Atlantic Wind Test Site in Prince Edward Island (PEI).

5.4. Financial Aspects

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

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

- Development of the High-Penetration-No-Storage Wind/Diesel system by Hydro-Quebec and the Atlantic Wind Test Site (AWTS) has been completed. Hydro-Quebec is now evaluating the implementation of a full scale system in a remote community.
- The Lagerwey 80-kW wind turbine is undergoing testing at AWTS and is being fitted with a control system and an inverter. The Northwest Territories Power Corporation has installed two additional units at Coppermine, NWT.

The program also supports two test sites:

- Atlantic Wind Test Site at North Cape, PEI, for testing electricity generating wind turbines and wind/diesel systems, and
- Alberta Renewable Energy Test Site at Pincher Creek, Alberta, for testing wind and PV water pumping systems.

Canadian industry has collaboration with Tacke Windtechnik of Germany, Lagerwey of the Netherlands and Atlantic Orient Corporation of Vermont, USA.

Figure 1. The 80-kW Lagerway wind turbine operated by Dutch Industries Ltd. at Cambridge Bay, Northwest Territories.

1. GOVERNMENT PROGRAM

1.1. Aims and Objectives

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

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

1.2. Strategy

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

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

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

A second 100-MW agreement between government and utilities reached in 1990 was finally implemented in 1996 after a delay of about 2.5 years due to various siting problems. According to a third executive order from the government, the electric utilities are now committed to install an additional 200 MW of wind power before 2000, 120 MW in the Elsam area and 80 MW in the Elkraft area. In view of the increasing problems of finding acceptable onshore sites, much work and many investigations are carried out to find offshore sites. Despite this, the effort to finish the ongoing planning work regarding onshore plants continues, as all Danish municipalities have been asked to prepare municipal planning for siting of a relevant number of wind turbines within their districts.

1.3. Targets

Recently, the government has published a new action plan called "Energy 21." In the section dealing with wind energy, it is specified that the final target for 2005 is a capacity of 1500 MW of wind power, supplying 10% of the country's electricity demand. This calls for an average installation rate of about 100 MW per year, including both private and utility installations.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed Wind Capacity

Installation of modern grid-connected wind turbines in Denmark began in 1976, but no significant progress was seen until ten years later. Cumulated data for number and power capacity by the end of 1986 was about 1250 turbines and 80 MW.

As of 31 December 1996, the total number of grid-connected wind turbines in Denmark, privately as well as utility owned, was 4168 units with a total electrical output capacity of 785 MW.

Data on privately owned turbines were 3545 units, totalling 590 MW installed power. The corresponding numbers for utility owned machines were 623 turbines, totalling 195 MW of capacity.

The total increase in 1996 was 343 turbines with an output capacity of 169 MW. The utilities installed 32 new turbines with an output capacity of 16 MW. Private individuals installed 307 turbines with a total capacity of 152 MW. In comparison, the total increase in 1995 was 136 turbines with a capacity of 80 MW.

The average capacity of all new installations in 1996 was 495 kW: 500 kW for utility turbines and 495 kW for private machines.

2.2. Installed Conventional Capacity

As of 31 December 1996, the maximum continuous net capacity of the Danish power generation system was just more than 10,000 MW (including wind turbines). Installed wind power capacity was 785 MW; i.e., 7.85% of the total national capacity. The domestic consumption of electricity in 1996 was about 32.000 GWh.

2.3. Numbers and Types of Wind Turbines

All wind turbines installed in Denmark are of Danish origin. About 20% of installed power is installed in wind power plants. The location of the utility-owned wind power plants is indicated in Figure 1, and the specifications are outlined in Table 1. With some exceptions,

Table 1. Utility Wind Power Plants in Denmark.

LOCATION	MANUFACTURER	NUMBER/ CAPACITY	TOTAL MW	SITING YEAR
Masnedø	Vestas/DWT	5 x 750 kW	3.750	1985
Syltholm 1-3	Vestas/DWT	25 x 400 kW	10.000	1988/90
Kyndby	Danwin	21 x 180 kW	3.780	1988
Bavnebanke	Danwin	7 x 225 kW	1.575	1990
Kappel	Vestas/DWT	24 x 400 kW	9.600	1990
Orø	Micon	5 x 200 kW	1.000	1990
Vindeby, offshore	Bonus	11 x 450 kW	4.950	1991
Nøjsomheds Odde	Vestas	23 x 225 kW	5.175	1992
Avedøre	Bonus	6 x 300 kW	1.800	1992
Jenslev	Vestas	5 x 225 kW	1.125	1993

Utility wind power plants, Elkraft Area: 42.755 MW

Table 1. Utility Wind Power Plants in Denmark (continued).

LOCATION	MANUFACTURER	NUMBER/ CAPACITY	TOTAL MW	SITING YEAR
Hollandsbjerg	Nordtank	30 x 130 kW		
		2 x 300 kW	4.500	1988
Ryå	Wincon	20 x 99 kW		
		3 x 200 kW	2.580	1988
Nørrekær Enge 1	Nordtank	36 x 130 kW	4.680	1988
Nørrekær Enge 2	Nordtank	42 x 300 kW	12.600	1990
Torrild	Bonus	16 x 150 kW	2.400	1989
Velling Mærsk 1	Vestas	34 x 90 kW		
	Vestas	2 x 200 kW	3.460	1987
Velling Mærsk 2	Vestas	29 x 225 kW	6.525	1990
Vedersø Kær	Vestas	27 x 225 kW	6.075	1990
Dræby Fedsodde	Wind World	12 x 220 kW	2.640	1991
Brøns	Micon	8 x 400 kW	3.200	1992
Fjaldene	Vestas	13 x 500 kW	6.500	1994
Abild	Wind World	5 x 500 kW	2.500	1994
Rejsby Hede	Micon	39 x 600 kW	23.400	1995
Tunø Knob, offshore	Vestas	10 x 500 kW	5.000	1995
Klim	Vestas	13 x 600 kW	7.800	1996
Hanstholm	H. møllen	3 x 525 kW	1.575	1996
Veldbæk	Nordtank	3 x 500 kW	1.500	1996
Emmerlev	Micon	4 x 600 kW	2.400	1996

Utility wind power plants, Elsam Area: 99.335 MW

a wind power plant is defined as a cluster of wind turbines comprising five or more adjacent units. Details regarding siting of private wind power plants were given in the *IEA Wind Energy Annual Report 1995*, see Reference 3.

2.4. Plant Types and Form of Ownership

Wind turbines installed in Denmark are owned by utilities, private co-operatives, 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 manufactures and in the following years are maintained by private service companies.

Developers, like those in the United States, do not operate in Denmark.

2.5. Performance of Wind Power Plants

Cumulated electricity generation by wind turbines in Denmark during the years 1976–1986 was about 300 GWh. By the end of 1996, the total output over all years increased to about 7952 GWh.

In 1996, the total electricity production by wind turbines was 1245 GWh, which supplied about 4.6% of the annual Danish electricity consumption. For privately and utility owned turbines, the numbers were respectively 939 GWh and 310 GWh (provisional data).

2.6. Operational Experience

The technical availability of new Danish wind turbines is usually in the range of 98%–99%. The capacity factor, also for new turbines, is site-dependent, but a typical value is in the range of 0.23–0.27 for sites with roughness class 1. This corresponds to 2000–2400 full load hours per year.

On a voluntary basis, operational statistics for about 2500 wind turbines installed in Denmark are reported every month to the Danish edition of the *Wind Stats Newsletter*, published by the Windpower Monthly News Magazine. In addition to monthly production records, all operational incidents/accidents are reported, subdivided into 15 categories. As far as possible, failure causes are also reported frequently, as well as lightning strikes and loss of grid accidents.

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

The problem of generation of "surplus power" by wind turbines has also called for attention. The Elsam utility has recently announced that the grid as a whole now faces that problem during about 1000 hours each year.

3. Manufacturing Industry

A Danish home market for wind turbines and a wind turbine industry was first established during the years 1979–1981, strongly stimulated by an installation subsidy of 30%, which was gradually reduced during the following years and finally expired in August 1989. 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.

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

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

As of December 1996, about 9500 people were employed by the Danish wind turbine industry: 1970 by manufacturers and 7530 by subcontractors, consultants, and service companies.

The number and capacity of domestic installations was reported in Section 2.1. Cumulative figures for the number of turbines and capacity sold abroad are approximately 12,425 turbines with a capacity of about 1950 MW. The total value of this production volume equals about DKK 13,350 million, and, assuming 30% of this amount being the value of imported components (gearboxes, generators, etc.), the net value is about DKK 9250 million.

Danish exports in 1996 accounted for 944 wind turbines (complete units) with a total capacity of 505 MW and a total value of about DKK 3000 million. This represents a slight decrease in relation to 1995. In return the home market expanded by about DKK 460 million. The total turnover in the industry was about DKK 4100 million. The turbines have over the years been sold to about 45 countries all over the world.

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

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

The power range is rapidly expanding. Machines with ratings of 600 kW are now commercially available, and at present, three Danish manufacturers (Bonus, Nordtank, and Vestas) have designed and installed one 54-m/1-MW and two 60–m/1.5-MW prototype machines at Tjæreborg in Jutland. These prototypes were ordered by the Elsam utility in order to promote the technological development of wind turbines. They are cofunded by the European Union, DG XII and XVII.

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

4. ECONOMICS

4.1. Electricity Prices

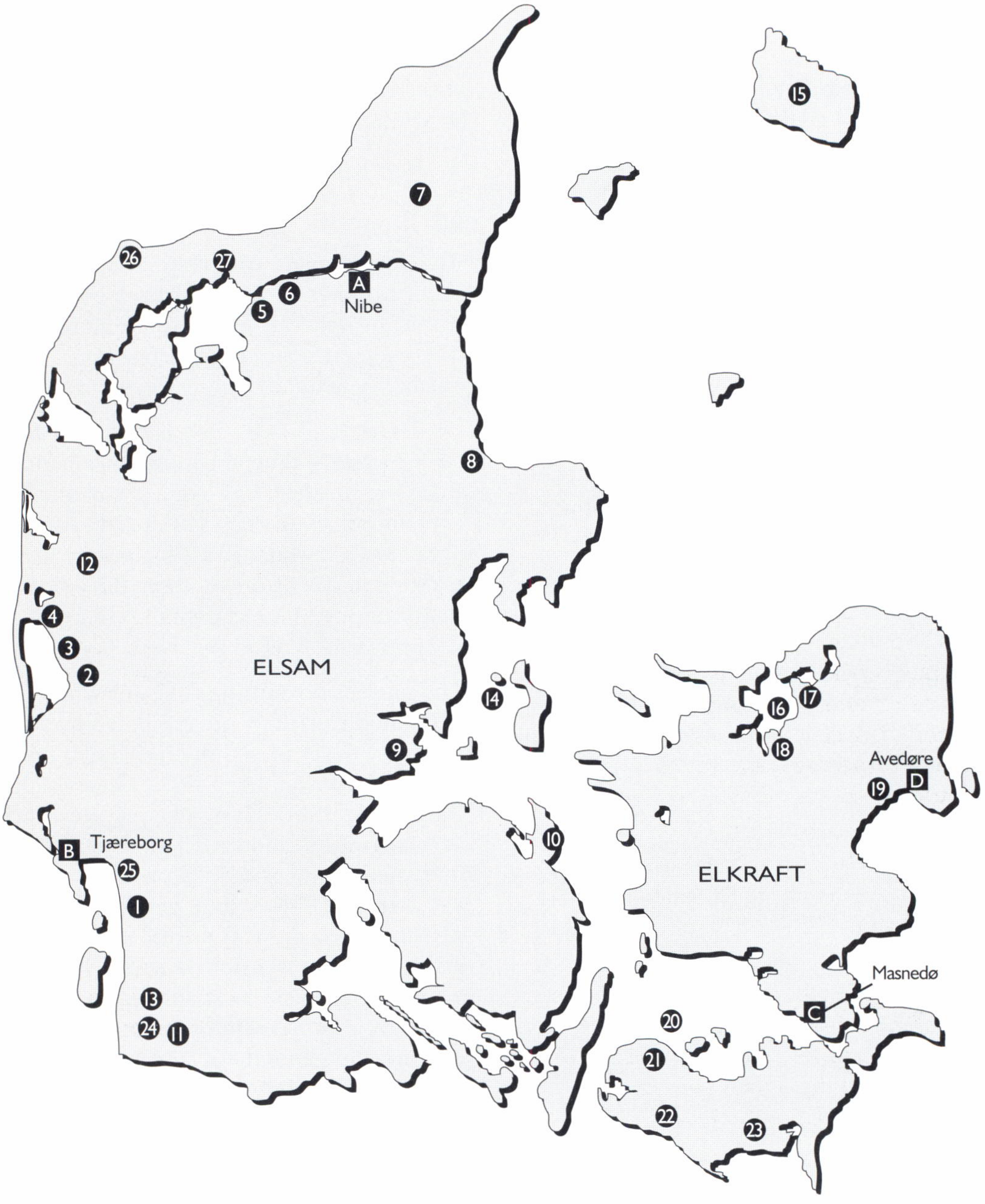
The development of private, small-scale wind turbines is no longer promoted by public installation subsidies. Reasonable buy-back rates and exemption from electricity taxation is now the main economic incentive.

At the present time, the average consumer price for a Danish low-voltage customer consuming about 3000 kWh per year is about DKK 0.94 per kWh, including taxation and VAT (generation: 0.28, distribution: 0.10, electricity tax: 0.27, CO_2 tax: 0.10, VAT: 0.19).

The present accounting rules for wind-generated electricity are regulated by a statutory order issued by the Ministry of Energy on November 1, 1993. On average, the electric utilities now pay private wind turbine owners about DKK 0.58 per kWh delivered to the grid. This price is calculated as 85% of total generation and distribution costs (DKK 0.31) plus a government subsidy of DKK 0.27 per kWh. The subsidy is considered to be partial reimbursement of the carbon dioxide and general electricity taxes paid by the wind turbine owners as private consumers.

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

The utilities get a production subsidy of DKK 0.10 per kWh of electricity generated in utility wind power plants as reimbursement of the general carbon dioxide tax. For utility production, the



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

Figure 1. Utility prototypes and wind power plants in Denmark 1996.

level of subsidy for 1995 was DKK 22 million paid out.

4.2. Invested Capital

It is difficult to calculate the total invested capital over the years exactly, but government subsidy figures give an indication. In the ten-year period 1979–1989, cumulative installation subsidies for about 2550 private wind turbines were DKK 275 million. As previously mentioned, the installation subsidy expired in 1989.

Invested capital in Denmark for 1996, assuming installation of 168 MW and an average cost of DKK 6500 per kW, amounts to DKK 1092 million. Assuming an average installation cost for all years of DKK 9.750 per kW, the total cost of the installed 785 MW is calculated at DKK 7654 million.

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

Adding the CO_2 tax, DKK 0.10, to this figure, the value of electricity produced by utility turbines amounts to DKK 0.40 multiplied by the power generation in 1996. That is DKK 124 million.

The value of privately wind-generated electricity is DKK 0.58 multiplied by the power generation in 1996. That is DKK 545 million.

4.3. Turbine and Project Costs

The total installation costs for 500–600 kW wind turbines installed in wind power plants are at present time in the range of DKK 6000–7000 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 costs, the total production cost is in the range of DKK 0.27–0.35 per kWh depending on the wind regime at the specific sites.

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

Neglecting the discussion about capacity credit, it can be added that new coal-fired plants generate electricity at an average price of DKK 32–35 per kWh, including distribution costs. The average cost on a national basis is about DKK 36.5 per kWh.

4.4. Financing and Warranties

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

Private wind turbines are usually owned by co-operatives, and currently the most common financing is by 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 the parties enter into various service agreements. In addition, an all risk insurance warranty is mandatory for the first five years covering machine breakdown, electricity production according to power curve and wind regime, and third-party liability. After the initial five years, the insurance warranty only covers machine breakdown and third-party liability.

5. MARKET DEVELOPMENT

5.1. Market Stimulation Instruments

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

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

5.2. Constraints

The subject is dealt with in the following two sections.

5.3. Institutional Factors

Planning Policy

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

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

Certification

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

The new approval system for wind turbines specifies requirements for documentation of all design criteria, such as load cases and loads, fatigue evaluation, safety levels, power curves, noise emissions, quality procedures 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 installed in Denmark after July 1, 1992, must be approved and certified according to the new system. Furthermore, it is a condition for obtaining export guarantees from the Danish Wind Turbines Guarantee A/S that wind turbines must be approved and certified according to the new system.

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

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

Safety Aspects

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

5.4. Environmental Impact

Visual Intrusion

The public attitude in Denmark is, in general, in favour of wind energy but the "not in my backyard syndrome" is becoming more widespread. This means that the planning procedure for both turbines and wind power plants is more complicated than in earlier days. Visualization studies are now normally required by authorities as part of planning applications. Manufacturers are trying to take the public attitude into account by reducing the wind turbines' noise level and improving the aesthetic design of the turbines.

Acoustic Noise Emission

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

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

5.5. Environmental Studies

Impact on Bird Life

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

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

The latest initiative in this area is implementation of a comprehensive study of bird life around an offshore wind power plant installed at Tunø Knob, see Section 6.5.

Ecology

In some parts of the world, installation of wind turbines has a damaging effect on ground conditions and vegetation 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.

5.6. Financial Aspects

Utility wind power plants are financed by utilities and the quoted interest rate is the so-called real interest rate. Private wind turbines are usually financed by a ten-year bank loan at the current bank rate.

6. GOVERNMENT SPONSORED R,D&D PROGRAM

6.1. Funding Levels

Total government funding of R&D work during the years 1976–1996 was about DKK 350 million, and for demonstration projects the funding was about DKK 170 million.

The total amount being spent by the Danish government on R&D for 1995 was DKK 40 million. Of this amount, DKK 12 million was used as support for generic research (60% of the total amount). 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.

6.2. Priorities

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

6.3. New Concepts

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

During recent years, much design and construction work has also been spent on new small-scale wind turbines (5–25 kW). The motivation for this effort is that such a turbine often suits the needs of individual farmers, and it may also be a good candidate for stand-alone purposes.

6.4. MW-rated Turbines

The status for the development of MW-sized machines was briefly mentioned in Section 3, and status for the older large-scale projects at Nibe, Masnedø and Tjæreborg has been reported regularly in the *Wind Energy Newsletter* published by the IEA.

The new 50-m/1-MW wind turbine at Avedøre south of Copenhagen was inaugurated in September 1994 and is performing well. It has for two years been operated in the stall mode, and lately additional experiments with vortex generators on the blades have increased the power production at wind speeds below rated power. The next step in the test procedure is to use pitch control for power limitation.

Status for the three new large-scale prototypes at the Tjæreborg site is as follows: the Bonus machine (50 m/750 kW) installed in 1994 suffered from an overspeed accident in October 1995, causing serious damage to the rotor. The accident was caused by failures in the pitch bearings preventing the blades to move to the stop position. A new and bigger machine (54 m/1 MW) is now in operation. The Nordtank machine (60m/1.5 MW) was installed in September 1995 and the Vestas machine (60 m/1.5 MW) at mid-1996. In all cases commissioning is now progressing well.

6.5. Offshore Siting

The first Danish offshore wind power plant was commissioned in 1991. The site is at Vindeby, Northwest of Lolland in the Baltic Sea. The wind power plant consists of 11 turbines in two rows. Each turbine is rated at 450 kW, and hub height and rotor diameter are respectively 37.5 m and 35 m. The total installation costs of the project were DKK 7 million, and assuming a depreciation period of 20 years and a real interest rate of 5%, the cost of energy is calculated at DKK 0.56 per kWh. In addition to the installation costs, the running measurement program accounts for DKK 4 million. The reported availability exceeds 96%.

A second Danish offshore wind power plant was installed by ELSAM in 1995 at Tunø Knob in the area between Jutland and Samsø. Installed capacity is 5 MW consisting of 10 Vestas V39 turbines. The total installation costs were about DKK 74 million, and by experience from the first 6 months of operation, the cost of energy is expected to be about DKK 0.47 per kWh. This calculation is based on the following assumptions: annual production 15 GWh, depreciation period 20 years, interest rate 5.5% and O&M costs DKK 0.055. The above-mentioned installation cost does not include about DKK 5 million to finance a comprehensive study of bird life around this offshore wind power plant, because it is located in an environmentally sensitive area.

6.6. International Collaboration

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

7. REFERENCES

(1) Ministry of Environment and Energy, Spatial Planning Department: "Municipal Planning for Wind Energy in Denmark. Examples and Experience." Published 1995.

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

(3) *IEA Wind Energy Annual Report 1995*, pp. 34–35.

FINLAND

The Finnish wind energy R&D activities are carried out under the new energy technologies research program NEMO2, coordinated by Helsinki University of Technology and funded by the Technology Development Centre. The public funding level has been maintained on a level of about 2 MFIM/year and it accounts for 60% of the funding (the rest is from industry, utilities and the research organizations). The focus has been on the development and adaptation of wind technology for the northern climate. The turbine blade heating system developed at the Pyhätunturi test site has had its first commercial application in two 450-kW Bonus turbines, operated by a daughter company of the utility Kemijoki Oy. Future activities will concentrate on further product development of the heating system. Research and measurements on ice loads will also be emphasised at the Pyhätunturi test site. A project to develop foundations suitable for offshore areas with notable sea-ice loads has been started with partial funding by two utilities operating on the coastal areas. The first offshore installation is planned to follow in 1998 in the Gulf of Bothnia. The development of direct drive generators using permanent magnets is at the prototype stage.

VTT and the Finnish Meteorologic Institute have been active in participation in a number of EU JOULE projects. Among them, FMI is coordinating the project Wind Energy production in Cold Climate (WECO) and VTT a feasibility study for Kola-region in Russia. The NEMO2 program comes to an end in 1998. The R&D program is planned to be continued with emphasis on the components for wind turbines. A number of projects that fit under this theme have been started or are in planning and funding stages. These include two JOULE projects concerning blade materials and design.

The Finnish industry continues to supply wind turbine components such as generators, gear boxes, blade materials and, as a new product, towers and their parts have been exported to a value of about 250-300 MFIM in 1996. The growth of the wind industry in general has been notable for the component manufacturers.

During 1996 only 0.9 MW new wind energy was installed, bringing the total capacity to 7.2 MW. Two turbines of 450 kW were erected on top of the fell "Lammasoaivi" in Northern Lapland. Several other projects were scheduled for 1996 but were delayed for different reasons. In 1997 about 5 MW new capacity is expected. Based on current feasibility studies and known plans, the best estimate of total installed capacity in 2000 is 20-35 MW. The 100 MW program of the Ministry of Trade and Industry, launched in 1993, has not yet got up to speed. The developers have faced several obstacles: difficulties in getting building permission, lengthy subsidy decision procedures and the non-existence of pay-back rules or energy production guidelines. A working group, set up by the Ministry of Environment, has written a recommendation that should make it easier for local authorities to issue building permits, and several regional studies identify windy areas that have no conflicting interests. These are now ready for the south-western archipelago, part of the western coast and for Lapland mountains. The Government is at present preparing the long-term energy strategy. It is probable that wind energy and other renewables (mainly biofuels) will receive a more important role than previously.

GERMANY

1. GOVERNMENT PROGRAMS

1.1. Aims and Objectives

The actual program, the 4th Program for Energy Research and Technology, has been in force since 1996 and has again been carried out by the Federal Ministry for Education, Science, Research and Technology (BMBF) (1).

The program consistently follows the goals of the former programs to conserve limited resources, to improve the security of the German energy supply, and to protect the environment and the climate. Two general objectives are emphasized

- creation of the necessary prerequisites to conserve finite sources of energy.
- contribution to the modernization of the national economy, to maintain the German technology position, and to improve exports.

Research and technology policy should set boundary conditions that allow the development of a sufficiently broad spectrum of technical options.

1.2. Strategy

The strategy of the R&D funding of the 4th program follows three aims.

a) Improvement of the performance and reliability of existing technology.

b) Development and demonstration of technological concepts for the future.

c) Support of basic research for a) and b).

In the short- and medium- term, an important contribution to decrease energy consumption and to reduce CO_2 emissions is expected from the improvement of thermal power stations and a further use of rational energy. From today's point of view, nuclear power has one of the largest potentials to reduce CO_2 emission, but its further utilization is politically disputed. The government politics maintain that this energy source should contribute to the energy mix of Germany.

In the medium- or long-term, renewable energies are considered to contribute significantly to the German energy supply and to reduce CO_2 emissions: Technically rather advanced but not economically competitive in all cases is the utilization of heat (solar thermal, heat pumps, biomass) and electricity (wind power, waste contribution, biomass, photovoltaic). A long-term perspective for the energy supply is controlled nuclear fusion. Here R&D is considered to be important and is thus supported considerably by the program.

The full range of strategy measures covers various technologies. For this report, the item Renewable Energies and Rational Use is of special interest. Table 1 shows the technologies of this part and the expenditure of BMBF for the period of the 3rd Program for Energy Research and Energy Technologies (see Reference 1). Wind energy R&D Projects are covered by "Wind energy-project funding" including the demonstration of large scale prototypes. The demonstration program 250 MW Wind is covered by "Wind energy-indirect-specific funding." The ELDORADO Program Wind, a further demonstration program, is part of "Application systems for southern climatic conditions" in Table 1.

1.3. Target

The 4th Program for Energy Research and Energy Technologies is related to the political target of the German government to reduce the CO_2 emissions until 2005 by 25% compared with 1990. The sustained implementation of the program will

Table 1. Expenditure of the 3rd Program of Energy Research and Energy Technologies for the area Renewable Energy Sources and Rational Energy Use, DEM million (1).

TECHNOLOGY	1990	1991	1992	1993	1994	1995
Photovoltaics-project funding	91.6	101.0	90.4	81.9	56.4	58.0
Photovoltaics-indirect-specific funding	0.3	3.0	20.7	30.8	10.0	0
Wind energy-project funding	18.1	9.8	9.3	7.4	11.0	6.9
Wind energy-indirect-specific funding	3.8	8.0	16.4	24.8	27.3	32.0
Application systems for southern climatic conditions	34.1	42.4	35.7	34.0	26.0	23.5
Biological energy storage and use	8.5	16.0	25.1	6.0	5.2	0
Biomass (Ministry of Agriculture)	2.3	2.6	3.3	7.0	3.2	3.0
Geothermal energy	5.6	6.6	5.0	4.6	5.7	3.7
Others and cross-section activities of renewable energies	8.7	10.0	11.7	15.9	9.6	12.8
Secondary energy systems	21.6	17.1	13.4	10.4	10.4	7.5
Energy-saving industrial processes	18.1	23.2	20.8	23.2	28.5	23.6
Electrochemical processes and hydrogen, electrical storage	12.0	16.6	12.2	13.4	13.7	10.4
Rational energy use and solar energy use in household and low power consumers, heat-storage	22.2	22.4	25.7	25.6	29.8	32.8
Solar energy-indirect specific funding	0	0	0	0	1.0	3.5
Totals without large research centers (project funding)	246.8	278.6	289.6	284.9	237.3	217.7
Large research centers (institutional funding)	44.9	54.8	85.2	67.5	78.1	77.6
Total	291.7	333.4	374.8	352.4	315.8	295.3

Preliminary estimates for 1996, the beginning of the 4th program: wind energy-project funding DEM 5.5 million and for wind energy-indirect specific funding DEM 44.3 million.

contribute to reach this target together with measures taken in other fields like traffic. The German industry contributes to the governmental obligation by reducing its specific CO_2 emissions until 2005 by 20% compared to 1990, as declared in March 1996.

Governmental targets for wind energy in Germany are not specified. In governmental publications, a yearly wind electricity production of up to several percent of electricity production is considered to be possible. Within the 250 MW Wind Program, a total of rated power of about 390 MW will be reached (250 MW refers to the turbine's power at 10 m/s wind speed), corresponding to a yearly electricity production of all turbines (including the early, smaller turbines) of roughly 1800 h x 390 MW ± 10% = 0.7 x billion kWh ± 10%, or almost 0.2% of the total actual produced electricity.

Two German Federal States published specific targets. Lower Saxony expects 1000 MW by 2000 (status, end of 1996: 426 MW) and Schleswig-Holstein expects 1200 MW by 2010 or 25% of Schleswig-Holstein electricity consumption (status, end of 1996: 540 MW, corresponding to

7.4% of Schleswig-Holstein's electricity consumption).

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed Wind Capacity

By December 31, 1996, the number of installed wind turbines was 4326, with a total rated power of 1546 MW (2). Eight-hundred and eight turbines with a total of 428 MW were installed in 1996. The year 1996 was the first year with a slight decrease of the annual installed wind power in Germany. Only about 85% of the wind power of 1995 was installed in 1996.

The total number of turbines in operation by December 31, 1996, within the 250 MW Wind Program was 1521 (35% of all wind turbines), corresponding to a total of 335 MW (22% of the total capacity) (3).

The development of wind power in Germany is shown in Table 2. The distribution of wind power for the 16 German states is given in Table 3. The total rated power of the three coastal federal states, Niedersachsen (Lower Saxony), Schleswig-Holstein, and Mecklenburg-Vorpommern was 1052 MW (68% of the total installed power) corresponding to 2867 wind turbines (66% of the total number of wind turbines). For the part of the wind turbines operating within the 250 MW Wind Program, the regional distribution of the rated capacity for different rated power classes by December 31, 1995, was evaluated (3), see Figure 1. Compared with Figure 7 in the IEA Wind Energy Annual Report 1995, a further increase in turbines in the 500–600 kW range is evident.

2.2. Comparison with Conventional Public Electricity Consumption

The total public electricity consumption in Germany for 1995 was 457 x billion kWh. According to the data given in the Table 2, it follows that during 1996, wind power contributed 0.5% to the German public electricity consumption (1995: 0.3%). The contribution of all renewables, mostly hydropower, is nearly 5%.

2.3. Numbers/Type, Make of Turbines/Ownership

For the number of turbines installed in 1996, and in total, we refer to Section 2.1,

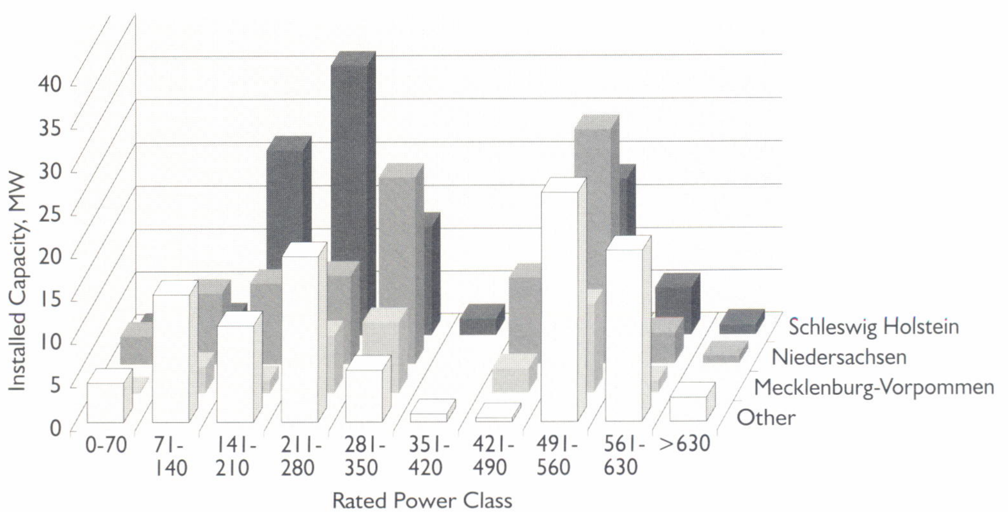


Figure 1. WMEP. Regional distribution of rated capacity for different rated power classes by December 31, 1996 (3).

Table 2 and Table 3 as well as Table 5. German manufacturers contribute about 65% of the installed wind turbines. The statistics of different wind turbine types are available for the wind turbines within the 250 MW Wind Program, see Figure 2. The figure represents the situation from the beginning of the program in about 1990 until today. At that time many smaller wind turbines—no longer sold today—came into operation. At least for the 250 MW Wind Program the statistics of ownership are known, see Table 4. The table shows categories of ownership and the related number of projects, number of wind turbines, and the total rated power. Private individuals and trade and industry (including the so-called power investors) by far erected the largest amount of total rated power, but trade and industry has the largest average wind turbine size. These numbers again reflect the development of wind power in Germany since 1989/1990: Farmers and private individuals bought the smaller wind turbines available at that time, whereas today trade and industry, mostly new firms, invest in projects with wind turbines of the actual commercial 500–600 kW class of European manufacture.

2.4. Performance and Operational Experience

The performance of the wind turbines in Germany is recorded in some detail in the 250 MW Wind Program. For this purpose, ISET carries out a Scientific Measurement and Evaluation Program (WMEP) on behalf of BMBF (3). The average technical availability for 1996 was again more than 98%. That means an average stand-still time of about 80 h per year per unit.

The climatic boundary conditions of 1996 (e.g., the low wind speeds and the long, cold winter) could be seen in the evaluation of the operator reports: The failure cause "storm" decreased to 2% (1995: 6%). For the failure cause "lightning stroke," a decease from 4% to 2% was recorded. An increase of "ice

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

DATE	NUMBER OF WECs		RATED POWER (MW)		WIND ELECTRICITY PRODUCTION (10^9kWh)	
	250 MW WIND	TOTAL	250 MW WIND	TOTAL	250 MW WIND	TOTAL
31.12.1989	15.0	256.0	1.4	20.0	0.0003	—
31.12.1990	187.0	506.0	30.8	60.0	0.016	0.58
31.12.1991	439.0	806.0	72.2	111.0	0.089	0.13
31.12.1992	738.0	1211.0	121.3	183.0	0.201	0.28
31.12.1993	1058.0	1797.0	183.9	334.0	0.302	0.5
31.12.1994	1317.0	2617.0	255.5	643.0	0.462	1.0
31.12.1995	1466.0	3528.0	311.0	1120.0	0.543	1.5
31.12.1996	1552.1	4326.0*	335.0	1546.0*	appr. 0.47	appr. 2.4

*Eight dismantled WECs corresponding to 2 MW rated power were subtracted.

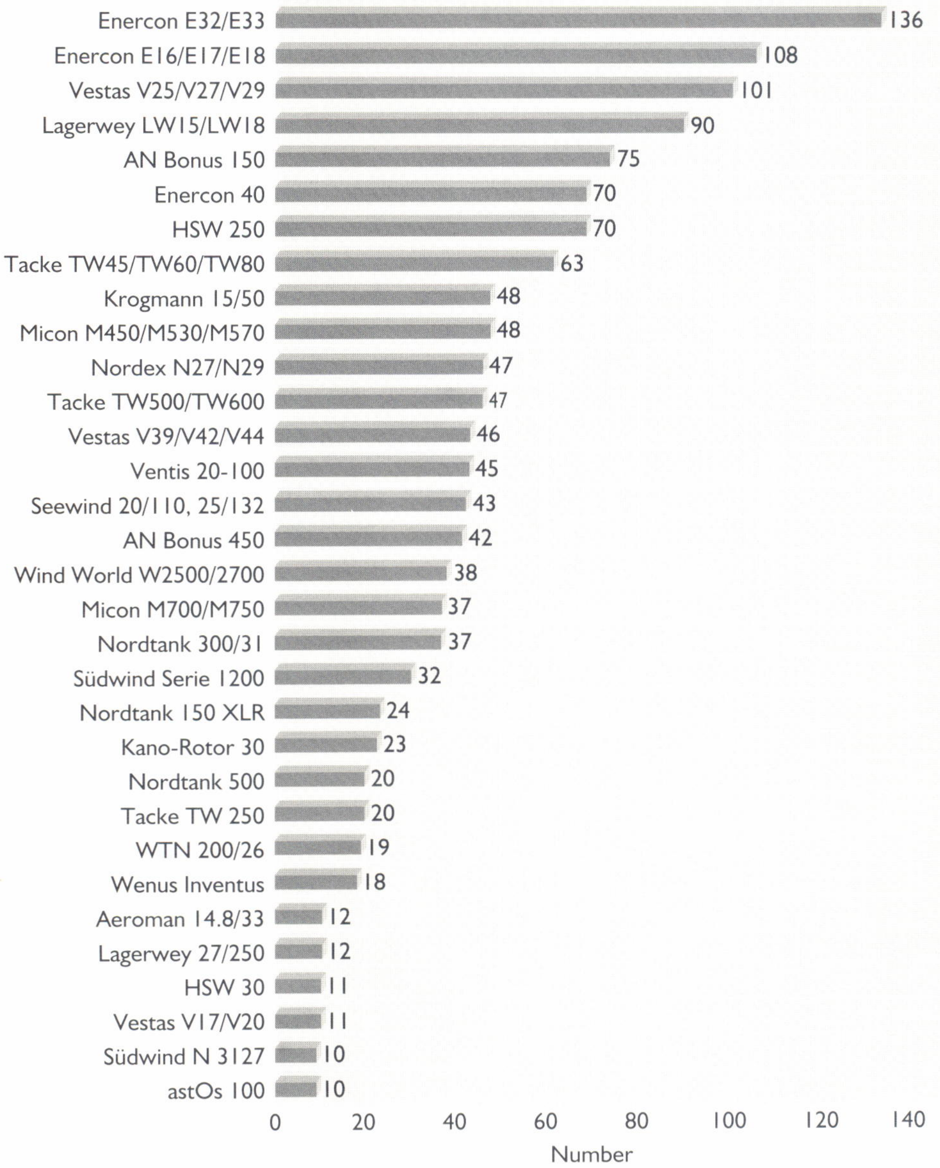


Figure 2. WMEP: WECs types by December 31, 1996 (3).

coating" of up to 9% (1995: 5%) and "grid failure" of up to 14% (1995: 9%) was observed. The other failure causes show the same order of magnitude as 1995. Figure 3 shows examples of failure statistics and statistics of repaired and exchanged parts.

3. MANUFACTURING INDUSTRY

3.1. Market Shares

Table 5 shows the shares of the suppliers on the German market in 1996. Turbines with a rated power of 500–600 kW were sold almost exclusively. Enercon could extend its leading position, followed by Tacke and Vestas. The fourth position was

Table 3. Distribution of Wind Power for the 16 German Federal States (2).

FEDERAL STATE	RATED POWER		NUMBER OF WECS	
	1996	TOTAL	1996	TOTAL
Schleswig-Holstein	108,500	540,141	196	1351
Niedersachsen	99,855	426,493	191	1259
Nordrhein-Westfalen	55,760	160,579	107	602
Mecklenberg	23,725	85,652	45	237
Brandenberg	25,400	73,996	47	179
Hessen	34,250	71,664	63	165
Sachsen	37,164	70,689	66	159
Rheinland-Pfalz	10,680	36,387	24	133
Sachsen-Anhalt	9,600	25,711	18	72
Thüringen	9,312	18,061	20	43
Hamburg	4,100	11,418	7	29
Bayern	4,480	9,447	10	41
Saarland	0,850	5,201	2	13
Baden-Württemberg	3,365	6,212	9	25
Bremen	0,600	3,950	1	14
Berlin	0	0,780	0	4

occupied by AN Maschinenbau followed by Micon. Number six and seven are Nordex and Nordtank. The small manufacturer Jacobs Energie GmbH took the eighth position.

3.2. New Products and Technical Developments

Especially for export, the German companies Enercon and Tacke developed advanced smaller size turbines, the E 30 (200 kW, gearless) and the TW 300 (300 kW). On the MW-size end of the power scale, the demonstration phase of the new prototypes E 66 (1500 kW, Enercon), TW 1500 (1500 kW, Tacke), and A 1200 (1200 kW, Autoflug) began last year. These types have to compete on the German market with similar machines from other European manufacturers and with the commercial 500- to 600-MW class.

3.3. Business Developments

The number of direct employees in the German wind power industry decreased from about 1400 in 1995 to about 1200 in 1996. The total turnover connected with wind turbines in Germany in 1996 amounts to about one billion (10^9) DEM. This corresponds to roughly 10,000 people a year in European wind power industries and auxiliaries. About two-thirds of the manufacturers are German, see Table 5. But the wind power companies in the countries neighboring Germany buy many components on the German market. On the other hand, some German wind turbines are equipped with blades from the Netherlands or Denmark. In addition, service teams have to be set up. On the average, one serviceman is required for 20 MW of installed capacity. These jobs are permanently needed for the lifetime of the turbines. Good service teams are most important in order to reach the excellent 98.5% average availabilities obtained in Germany.

4. MARKET DEVELOPMENT

The rated power of the installed turbines increased significantly over the years. In 1989 and 1990, the market offered wind turbines with a maximum power of 250 kW, which was soon followed by 300–kW turbines. Nevertheless, the majority of plants still had a rated nominal power of 100 kW or even less. The typical operator was assumed to be a farmer who produced electricity for the needs of his own farm and fed the surplus electricity into the grid, see Table 4. This situation has rapidly changed owing to the technical and economical development of wind turbines. Most of the wind turbines erected in 1995 and 1996 have a rated power of 500 kW or more. In 1997, the introduction of the 1500-kW class is expected.

Market stimulation instruments are favorable financial conditions (see Section 5, Economics). Complaints are growing, especially in the German coastal areas, that wind turbine installations are disturbing the landscape and disturbing birds and wildlife. Neighbors of wind turbines complain of noise and moving shadow effects. Germany has a high population density and is short of good wind sites, where different users are often competing. Owing to the necessity of noise emmision reduction, a distance of about at least 500 m to the next resident is recommended for LS-wind turbines. Although the corresponding land around a wind turbine can still be used as farmland, there are a lot of complaints. Over the past few years, it has become more and more difficult to get a construction permit for wind turbines. The relevant law has to be modified to facilitate the permission procedure.

5. ECONOMICS

The rapid market development was driven by the favorable financing conditions in the period of the late eighties to the nineties. The 250 MW Wind Program, at that time the 100-MW Wind Program of BMBF led the way. For details, refer to Section 6.3.

Table 4. Ownership of WECs of 250 MW Wind Program by January 29, 1997 (including 15 WECs [1.5 MW] of approvals given back and/or with total power) (4).

OWNERSHIP	PROJECTS	WECS	RATED POWER (MW)	AVG. PWR. (kW)/ TURBINE
Private individuals	642	737	135.5	184
Farmers	255	262	36.0	137
Trade and industry	202	410	138.6	338
Communities	52	58	7.7	133
Electricity companies	34	69	19.1	277

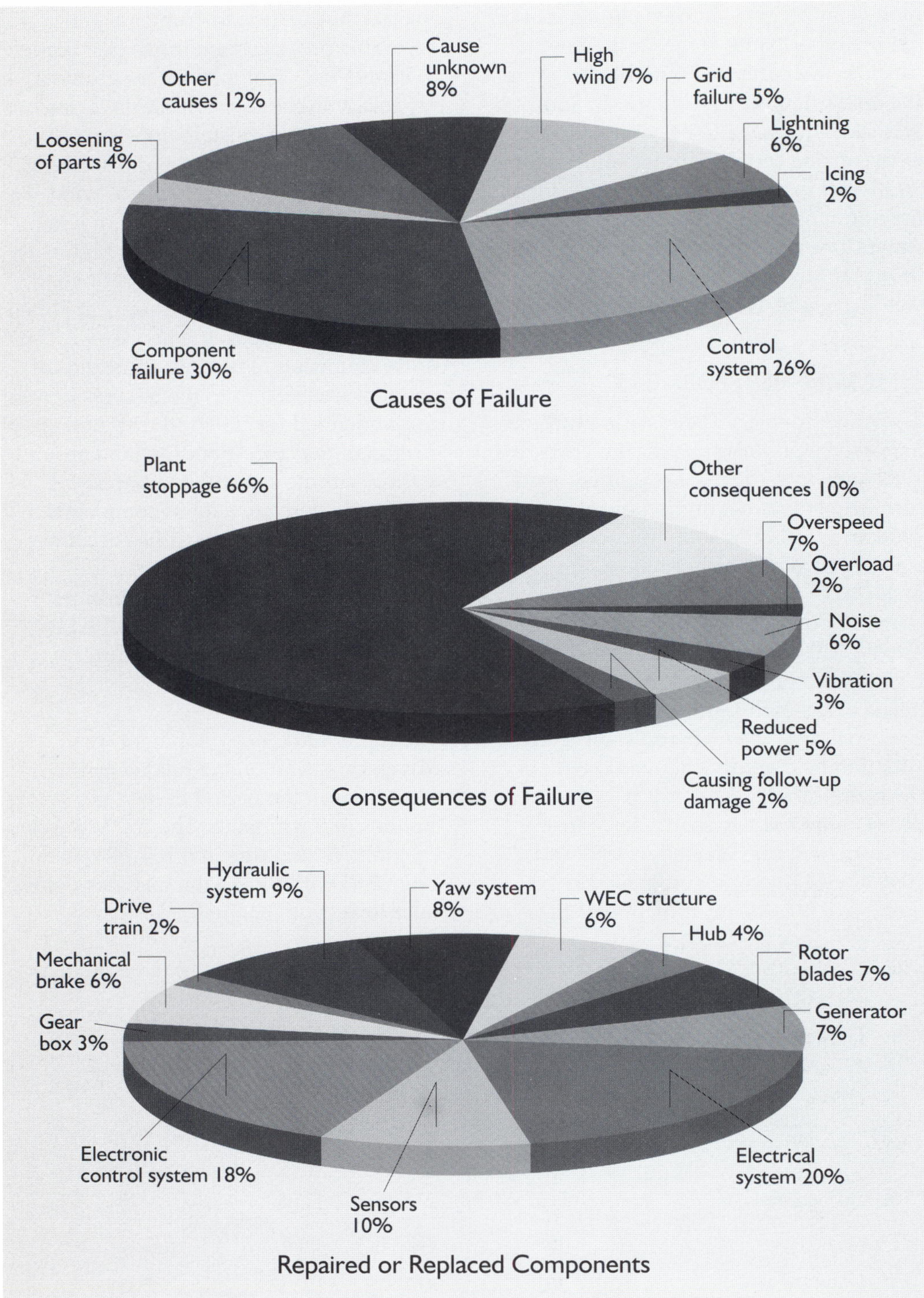


Figure 3. WMEP. Examples of failure statistics in 1996 (preliminary) (3).

Component	Failures
ELECTRICAL SYSTEM	670
Inverter	100
Fuses	203
Contactors/Switches	204
Cables	71
Others	92
ELECTRONIC CONTROL SYSTEM	555
Microprocessor	401
Relays	63
Wiring/Contacts	26
Others	65
SENSORS	319
Wind Speed & Wind Direction	150
Vibration	16
Temperature	38
Oil Pressure	23
Electric Power	9
RPM	45
Others	38
HYDRAULIC SYSTEM	311
Hydraulic Pump	59
Pumpdrive	13
Valves	67
Hydraulic Pipes	43
Others	129
ROTOR BLADES	255
Blade Joints	30
Blade Body	90
Tip Brakes	73
Others	62
YAW SYSTEM	256
Azimuth Bearing	25
Motor	74
Gear	16
Others	141
MECHANICAL BRAKE	189
Brake Dick	18
Brake Lining	83
Brake Shoe	33
Others	55
GENERATOR	187
Winding	8
Collector/Brushes	50
Bearings	61
Others	68
HUB	126
Hub Body	21
Blade Adjustment	68
Blade Bearings	11
Others	26
WEC STRUCTURE	116
Foundation	5
Tower/Bolts	51
Nacelle Structure	7
Nacelle Cover	40
Others	13
GEAR BOX	138
Bearings	17
Gearwheels	5
Gear Shafts	2
Sealings	39
Others	75
DRIVE TRAIN	52
Rotor Bearings	15
Shafts	13
Couplings	17
Others	7

Figure 3. WMEP. Examples of failure statistics in 1996 (preliminary) (3) continued.

Table 5. Market Shares 1996 in Germany (2).

MANUFACTURER	TOTAL RATED POWER		WECS	
	%	MW	%	NUMBER
ENERCON	31.3	133.43	33.5	269
TACKE	17.2	73.40	15.0	121
VESTAS	14.5	62.05	13.2	106
AN MASCHINENBAU	10.1	42.90	9.5	76
MICON	7.2	30.80	7.3	59
NORDEX	6.3	27.05	5.3	43
NORDTANK	5.3	23.50	5.7	46
JACOBS ENERGIE	2.3	9.90	2.4	19
GET	1.8	7.57	2.0	16
OTHERS	3.8	15.82	6.1	49
TOTAL	100	426.44	100	804

The Electricity Feed Law (EFL) became effective January 1, 1991. From that time the utilities are obliged to pay the same 90% of the average tariffs per kWh that private consumers had to pay with taxes of 15% excluded. In 1996, this amounts to 0.1721 DEM/kWh. EFL and 250 MW Wind Program are cumulative.

In addition to the reimbursement according to the EFL, a wind turbine operator might get soft loans. The Deutsche Ausgleichsbank offers soft loans for wind turbines with an interest rate 1% or 2% lower than on the capital market. Some states in Germany have terminated their investment funding programs or switched over to soft loans while some other states, especially in the German inland, still conduct programs with direct funding.

It can be stated that over the last seven years a market for wind turbines has been established in Germany that does not depend on direct funding. Nevertheless, this market depends essentially on the actual conditions for reimbursement regulated in the EFL, on the development of turnkey prices of wind turbines, and on the interest rate for loans and mortages. A high value for interest rates for mortages with a payback time of 10 years was reached at about 10% by April 1991, followed by a fluctuating decrease to less than 7% today. Assuming a payback time or a depreciation time of 10 years, it can be calculated by established methods that a decrease of 3% in interest corresponds to a price decrease of 25%.

The revenue from wind turbines is mainly determined by electricity production, which can be expressed by hours of operation per year at nominal power. Under German meteorological and financial conditions, it is more or less generally accepted that for a wind turbine erected in 1996, the revenue will be higher than the expenses when 2200 hours at nominal power are obtained. At good sites close to the German coast or the

Table 6. Wind Energy R&D Projects, 1996 ff and the WMEP Phase III.

SUBJECT	PARTICIPANTS	PERIOD	COSTS [DEM]	BMBF (%)
Wind powered desalination plant, Rügen	Rügenwasser GmbH	06.93-05.97	3,891.5	70
Partial supply of the hydro pumped storage plant at Geesthacht with wind and PV	Hamburger Electricitätswerke	02.89-05.96	10,034.6	40
Evaluation of energy economics of Aeolus II	Preussen Elektra Windkraft NDS	10.91-12.96	0,577.4	50.0
Processing of wind measurement data up to 150 m for a planned archive of wind data	Deutscher Wetterdienst	04.92-01.98	0,607.0	100.0
Construction and installation of a quiet and economic 1.5 MW WEC	Enercon	01.93-04.96	7,745.0	14.20
Special wind data and programs for complex terrain	Deutscher Wetterdienst	07.93-06.97	1,641.9	100.0
Phase III of 250 MW wind measurement and evaluation program WMEP	ISET	07.9-06.00	13,683.5	100.0
Early recognition of turbine failure	ISET	01.94-12.96	1,431.8	50.0
Installation and measurement program Ventis V 12	Deutsche Windenergie Institut DEWI	04.94-03.99	1,085.0	36.9
Development and construction TW 1500 with 1 MW rated power	Tacke-Windtechnik	06.94-09.96	5,813.5	25.0
Detailed Investigation WT Flicker	Windtest Kaiser-Wilhelm-Koog	01.95-12.96	0,416.8	50.0
Fatigue Loads WECs	VDMA	07.95-6.97	0,443.6	50.0
MW WECs inland	RWE	06.95-12.97	4,893.6	20.43
Control LS WECs	ISET	07.95-06.98	1,192.9	40
Noise reduction WEGs	Fördergesellschaft Windenergie	12.95-11.96	0,283.2	100.0
Active stall rotor blade	Abeking & Rasmussen	08.96-07.98	2,505.1	50
Lightning protection WECs	Fördergesellschaft Windenergie	10.96-09.99	0,600	50

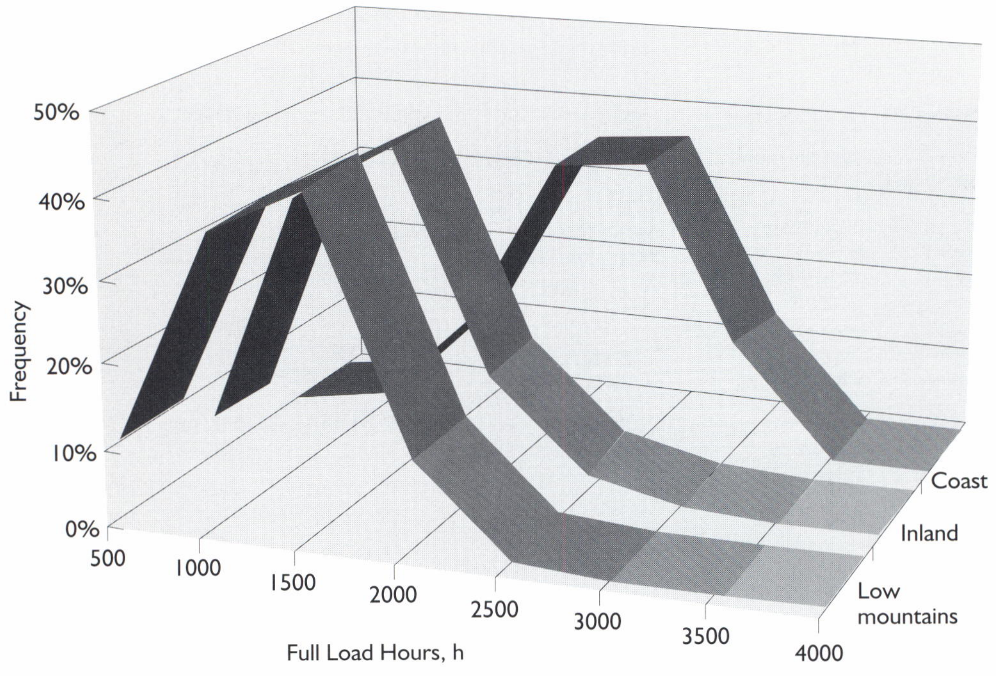


Figure 4. Distribution of full load hours in 1994 for three different site categories (4).

Baltic Sea, where the mean wind velocity at a height of 10 m is between 5.5 and 6 m/s, the majority of wind turbines have lower production costs than revenue per kWh according to the EFL. The inland situation, where typical wind velocities of 4 m/s dominate, might be different. The actual distribution of full load hours for different site categories for wind turbines within the 250 MW Wind Program is shown in Figure 4. The distribution of full load hours is remarkably broad for the three site categories. This indicates that besides the general wind regime, other factors like the size and type of the turbine and the local wind conditions may influence the full load hours considerably.

Financing of wind turbines is often managed with low equity; even on inland sites the projects are sometimes financed completely by loans. Here, the revenue from the wind turbines is needed in the first 10 years to pay for the capital costs, the insurance, and O&M. But nevertheless the investor may make some profit. A depreciation time for wind turbines of 10 years is generally accepted by inland revenue offices. With a linear depreciation, an investor can reduce his taxable income by 10% of the turnkey costs per year. This corresponds to approximately DEM 100,000 per annum. With an assumed tax rate of 30%, the taxes to be paid by the investor will be reduced by about DEM 30,000 per annum. Under the circumstances considered, almost no corporation taxes will have to be paid in the first 10 years. The possibility of reducing the taxable income is one of the further driving forces of the German wind turbine market. On average, every investor is reducing his annual taxes considerably.

Table 7. Projects of the ELDORADO Wind Program, status December 1996.

COUNTRY	SITE	NO.	TECHNOLOGY	APPLICATION	TOTAL RATED POWER
ARGENTINA	Santa Cruz	10	Ventis 20-100	Wind Farm	1.000 kW
	Bariloche	3	AN-Bonus 450	Wind Farm	1.350 kW
	Patagonia	2	TW-600	Single Turbines	1.200 kW
	Buratovich	2	AN-Bonus	Single Turbines	1.200 kW
BRAZIL	Minas Gerais	4	Tacke TW 250	Wind Farm	1.000 kW
	Fortaleza	4	Tacke TW 300	Wind Farm	1.200 kW
CHINA	Zhurihe	4	HSW 250	Wind Farm	1.000 kW
	Dalian	4	HSW 250	Wind Farm	1.000 kW
	Luoyang	10	HSW 250	Wind Farm (4,6)	2.500 kW
	Qinghai	7	AN 150/30	Wind Farm	1.050 kW
	Xinjiang	2	Tacke 600	Wind Farm	1.200kW
	Xinjiang	3	AN-Bonus 450	Wind Farm	1.350 kW
	Hainan	5	Jacobs	Wind/Diesel	165 kW
	Inner Mongolia	10	Wenus	Wind/Diesel	50 kW
	Luoyang	3	HSW 250	Wind Farm	750 kW
	Urumqi	3	Jacobs	Wind Farm	1.500 kW
	Inner Mongolia	10	Wenus	Wind Farm	50 kW
EGYPT	Zafarana	10	Ventis 20-100	Wind Farm	1.000 kW
JORDAN	Hofa/Juhfiyya	5	Vestas V27/225	Wind Farm	1.125 kW
LATVIA	Ainazai	4	Tacke TW-600	Wind Farm	1.200 kW
POLAND	Gdansk	2	Tacke 600	Wind Farm	1.200 kW
	Plock	5	Seewind	Wind Farm	1.660 kW
RUSSIA	Rostov/Don	10	HSW30	Wind Farm	300 kW
	Wolgograd	1	Südwind N1237	Single Turbine	37 kW
	Wolgograd Region	2	Südwind N1237	Single Turbines	74 kW
TOTAL		125			26.091 kW

6. GOVERNMENT-SPONSORED PROGRAMS

6.1. Funding 1996

The BMBF 1996 funding levels for wind power were (1995 in brackets) (4):

R&D	DEM 5.5 (6.9) million
250 MW Wind	DEM 44.3 (26.8) million
ELDORADO	DEM 6.8 (5.8) million
Total	DEM 56.6 (39.5) million

In addition, the Federal Ministry of Economics supports renewable energies within special guidelines for the period 1995–1998. The guidelines include the investment grants for wind turbines of rated power from 450 kW to 2 MW at sites with average wind speeds up to 4.5 m/s at 10 m height above ground. About 10 projects per year with a total of about DEM 1 million are being realized.

6.2. R&D/WMEP

The actual R&D projects by BMBF are shown in Table 6. It includes the development and test of three LS-wind turbines: the E-66 by Enercon, the 1.2-MW (two-bladed) A-1200 by Autoflug, and the TW 1300 by Tacke. The Scientific Measurement and Evaluation Program, Phase III (WMEP) is indicated in Table 6. It involves a DEM 13.683 million contract for the period of July 1996 to June 2000. Some results of the WMEP are given in Section 2.4; we refer to the Annual Report 1996 of ISET (3) and BMBF Annual Report 1996 (5).

6.3. 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. 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 installations. 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 or is being used by the owner of the wind turbine. The latter applies, for instance, to a farm, a factory or a private household, and also to a utility as a wind turbine owner. The grants are limited to a maximum of 25% of the total investment costs. In certain cases (private individuals, farmers) a subsidy of the investment, limited to DEM 90,000, is possible.

The interest in support of the 250 MW Wind Program was high. Until the closing date for proposals, December 31, 1995, more than 6000 proposals were registered. This corresponded to a total rated power of more than 3500 MW. During the development of the program, a total of 1223 proposals were approved, corresponding to 1573 wind turbines and 384.5 MW. The last approvals were for some projects with the new MW-size turbines being erected in 1997 (see Sections 1.3 and 2.3 and Table 4). The program will end around the year 2008 after 10 years WMEP participation of the MW-size turbines. It is expected that the total support will exceed DEM 350 million. The costs of the measuring program are not included in this sum and could reach an additional DEM 60–70 million for the period 1990 to around 2007.

6.4. ELDORADO Wind Program

BMBF's interest also includes the application of wind energy in overseas countries. According to a study by the World Bank, almost 50% of the inhabitants in developing and threshold countries don't have access to central energy supplies (electricity, oil, gas, etc.). They could be assisted by decentralized concepts, and renewable energies are considered to be an option for decentralized energy supply. Therefore, BMBF launched the ELDORADO Wind Program in 1991, which is now being jointly carried out with 8 partner countries. The aim of BMBF is to promote the motivation of a large number of users in southern climatic zones to construct and operate wind turbines in co-operation with German partners. By December 31, 1996, 24 projects were approved by BMBF, most of them with installations in operation. The total rated power is more than 26 MW (see Table 7).

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GREECE

1. GOVERNMENT PROGRAMS

There has been no revision of the National Program of Greece during 1996. Greece is one of the European countries possessing high wind energy potential. It is among the aims of the government to substitute expensive imported fuel, currently used for electricity production in a large part of the Greek territory, by exploiting the country's wind potential. Government support for wind energy exploitation is part of a larger new policy concerning renewable energy sources. The major strategic goals of the national policy for the development of the renewable energy sources are

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

The target of 350 MW of installed wind energy capacity by the year 2005, set by the Ministry for Development in 1995, has not been updated. The expected stimulus to the development of wind energy in Greece, as a result of the introduction of a new legal framework in 1995, has only recently started to produce valuable results. The main features of the new framework, regarding wind energy, were the opening of the market to the private sector and the precise definition of the tariffs for the energy produced. In addition, the Public Power Corporation of Greece (PPC) is obliged to buy the wind-produced electricity with contracts having a 10-year duration.

In addition, two national programs are currently supporting wind energy projects:

- The so-called Operational Energy Program—Renewable Energy within the Community Support Framework, for the years 1994–1999, implemented by the Ministry for Development. The budget is 65 million ECU and the support for wind energy projects is 40% (maximum subsidized project cost 1200 ECU/kW).
- Wind projects may be subsidized up to 45% of the project cost and get a 45% reduced soft loan for 30% of that cost. This results in an 11% interest rate compared to a standard rate of 18%. This is implemented within a continuous program according to the Law for the Economical Development 1892/90 of the Ministry for National Economy.

2. COMMERCIAL IMPLEMENTATION OF WIND ENERGY

The development of wind energy within the last 13 years is shown in Figure 1, where the annual and cumulative capacity of installed wind turbines are illustrated since 1984. In the same period, the installed conventional capacity was increased from 6.7 GW in 1984 to 9.2 GW in 1995. It is clear that, in large, the development was between 1991 and 1993, when PPC put into operation its MW-scale wind power plants. The contribution of PPC to the total installed capacity is today as high as 88%. The rest of the capacity belongs to public companies and local authorities and only a few hundred kW are owned by individuals.

No wind turbines have been connected to the electricity supply network in 1996 and the total installed wind energy capacity remains 27.6 MW and 156 machines.

The wind turbines installed in Greece are constant-speed, stall- or pitch- regulated machines, constructed in Denmark, Belgium, and Germany. The only wind turbine of variable-speed technology is a 150-kW stall-regulated machine, which has been designed and manufactured in Greece.

The power produced from wind turbines during 1996 was approximately 37.2 GWh, while the power produced in 1995 was 33.4 GWh. Figure 2 shows the electricity produced from wind turbines for the last six years and the corresponding capacity factor. The last was calculated excluding the two PPC wind power plants (10.2 MW in total), which have been out of operation since January 1994.

Operational experience

The two biggest wind power plants of PPC, 5.1 MW each (17 x 300 kW Windmaster WT), are out of operation since the beginning of 1994 due to serious damage on their rotor blades. During 1996, a redesign of some of the crucial components of the machine has been attempted and an extensive measurement campaign is on-going both on site and at the Center for Renewable Energy Sources (CRES) Full-Scale Blade Testing Facility.

Lightning is another issue that has to be considered, leading to long machine breakdown periods in some cases. Numerous strikes have been recorded. As an example, a 500-kW wind turbine on Crete Island has suffered three lightning strokes, since its commissioning in early 1994.

Overspeeding due to control system malfunctioning during a storm caused serious damage to the blades of the 150–kW variable-speed experimental machine.

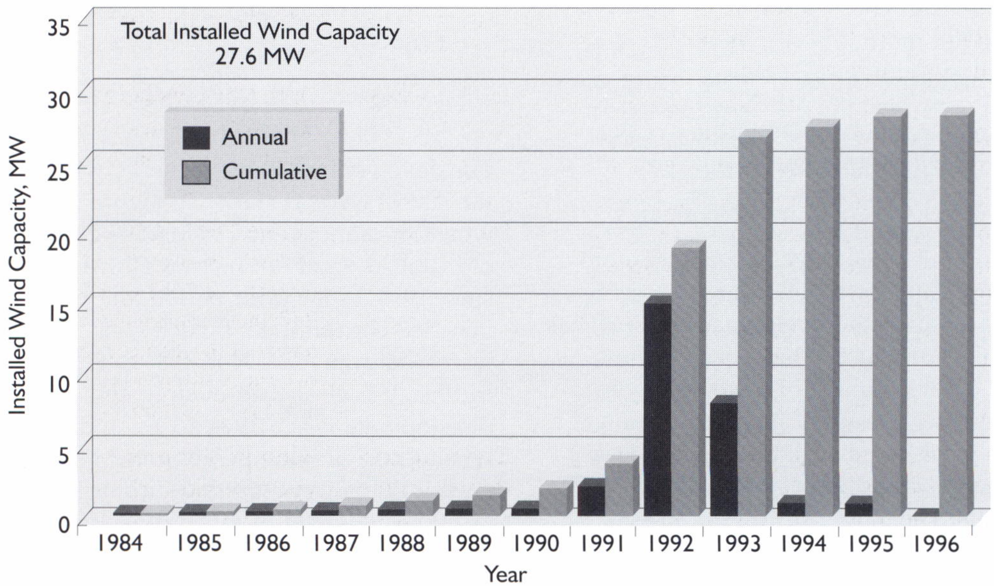

Figure 1. Installed wind capacity in MW.

3. MANUFACTURING INDUSTRY

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

During 1996, there was a remarkable progress in the field of wind turbine blade manufacturing. A Greek company, active in the field of boat manufacturing, has been successful in manufacturing a 10-m long blade, which has undergone extensive full-scale testing at CRES facilities.

Certification

To operate a wind turbine in Greece with a rating of more than 20 kW, a certificate is required, unless it is owned by PPC. CRES is, by law, the certifying authority for wind turbines in Greece. Until now, CRES is accepting those type approval certificates issued by authorized institutions, while it is working on certification procedures and standards to be followed nationwide, taking into account the individual climate characteristics of Greece.

4. ECONOMICS

There has been no change in 1996 as far as the tariff system is concerned. The system of power generation in Greece consists of the so-called interconnected system of mainland and the autonomous power plants of the islands. PPC is the only utility responsible for production, distribution and exploitation of electricity. Despite the different production costs in the two systems, a single charging price exists all over the country, depending on the identity of the consumer and the voltage class. The following tariffs for the three voltages are the most typical:

Low voltage	24.96 GDR/kWh
Medium voltage	20.96 GDR/kWh and 932 GDR/kW (peak power value)
High voltage	13.18/6.77/9.14 GDR/kWh, peak/min load/rest hours respectively 2117 GDR/kW (peak power value)

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

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

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

The total cost of wind power projects depends on the type of wind turbine, the size and accessibility and varies between 330.000–400.000 GDR/kW. The generated wind power cost could be assumed between 9.0 and 16.0 GDR/kWh, depending on the site and project cost.

The typical interest rate for financing any project without subsidies has declined to about 18%. However, many investments including wind projects may be profited by 40% reduced soft loan according to the so-called Law for the Economical Development 1892/90.

5. MARKET DEVELOPMENT

As soon as the new law 2244/94 was issued in early 1995, a great interest has been shown by the private sector in developing wind power projects. According to the law, anyone can develop power plants up to 50 MW from renewable energy and sell electricity to PPC, ending the monopoly of PPC on power generation from wind energy. Other features affecting the development are the more simplified procedures (less bureaucracy) and attractive buy-back prices. However the boost foreseen last year has only recently started to emerge. Until now, applications for a total of 500 MW are pending, mainly due to difficulties in contracting with PPC for buying the electricity production. These problems were resolved in 1996, thus it is expected that the wind energy deployment shall continue without any further delays. Up to now, 4 projects for a total of 32.7 MW have been granted installation permits for the island of Crete and Euboea. The projects are to be implemented in 1997.

Environmental Impact

Due to the landscape characteristics of Greece, almost all wind power plants are sited on remote areas, thus minimising both the visual impact and noise emissions. On the other hand, no bird kills have been reported.

Apart from a strong opposition against a wind farm on Lesvos Island (due to archaeological interest of the greater area), no other significant nor massive opposition has been mentioned to date against wind energy. The public attitude is rather positive in general. However, special attention should be given when planning projects on small touristic islands with strict traditional architecture.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

The Ministry of Industry, Energy and Technology (MIET) promotes all R,D&D activities in the country. Government sponsored R,D&D activities include applied and basic R&D as well as demonstration projects. In 1995, the total amount spent by the Greek government for R&D activities was approximately 300 million GDR, compared to 200 and 250 million spent in 1995 and 1994 respectively.

Key areas of R&D in the field of wind energy in the country are wind assessment and integration, standards and certification, development of wind turbines, aerodynamics, structural loads, blade testing, noise, power quality, wind desalination, and integration. There is no activity in Greece concerning MW-size wind turbines or offshore deployment.

An ECU 1.9 million project for the development of a 450-kW wind turbine, initiated in 1995 within the framework of the EPET-II National Program, has been progressing successfully. The project is aiming at both the development of a 450-kW, variable-speed, stall-regulated wind turbine, and the development of blade manufacturing technology. The contract has a duration of three years and the prototype is expected to be installed at the test site for extensive measurements by the end of 1997.

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

The development of a national certification system for wind turbines is considered as a crucial parameter for the successful implementation of new strategic plans for extensive use of wind energy in the country. In 1996, CRES coordinated the activities for the development of the national certification system. Within this framework, TC81, Wind Turbines, has been working under the Hellenic Organization for Standardization, for the development of national standards in the field of wind energy. TC81 has been working within the IEC and CENELEC mandates and Greek representatives participated in the work of their committees and working groups. In parallel, special effort has been given in developing the technical basis and the administrative procedures in order to make such a system operational. The effort is part of the National Program for Renewable Energy under MIET.

The CRES Full-Scale Blade Testing Facility, which is one of the most advanced testing facilities in the world, is going to be used as an integral part of the certification system under way. Several blade tests were carried out in 1996, while new tests are in planning.

The CRES Wind-Diesel Hybrid System, which simulates small autonomous grid operation, common in the islands of the Aegean sea, has been fully operational. The system can be effectively used in optimizing the integration of renewable energies in such systems.

CRES has also developed its Test Station, where in 1996 a large-scale experiment, using several masts and various types of anemometers, for the investigation of the wind inflow characteristics in complex terrain in connection to the wind turbine's performance was concluded. Moreover the Mobile Measurement Units have been

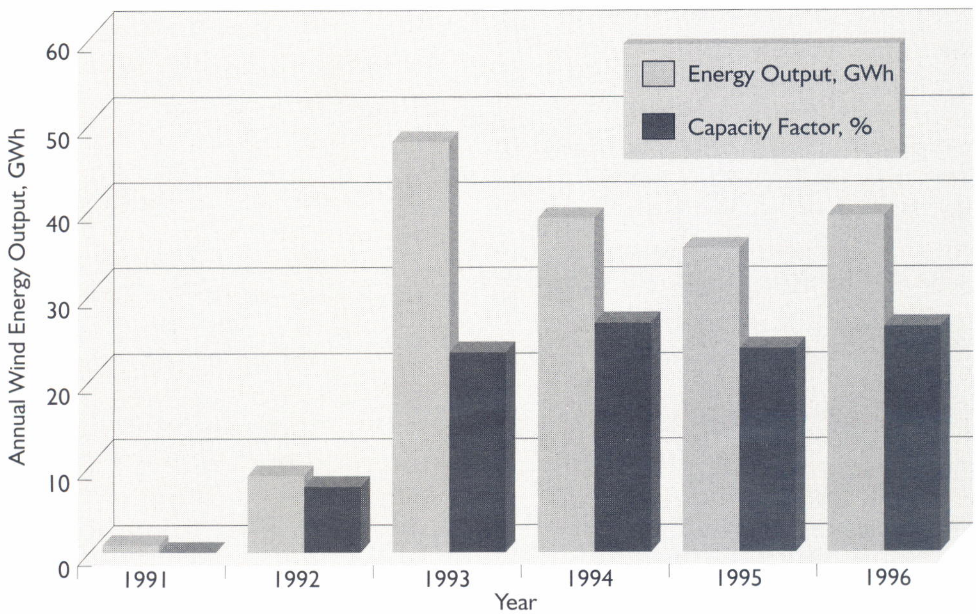

Figure 2. Wind power annual output and capacity factor.

used for extensive measurement campaigns at various wind turbine locations all over the country.

A number of research programs were running or initiated at CRES during 1996, aiming at characterizing the main features of complex or mountainous sites, as most of the sites favorable for wind energy development are of such topography. In that respect, JOULE-IIA project MOUNTURB (partially funded by DGXII) was finalized in 1996. The project provided valuable results on the power performance and loading conditions of wind turbines operating in complex mountainous areas. JOULE-III project COMPTER-ID, which in 1995 gained support by DG-XII, is focusing at identifying the crucial parameters affecting both the power performance and the loading of different types of wind turbines operating in such environments. In that direction, new techniques are under development for power-curve measurement of wind turbines operating in complex terrain (National Wind R&D projects with partial support from DG XII).

Basic R&D on wind energy is mainly performed at the country's technical universities.

In 1996, the R&D activities at the Fluids Section of NTUA focused on producing data on site-induced effects, developing noise propagation models, and on further improving existing numerical tools.

In siting, a fast three-dimensional (3D) Navier-Stokes solver was implemented in parallel FORTRAN. Significant speed-up was achieved, permitting a reduction of the grid size to 15 m for a region of 3000 m. Also local grid refinement techniques have been developed and implemented aimed at a better resolution of the flow equations.

In the field of rotor aerodynamics and load calculation, a General Aerodynamic and Structural Tool for a complete aeroelastic modelling of wind turbine rotors has been completed, tested, and used for producing data. The aerodynamics is accounted by models of varying complexity ranging from blade element calculations up to free wake approximations. The components of the turbine, blades, drivetrain and tower are fully articulated, permitting all types of designs. Based on detailed calculations of this type, a parametric analysis was conducted on the effects of extreme sites on the fatigue loads. It revealed the importance of 3D effects (spatial and cross correlations) and non-linear aerodynamics (in particular yaw misalignement).

In design, genetic algorithms were developed and used to give optimal blade shapes. The whole methodology was applied to the design of blades ranging from 10 m up to 17 m long. The airfoils used in these designed are new. They were designed as low-drag airfoils by means of a new method. A complete series has been produced. In progress is a detailed study of the behaviour of these new shapes. It includes wind tunnel testing as well as detailed Navier-Stokes calculations.

In aeroacoustics, a noise propagation model in atmospheric environment was developed. Also a model for the prediction of noise emissions from wind parks has been synthesized.

The Applied Mechanics Section of the Mechanical and Aerospace Engineering Department of the University of Patras (UP) has since 1990 focused on educational and R&D activities involving composite materials and structures. Emphasis has been given on structural design and dynamics of composite rotor blades of wind turbines. Experience has been acquired as a result of involvement in research projects supported either by the GSRT and/or the European Union. UP has successfully completed the structural design of a 5.5-m GRP blade of a 30-kW wind turbine, the verification of which was performed by full-scale static and modal tests at the CRES blade testing laboratory. During 1996, in the framework of the EPET-II National Program, a 10-m GRP rotor blade designed by UP was manufactured by a Greek industrial partner and full-scale tests, modal, static and fatigue, are in progress at the CRES facilities. Research activities of the Applied Mechanics Section, both analytical and experimental, have mainly focused on (a) fatigue failure prediction of multidirectional laminates under combined stress state and variable amplitude loading, (b) the development of analytical tools and dedicated software for probabilistic structural design with composites.

In 1996, the Department of Electrical and Computer Engineering of NTUA has continued its research activity in developing methodologies and tools for the examination of technical and economical issues related with the integration of renewable energies in the electrical grids, as well as for the design and selection of electrical components for variable-speed wind turbines.

In collaboration with CRES, methodologies have been developed for the GIS-assisted optimal site selection and integration of renewable power sources in distribution networks. The technical problems arising by the installation of wind parks in islands connected by submarine cables have been investigated and case-specific solutions have been provided. The advantages from the connection of variable-speed wind turbines with controlled reactive power to distribution networks have been analyzed and algorithms and tools have been developed, which permit the design and optimization of the electrical components and the control system of wind turbines connected to the grid through AC/DC/AC converters.

7. DEMONSTRATION

The main demonstration programs in wind energy currently under way in Greece are financed within the framework of the Thermie program of the EU.

The following three demonstration projects of PPC were on-going in 1996:

Three Wind Turbines in Moni Toplou, Crete

Two Tacke 500-kW wind turbines were commissioned in December 1993, and produced 7890-MWh during their three years of operation (2720 MWh in 1996). Serious damage to the blades from lightning has occurred twice up to now. The third wind turbine is a Nordtank 500 kW, commissioned in April 1995. It has produced 2621 MWh until the end of 1996 (1473 MWh in 1996).

Wind-Diesel System in Astypalea

A 500-kW V-39 Vestas pitch-regulated wind turbine and a new 500-kW diesel generator would be installed in Astypalea in 1996. The project was delayed due to siting problems, which are expected to be resolved in early 1997. The aim of this project is to maximize the penetration of wind energy through a load management system based on setting the power limit of the wind turbine.

Large Advanced Autonomous Wind/Diesel/Battery Power Supply System in Kythnos

The aim of this project is the demonstration of the technical feasibility of the integration of a very high penetration of wind energy in large supply systems. This large modular system for the island of Kythnos is designed for the combination of diesel generator sets, battery storage, rotating phase shifter, five small wind energy converters, and one additional large wind energy converter. This large wind energy converter with a power output of 500 kW will supply a great portion of the power demand. It will be one of the first times that such a high portion, more than 50%, of the energy demand is realized by wind turbines. Because of this, the diesel generators can be totally stopped when the power output of the wind turbines is sufficient. Furthermore the already existing PV system with a nominal power of P_p= 100 kW as well as the existing five energy converters of type Aeroman (5 x 33 kW) will be integrated into the wind/diesel/battery system. The project will be carried out from PPC and SMA. The project is close to getting an installation permit and construction work is expected to start in 1997.

Another Thermie project, originating from the local authorities of Crete, was also on-going during 1996:

5-MW Wind Power Plant on Complex Terrain in Sitia, Crete

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

Figure 3. One of the 500-kW wind turbines installed by PPC in Moni Toplou, Crete, in the framework of the Thermie demonstraton program of the EU.

Finally, two older Thermie projects were on-going on two islands in the Aegean Sea:

100-kW Windharvester WT on Agios Efstratios Island

The remote island of Agios Efstratios has an autonomous power supply system consisting of four 90-kW diesel gensets. The minimum load in winter is as low as 40 kW. The aim of the project is to achieve high penetration levels of wind energy saving (wind diesel system) and alternatively to operate as an autonomous system, supplying power to a separate grid. The project is proceeding to the commissioning phase.

300-kW Induction Wind Turbine Connected to the Desalination Plant of Mykonos Island

The project was originally planned for the Island of Ithaki and recently transferred to the Island of Mykonos due to difficulties of implementation. The aim is to couple a medium-size wind turbine with a desalination plant with the opportunity of operation as a standard grid-connected machine, if necessary. The new contract with EC is to be signed soon.

ITALY

1. GOVERNMENT PROGRAMS

As already explained in more detail in previous years, the Italian Government has, during the past decade, been encouraging the development of renewable energy sources through the Ministry of Industry, Commerce and Trade (MICA). As far as wind energy is concerned, however, it should be underlined that MICA has not been implementing directly a specific research, development and demonstration (R,D&D) plan, but has only been co-ordinating the programs of other state-owned organizations.

The latter have included, for several years now, the research agency ENEA (the Italian National Agency for New Technology, Energy, and the Environment) and the electricity utility company ENEL S.p.A. (formerly the Italian National Electricity Board).

ENEA has, among other things, long supported the wind energy industry by providing Italian wind turbine projects with technical and financial assistance and, more recently, by working on setting up a national wind turbine certification system.

ENEL, as a potential wind turbine user, has been characterizing a number of wind turbine models at its own testing facilities and building demonstration wind power plants. A co-operation agreement on medium- and large-sized wind turbines was also signed by ENEA and ENEL in 1987 and is still in force, at least as far as the development and testing of the large GAMMA 60 machine is concerned.This situation has however been changing during the last few years, mainly as a consequence of the impending privatization process of the utility ENEL. Formerly a state board, ENEL was set up as a joint-stock company (in Italy, Società per Azioni - S.p.A.) in August 1992. Since then, ENEL's stock has been held by the Government, and the actual sale of shares to the public has been put off until now, as the political debate on this matter went on. The privatization process is however set to go ahead and, in this connection, the ENEL company is currently undergoing a thorough restructuring process, which will continue in 1997.

It is not yet possible to foresee how far this process will affect the policy of ENEL towards wind energy and other renewable sources. At present, work is still going on along the guidelines set by the programs of the former state board, with a view to completing the projects already under way.

Considering that they are the issue of programs launched in the past, and to be consistent with previous IEA reports, an update on ENEL's wind energy activities is still provided, in the 1996 report, in the section on "Government Sponsored R,D&D Programs," together with ENEA's activities.

Coming back to the role of the Italian government, it should be confirmed that the targets set by the government's 1988 National Energy Plan (PEN) still apply to renewable energies. As for wind energy, the 1988 PEN set a target of 300-MW capacity (600 MW if large machines should become commercially available) to be installed by 2000.

It should also be recalled that the Italian government took measures in the past to encourage the pursuit of these goals. Laws No. 9 and 10, aimed at creating conditions for autonomous producers to undertake privately owned wind power plant projects, were passed in January

1991. Moreover, the Interministerial Committee for Prices (CIP) issued Directive No. 6 of 29th April 1992, which provided for premium purchase prices (to be updated every year—see below) for the electricity produced from renewable sources or from other sources recognized as similar (e.g., thermal cogeneration plants) and fed into the public grid.

These incentives, along with capital cost subsidies from some regional authorities, have raised a striking surge of interest towards wind power plant ventures among private investors. As of 30 June, 1995, private wind power plant projects for a total capacity of 723 MW had already been approved by the Italian Ministry of Industry and classed in a list of projects entitled to the special energy tariffs under the aforementioned CIP Directive No. 6/92. Other projects totalling several more hundreds of megawatts have been submitted during 1996, although they are still being evaluated for possible inclusion in further lists. For the time being it is very hard to anticipate the result of these applications, as it will depend on the new decisions that are expected from the government, as specified below.

Meanwhile, a significant capacity (nearly 40 MW) has been put on-line by private investors in the course of 1996. Considering that another wind power plant has been completed by ENEL, the total wind capacity in Italy has risen from about 22 MW in 1995 to about 70 MW at the end of 1996, thanks to the government's spurring action.

A potential drawback to large-scale wind plant deployment has recently arisen from a decree promulgated by the government itself on 19th July 1996. This matter will be explained in more detail in Section 5.3 hereunder. However, it is still being discussed whether this decree should apply also to really renewable sources such as wind (the government has recently confirmed its intention to continue supporting renewable sources).

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed Wind Capacity

During 1996 wind power plants totalling 48.4 MW were installed in Italy; all of these have already been connected to the grid, with the exception of the Collarmele wind power plant, built by ENEL S.p.A., which is going to be commissioned in the first months of 1997. As a consequence, Italy's total wind power has risen to 70 MW (for more details, see Figures 1 and 2 and Table 1).

This good result—it must be noticed that the previous year only one turbine was installed—could be improved during 1997, due to the growing activities of private investors.

As compared to Italy's conventional generating capacity, totalling about 54 GW in 1996, the penetration of wind power still remains negligible.

2.2. Plant Type

The new capacity installed in the 1996 consisted of 105 machines, 63 of which were made by Danish manufacturers and 42 by Italian manufacturers; they are subdivided in six wind power plants, including the Collarmele plant. All the plants have been installed in the Apennines between 500 m and 1,000 m above sea level.

Of these, four wind power plants totalling 37.8 MW have been installed by IVPC (Italian Vento Power Corporation), a new wind plant developer that has come up in the last few years (see Section 3.3); they are all made up of Vestas V-42 machines of 600 kW each and are located in the Apennines between Apulia and Campania (see Figures 3 to 5).

The other two wind power plants are located near Collarmele; the former (already in operation) consists of six Riva Calzoni M30-A machines of 250 kW each and was commissioned by Marsica Gas; the latter (completed but not yet commissioned) has been built by ENEL and is composed of 35 M30-A of 250 kW and 1 M30-S2 of 350 kW for a total power of about 9 MW (Figure 6).

At the moment in Italy, a total of 193 machines have been installed with an average rated capacity of around 350 kW. The average power of the machines installed in 1996 has risen to 460 kW.

Except ENEL's wind power plant of Collarmele, all the plants are owned by local public bodies or private companies.

2.3. Performance

The first three plants installed by IVPC at Montefalcone Val Fortore (7.2 MW—see Figure 3), Alberona (3 MW—see Figure 4) and Sant'Agata di Puglia (3.6 MW—see Figure 5) started their production respectively in March, April, and June 1996 with a total output, by the end of the year, of around 18.5 GWh. The last IVPC plant, located along a range in two communes (local municpalities) in Apulia (Anzano di Puglia and Monteleone di Puglia), is made up of 40 machines (40 x 600 kW) and was completed in December 1996. The only problem met during the operation of the above plants, according to IVPC, ensued, at the beginning, from the connection to a weak grid. Such a problem was soon solved.

The energy output of all the other plants, except the machines running at ENEL's test sites (totalling about 3.6 GWh in 1996), is not easily available, since many of these plants are for demonstration and the others are generally owned by a large number of local public bodies or private companies dispersed across the country.

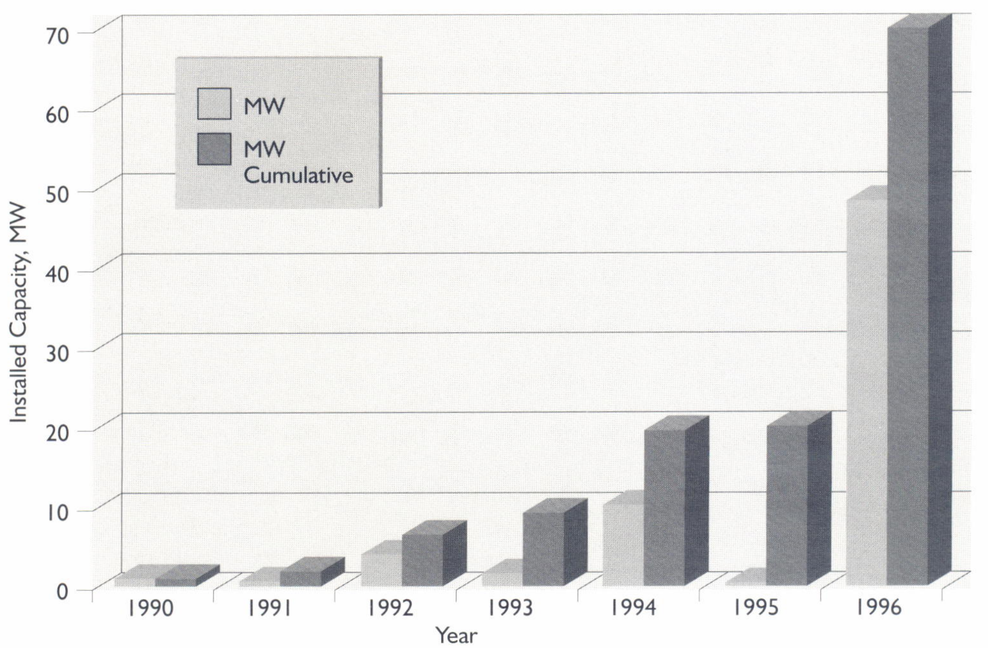

Figure 1. Installed and cumulative installed wind plant capacity in Italy.

A total energy output during 1996, including the IVPC plants, is however roughly estimated around 30 GWh.

3. MANUFACTURING INDUSTRY

3.1. Manufacturers

There are two companies involved in the manufacturing of wind turbines in Italy: Riva Calzoni and WEST. Both these companies are engaged in the construction of medium-sized machines. WEST is also the manufacturer of the 1.5–MW GAMMA 60 turbine. During 1996, no machines were sold by Italian manufacturers, since the turbines installed during 1996 had been ordered before.

Riva Calzoni

During 1996, Riva Calzoni completed the supplying of 42 turbines. Within 1997, at least 20 units of the commercial, monoblade M30-S2 product of 350 kW will be sold, assembled and installed in southern Italy.

Riva Calzoni is also present on the Italian market as a wind developer. In this sector, the company has stipulated preliminary agreements with the ENEL S.p.A. utility for the installation of wind capacity totalling more than 150 MW.

WEST

In 1996, the main activities of the company, now belonging to the Ansaldo Group, were the design review of the large machine GAMMA 60 and the construction of blades for foreign manufacturers. WEST was also involved in activities for improving the performance of the Medit 320 machine.

WEST, too, is now a developer. In the next three years, on the basis of preliminary agreements with ENEL S.p.A., the company plans to install wind power capacity around 230 MW in southern Italy

3.2. Other Industries

Both Italian and foreign component suppliers are present on the Italian market. Among the first ones

- Lucchini (hub)
- OTO Meccanica (gearbox)
- Ansaldo, Marelli (electrical components)
- Siderpali, Simi, Stanisci, S.G.M. (tower).

Among the second ones

- Rexroth (hydraulic system)
- Atout Vent (blades)

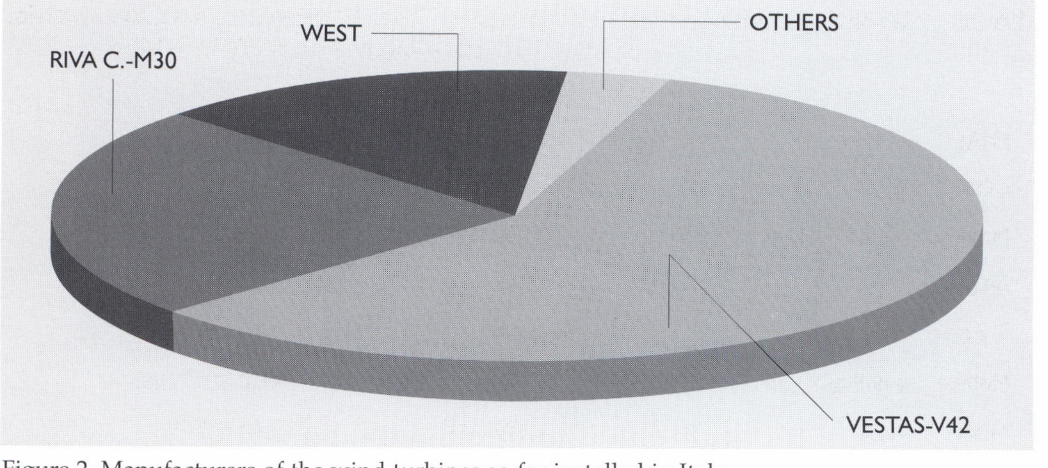

Figure 2. Manufacturers of the wind turbines so far installed in Italy

- Sulzer, Oils States (hub, drivetrain shafts)
- Desh (gearbox).

Also, Vestas supplies IVPC with assembled nacelles.

In the perspective of a significant market growth, according to the preliminary agreements signed with ENEL, the wind turbine manufacturers will introduce significant changes in their supply system, trying to develop local component factories.

3.3. New Developers

Also in 1997, IVPC is likely to be the developer with the largest number of wind installations, which will still be located in the Apulia-Campania area.

IVPC S.r.l. (Italian Vento Power Corporation) was set up on September 3, 1993, in Avellino, where both its business place and operation offices are based. The shares are 50% owned by IVPC Energy B.V., which is part of UPC Groups of Companies and 50% by Tomen Power Corporation.

Since 1993, careful wind surveys have been carried out by IVPC through numerous anemometer stations in order to select the most promising sites. It must be mentioned that the sites that have been identified and chosen are located in a very limited extension of mountainous and marginal areas in the Apulia and Campania Regions. At the same time, a large activity has been conducted in order to gain the favor of the local population.

Subsequent studies on project feasibility led IVPC to develop a two-phase plan, which will finally result in the construction of five wind power plants with an overall capacity of 109 MW. The plan has been conceived and developed following the philosophy of synergy with important banks and with the main leading companies in the field of wind power plant equipment.

This two-phased plan is organized as shown below and on the following page.

Other installations for about 130 MW are likely to be made by IVPC within two or three years. Besides the main actions planned by the developers IVPC, Riva Calzoni, and WEST, there are some smaller initiatives (in terms of MW involved) planned by communes and private investors.

4. ECONOMICS

The utility ENEL sells electric energy to final consumers at prices that vary over a wide range depending on quite a number of technical and social factors. Roughly speaking, the average selling price to domestic consumers can be estimated around ITL 215/kWh (USD 0.138/kWh) and the average selling price to industrial consumers around ITL 125/kWh

PHASE I (1995–1996)

COMMUNE	PRODUCTION	POWER
Montefalcone Val Fortore	from 03/96	7.2 MW
Alberona	from 04/96	3 MW
S. Agata di Puglia	from 06/96	3.6 MW
Monteleone di Puglia	from 12/96	16.8 MW
Anzano di Puglia	from 12/96	7.2 MW
TOTAL		37.8 MW

PHASE II (1997–1998)

COMMUNE	INSTALLED POWER	UNDER CONSTRUCTION	WORK START DATES
Montefalcone Val Fortore	7.2 MW	16.8 MW	10/96
Alberona	3 MW	33 MW	03/97
S. Agata di Puglia	3.6 MW	21.6 MW	03/97
TOTAL	13.8 MW	71.4 MW	

Total Capacity: 109.2 MW

(USD 0.081/kWh). These are net prices without taxes.

CIP Directive No. 6 of 29 April 1992 has allowed special buying prices for wind-generated electricity fed by autonomous producers into the ENEL system. The 1996 rates have been fixed at

- ITL 183.7/kWh (USD 0.118/kWh) for the first eight years of plant operation (on condition that the plant make available its whole rated capacity or a fixed share of it);
- ITL 89.9/kWh (USD 0.058/kWh) for the remaining lifetime.

The latter rate is intended to pay the producer for the cost ENEL would bear in generating the same amount of energy, while the additional amount (i.e., ITL 93.8/kWh, around USD 0.06/ kWh) allowed for the first eight years is intended to help bear the extra cost of setting up wind energy plants rather than conventional plants.

It has not yet been possible to gather generally applicable figures on invested capital in commercial plants. For the same reason, no general information can be given on typical rates of interest applied to financing wind power plants. It can, however, be stated that some Italian banks, too, have now shown to be willing to take into consideration the financing of wind projects as a possible business.

However, some ex-factory prices quoted by Italian manufacturers for their industrial products seem to set today's selling price of wind turbines around USD 1000–1100/kW. Overall plant cost will depend strongly on the site. It should always be borne in mind that most Italian sites are located in rough mountain terrain, so that "balance of system" costs are often a rather high percentage (30%–40%) of total investment.

5. MARKET DEVELOPMENT

5.1. Market Stimulation Instruments

As already stated, in 1992 the electricity produced from renewable sources and fed into ENEL's networks was granted premium purchase prices, to be periodically updated, by Directive No. 6 issued by CIP (Interministerial Committee for Prices). As stated above, the 1996 rates are ITL 183.7/kWh for the first eight years of plant operation and ITL 89.9/kWh for the remaining lifetime.

Very recently, some important financing programs launched by the Apulia, Campania, and Umbria Regions have been implemented at a quicker pace. In this framework, several applications for funding submitted by wind developers have been accepted by regional authorities. As an example, the Apulia Region resolved to support seven wind power plants having a cost of about ITL 90 billion (USD 58 million), with a capital provision totalling ITL 24.6 billion (USD 16 million).

5.2. Constraints

From the foregoing, it could be inferred that the goal of 300–600 MW wind capacity by 2000 set by PEN will be attained. Nevertheless, the deployment of such a large wind power plant capacity does not seem to be so straightforward, as most proposed projects would fall in rural mountain areas of central and southern Italy. Here, the distribution networks have been designed by ENEL for supplying power to villages and dispersed farmhouses and would now need substantial reinforcement to become able to accept large amounts of wind generating plants.

The attitude of the utility ENEL is, in this respect, a pretty open one. With particular regard to a major share of the projects already on the government's list, ENEL has shown its willingness to make available suitable power collection points on its local 150-kV high-voltage distribution system, but it is clear that this process would, in any case, require some time.

A certain number of public debates have also been held by ENEA, ENEL, and private investors in the communes more involved by wind installation projects in order to explain, in a proper way, the characteristics of the plants, environmental and institutional aspects and possible benefits in terms of new jobs and tourist/cultural attractions. As a result, the response of people was generally in favor of these projects. For the time being, the developers are taking advantage of this favorable situation, although in the future different framework with a larger diffusion of wind plants, the public's opinion might change.

Unfortunately, so far it has not been so easy for developers to obtain the necessary permits from local municipalities in an acceptably short time, as, till now, no local planning regulations have made provisions with specific

Figure 3. The 7.2-MW wind power plant built by the IVPC Company at Montefalcone Val Fortore (Campania–Southern Italy) with 12 Vestas V42 machines (600-kW rated power).

Table 1. Wind Turbine Generators Installed in Italy (as of 31 December 1996).

SITE	OPERATOR	GRID CONNECTION	NO.	WTG TYPE	WTG POWER (kW)	ROTOR DIAMETER (m)	TOWER HEIGHT (m)	PLANT POWER (MW)
Alta Nurra	ENEL S.p.A.	Nov. 89	1	M30	200	33	33	0.20
		Apr. 92	1	MEDIT I	320	33	26	0.32
		Mar. 91	1	MS-3	300	33	25	0.30
		Apr. 91	1	WD34	400	34	32	0.40
		May 92	1	GAMMA 60	1500	60	66	1.50
Bisaccia	WEST	Jan. 92	4	MEDIT I	320	33	26	1.28
	Regione Campania	Apr. 93	2	MEDIT I	320	33	26	0.64
		Jan. 92	3	AIT-03	30	10	12	0.09
		Apr. 93	13	AIT-03	30	10	12	0.39
Palena (Sangro)	Consorzio Bonifica del Sangro	Feb. 94	3	MEDIT I	320	33	26	0.96
		Feb. 94	1	VESTAS V27	220	27	31	0.22
		Feb. 94	1	VESTAS V20	100	20	24	0.10
Villagrande	Comune	Apr. 93	2	MEDIT I	320	33	26	0.64
Acqua Spruzza (Frosolone)	ENEL S.p.A.	Winter 94	2	M30	200	33	33	0.40
		Winter 94	2	MEDIT I	320	33	26	0.64
		Winter 94	2	MS-3	300	33	25	0.60
		Winter 94	2	WD34	400	34	32	0.80
Frosolone	Comunità Montana Sannio	1994	1	MEDIT I	320	33	26	0.32

Table 1. Wind Turbine Generators Installed in Italy (as of 31 December 1996) (continued).

SITE	OPERATOR	GRID CONNECTION	NO.	WTG TYPE	WTG POWER (kW)	ROTOR DIAMETER (m)	TOWER HEIGHT (m)	PLANT POWER (MW)
Frosolone	Comunità Montana Sannio	1994	1	MEDIT I	320	33	26	0.32
Oristano	Consorzio Industriale	May 92	1	MEDIT I	320	33	26	0.32
Carloforte	N.A.	June 94	3	MEDIT I	320	33	26	0.96
Monte Uccari (Nurra)	Consorzio Bonifica di Nurra	End 94	5	MEDIT I	320	33	26	1.60
San Simone (Nurra)	Consorzio Bonifica Sardegna	Jan. 93	1	M30	200	33	33	0.20
Brunestica (Nurra)	Consorzio Bonifica di Nurra	1994	3	MEDIT I	320	33	26	0.96
Tocco da Casauria	Comune	June 92	2	M30	200	33	33	0.40
Campanedda	Consorzio Bonifica di Nurra	1994	4	M30 A	250	33	33	1.00
Ottava	Consorzio Bonifica di Nurra	1994	4	M30 A	250	33	33	1.00
Villacidro (CA)	Consorzio Industriale	N.A.	4	HMZ Windmaster	150	21.8	23	0.60
		Spring 87	2	HMZ Windmaster	160	21.8	23	0.32

Table 1. Wind Turbine Generators Installed in Italy (as of 31 December 1996) (continued).

SITE	OPERATOR	GRID CONNECTION	NO.	WTG TYPE	WTG POWER (kW)	ROTOR DIAMETER (m)	TOWER HEIGHT (m)	PLANT POWER (MW)
Villa Favorita	Società Villa Favorita	N.A.	1	HMZ Windmaster	150	21.8	23	0.15
Frontone (PS)	ANAS	N.A.	1	Leroy Sonas LS PL 315	216	N.A.	N.A.	0.216
Collarmele (AQ)	Marsica Gas	July 93	1	Riva M30 A	250	33	33	0.250
Ostuni (BR)	Massari V.	Apr. 92	1	N.A.	150	N.A.	N.A.	0.150
Assemili (CA)	CO2 Industriale	Oct. 92	1	VESTAS 227	225	27	31	0.225
Casone Romano (FG)	Local	Dec. 94	9	M30A	250	33	33	2.25
			1	M30-S2	350	33	33	0.35
Mazara del Vallo (TP)	Sicil Marin	Aug. 95	1	Floda 600 (Markhams)	600	36	42	0.6
Montefalcone (BN)	IVPC	Apr. 96	12	Vestas V42	600	42	40	7.2
Alberona (FG)	IVPC	Apr. 96	5	Vestas V42	600	42	40	3
S. Agata di Puglia	IVPC	June 96	6	Vestas V42	600	42	40	3.6
Monteleone di Puglia	IVPC	Dec. 96	28	Vestas V42	600	42	40	16.8

Table 1. Wind Turbine Generators Installed in Italy (as of 31 December 1996) (continued).

SITE	OPERATOR	GRID CONNECTION	NO.	WTG TYPE	WTG POWER (kW)	ROTOR DIAMETER (m)	TOWER HEIGHT (m)	PLANT POWER (MW)
Anzano di Puglia	IVPC	Dec. 96	12	Vestas V42	600	42	40	7.2
Collarmele (AQ)	Marsica Gas	Sep. 96	6	M30A	250	33	33	1.5
Collarmele (AQ)*	ENEL S.p.A.	Jan. 97	35	M30-A	250	33	33	8.75
			1	M30-S2	350	33	33	0.35
						TOTAL		69.8

*The wind power plant was completed at the end of 1996 and will be connected to the grid in the first few months of 1997.

reference to wind plants. The current increase in the deployment of wind plants could play an important role in solving the problem.

5.3. Institutional Factors

The Italian government has undertaken a policy to reorganize the electricity sector, with the aim of fulfilling the European Union's directives and privatizing a great part of the present system. In this framework, the Government Decree No. 371 of 15 July, 1996, concerning transparency of electricity tariffs, decided that the already instituted authority for electric energy and gas must cancel all "overprices" on energy tariffs by 30 June, 1997. Among these, there is also the overprice used to support the CIP Directive No. 6/92, which established incentive tariffs for energy produced by renewable sources and sources "assimilated" to the renewable ones (see Section 1).

Due to this decree, and considering the deficit accrued by the "Cassa Conguaglio Settore Elettrico"— which manages financial resources devoted to CIP 6/92— the Minister of Industry promulgated the Decree of 19 July, 1996. This decree established that, concerning new plants fed by renewable and assimilated sources, whose contracts for transferring energy to the electric grid had not yet been signed with ENEL, the incentive part of the tariff (for wind energy this part amounts to LIT 93.8/kWh, out of a full tariff of LIT 183.7/kWh) will be paid according to the actually available financial resources.

On the other hand, the government has declared its intention to continue supporting renewable energy sources, and participants in an animated debate have started to suggest ways to make this intention a reality. At the moment, studies concerning this matter are under way at the Ministry of Industry in order to find and verify alternative measures with the

Figure 4. The 3-MW wind power plant set up by IVPC at Alberona (Apulia–Southern Italy) with five Vestas V42 machines.

aim of preserving the great interest lately shown by wind energy investors. Meanwhile, some regions are going on with their programs to support wind initiatives (see previous description).

In any case, nearly 700 MW of wind power capacity should, in principle, be installed in Italy in the next three to four years, according to the preliminary agreements that have already been signed between developers and ENEL S.p.A.

5.4. Environment

Neither additions nor changes have been introduced in 1996 concerning this matter. ENEA carried out a study on visual impacts of wind turbines in a mountain landscape.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

In past years, as already said in the foregoing, the state agency ENEA and the utility ENEL launched some wind energy programs under the government's co-ordination (acting through the Ministry of Industry, Commerce and Trade [MICA]). Although ENEL is now in the process of becoming a private-sector company, information on the progress of the activities carried on by both organizations is still given in this section, as done in the past.

6.1. ENEA's R&D Program

Funding levels

The financial resources allocated to 1996 activities under the ENEA–MICA Wind Energy Agreement, described as follows, have been around USD 5.8 million, 40% more than the previous year. It must be said that about half of the total funding regards activities made in 1996 but not yet approved by the public control body.

GAMMA 60

The whole activity on the 1.5 MW GAMMA 60 prototype is managed through a co-operation among ENEA, ENEL S.p.A. and the manufacturer WEST. A design review, performed by WEST under an ENEA contract and aimed at improving system safety and control, has been completed.

This activity has led to identify a number of possible improvements, which have been implemented on the machine taking the opportunity of the work already in progress to repair or replace the components damaged by fire in 1995.

Particularly, the yaw control and the hydraulic system have been modified; the U-valves have been eliminated and a wind vane has been fitted in the lower side of the nacelle where the machine anemometer is also located; a new parking brake system has been fitted on the high-speed shaft, in addition to that existing on the low-speed shaft.

The control system has been completely renewed, with the full separation of control functions and data acquisition. The new control system has been installed in the nacelle, while it was previously located on the ground. A careful safety analysis has been performed by Ansaldo, in order to check the viability of new solutions.

At the end of 1996, all work on the GAMMA 60 has been completed. The wind turbine is going to be put back into operation in early 1997.

Certification and Siting

Activities on certification are in progress. The wind tunnel for anemometer calibration and component testing is under construction. In the meantime the organization of the certification body has been defined, while the arrangements of the experimental facilities are in progress.

Work on siting is also in progress: monitoring of about ten sites is under way and two other ones around La Maddalena Island (north of Sardinia) have been identified. At the beginning of 1997, at this last site, one or two anemometer stations should be installed and monitored through the remote system developed by ENEA.

Wind data are continuously transmitted to the ENEA Casaccia Centre by four other stations in the Teramo Province. So far, the data collected are not interesting, so it has been thought to continue the monitoring in mountain areas.

Figure 5. The 3.6 MW wind power plant built by IVPC at Sant' Agata di Puglia (Apulia, Southern Italy) with six Vestas V42 machines.

Lately a meeting between members of several Italian regions and ENEA took place at the ENEA center. Some regions decided to draw up regional energy plans taking into account a growing insertion of renewables and verifying, through agreements with ENEA, the possibility to evaluate the local wind potential.

International Collaborations

Concerning the international collaboration to study hydrogen production by a small wind turbine generator, carried out at the Casaccia Centre, preliminary operational tests were completed at the end of 1996.

In the offshore sector, ENEA and ATENA (Italian Association of Naval Engineering) have organized a second European Seminar on "Technology and Potential Applications," which will be held on La Maddalena Island on 10th and 11th April 1997.

6.2. ENEL's R,D&D Program

Funding Levels

The expenditure borne by ENEL for wind energy activities in 1996 has been around USD 9.3 million. This amount has been less than was budgeted in the *IEA Wind Energy Annual Report 1995* because of unexpected delays in completing some activities. The wind energy budget for 1997 is around USD 10.5 million.

Wind Plant Siting

During 1996, ENEL has continued wind surveys and micrositing activities in several regions of Italy. The actual feasibility of plants at a number of the most promising sites has been carefully assessed, taking into account technical, environmental and permitting aspects. This sector has seen a close co-operation with the Conphoebus and ISMES companies.

Wind Turbine Testing

At the Alta Nurra test site (Sardinia), apart from the running of three medium-sized units that had been installed in previous years (with a total 1996 production of 810 MWh), the 1996 highlight has been the repair of the GAMMA 60 prototype after the fire that occurred in 1995. Despite the extreme operating conditions experienced by the unit in that circumstance, its main

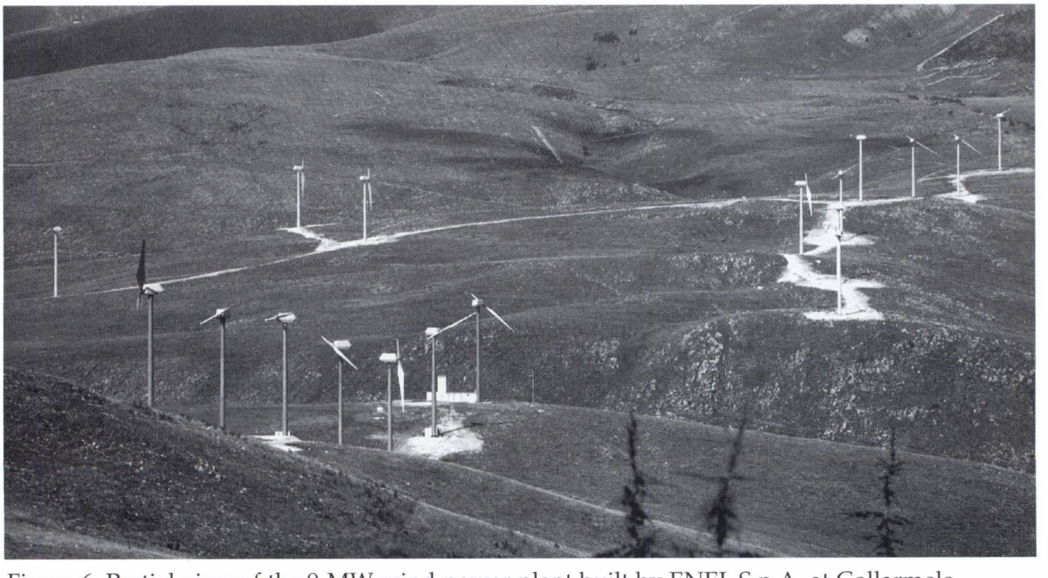

Figure 6. Partial view of the 9-MW wind power plant built by ENEL S.p.A. at Collarmele (Abruzzo, Central Italy) with 36 single-bladed Riva Calzoni machines.

structural components have not shown any major damage. However, work has been required to repair or replace all parts damaged by fire inside the nacelle and to carry out the improvements suggested by the ENEA–WEST design review (see the ENEA section). Recommissioning tests are to start in early 1997.

ENEL's testing activities have, in 1996, been focused mainly on evaluating the performance of medium-sized wind turbines at the Acqua Spruzza mountain site near Frosolone, equipped with eight wind turbines of four different models, for a total power of 2.5 MW. Here, seven out of the eight machines have been running during the year (with a total 1996 production of 2750 MWh) while the last one has been taken down for major repairs to the gearbox.

So far, experience has shown that the set up and operation of wind turbines at a high altitude (1350 m) and in a harsh environment poses peculiar problems, mainly ensuing from ice accretion and the impossibility for personnel to reach the plant in case of snowfalls in the winter months, as well as from lightning overvoltages affecting specially the measuring, control, and monitoring system in all seasons of the year.

It has been found that all these aspects require special consideration when choosing machines and measuring instruments and when outlining operations and maintenance criteria for power plants at such kinds of site. Further test results, concerning specially the structural effects of turbulence, are awaited during the winter 1996-1997. Test results from Acqua Spruzza are also provided to a few international research projects financed by the European Commission within the framework of the JOULE program.

Demonstration Wind Power Plants

As for ENEL's two wind power plants under construction, a delay has been suffered in the completion of the Monte Arci plant in Sardinia (34 WEST machines totalling 11 MW). Here, the civil and electrical engineering work had already been completed, when the manufacturer WEST found some defects on the 320-kW Medit machines that were to be installed. This has brought about the need to modify all 34 wind turbines. As a result, work on the completion of Monte Arci is likely to be resumed only in the second half of 1997.

The construction work on the other wind power plant at Collarmele in Abruzzo (36 Riva Calzoni units totalling 9.1 MW) has been completed (Figure 6) and all the wind turbines (35 of the 250-kW-rated M30-A type, plus one of the more advanced, 350-kW M30-S2 model) have been erected. The plant is connected to a 20-kV network. Commissioning tests will start at the beginning of 1997.

For both the Monte Arci and the Collarmele wind power plant (located in mountain areas at 750 and 1000 m above sea level, respectively), a visibility study had also to be made, in order to devise and implement the signalling system that could best meet the requirements of the Air Force against hazards to low-altitude flight.

International Collaborations

In 1996, ENEL has also been working within the framework of the EURE Utility Wind Farm Project, a study carried out by 14 European utilities and sponsored by the European Commission (JOULE program). The aim of the study is to ascertain the feasibility of building jointly one or more wind power plants with large (750 to 2000 kW) wind turbines for a total capacity of 100 MW. Among others, ENEL has proposed an area of southern Italy as a candidate site.

JAPAN

1. NATIONAL PROGRAMS

The government decided a guideline of a new energy policy in December 1994, in which wind energy will be promoted up to 150 MW capacity by 2010. As a result of this policy, "Field Test Program" was newly initiated since 1995 to attain the target by 2010 in addition to the running R&D program, "New Sunshine Wind Project."

1.1. New Sunshine Project: Research & Development

In 1978, Japan started its wind energy R&D program, which is part of the general R&D Program for renewable energy called "New Sunshine Project." It 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). In this program, the following activities have been conducted:

1. wind resource measurement (now transferred to Field Test Project)

2. R&D of large-scale wind turbine generator systems (LS-WTGS)

3. demonstration of a MW-class power plant

4. R&D for basic innovative and environmental technologies.

The New Energy and Industrial Technology Development Organization (NEDO) carries out the first three, while the last one is undertaken by Mechanical Engineering Laboratory (MEL) and National Institute for Resources and Environment (NIRE), both of which are national laboratories of AIST, MITI and support the first three mainly through technology evaluation.

The outline of the national wind energy activities in Japan is shown in Table 1.

Table 2 shows the history of the budget for wind energy R&D in the NSS Project and Field Test Program.

a) Wind Atlas

As a complement to the nationwide network for local meteorological observations called AMeDAS, which has about 1000 meteorological stations all over Japan, NEDO has measured wind characteristics at selected sites since 1983. In 1994, NEDO completed a new wind

Table 1. Wind Energy Activities in Japan.

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

Table 2. Budget for National Wind Energy Projects in Millions of Japanese Yen (JPY).

YEAR	1991	1992	1993	1994	1995	1996	1997
NSS project	549	981	982	744	635	608	556
Field Test Project	–	–	–	–	80	320	460
Total	549	981	982	744	715	928	1016

database for wind energy development which covers the data at 737 stations in AMeDAS networks and those at 38 locations of NEDO's own. In total, data from 964 stations were analyzed to create the wind atlas. In 1995, Japan Wind Atlas was published by NEDO.

The wind energy potential was also estimated. Three scenarios were considered according to different restricting factors for wind power plant construction in the analysis. A common condition is that the sites where their annual wind speed is above 5 m/s at 30 m height above ground level are considered as practical candidates. The results are shown in Table 3. The minimum and maximum values correspond to the array conditions of WTGS in a wind power plant of 10D x 10D and 10D x 3D respectively, where D is the diameter of a WTGS. According to scenario 2, which is a moderate one, it is expected that a few percentages of the electricity demand of Japan can be supplied from wind.

b) R&D of LS-WTGS

After completion of the 100-kW pilot plant in 1986 and further research for a large-scale wind turbine, a new R&D program to develop a 500-kW class wind turbine prototype was initiated in 1990. Conceptual design of the 500-kW prototype was completed in FY 1992. It has a three-bladed 38-m diameter rotor mounted to a rigid hub. Detailed specification of this machine is shown in the IEA Wind Energy Annual Report 1995.

In FY 1994 and 1995, 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.

In October 1996, the machine was erected on a hilly site in the centre of Tappi Wind Park owned by Tohoku EPC. On 15 October, the turbine was damaged by

Table 3. Wind Energy Potential in Japan.

SCENARIO	AREA km^2 (ratio of total land surface in %)	POTENTIAL NUMBER OF UNITS*	POTENTIAL CAPACITY MW (ratio to total in %)	POTENTIAL WIND GENERATION GWh (ratio to total generation in %)
1	23,280 (6.4%)	125,519 – 565,278	not completed	not completed
2	3,599 (1%)	18,430 – 70,481	9,220 – 35,240 (4.61% – 17.62%)	8,916 – 34,127 (1% – 3.84%)
3	759 (0.2%)	2,792 – 13,743	1,440 – 6,870 (0.7% – 3.43%)	1,325 – 6,537 (0.15% – 0.74%)

*500 kW WTGS

Figure 1. NEDO 500-kW WTGS at Tappi wind power plant.

lightning on its sensors, a part of control systems and other apparatus, but started its operation on 21 October, 1996 (see Figure 1).

A series of field tests are actively undertaken now. The main items of the tests are:

1. reliability tests of the WTGS and its components
2. performance tests: WTGS, pitch control system, grid connection system, aerodynamics of rotor blades
3. construction/vibration tests
4. data acquisition and economics analysis
5. noise measurement

c) Demonstration of a MW-Class Wind Power Plant (Miyako Project)

An experimental MW-class wind power plant of 1.7 MW rated power was completed in October 1995 on Miyako Island in Okinawa. The wind power plant consists of two units of MHI 250 kW WTGS and three units of Micon 400/100 kW WTGS. One of the purposes of this project is to demonstrate the availability of wind energy connected to a grid of small capacity on such an island.

The site is an open narrow flat cap covered by ocean with open 7 m/s of annual mean wind speed. The highest record of monthly capacity factor was 53.2% obtained in December 1994. The annual capacity factor in 1996 was 31.1%.

d) Generic Research

MEL has been carrying out research of generic aspects of rotor aerodynamics, structural dynamics, vibration, wind/diesel systems and acoustic noise,

Table 4. Operational Data of the Miyako Wind Power Plant (two units of MHI 250 kW machine).

YEAR	WIND SPEED (m/s)	GENERATION (MWh)	CAPACITY FACTOR (%)
1992*		371,510	20.0
1993		1,000,740	22.8
1994	7.6	1,247,280	28.5
1995	7.1	1,361,990	31.1
1996		1,362,490	31.1

*One unit

Table 5. Installation of Wind Turbine Generating Systems in Japan.

YEAR	INSTALLED CAPACITY kW	TOTAL CAPACITY kW	NUMBER OF INSTALLED UNITS	TOTAL NUMBER OF UNITS
Before 1990	357.5	357.5	9	9
1990	533.0	890.5	4	14
1991	1475.0	2365.5	6	19
1992	783.0	3148.5	5	24
1993	1800.0	4948.5	9	33
1994	907.5	5856.0	8	41
1995	3655.2	9511.2	13	54
1996	4408.9	13920.1	16	70

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 on this machine, a new experimental machine, WINDMEL-II, has been developed and 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 teetered/rigid hub, constant/variable speed, etc.

As for technical results from the research operation of the WINDMEL-II, the concept of flexible design proved to have a high advantage in reduction of mechanical stress, as well as in stabilization of output power.

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

1.2. Field Test Project

To attain the national target of the new energy/environmental policy, in which wind energy shall be promoted up to 150 MW capacity by 2010, national NEDO's field test project was started in 1995. In the project, subsidies from the government are provided for those who are active in developing wind power plants. As a framework, the term of a project is five years. In the first year, meteorological measurement is undertaken with 100% subsidy. In the second year, one of the most optimal wind power plants is designed with a subsidy up to 50% of the design cost, if the wind measurement proved to be available enough for wind power generation. In the third year, the wind plant is constructed with a subsidy up to 50%.

Among many candidates who apply to this field test project, more than ten are subsidized for wind measurement, while a few are subsidized for plant design and construction.

1.3. IEC Standard and JIS Standard

The national program covers the cooperation in IEC Standard activities in the wind energy category. MITI also promotes the policy to have international consistency in standards. Therefore, national JIS standards for wind turbine generator systems are also on the table for publication in near future in parallel with IEC standards.

Table 6. List of Wind Turbine Generator Systems in Japan, 1995 and 1996.

OPERATION	OWNER	LOCATION	MACHINE	RATED POWER kW	ROTOR DIAMETER	NO. OF UNITS m	CAPACITY kW	PURPOSE
1995-	Kochi-ken	Noichi-cho	Micon	250/50	27.8	1	250	Power Supply
1995-	Fukuoka-Nihon Shokuhin	Koga-machi	Vestas	150/30	27	1	250	Power Supply
1995-	Tohoku EPC	Tappi	MHI	300	29	5	1500	R&D
1995-	NSS/NEDO Okinawa EPC	Miyako Island	Micon	400/100	31	3	1200	R&D (NSS Project)
1995-	Heiwa-Kanko	Fukushima	Micon	225/40	28.8	2	450	Power Supply
1995	Hokkaido	Teshio-cho	Hokoku	5.2	6.5	1	5.2	R&D
1996-	Chugoku EPC	Hekimachi	Kenetech MHI	107 300/100	 29	1 1	107 300	Demo Demo
1996-	Kansai EPC	Kuorkawa	Nordex	150/30	27	1	150	R&D
1996-	Omaezaki	Omezaki	MHI	300/100	29	1	300	Power Supply
1996-	NSS/NEDO	Tappi	MHI	500	38	1	500	R&D (NSS Project)
1996-	Yamagata-Furyoku	Tachikawa	Micon	400/100	31	2	800	Power Supply
1996-	Nadachi-Furyoku	Nadachi	Micon	400/100	31	2	800	Power Supply
1996-	Sado-Shizen-Ene.	Sado	Micon	225/40	28.8	1	225	Power Supply
1996-	Erimo-Furyoku	Erimo-machi	Micon	400/100	31	2	800	Power Supply
1996-	Kazamaura-Furyoku	Kazamaura	Micon	400/100	31	1	400	Power Supply
1996	NTT	Okaki-cho	Yamaha	16.5	15	1	16.5	Power Supply
1996	Hokoku	Hiroshima	Hokoku	5.2	6.5	1	5.2	R&D
1996	NTT	Yokoshuka-shi	Hokoku	5.2	6.5	1	5.2	R&D

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

Table 7. Performance of WTGS in Japan.

START DATE	OWNER	LOCATION	CAPACITY kW	GENERATION MWh	CAPACITY FACTOR %	AVG. WIND SPEED m/s
1989	Suttsu-machi	Suttsu	82.5	21		3.3
1990	Kyushu EPC	Koshiki Isl.	250	434	19.8	6.1
1991	NSS/NEDO/ Okinawa EPC	Miyako Isl.	500			
1991	Tohoku EPC	Tappi	2875	7870	31.0	8.1
1993	Matto-shi	Matto-shi	100	87	-	4.2
1993	Hokkaido EPC	Tomari-mura	1100	1540		-
1994	Kantoukokusai Schl.	Katsuura	250	132		6.0
1995	Kochi-ken	Noichi-cho	250	112	-	-
1996	Yamagat-Furyoku	Tachikawa	400	1090	15.6	5.9
1996*	Erimo-Furyoku	Erimo-machi	400	383	26.3	8.0

*Two months

2. NATIONAL STATISTICS ON WIND POWER

2.1. Installed Capacity

As of 1 January, 1997, the total capacity of WTGS is close to 14 MW with 70 units including research machines. Installed capacity/number of machines over recent years is shown in Table 5.

2.2. Machine Details

A list of WTGS starting operation during 1995 and 1996 in Japan is shown in Table 6 with machine data. See *IEA Wind Energy Annual Report 1995* for data from previous years.

2.3. Performance

In Table 7, performance and operation data of some active WTGS excluding research machines are shown.

2.4. Operational Experience

There is not enough operational experience in Japan. However, it must be pointed out that siting is very important. Sometimes the performance of a WTGS does not fit the wind characteristics. Much more understanding and scientific approach are necessary.

3. CONSTRAINTS ON MARKET DEVELOPMENT

3.1. Environmental Impact

So far no significant environmental problem has occurred. It is of course because the history of wind power plant development is very young. At Tappi wind power plant, a complaint of noise was heard but it was solved by soundproof construction. At Hekinan, the WTGS stops its operation during the night.

No bird has been killed by the WTGS in Tappi Wind Park. The behavior of migratory birds was observed by Tohoku EPC to find they are clever enough to recognize the rotating blades.

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 Power	443.8	81.7	0.825	485.2
Tachikawa Wind Power	241.7	37.8	0.806	6.9
Izumo-shi Wind	104.335	50.1	1.043	—

3.2. Institutional Aspects

The most important changes in electricity regulation were made in 1992. Reverse current was permitted for the first time, which created the way for actual utilization of grid-connected WTGS. However, it is often discussed that wind power generation connected to a grid of small capacity or to the end of the grid might disturb the quality of electricity. Some projects have been delayed or canceled due to this issue because there is no legal support for selling electricity from wind. The problem is that we have no technical data to give some numerical guidelines on the penetration ratio. The Miyako project is expected to obtain technical data in a couple of years.

The price of wind electricity is decided by negotiation between owner and electric power companies. On average, the price is approximately 15-20 JPY/kWh.

4. ECONOMICS

4.1. Economics, Financing, and Subsidies

A statistical evaluation of economics of wind generation in Japan is far from happening, because only a few wind power plants can provide available information and even the largest wind power plant is still operated as a R&D plant. However, some examples of economics and financing are shown in Table 8.

5. INDUSTRY

5.1. Market Development

At the aim of 150 MW capacity by 2010, MITI/NEDO, as mentioned above, started the National Field Test Project in 1995, which takes an incentive to develop wind markets in Japan. This project has actually raised interest on wind energy among developers, local authorities, private companies/persons, etc.

5.2. Manufacturing

Main information can be obtained from Table 6, as manufacturers and the technical data of their commercial wind turbines are shown in the list.

6. INTERNATIONAL COLLABORATION

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

THE NETHERLANDS

1. GOVERNMENT PROGRAMS

1.1. Aims and Objectives

The energy policy of the Netherlands is integrated into its environmental policy. Reducing CO_2 emissions is one of the key objectives. The Ministry of Economic Affairs set new targets for energy conservation and renewable energy in the Third Energy Memorandum issued in December 1995. The goal for renewables was raised from a 3% contribution in 2000 to a 10% contribution from renewables in 2020. The targets have been set in annual savings of fossil fuels in petajoules (See Table 1). Renewables will mainly contribute to electricity production. Diversifying energy supplies and maintaining a healthy wind turbine industry are part of the objectives. In September 1996, the Dutch government allocated NLG 750 million for investments to speed up CO_2 reduction, a quarter of which will be devoted to renewables. Projects will be funded that give a substantial CO_2 reduction in the immediate future with technologies that have great potential in the long term.

1.2. Strategy

Various instruments are being used in order to meet these objectives. The coordinated R,D&D programs of NOVEM (Netherlands Agency for Energy and the Environment), the Dutch Energy Research Foundation (ECN), and DUT are contributing to industrial and technical development of wind turbines and blades, which should result in a 30% price/performance reduction of wind turbines by 2000. The extra budgets for research and market introduction of new technologies from the Third Energy Memorandum came into effect in 1997. For market stimulation, there are a variety of instruments consisting of tax incentives, a carbon tax, and a premium price for electricity from renewables. A new tax incentive in 1997 is an investment deduction.

1.3. Targets

The national target for renewable energy are specified in avoided primary energy (PJ), which for wind energy translates in a needed installed capacity of about 1,000 MW by the year 2000; 2,000 MW by the year 2007 and about 3,000 MW in 2020. For the period 1996 to 2000 the target is an annual installed capacity of 100 MW at "traditional" sites.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed Wind Capacity

The installed capacity of wind turbines in 1996 was about 50 MW, bringing the total installed capacity per December 31, 1996, to about 300 MW (see Table 1). The slower installation rate, 50 MW in 1996 versus 100 MW in 1995, was caused by the severe winter conditions in January, February, March, and December and the change from a subsidy regime to stimulation with other market incentives. In 1996, about 10 MW of wind capacity were built without subsidy.

National installed conventional capacity in 1995 was about 13,000 MW. Total installed capacity of wind turbines is 305 MW, which is 2.4% of national capacity.

2.2. Numbers/Type, Make of Turbines

There were 129 machines installed in 1996 bringing the total to 1,181 machines. The average installed capacity per turbine was 364 kW, the ratio between swept area and capacity was 2.5 m^2/kW. About a quarter of the installed capacity in 1996 was from turbines manufactured in the Netherlands, the rest from foreign origin.

2.3. Plant Types and Form of Plant Ownership

The new wind capacity consists of three medium-sized, 13 small wind power plants and about 50 individual machines. About 60% of the 1996 wind capacity is

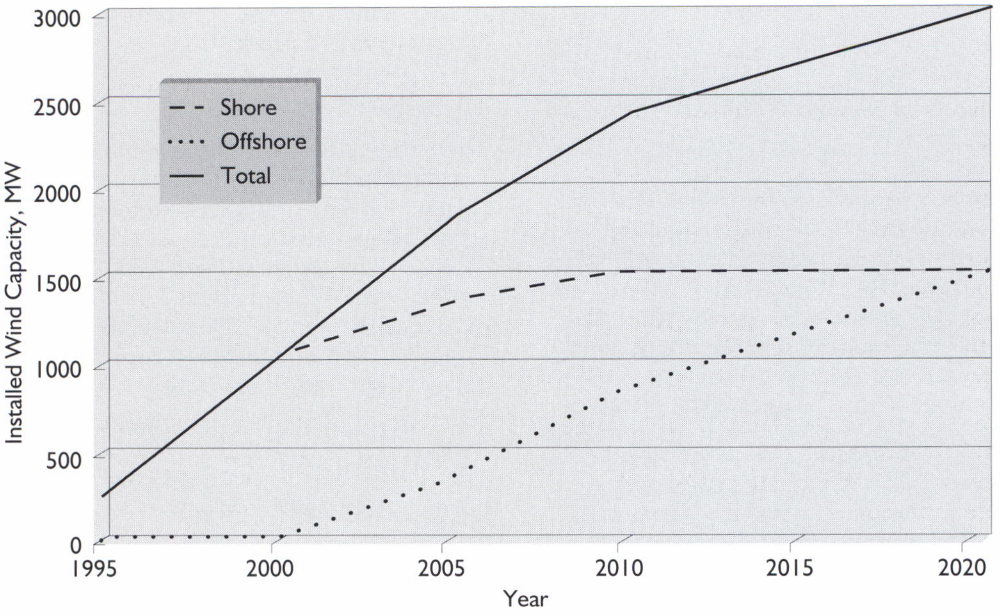

Figure 1. Approximate national targets for installed wind capacity.

owned by utilities, the rest by farmers, industries, developers and cooperatives. In general the following types of owners/operators are operating wind turbines:

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

2.4. Performance of Installed Plant

During 1996, electricity production from wind energy was approximately 430 GWh, an increase of 113 GWh from 1995. Avoided fuel equals 3.7 PJ (and 118 Mm^3 of CH_4); avoided emissions equal 252 kton of CO_2, 546 tons of NO_X, and 105 tons of SO_2. See the *IEA Wind Energy Annual Report 1995* for such annual data from 1986 through 1995. National electricity production in 1996 is estimated at 90,000 GWh.

The year 1996 was not a good wind year. The Windex indicator was about 68%. The specific production, load factor and capacity factor are corrected for the long-year average wind regime. The averages for 1996 are not available yet. Typical ranges for machines >500 kW are for specific production from 900 to 1420 kWh/m^2, and for load factor from 1120 to 2360 hours. With these corrections it can be calculated that in an average wind year the 300 MW could produce 615 GWh and avoid 5.3 PJ annually.

2.5. Operational Experience

In 1996 there were two blade failures with the Kenetech wind power plants consisting of 39 VMS33/360-kW turbines. After research by NLR it was found this was not due to a design problem but to a systematic production failure. The blades were made by TPI from Rhode Island. The maximum output power is reduced at 13 m/s and the turbines are stopped at 17 m/s to reduce the loads on the blades. Whether the blades are repaired or replaced is not clear yet.

There were two blade failures with the seven Tacke turbines (43 meter rotor diameter, 600 kW, hub height 50 meter) in the Netherlands. The turbines were in normal operating conditions. French blade producer A Tout Vent will no longer provide blades for Tacke. The German manufacturer has ended all contracts with A Tout Vent because, according to a press release, A Tout Vent is not able to maintain sufficient quality management. All blades from the seven turbines were replaced with blades from another blade manufacturer at no extra costs for the owners, who were also reimbursed for the loss in electricity production.

3. MANUFACTURING INDUSTRY

3.1. Status/Number/Sales of Manufacturers

The number of Dutch wind turbine manufacturers has not changed over the last years. They are Lagerwey, NedWind, and WindMaster. Their turnover was NLG 74 million in 1994 and NLG 150 million in 1995. Half of this turnover came from exports. Data for 1996 are not available yet. The three Dutch blade manufacturers are Aerpac, Polymarin, and Rotorline. Their turnover in 1994 was NLG 27 million and NLG 38 million in 1995. Most of the blades are exported to Dutch, German, Danish, Spanish, and U.S. wind turbine manufacturers.

In 1996, about 800 people were employed by the wind industry, about 400 people by manufacturers and the remaining by subcontractors, consulting firms, service companies, research institutes and universities.

Table 1. Installed Capacity, Swept Area, Number of Turbines, 1986-1996 (Reference 2).

WIND ENERGY	INSTALLED CAPACITY		SWEPT AREA		NO. OF TURBINES	
Year End	Accum. Total	Annual	Total	Increase	Total	Increase
December 31	[MW]	[MW]	[m^2]	[m^2]	[–]	[–]
1986	7	0	15,782	0	138	0
1987	16	9	31,277	15,495	168	30
1988	22	6	43,748	12,471	223	55
1989	33	11	66,427	22,679	255	32
1990	49	16	101,692	35,264	318	63
1991	82	33	159,017	57,325	426	108
1992	105	23	208,745	49,728	510	84
1993	132	27	272,453	63,708	636	126
1994	154	22	328,311	55,858	727	91
1995	250	94	583,763	255,452	1052	325
1996	297	47	700,981	117,218	1181	129

3.2. New Products/Technical Developments

Lagerwey has certified its 30-m/250-kW turbine. The prototype Lagerwey 45–m/750-kW turbine, a variable-speed, direct-drive, three-bladed machine, each blade separately pitch-controlled, has been tested for nine months. Measurements showed that the machine operated satisfactorily and that the rotor diameter could be enlarged to 50 meters. The prototype will be fitted with a 50-m diameter rotor in the first quarter of 1997. A first series of five machines will be built in the first half of 1997.

WindMaster designed a 48-m/750-kW turbine on the basis of their 43-m/750-kW machine with help from advanced dynamic rotor optimisation computer codes. WindMaster has bought the rights of the Markham 45/600 technology. This is a variable-speed, three-bladed, pitch-controlled machine. After some reengineering, a range of machines for high- and low-wind speed sites will be available in 1997.

Blade manufacturers are completing their product range for 250 to 300 kW, 500 to 600 kW, 750 to 850 kW and 1 MW machines. They adapted their designs through co-makership with customers with a large variety of machines, e.g., stall and pitch regulated, constant or variable speed. Emphasis is on aerodynamic efficient profiles, flexible use of molds, and improving production technology.

3.3. Business Developments

In 1995, Lagerwey started a joint venture in India for local assembly of wind turbines and the manufacturing of towers. Also in 1995, NedWind started a joint venture, called Windia. In 1996, the blade manufacturers continued the trend of expanding the volume of production. They have set up joint ventures for local manufacturing of blades in the Unites States, the United Kingdom, and Spain.

3.4. Support Industries

There are three major developers of wind power plants and four consultant and engineering companies. O&M services are supplied by the wind turbine manufacturers.

4. ECONOMICS

4.1. Electricity Prices

During 1995 and 1996, an agreement was in force between the association of energy distribution companies EnergieNed and the association of privately owned wind turbine operators PAWEX to pay NLG 16.3 cents/kWh for wind electricity for projects of up to 2-MW capacity for which no government subsidies were granted and for a period of 10 years. For projects with government subsidies, the pay-back rate was 13.3 cents/kWh. For projects with more than 2 MW capacity, pay-back rates have to be negotiated with the distribution utilities on a case by case basis. The pay-back rate is composed of the standard pay-back rate of 7.9 cents/kWh plus 3.0 cents/kWh CO_2 tax and a contribution from the utilities' environmental action plan fund, the latter paid for by a small levy on electricity consumption. Negotiations between PAWEX and EnergieNed on a price for produced wind energy in 1997 came to an end on October 25. The final EnergieNed offer was 13.5 cents/kWh and not acceptable to PAWEX. Negotiation parties are seeking arbitration by the Ministry of Economic Affairs. As a result, pay-back rates for wind energy may vary from 12.3 cents/kWh for older projects to 16.3 cents/kWh for new projects.

4.2. Invested Capital

Total invested capital at the end of 1996 for 297 MW is estimated at NLG 825 million. The prices are not corrected for annual inflation. Based on the 1995 average of 2,543 NLG per installed kW, the invested capital during 1996 was NLG 120 million for 47 MW.

4.3. Turbine/Project Costs

The development of project costs during 1991 to 1995 is given in Table 3. The average project cost of wind power plants in 1995 was 2,543 NLG/kW. Turbine costs are about 70% of the project costs. The calculated average production cost from a wind power plant built in 1995 was 0.111 NLG/kWh. The average project cost per unit area was 1,024 NLG/m^2.

The data and assumptions for the calculations are

- Investment costs are gross investments without subtraction of investment subsidies or tax incentives and taken from the collected data from the Dutch wind turbine database
- Average availability 95% in 1995
- Depreciation time 15 years
- Interest rate 5%
- Insurance maintenance, etc., 3.5% of project costs
- Performance factor of turbines 3.38 kWh x s^3/m
- Average wind speed at 30 m hub height of 7.0 m/s.

Generating costs have decreased 30% in the years 1991 to 1995. This is due to a decrease in investment costs, improved production methods and the effects of the "economy of scale" and competition. Also, there has been a marked improvement in the performance of wind turbines. Technological developments have led to improved P(v) curves and a higher reliability.

5. MARKET DEVELOPMENT

5.1. Market Stimulation Instruments

From 1986 to 1995, gradually decreasing investment subsidies were available for investments in wind turbine installations. From 1996, a variety of financial instruments and incentives are available. In January 1995, the green investment scheme became operational. So-called Green Funds are operated by major banks and recognized by the Ministry of Finance. Green Funds have to invest in green projects like wind turbine installations. Capital is supplied by private citizens. Private income from Green Funds, e.g., the dividend or interest, is exempted from income tax. This allows Green Funds to offer a lower interest rate on capital of about 1.5% points. In a first call for capital, NLG 550 million was collected from private investors within a week at an interest rate of approximately 4%.

From January 1996, under the Accelerated Depreciation of Environmental Investment Scheme, a provision of the Ministry of Finance, companies will be allowed to freely amortize investments in wind turbine installations, e.g., profit-making companies can write off the investment in a wind power plant in one fiscal year. This accelerated depreciation keeps taxable income down so that in that year companies pay less income or corporation tax. Of course in later years there will be less to write off. This deferral of tax payments is of benefit to companies' cash and interest position. Company tax is 37%.

Also from January 1996, the Regulatory Energy Tax, a kind of CO_2 tax for small consumers came into effect. The tax applies to electricity, natural gas, medium heavy oil, gas oil and liquid petroleum gas. Renewables are exempted from the carbon tax. Also exempted are transport fuels. For electricity the CO_2 tax is NLG 0.03 per kWh (excl. VAT) in 1996, 1997 and 1998 for a maximum consumption of 50,000 kWh/year, but the first 800 kWh are not taxed. The energy tax is paid to the utilities, who in turn pay to the taxation authority (Ministry of Finance). However, utilities are exempted from payment for energy generated from renewables. Instead, they have to pay NLG 0.03 per kWh to the generators of renewable energy, e.g., wind turbines, hydro, or biomass.

One new market incentive has been introduced per January 1, 1997. The Investment Deduction Scheme, also a provision of the Ministry of Finance, allows profit-making companies to deduct 40% of the investment in wind turbine installations from company profits in the year of investment. As company tax is

Table 2. Development of Project Costs and Calculated Production Costs Corrected for Inflation, Price Levels 1995.

Year	Project Costs/ Unit Area	Project Costs/ Unit Power	Calculated Production Costs
	[NLG/m^2]	[NLG/kW]	[NLG/kWh]
1991	1,808	3,141	0.182
1992	1,507	3,257	0.155
1993	1,237	2,919	0.131
1994	1,076	2,920	0.116
1995	1,024	2,543	0.111

37%, this implies a 15% reduction on invested capital.

5.2. Planning and Grid

The main constraint for short-term implementation is the availability of enough suitable locations for a continuous growth of around 100 MW of installed capacity per year until the year 2000. The bottleneck for acquiring a building permit lies in provincial and local planning procedures. The environmental targets of the distribution utilities for wind energy were decreased. There is no firm agreement between distribution utilities and owners of wind turbines for wind projects with a higher installed capacity than 2 MW.

A study into the possibilities of finding large scale locations (20-50 MW), asked for by Parliament, has been concluded in 1996. Its preliminary finding is that only when the present restrictions, stemming from bird protection policy, are removed it is possible to find sufficient locations for very large wind farms in areas with a large wind resource. Local councils play a key role in finding locations for wind energy. NOVEM is developing a method, together with three selected local councils, to stimulate and support officials and administrators to develop a positive policy for wind energy. In 1997, this method will be offered to other local councils.

Local support

In areas where a lot of solitary turbines have been built (Friesland) resistance from neighbors and other interest groups is building up. The importance of good landscape design is becoming more important.

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

In 1996, KEMA (the research institute of the utilities) together with utility NUON started a network study in Friesland. In this feasibility study the possibilities of a load- and production-management system will be researched with the goal to increase the wind capacity in the existing network with sophisticated control mechanisms.

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, estimated at about 1500 MW in the period 2005 to 2010. The possibilities have been surveyed for non-traditional sites in order to meet further demand for wind capacity in the longer term. As a result of discussions on new locations in 1996 it was decided to concentrate efforts for new sites on inland (low wind) and near-offshore sites. A study in 1996 revealing an inland potential of 1000 MW is followed with wind site measurements and demonstration projects in the near future. Within a range of 20 km of the Netherlands coast several hundreds of MW could be installed in up to 10 m deep water. A feasibility study to investigate the possibilities has started in October 1996.

5.3. Institutional Factors

NOVEM has now set up six groups of regional wind energy experts who will assist local authorities with their specific know-how on planning issues. Typically these experts have specific experience with wind turbines and are local planners, representatives from utilities, bird societies, environmental groups, owners of wind turbines and people living in the vicinity of (newly planned) wind power plants. In 1996, work has started to formulate national uniform rules for wind turbines, e.g., allowed tower heights, acceptable noise levels, distance to residential housing, and requirements for building and environmental permits.

5.4. Impact of Wind Turbines on the Environment

In 1995, a bird migratory study was started using radar for tracking bird flights at night. The study will be finished in 1997. In 1996, a study in landscaping with wind turbines was started. Also an industrial design study to establish general rules for aesthetic design of a wind turbine was begun.

5.5. Financing

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

The transition in 1996 from investment subsidies to tax incentives has created a disturbance in the market. So far especially farmers are hesitating. Some reasons are (1) the pay back rate for 1997 has not been settled between the association of Dutch wind turbine owners (PAWEX) and the association of distribution companies (EnergiNed) and (2) under the scheme accelerated depreciation of environmental investments, some local internal revenue inspectors have decided that investments in wind turbines are in their opinion deposits and do not fall under the scheme.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

6.1. Funding Levels

Allocated funds for all RD&D in the Netherlands during 1991–1997 was NLG 102.2 million (see Table 3). The 1991-1995 TWIN program administered by NOVEM is now followed by the next 1996-2000 program. In 1996, a slight increase in the budget has been effectuated. Levels of funding for R,D&D have been raised for the TWIN program, 1997 to 2000.

6.2. Priorities

The overall aim of technological development of wind turbine technology is competitiveness with fossil fuels after the year 2000. In 1995, a new Netherlands R&D Plan Wind Energy was discussed on the initiative of Novem, ECN, and TU Delft. The topics for the first Dutch R&D Plan Wind Energy 1996–2000 were based on insight of knowledge users and knowledge providers. After discussion during a workshop with industries, designers, consultancy firms, scientists,

Table 3. Levels of R,D&D Funding in the Netherlands 1991-1997, in NLG million.

R,D&D 1991-1997	1991	1992	1993	1994	1995	1996	1997	Total
TWIN R,D&D PROGRAM (subtotals)								
Short-term implementation	1.5	1.7	1.1	1.1	0.7	0.9	2.5	9.5
Long-term implementation	0.1	0.2	0.4	0.3	0.2	1.8	2.2	5.2
Industrial development	4.0	3.6	3.5	3.5	3.3	3.3	6.1	27.1
Technological development	3.0	3.4	3.0	3.0	2.4	2.4	3.3	20.4
Dissemination of know how	0.4	0.5	0.3	0.3	0.5	0.7	0.7	3.4
TWIN R,D&D PROGRAM (total)	9.0	9.4	8.3	8.1	7.0	9.0	14.7	65.5
APPLIED R&D (ECN)	2.5	2.5	3.0	3.0	3.0	3.0	3.5	20.5
R&D UNIVERSITIES (est.)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	14.0
R&D UTILITIES	0.6	0.6	0.6	0.4	0.0	0.0	0.0	2.2
TOTAL	14.1	14.5	13.9	13.5	12.0	14.0	20.2	102.2

program managers and funders the meeting participants agreed on the process of continuous updating of the plan, the content for the first year, and the priorities.

The R&D priorities are aerodynamic modeling; development of design tools; testing; modeling of buckling of blades; direct-drive generator; condition monitoring of rotors; wind field description; reduction of aerodynamic noise. The manufacturers asked special attention for training of engineers at the research institutes. The new NRW is unique for the Netherlands since it is based on consensus on the contents of all involved parties. The model of the plan could be used for international R&D programs.

6.3. Results in 1996

Results from the long-term (1990–1995) Netherlands projects on fatigue behavior of plastic reinforced materials are (1) long-term fatigue properties are sufficiently known to be able to design reliable wind turbine blades; (2) certifying bodies CIWI, GL, DNV, and Risø are incorporating the S/N-curves in their rules; (3) some doubts still exist about the effect of moisture on fatigue behavior.

Results from the long-term (1991–1995) research projects on noise reduction include an overall reduction of 3 dB(A) in mechanical noise. Wind tunnel research provided knowledge about turbulent inflow and trailing edge noise. This knowledge has been incorporated in a (proprietary) computer code, able to predict the relative noise differences of wind turbines. Field measurements on the 1-MW NedWind turbine at Medemblik, equipped with serrated trailing edges, demonstrated the feasibility of an overall noise reduction of 3 dB(A).

The objective of the project Three-Dimensional Effects in Stall was to improve the methods that are used in order to predict the effect of rotation on sectional aerodynamic coefficients, particularly the lift coefficient. This project was a cooperation between the Dutch Energy Research Foundation-Renewable Energy (ECN), Institute for Wind Energy-TU Delft, and National Aerospace Laboratory (NLR). In the first stage, following ideas of Snel, boundary layer equations in a rotating frame of reference were developed by NLR and subsequently put into an integral form. In parallel, the aerodynamic analysis program XFOIL was improved by TU-Delft resulting in a more accurate prediction of lift coefficients near stall. In the second stage, the integral form of the "rotating" boundary layers was implemented in the improved version of XFOIL by NLR. The resulting program, called RFOIL, was validated by using aerodynamic field data from ECN's HAT25 experimental wind turbine. Also, power curves of three commercial wind turbines were predicted on the basis of data obtained with RFOIL, and subsequently compared to the measured curves. In the third stage, an engineering equation was developed by ECN, allowing the effect of rotation on the lift coefficient to be obtained without having to perform a computation with RFOIL. The main result of the project is the aerodynamic analysis program RFOIL, which is more accurate than its precursor near stall in the "non-rotating" mode, and allows one to obtain sectional aerodynamic data under the effect of rotation. Application of RFOIL will result in a systematic and improved prediction of sectional aerodynamic coefficients under rotating conditions.

In a 1996 workshop on validation of rotor aerodynamic phenomena with measurements, it was concluded that the most important measurements for validation are 2-D (two-dimensional) airfoil measurements in wind tunnels (also in deep stall); 3-D wind turbine measurements in wind tunnels to investigate under controlled conditions 3–D effects, tip effects and possibly combine this with noise measurements; and 3-D wind turbine field measurements. The 3-D wind turbine wind tunnel measurements would almost certainly require a large and expensive wind tunnel. This type of research seems very well suited for international cooperation in the EU or IEA framework.

A workshop on dynamic stall and 3-D effects evaluated the Dutch part of the JOULE project. Novem concluded that the objectives were not met. Especially dynamic stall is a phenomena for which no engineering rules validated with measurements can be given.

An updated version of the Dutch database Wind in Progress which contains titles and abstracts of research from 1986 to the present will be available from the Novem Internet site for downloading.

6.4. New Concepts

All Dutch wind turbine manufacturers are investigating the direct-drive concept and variable-speed machines.

6.5. MW-Rated Turbines

In 1995, the second NedWind 52.6–m/1–MW wind turbine was built on the existing tower of the NEWECS-45 at Medemblik. The turbine is operating above expectations.

One of the projects finished in the first quarter of 1996 consists of 4 x 1 MW turbines from NedWind, at an industrial site in the southwest. It is a low wind site with average wind speed of 4.6 m/s at 10 m height. At hub height 70 m, average wind speed will be 6.2 m/s. With an increased rotor diameter from 52.6 m to 55 m, the turbines will reach to 91.3 m, making it the highest ever in the Netherlands. Production per turbine was estimated at 1.7 GWh, totaling 6.8 GWh annually (electricity from wind in 1996 was 430 GWh). The private investor is

For the purpose of aerodynamic rotor blade optimization, the program PVOPT has been developed at the Dutch Energy Research Foundation This program is able to determine the optimal chord and twist distribution of a rotor blade such that the maximum energy yield is obtained. The program consists of a dynamic link library, written in ANSI Fortran 77 containing the optimization code and a Visual Basic program with the graphical user interface. It can run on a PC using Windows 95, Windows NT, or Windows 3.1. Much attention has been paid to the user friendliness of the program. The program is documented by means of a theory description and an online context-sensitive user's manual.

Windfarmers BV. In 1997 another 20 of these machines will be built.

6.6. Offshore Developments

See Section 5.2.

6.7. International Collaboration

Novem and ECN are co-financing numerous research projects of the European Union. A list is given below.

Comterid, Investigations of Design Aspects and Design Options for Wind Turbines Operating in Complex Terrain Environments.
Partners: CRES, CIEMAT, RISØ, TG, ECN.

Data Base on Wind Characteristics.
Partners: RISØ, DTU, MIUU,CRES, VESTAS, ECN.

Stallvib, Prediction of Dynamic Loads and Induced Vibrations in Stall.
Partners: RISØ, Imperial College, FFA, DTU, DUT, Teknikgruppen, Bonus Energy, ECN.

Tentor Blades The Tentor Tube: An Innovative Improvement of a Passive Tip Mechanism.
Partners: SPE, AERPAC, IPA, Univ. Edinburgh, ECN.

Prodeto, Development of a Design Tool for Structural Reliability Analyses of Wind Turbine Components
Partners: (ECN), RISØ, Germanische Lloyd, MICON, AERPAC.

Noise emmission, Noise Emmission from Wind Turbines.
Partners: DDE, ECN, CRES, NEL, RES, DEWI, Univ. Oldenburg, KTH, DK-Teknik

EWTS-II, European Wind Turbine Standards-II.
Partners: EUREC, ECN, RISØ, DEWI, Germanische Lloyd, CRES, NEL, Teknikgruppen, WindTest.

New fiber blades, Development of a Large Rotor Blade with New Fibre Composites.
Partners: Lagerweij, ECN, Atout Vent.

Bioblade, Development of a Rotor Blade Using Renewable Materials.
Partners: DEWI, FhG-WKI, A Tout Vent, Lagerweij, ECN.

Steno, Investigations of Serrated Trailing-Edge Noise.
Partners: Univ. Stuttgart-ICA, AERPAC, SPE, NLR, TNO-TPD, ECN.

European Wind Turbine Testing Procedure Developments.
Partners: RISØ, ECN, CRES, NEL, TU-Delft.

Trainre, Training Research and Information Networks in Renewable Energy.
Partners: EUREC, Univ.Northumbria, Fraunhofer, Univ. College Cork, Hyperion Energy Systems, ECOFYS, Univ. de Corse, Faculdae de Ciência e Technologia, CEA, Ecole des Mines, Conphoebus, ECN.

Buckblade, Buckling Load Analyses Methods for Rotor Blade Design.
Partners: (ECN), AERPAC, DFLR, LASSO, LM-Aeroconstruct, LM-Glassfibre, SPE.

DRAW, Development of a Rotor Acoustic Wind Turbine Prediction Tool.
Partners: IAG Stuttgart, NLR, TNO-TPD, Uni Leuven.

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

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NEW ZEALAND

1. GOVERNMENT PROGRAMS

The government's overall energy policy for energy is to ensure the continuing availability of energy services at the lowest cost to the economy as a whole, consistent with sustainable development.

Direct government funding is not available for the development of renewable energy, however the Energy Efficiency and Conservation Authority (EECA) was set up in 1992 by the government with the aim of promoting the uptake of energy efficiency, conservation, and renewable energy. EECA's primary function is to disseminate information on potential energy sources and their application.

EECA, with the help of the newly formed New Zealand Wind Energy Association, will soon be applying for a more accurate depreciation rate from the Inland Revenue Department (IRD) which will benefit wind power plant economics.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

During 1996 New Zealand's first wind power plant (Hau-Nui), comprising of seven Enercon E40 machines totaling a capacity of 3.5 MW, was commissioned by local power company Wairarapa Electricity. The wind power plant adds to the existing Electricity Corporation of New Zealand (ECNZ) owned Vestas V27 and various smaller turbines owned by other parties, bringing the total grid connected installed wind turbine capacity in New Zealand close to 4 MW.

Due to the strong equinoctial winds, the wind turbines installed in New Zealand have enjoyed capacity factors ranging from 46% to 52%. Availabilities of turbines installed to date have been high, at 95% or greater. Research has indicated however that the large amount of strong wind conditions prevailing can cause significant production losses due to frequent shut-downs in high wind speeds. The amount of energy lost depends on the type of control system employed by the wind turbine.

Commercial interest in wind power plants is steadily increasing as wind energy becomes competitive in a fully deregulated market. During 1996 Resource Consents for a wind power plant of 137 turbines, and for a prototype Diffuser Augmented Wind Turbine (DAWT) were also approved. A resource consent application for a 12-MW wind power plant at Baring Head near Wellington was however turned down by the regional authority due to adverse environmental effects.

Resource consent applications for a further 85 MW of installed capacity are expected to be submitted by various parties during 1997, on sites with average annual wind speeds of approximately 10 m/s. The high wind speeds are expected to make wind power plants developed on these sites economically attractive. Further wind sites totaling up to 600 MW of installed capacity are currently being investigated.

In New Zealand the majority of electricity is produced by hydropower stations with an installed capacity of approximately 4,800 MW. The remainder of electricity is produced by fossil fired and geothermal power stations, which together have an installed capacity of approximately 2,600 MW.

3. MANUFACTURING INDUSTRY

A New Zealand company is planning to begin production of a two-bladed, teetering hub turbine which incorporates a "Torque Limiting Gearbox" to allow variable-speed operation.

A demonstration "Diffuser Augmented Wind Turbine" (DAWT) has been developed and is currently under construction, being scheduled for installation during February and March 1997.

A low-cost vertical-axis wind turbine is being developed privately with the aim of producing a low cost turbine for developing countries. The machine is variable speed with a direct drive, and makes use of extruded aluminium parts.

Local industry has the expertise to manufacture turbine towers, which was proven recently with the construction of seven towers for the newly commissioned Hau-Nui wind power plant.

Interest has also been expressed by the local fiberglass industry in the manufacture of wind turbine blades. Experience already exists in high technology and industrial applications, as well as in New Zealand's highly successful boat building industry.

4. ECONOMICS

On October 1, 1996, New Zealand started a deregulated wholesale electricity market. Wind power therefore competes directly with other forms of generation. Wholesale power prices have varied between 0.02 NZD/kWh to 0.11 NZD/kWh on the spot market, however the overall average price for October and November 1996 was approximately 0.04 NZD/kWh. Extra charges are applied to the wholesale price for transportation of electricity. The open electricity market therefore provides a natural incentive to produce electricity close to load sources, which can allow electricity transportation charges to be reduced or avoided.

Wind power plants constructed at the best sites in New Zealand are expected to produce electricity at a cost of between 0.055 NZD/kWh and 0.075 NZD/kWh given current wind turbine prices.

5. MARKET DEVELOPMENT

Considerable research has been udertaken on the ECNZ V27 machine over the last three years to understand the performance of wind turbines in high wind speed locations. The commissioning of New Zealand's first wind power plant will extend the experience and help alleviate the perceived negative effects of wind power plants.

Recently the New Zealand Wind Energy Association (NZWEA) was formed with members from all parts of the wind power industry. The NZWEA's mission statement is "To promote the uptake of New Zealand's abundant wind resource as a reliable, sustainable and clean energy source."

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

The New Zealand government is funding wind power related research work through its contestible Public Good Science Fund. The goverment expects to contribute up to NZD 660,000 (~USD 460,000) over the next two years to renewable energy projects. A current project is to revise the procedures for the prediction of energy produced by wind turbines erected in New Zealand's high wind speed conditions. A significant amount of energy can be lost due to the hysterisis effect of high wind speed shut downs if wind turbines do not include appropriate control algorithms.

NORWAY

1. GOVERNMENT PROGRAMS

1.1. Research and Development

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

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

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

The budget for government support of the program in 1996 was NOK 17 million (about USD 2.6 million). In general, up to 50% of the development costs can be covered by the program, except for basic research activities, which may be covered up to 100%.

Only a minor part of the R&D budget, about NOK 2.0 million (USD 0.3 million) has been assigned for wind energy activities in 1996.

1.2. Demonstrations

The Norwegian Water Resources and Energy Administration (NVE) is responsible for running a market introduction program on efficient energy technologies, which also includes technologies for new and renewable sources of energy. A government grant of up to 50% of the total cost is available from NVE for such activities. About NOK 87,000 has been used for running a wind/diesel demonstration project under this program in 1996.

2. NATIONAL STATISTICS ON WIND POWER

The national target in the former demonstration program was to have wind turbines with a nominal capacity of 3–4 MW connected to the grid system by the end of 1993. At present, 12 wind turbines (3.9 MW, all of Danish manufacture) are installed along the Norwegian west coast, as listed in Table 1. There have been no installations or removals of wind turbines during 1996.

The wind turbines are installed as single units, except for two units at the test site Frøya and five turbines installed in a wind power plant (2.2 MW) at Vikna, northwest of Trondheim. All turbines are connected to the grid system, except for the oldest one at Frøya, which during experimental periods makes up part of an autonomous wind/diesel demonstration project. Ten of the wind turbines are owned by power companies. These have been installed with the help of a 50% investment subsidy from the wind energy demonstration program. The two others are privately financed and owned.

Hydropower is the dominant form of electricity production in Norway. An installed capacity of about 27,355 MW hydropower provides more than 99% of the energy for electricity supply in a normal year. In addition comes 265-MW thermal power, making a total sum of 27,620 MW installed conventional capacity at the end of 1996. The energy production from wind turbines represents only a minor part of a total electricity consumption of about 113.6 TWh for the year 1996.

The wind power plant at Vikna (2.2 MW) yielded during 1996 an energy output of about 6.4 GWh, corresponding to 1,216 kWh/m^2 rotor area. This output was attained at an average wind speed of

Table 1. Wind Turbines and Output.

WIND TURBINE PROJECTS	RATED POWER (kW)	YEAR OF COMMIS-SIONING	PRODUCTION IN 1996 (GWh)	TOTAL OUTPUT OVER ALL YEARS (GWh)
Frøya	1 x 55	1986	0.118	1.342
Frøya	1 x 400	1989	0.532	5.293
Vallersund	1 x 75	1987	0.157	1.717
Kleppe	1 x 55	1988	0.048	0.309
Smøla	1 x 300	1989	0.518	4.207
Andøya	1 x 400	1991	0.786	5.110
Vesterålen	1 x 400	1991	1.058	5.953
Vikna	3 x 400	1991	3.460	19.335
Vikna	2 x 500	1993	2.912	10.049
TOTAL	3,855 kW		9.589	53.315

7.1 m/s, a capacity factor of 0.33, and an average technical availability at the wind power plant of 97.7%. On an average the wind turbines showed a capacity factor of 0.28, and an average technical availability of 78.9%.

Most of the failures and problems that have occured with the wind turbines during 1996 are due to component defects on a hydraulic unit (Frøya) and injury on a turbine blade by lightning (Vesterålen).

3. CONSTRAINTS ON MARKET DEVELOPMENT

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

The home market for exploitation of wind energy will obviously be quite limited as long as conventional power plants are able to generate electricity at a lower cost than wind turbines, even in places with favourable wind conditions. A local generation of wind power may, however, in some areas lead to savings in energy transmission losses, which can make it a cost effective alternative for the utilities.

It may be difficult to indicate savings in environmental benefits with the use of wind energy in a hydropower dominated energy market. Nevertheless, fuel oil is also used for heating purposes in Norway. If the energy output from wind turbines in 1996 was used to substitute for fuel oil for room heating, it would be estimated to represent a savings of approximately 1,000 TOE (0.105 kg fuel oil/kWh utilized, energy efficiency 0.80).

4. ECONOMICS

The total invested capital in the Norwegian wind turbine systems may be estimated at about NOK 42 million (USD 6.5 million). About one half of this amount has been given as government grants to wind turbine owners.

The value of the total wind-generated electricity so far (53.3 GWh) may be estimated at about NOK 10.6 million. An average generating cost in the hydropower system of NOK 0.20/kWh has been used as a reference for this estimation.

The production cost of electricity from the Norwegian wind turbine systems may as an average amount to

NOK 0.30–0.45/kWh, depending on the wind regime and local conditions. This cost estimate is based on an interest rate of 7%.

Norway has in 1996 had particularly dry weather. One result of this was that the energy production from the hydropower system did not completely cover the domestic demand of electricity. Under these circumstances there was a need for some importing of electricity, which increased electricity prices, as indicated in Figure 1. The given spot market price may also represent a typical buy-back price for wind generated electricity delivered into the grid transmission system. In addition to the prices shown in Figure 1, there are also the grid transmission and distribution costs, taxes and levies. This gives a total price of electricity in the range of 45–55 øre/kWh delivered to household in 1996. The industrial electricity prices may vary considerably, but are usually somewhat lower than for households.

The increase in the prices of electricity has aroused some interest in wind energy during the year 1996 and induced activities in planning of wind power plants, and even given industrial impulses to carry out feasibility studies with intent to produce wind turbines domestically.

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

Even if no investment subsidies for the installation of wind turbines have been granted since the reorganization of the wind energy program in 1994, the question about support in the financing of a planned 1.5-MW wind turbine demonstration unit at Vikna have been raised.

5. INDUSTRY

At present, there are no Norwegian manufacturers of wind turbines. The reason is that the home market for wind turbines seems to be too small. Generally, there is a need for cost reduction and

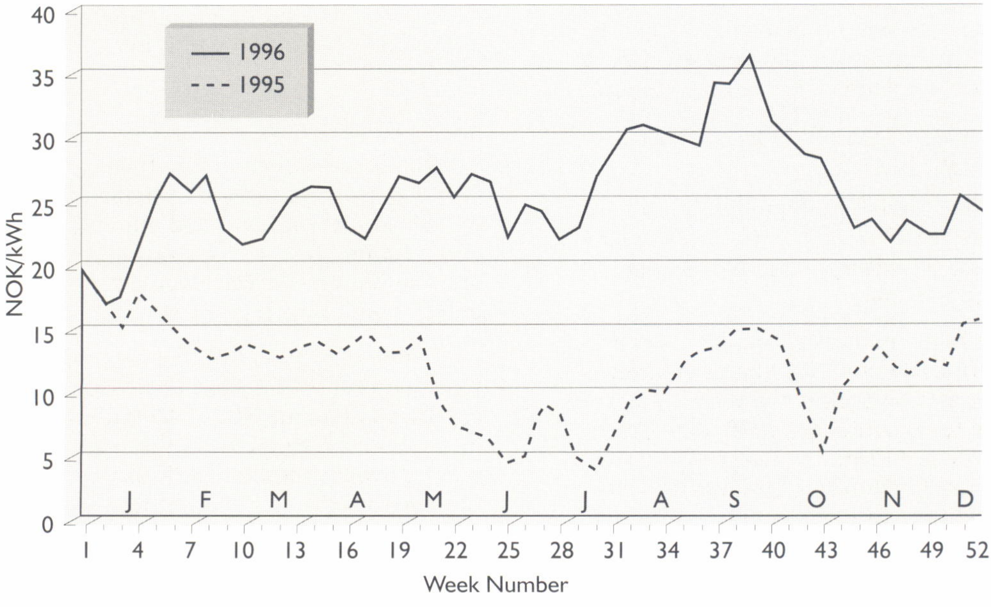

Figure 1. The spot market price of electricity in Norway during the years 1995–1996.

improvements in the wind energy sector if any essential expansion of the wind turbine market is to be achived.

Only a few industrial companies are deeply involved in R&D activities on wind energy, with the exception of the industrial involvement regarding the Norwegian wind/diesel prototype system.

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

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

At the end of 1995, the prototype had attained operating hours corresponding to 7.5 months of continuous operation. Some trivial problems limited the system availability during the first year of operation. However, the prototype delivered an electricity supply with excellent voltage quality during operation. The total fuel saving in 1995 was 54.3% of the corresponding consumption when running the diesel generator set only.

The system has, however, had more serious availability problems in 1996 caused by defects in the battery system. The battery system includes 170 Ni/Cd battery cells with a nominal 5-hour capacity of 27 kWh. The particular batteries were chosen because of their expected superior quality concerning long-term operation, deep cycling, rapid charging and discharging, and their ability to withstand a very high number of discharge cycles.In March 1996, it was discovered that about 15% of the battery cells did not accept recharging. The operation of the system was then stopped and the battery units were sent to the manufacturer for a thorough examination.

After a series of investigations it was concluded that the battery problems are due to a manufacturing fault. Consequently, the battery units will be replaced as a matter of guarantee. The present aim is to resume the system operation as soon as the battery units are restored early 1997. The intention is to achieve the planned one year of accumulated operation. The next step will be to work out a market analysis program for this wind/diesel system.

Other industrial products for the wind energy sector are delivery of 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 studied in 1994 from a material and structural point of view. This investigation was continued in 1995–1996 with a more extended study of the structural and aerodynamic design of a selected turbine blade. The next step will be to produce a prototype blade for testing.

6. INTERNATIONAL COLLABORATION

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

ABB Kraft A/S participates in the JOULE III project "Power control for wind turbines in weak grids." Some of the experiences from the work with the second generation wind/diesel system may be exploited in this project.

The Norwegian University of Science and Technology, Trondheim, participates in the JOULE project "Database on wind characteristics."

The electricity company NTE and the research institute IFE has given assistance in the pre-engineering planning of a wind power plant (3.6 MW) in Lithuania. The intention is to continue this activity also in 1997 in order to assure an appropriate financing of the project.

SPAIN

The Spanish Government continues supporting renewable energy according to the objectives defined in the European Union—economic growth, creation of employment, maximum self-sufficiency, and raising the quality of life of its inhabitants through improved environmental conditions.

The main participants in the structure of the Spanish electric supply system are coal-thermal plants (47%), hydroelectric plants (36%), and nuclear plants (16%).

The targets relating to the use of renewable energy sources are described in the Energy Saving and Efficiency Plan (PAEE), contained in the Spanish National Energy Plan. This plan foresees an increase of 25% in the participation of renewable energy in the structure of primary energy consumed compared to its contribution in 1990.

The wind goal of 168 MW by the year 2000 foreseen in the PAEE has been widely surpassed, reaching and exceeding such amount in the year 1996.

Figure 1 shows the existing wind installations distributed by regions on December 31, 1996.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed Capacity

During 1996, a significant advance was produced in wind energy in Spain and 215 wind turbines were installed with a total output capacity of 94 MW.

The total power installed at the end of 1996 is 216 MW and 955 wind turbines.

The increase in power during the year was 75% (125 MW at December 1995). The predictions for the next year (based on

Figure 1. Distribution of installed wind energy capacity at the end of 1996.

Table 1. New Renewable Energy Projects in 1996.

AREA	NO. PROJECTS	ENERGY (Toe)	TOTAL INVESTMENT (ESPM)	PUBLIC SUPPORT (ESPM)
Small Hydropower	31	15193	7687	348
Biomass	9	27007	2164	758
Municipal Solid Waste	2	58050	12450	2500
Wind	40	38671	28764	2956
Photovoltaic Solar	148	34	652	275
Thermal Solar	82	330	323	112
Geothermal	1	140	72	30
TOTAL	313	139426	52113	3979

on-going projects) foresee the installation of another 250 MW and almost 600 wind turbines, an increase for 1997 of 116% in power. So, as a conclusion the present tendency in Spain is to duplicate the power installed every year, a tendency that according to the plans of the local regions and with the market situation seems likely to continue in the next years.

Figure 2 shows the evolution of wind energy in Spain since 1988. (Data for 1997 are predictions based on present data.)

The majority of the autonomies (regions) have local wind energy programs, which makes a total target of more than 5000 MW to be installed in the next decade.

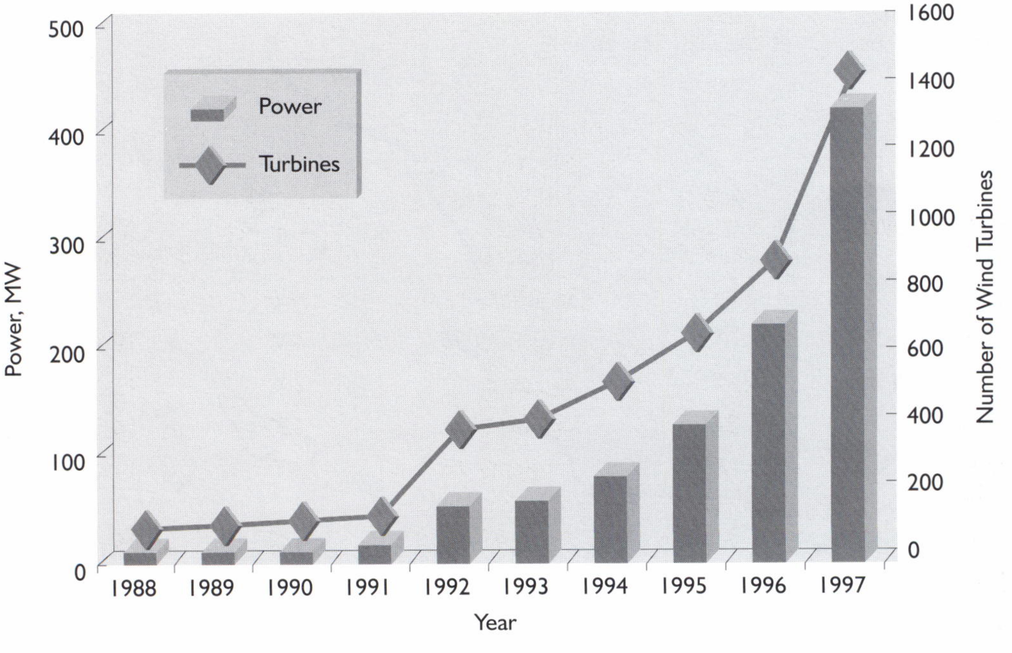

Figure 2. Capacity power evolution in Spain.

The most important programs are the Galicia Program for the installation of 2800 MW for the year 2005, the Navarra Program with the target of 600 MW for 2010, the Aragon target of 1000 MW and the Andalucia one of 400 MW for 2000.

About the technologies used in the installations in 1996, the unit average power increased to 440 kW, which means that the wind turbines used a range from 300 to 600 kW of rated power per unit.

The new wind power plants are large and medium sized (see Table 2), the smallest being a 15-unit wind power plant of 9 MW, and the biggest a 66 unit, 20 MW wind power plant. The tendency is going to be maintained for the next installations and only one small wind power plant is foreseen to be installed in the next year.

The wind power plants installed in Spain are mainly owned by consortiums formed by utilities, regional institutions involved in local development, private investors, and in some cases the manufacturers. Private individuals are not taking an important role in the development of wind energy in Spain.

2.2. Operational Experience

Analyzing the production data (71% of the installed power) of the wind turbines operating in Spain in 1995 shows the average capacity factor is 0.28, which corresponds to 2453 hours per year at full load. The following is the result of the analysis:

Capacity Factor %	Wind Turbine %
<20	10.3
20-30	38.0
30-40	47.0
>40	4.7

Regarding the specific energy production (ratio between annual energy and rotor area of the wind turbine), the average value for 1995 was 1040 kWh/m^2, with the following distribution:

Specific Energy (kWh/m^2)	Wind Turbine %
<500	2
500–1000	35
1000–2000	52
2000–3000	10

In comparison with the year 1994, there is an increase in the average capacity factor and in the specific energy of around 6%.

Table 2. Wind Power Plants Installed in 1996.

WIND POWER PLANT	NO. WIND TURBINES	MANUFACTURER AND MODEL	RATED POWER PER UNIT (kW)	TOTAL POWER (MW)
Leitza	15	Gamesa G-42	600	9.0
Beruete	17	Gamesa G-42	600	10.2
La Plana III	25	Gamesa G-42	600	15.0
Borja	27	Gamesa G-42	600	16.2
El Perdón (Phase II)	15	Gamesa G-39	500	7.5
Capelada	50	Made AE-30	330	16.5
Juan Grande	66	Desa 300	300	19.8
TOTAL	215			94.2

3. ECONOMICS

3.1. Electricity Prices

The Spanish government introduced in December 1994 (Royal Law 2366/1994 9th of December) the regulation of the price to be paid to the self-generators that cover cogeneration plants, minihydro, photovoltaic, and wind power plants. The aim of the regulation is to increase the energy production from non-conventional power generation plants from 4.5% in 1990 to the target of 10% in the year 2000. This regulation brings together the existing regulations to a single text and develops the basic criteria of the technical and economical relations between owners and utilities. The regulation applies to wind power plants up to 100 MW.

The average value paid for the electricity generated for the wind power plants during 1996 was 12 ESP/kWh, with small variations depending on some specific conditions. The average sale price of the electricity to the consumers for 1996 was 14.54 ESP/kWh, going from average prices for the industrial sector between 9–11 ESP/kWh to 16.3 ESP/kWh for domestic users.

4. INDUSTRY

The intense activity in the wind energy field has activated intensively the development of the Spanish wind industry, covering not only the manufacture of complete wind turbines but also the manufacture of components for the wind industry such as blades, gearboxes, wind sensors, etc.

Four companies lead the national Spanish industry: ECOTECNIA S. Coop., MADE, DESA, GAMESA Eólica.

ECOTECNIA, a pioneering enterprise in wind energy in Spain with more than ten years developing, manufacturing, and installing wind power plants, has more than 300 wind turbines in operation of the models ECO/24 (200 kW) and ECO/28 (225 kW). During 1996, ECOTECNIA installed the two prototypes ECO/41 and ECO/44 of 500 kW and 600 kW that are in the testing phase. Both designs are three-bladed, stall-controlled wind turbines, incorporating a very advanced design in the drivetrain. The ECO/41 will be ready for commercialization in early 1977. In 1996 ECOTECNIA installed nearly 100 wind turbines.

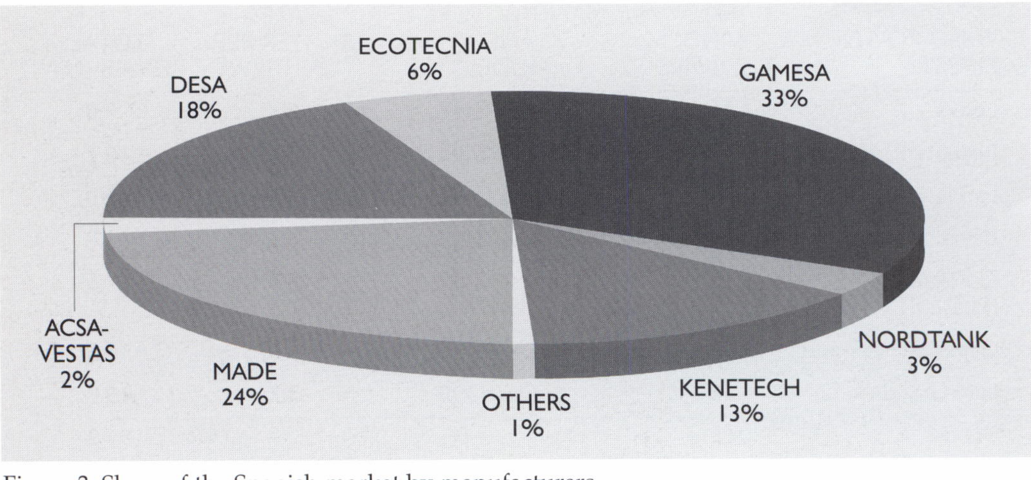

Figure 3. Share of the Spanish market by manufacturers.

MADE is the leading company in number of wind turbines in operation in the Spanish wind power plants. At the present time, MADE is concentrating their commercial effort on the model MADE AE-30 (330 kW), and two prototypes (one using aerodynamic stall control and the other pitch control) of 500 kW, the AE-41, and are also in the testing phase at the Monte Ahumada Wind Farm, in the Tarifa area. MADE will start the production of the AE-41 for 1997. Also a prototype of 600 kW, specially designed for low wind conditions will start operation in February 1997.

DESA manufactures 300-kW wind turbines and is developing a new wind turbine in the range of 600-700 kW.

GAMESA Eólica is manufacturing wind turbines of 500 kW and 600 kW using Vestas Technology The majority of the components are already manufactured in Spain (including blades). The company has installed more than 50 units during 1996.

Also there are other manufactures active in the wind energy industry using foreign technology (TAIN-Nordtank, ACSA-Vestas, etc.), that will increase the capacity of the Spanish industry to fulfill not only the internal market but also others markets. In particular, Spanish manufacturers are participating at the present time in projects in North Africa (Tunez, Morroco, etc.) and also increasing the marketing activities in other countries (India, South American countries, etc.).

During 1996, the manufacture of blades started in three new factories. LM Spain is manufacturing blades in two factories: LM Composites Toledo S.A. and LM Composites Galicia S.A. IMETUSA continues the production of the Aerpac blades in Tudela (Navarra). Gamesa

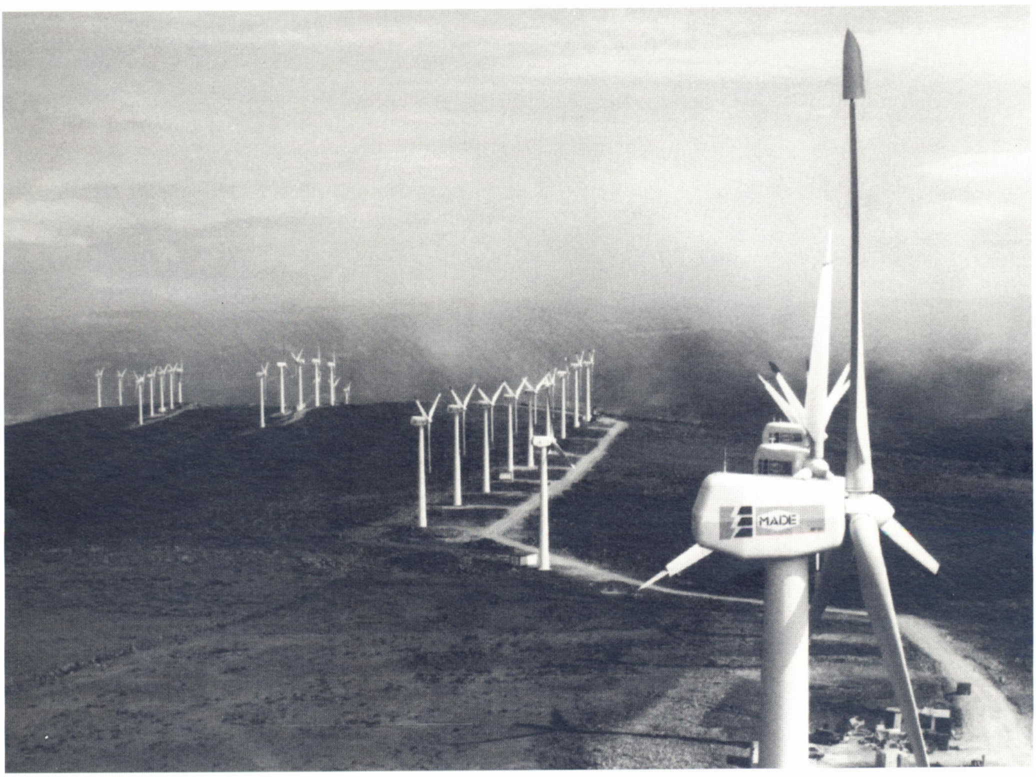

Figure 4. A Capelada 16.5-MW wind power plant (50 MADE AE/30 of 330 kW).

manufactures the blades of its wind turbines in the new factory in Pamplona (Navarra), and SEVIPOL is manufacturing blades in the factory located in Sevilla for the DESA wind turbines. DESA has created a new factory in the Canary Islands the will produce blades for the DESA-300 model.

5. RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM

5.1. R&D Program

The majority of the R&D activities in wind energy in Spain are developed under the umbrella of the R&D European programs. Table 4 presents a list of the main European projects with Spanish participation.

The main R&D organization in the field of wind energy in Spain is the CIEMAT, a public center for research in the technologies and environmental aspects of the energy production. Inside CIEMAT, the Institute of Renewable Energies (IER) is active in several projects ranging from resource evaluation, blade development and testing, wind turbine testing, design and modeling of components, and stand-alone application with emphasis on water desalination.

The funding levels for wind energy R&D is basically the budget of the wind energy department of CIEMAT, which, for 1996 was around 300 MEPS. For demonstration projects in 1996 the public funding was 3000 MEPS (20 MECU).

The only megawatt wind turbine is Spain is the AWEC-60 project installed inside the WEGA I program of the DG XII in 1989. The wind turbine is going to be retrofitted with a new set of blades, and is expected to restart operation in middle 1997. On the other hand there is not, at the present time, activity in the megawatt size wind turbine, but the Spanish manufacturers are considering now starting new developments as soon as their present developments in the range of the 500-700 kW begin the commercial phase.

5.2. Demonstration Program

The National Energy Plan (PEN-91) includes the 1991-2000 Energy Saving and

Table 3. Wind Turbines Manufactured in Spain with Rated Power >100 kW.

MANUFACTURER	MODEL	DIAMETER (m)	RATED POWER (kW)	POWER REGULATION
ECOTECNIA	Eco 40/500	40	500	Aerodynamic Stall
ECOTECNIA	Eco 24/200	24	200	Aerodynamic Stall
ECOTECNIA	Eco 28/225	28	225	Aerodynamic Stall
MADE	AE-41	41	500	Aerodynamic Stall
MADE	AE-20	20	150	Aerodynamic Stall
MADE	AE-23	23	180	Aerodynamic Stall
MADE	AE-30	30	300	Aerodynamic Stall
GAMESA	Vestas G-39	39	500	Blade Pitch
GAMESA	Vesta G-42	42	600	Blade Pitch
DESA	DESA 300	27	300	Blade Pitch

Table 4. Spanish Participation in European R&D Projects.

PROGRAM	COORDINATOR	SPANISH PARTICIPANTS	PROJECT TITLE
JOULE	CRES (GR)	CIEMAT MADE	Measurement of load and power in complex mountainous terrain (MOUNTURB)
JOULE	CRES (GR)	CIEMAT	Investigation of design aspects and design options for wind turbines operating in complex terrain environments (COMTER.ID)
JOULE	EUREC AGENCY	CIEMAT	European Wind Turbine Standards II (EWTS-II)
JOULE	City University (UK)	ECOTECNIA	Optimizing the aerodynamic performance and control of wind turbines
JOULE	Univ. of Madrid (SP)	Univ. of Madrid CIEMAT	Smart Technologies Applied to Wind Turbine Blades (SMART-BLADES)
JOULE	DEWI (D)	CIEMAT	Harmonization and Improvement of Rotor Blade Quality Control (HIROQ)
APAS	RISØ (DK)	CIEMAT	Feasibility studies on combined wind-diesel desalination in Greece and Spain
APAS	LAMDA (GR)	CIEMAT	Utilization of wind, solar and biomass resources in Mediterranean rural regions
APAS	ITER (SP)	ITER CIEMAT U. LAS PALMAS	Towards the large scale Development of Decentralized Water Desalination (Prodesal - Pro Desalination)

Efficiency Plan (PAEE), which describes the subsidies for renewable energy. These subsidies vary according to specific circumstances. For the wind sector in 1995 the subsidies affected three options:

a) Innovative wind turbines with rated power greater than 300 kW and lower than 1000 kW. It was possible to obtain a subsidy for one or two turbines if the designs are different or complementary. The maximum subsidy was up to 40% of eligible cost.

b) Wind power plants with exceptional conditions: access complicated, high cost in the power line or areas with low winds. It was possible to get subsidies up to a maximum of 20 MW of power installed, in one or some wind power plants, with

Figure 5. ECOTECNIA 44/600 prototype at Tarifa wind power plant.

commercial wind turbines of same technology. The maximum subsidy was up to 30% of eligible cost.

c) Single wind turbines for particular applications: isolated systems (including non-grid connected application) and applications accessing high or very low winds. The maximum subsidy was up to 30% of eligible cost.

In 1996 only the last two options qualify for subsidies in the same conditions.

SWEDEN

1. GOVERNMENT PROGRAMS

1.1. Aims and Objectives

As set out in 1991, the objective of Sweden's energy policy is to secure the long-term and short-term supply of energy on internationally competitive terms and to promote economic and social development based on environmental sustainability. The policy specifies that the national energy supply is to be secured by an energy system based as far as possible on sustainable, preferably indigenous and renewable resources and on energy efficiency. Sweden's energy policy approach places considerable emphasis on economic and environmental objectives.

Based on these principles, an Energy Commission (published Dec. 95) made up of Parliamentary representatives was established in 1994 to review the basics of Sweden's energy policy. The Commission's work is meant to clarify among other things whether current energy policy programs are sufficient to meet the combined targets and aims of energy, economic, and environmental policies.

The findings of the Commission reaffirm the policy objectives set out in the 1991 Energy Bill, as stated above. It underscores that a number of conflicting policy objectives remain to be resolved: the climate change issue, employment, welfare, and difficulties in retaining competitiveness if all nuclear power is to be phased out by 2010. Results of energy efficiency improvements, supply of renewable energy, and the options for maintaining internationally competitive prices are to determine the speed at which nuclear power is phased out. Further, the Commission finds that an exact time limit setting out the year in which the last reactor is to be taken out of service should not be specified. On the other hand, it finds that the phase-out should be commenced at an early stage to ease the adjustment process, and that it is possible to close one nuclear reactor by 1998 without adverse effects on the power balance. Within this framework, the Commission presents a number of proposals for further analyses, emphasising that special attention should be paid to cost-effectiveness and financing aspects.

The findings and recommendations of the Energy Commission are now being discussed and debated in Sweden by political parties, market players, and the general public. On 4 February, 1997, an inter-party Energy Policy Agreement between the Social Democrats, the Centre Party, and the Left Party was reached, one reactor shall be closed down before July 1, 1998, (Barsebäck I), and the second reactor (Barsebäck II) before July 1, 2001. A new, long-term transformation program to develop an ecologically sustainable energy supply system has been proposed. It is expected that this will lead to a Parliamentary Bill in March 1997 that will set the policy direction for the energy sector in Sweden for the coming decade.

1.2. Government R,D&D

Sweden has a good wind energy resource and was one of the first countries to embark on a wind energy program in 1975. The government is supporting the development and installation of wind turbines in two 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.

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

NUTEK has begun a discussion with different companies and organizations in Sweden in order to start a co-financed research and development program. The program is planned to start by January 1, 1998. Preliminary content is presented in Table 1.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. The Electricity Market

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

As a consequence, the Swedish State Railways made the decision to buy electricity produced by wind power through their supplier Sydkraft AB. An other example is McDonald's at Rissne outside Stockholm. They have signed a contract with Vattenfall AB for the delivery of electricity produced with wind turbines.

Table 1. Preliminary Content of a Cofinanced Research and Development Program.

PARTICIPANTS

Utilities

Small electricity producers

End users buying wind electicity

Research organizations

Government authorities

ISSUES UNDER DISCUSSION

ACCEPTANCE	INTEGRATION	DEVELOPMENT/ DEMONSTRATION
• Siting • Noise • Radar interference • Impact on the landscape	• Grid integration -value (grid/capacity) -neg./pos. effects on grid losses • System efficiency	• Design/analysis tools (models) • Demostration of new and innovative technology • Offshore

The New Electricity Market—Regulations for Small-Scale Production

Before the reform, the holder of a regional power concession was responsible for purchasing electricity from all small power generation plants up to 1500 kW located within the distributor's region. The price was set as "avoided cost."

With the aim of protecting the small power producers during the transition to the new competitive electricity market, a delivery concession has been introduced in the Act, for a limited period of time (five years). The holder of a delivery concession is responsible for purchasing electricity from each power generation plant (<1500 kW) located within his region.

The price is decided to be equal to the household tariff minus reasonable costs for administration and profit. The wind turbine owner also gets income from the net owner related to the value of the decreased net losses. The deregulated market also provides the possibility for the turbine owner to sell his electricity to any customer. This provides the opportunity for a "wind electricity market."

2.2. Installed Wind Energy Capacity

In the early '80s, two MW-sized prototypes and a few 50-kW units were erected in Sweden. From 1988 onwards, commercially available wind turbines were introduced at a notable rate, amounting to a total of 5 MW when the investment subsidy was introduced in July 1991. Since then the amount has increased to a total of 105 MW (December 1996) and an annual electricity production of about 142 GWh (about 220 GWh during a "normal" year). The total installed capacity in Sweden is shown in Table 2.

Historically, wind power plants have been owned by private companies, either directly by individuals and private companies (mainly active in other areas than energy production) or owned as shares in companies and partnerships. Over recent years, this dominance has increased. During 1996, however, the utilities have increased their market share compared to 1995 (Figure 1).

3. MANUFACTURING INDUSTRY

3.1. Status/Numbers/Sales of Manufacturers

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

Kvaerner Turbin AB has developed and sold Näsudden I (2000 kW) and Näsudden II (3000 kW). Vattenfall AB is the purchaser of both turbines.

Table 2. Total Installed Electricity Capacity in Sweden.

GENERATOR TYPE	1996 MW	1996 TWh
HYDRO POWER	16,150	51.6
NUCLEAR POWER	10,050	70.9
THERMAL POWER PRODUCTION (CHP, cold condensing)	7,400	12.6
WIND POWER	105	0.14
NET IMPORT		5.1
TOTAL	33,705	140.0

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

Zephyr Energy AB has developed and sold six 250-kW turbines. The local distribution company Falkenberg Energy and Vattenfall AB are the purchasers of the turbines.

4. ECONOMICS

4.1. Electricity Prices

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

The prices on the market for high-voltage electricity paid by certain customers, industrial plants, and distributors may be close to the bulk power price. On the market for low-voltage electricity, the distribution costs are considerably higher, and the price of bulk power as a proportion of the price paid by the end customer is consequently relatively low at just under one-third of the price, excluding taxes, payable by a household without electric heating (Table 3). The prices charged to various customer categories are determined by tariff systems which are made up of a mixture of variable and fixed charges.

4.2. Turbine/Project/Generation Costs

At good sites, today's commercial wind power plants of up to 600 kW can produce electricity at a cost of SEK 0.26–0.32 /kWh (without state subsidy) depending on the site. In Sweden, support is generally required for wind power to be viable.

The wind power plants that are erected today have a capacity between 150 and 600 kW with a majority towards larger wind energy conversion systems. The total investment (average) costs for different Swedish wind turbine projects

Table 3. Total Price of Network Service and Electricity on July 1, 1996, in Sales of Electricity under the Terms of a Delivery Concession to Various Typical Customers, 0.01 SEK/kWh.

CUSTOMER TYPE	TOTAL PRICES WITH TAXES	PRICES OF NETWORK SERVICES AND ELECTRICAL ENERGY WITHOUT TAXES	
	MEAN VALUE	NETWORK	ELECTRICAL ENERGY
Apartment	98.1	40.8	28.2
Single-family house without electric heating	90.0	35.8	26.7
Single-family house with electric heating	65.5	18.5	24.7
Agriculture or forestry	68.0	21.6	23.7
Small industrial plant	33.5	10.0	24.0
Medium-sized industrial plant	27.9	5.5	22.3
Electric-intensive industrial plant	24.3	3.8	22.0

Source: "Prices of electrical energy and network service in 1996," E11 SM 9602, Statistics Sweden are shown in Table 4. As an average, the costs for the wind turbine is about 80% of the total investment cost.

4.3. Invested Capital and Value of Generated Power

The total invested capital from installation of commercial wind turbines in Sweden so far is approxamately 960 million SEK (calculated from the year 1991).The price paid for wind-turbine-produced electricity during 1996 was between SEK 0.26/kWh and SEK 0.28/kWh (included net value payment). The value is increased by an "environmental bonus," at SEK 0.113 per kWh. From 1 July 1997 the "environmental bonus" is set at SEK 0.138 per kWh. The "environmental bonus" is a subsidy from the government and corresponds to the electricity tax for households.

5. MARKET DEVELOPMENT

5.1. Market Stimulation Instruments

A market stimulation program (35% investment subsidy) started in 1991 and ended in June 1996. Today there is no subsidy except for the environmental bonus for wind turbines with a capacity less than 1500 kW.

In 1995, NUTEK initiated a technology procurement process in order to further reduce the cost for electricity produced by wind turbines. The key purpose was to minimize the technical and economic risks for the buyer by clarifying important technical and economic requirements, and to make sure that predicted performance actually will be delivered.

Table 4. Total Average Investment Costs and Production from Wind Turbines in Sweden.

TURBINE SIZE	SEK/kW	MWh
200-250 kW	9,700	500
400-500 kW	8,800	1,100
600 kW	7,100	1,250

The Swedish Wind Turbine Buyer Consortium (SWTBC) was formed for this purpose. SWTBC contains five members: Göteborg Energi AB, MIT Energi AB, Slitevind AB, Vattenfall AB, and Sydkraft AB. SWTBC main objectives were

1. Joint procurement of wind turbines. The procurement includes firm orders and optional deliveries.

2. Application of an elaborate tender evaluation process, which aimed at finding the most cost-effective wind turbine on the international market.

3. Introduction of a supply contract standard comparable with common standards of procurement for other sorts of power production units.

4. Negotiations with a bank consortia about a financing scheme convenient for wind power.

Unlike most other requests from wind turbine tenders, SWTBC refrained from specifying nominal power or design concept in order to allow manufacturers to optimize these.

The winner of the competition was the Danish manufacturer Bonus Energy A/S with its 600-kW Mark IV. The price for the turbine and tower is between 5600 SEK/kW (850 USD/kW) and 5900 SEK/kW (900 USD/kW) depending on tower height (40–50 m). Average additional cost is in Sweden about 20%; the total investment cost will then be between 6700 SEK/kW (1020 USD/kW) and 7100 SEK/kW (1070 USD/kW)

5.2. Constraints

5.2.1. Environmental Impact

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

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

5.2.2. Public Attitudes

An investigation on public attitudes towards two wind power plants has been carried out by Vattenfall AB at its test station Lyse in the municipality of Lysekil on the West Coast (north of Gothenburg). The investigation has included both inhabitants and summer residents around the plants and some politicians and civil servants from the municipality. A majority of those interviewed had a positive attitude towards wind power. In the summer resident area there were more doubts about wind power plants.

5.2.3. Noise

Noise is a subject frequently discussed in wind turbine projects. The studies on assessment of wind turbine noise have shown that not only the sound level and its temporal pattern, but also several other factors are important for the subjective responses. The major interest is presently concentrated on noise immission, that is, how to measure and assess wind turbine noise at sensitive areas in the vicinity of a

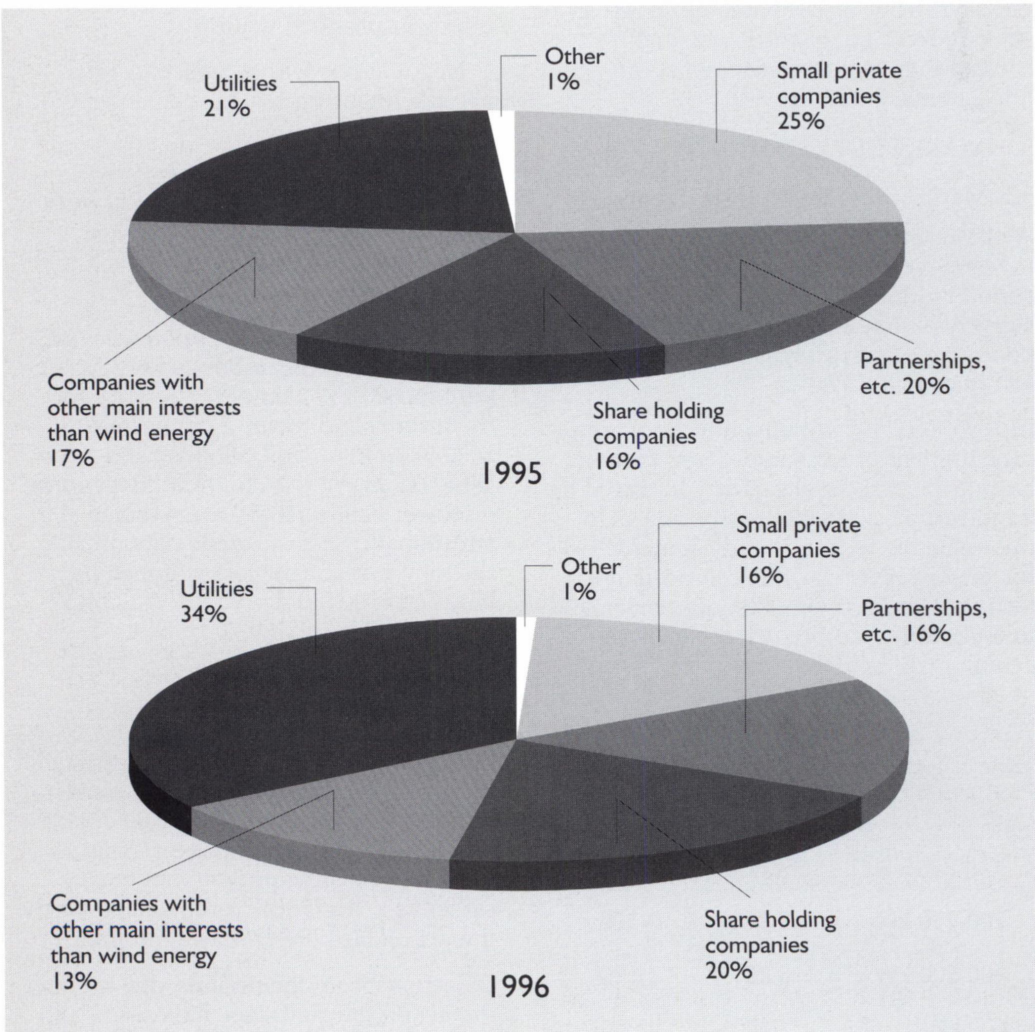

Figure 1. Owners of wind turbines in Sweden (December 31, 1996).

turbine or a group of turbines. Work is continuing on how to describe the noise disturbances in physical terms.

5.3. Institutional Factors

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

Being Sweden's central governmental agency regarding energy, NUTEK also has the responsibility for claiming areas of national interest for energy production. For windpower, NUTEK has in December 1996 decided on the principals for how to proceed. Primarily, areas corresponding to an electricity production of 1 TWh will be identified and another 1 TWh will be identified as a reserve. These areas will need to have a minimum energy content of 4000 kWh/m^2 at 100 m height. Areas concerning national parks, nature resorts, and animal protection areas will not be included. So far NUTEK's work with areas of national interest for wind power production only include land-based plants in the southern parts of Sweden.

6. GOVERNMENT SPONSORED R,D&D PROGRAMS

6.1. Research and Development

6.1.1. Scope

The overall goal for the Swedish wind energy research program is to develop the knowledge within the wind energy area so it will be possible to manufacture and develop wind turbines and utilize wind energy efficiently in the Swedish Energy system.

6.1.2. Financing

Wind Energy research and development in Sweden has a budget of 7 million SEK during the fiscal year 96/97 (1 July 1996 to 30 June 1997). The work has mainly been carried out and administrated by a consortium named Vindkraftskonsortiet (VKK). The consortium was formed in 1994 and comprises the following three organizations: The Aeronautical Research Institute of Sweden (FFA, leader of the consortium), Department of Power Electronics at Chalmers University, and Department of Meteorology at Uppsala University. More information can be found at the following web page: http://www.ffa.se/windenergy/windenergy.html.

6.1.3. Research Topics

The participants in the consortium are responsible for the following research areas: FFA (aerodynamics, structural mechanics, materials), Chalmers (electric machinery and control technology, test station at Hönö) and Uppsala University (atmospheric research, wake effects and boundary layer phenomena).

The basic research within these topics are combined into co-operation projects with the goal to develop suitable tools for analysis and design of wind energy conversion systems. These projects will aim at developing methods for lighter and more flexible wind energy conversion systems. Such machines require better understanding and prediction methods for the general behaviour and structural response of the wind energy conversion systems.

An area of uncertainty is within the field of aerodynamics. Questions regarding blade behavior at stall and the influence of three-dimensional flow have been given extra attention lately. Methods suitable for implementation into structural codes have been developed. These calculation tools have been verified during the evaluation of Nordic 400.

Wind resource assessments in the northern mountainous parts of Sweden as well as off shore have been studied in order to make wind resource knowledge more complete. Special attention has been put into understanding turbulence, shear, and wind direction behavior at such sites.

Table 5. Project Data Bockstigen, Valar 2.5 MW

Capacity	5x500 kW
Calculated average wind, 40 m height	8 m/s
Calculated annual electricity production	8 GWh
Calculated construction cost	32.2 million SEK

Meteorological phenomena in wind power plants have also been studied. Results illustrate the importance of considering atmospheric conditions when describing the structure of a wind turbine wake.

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

6.2. MW-Rated Turbines

6.2.1. Nordic 1000

The 1 MW Nordic 1000 wind turbine—thoroughly described in *IEA Wind Energy Annual Report 1994*—was erected in early April 1995. During 1996 it produced 1264 MWh. Total from start of operation is 1726 MWh during 8118 hours of operation.

6.2.2. Näsudden II

The 3000 kW Näsudden II has up to December 31, 1996, produced 17 521 MWh during 16 387 hours of operation. In November it was taken out of operation for a gearbox repair, which will be finished in February 1997.

6.2.3. Development Study III

The development of the multi-MW turbines has continued during 1996 at Kvaerner Turbin AB. The company is performing the third phase of the Development Study III for the third generation of large WTS. This project has as a main goal to develop the Näsudden II/Aeolus II turbine concept into a commercially competitive machine. The cost goal for the project is an investment cost of SEK 3.00/kWh/year. The study is ordered from Vattenfall AB and financed by NUTEK, Vattenfall AB, and Kvaerner Turbin AB and is a continued cooperation with the German parties as in Näsudden II-Aeolus II.

6.3. Offshore Siting

6.3.1. Nogersund

Since 1991, a research program is going on concerning the impact on the environment from the 220-kW offshore wind power station at Nogersund. The bird migration lines pass very near the station. Despite this, the impact on birds turned out to be none. The resting birds got used to the station and the migratory birds noticed the station and flew further away from the turbine. Nogersund is the biggest fishing harbour in the south of Sweden. Therefore it was important to examine the impact on fish and fishing. The foundation of the station turned out to be construction which attracted many fish. Another result, concerning radar in fishing boats, was that there were no disturbances from the power station.

6.3.2. Bockstigen, Valar

Vindkompaniet anticipates building a demo-plant 4 km offshore of Näsudden on Gotland. The project consits of five plants, each of 500 kW (Table 5). The Bockstigen Valar project is sponsored by EU (THERMIE).

6.4. International Collaboration

International co-operation has increased significantly during the last years. Most of the co-operation is carried out in the framework of EU and IEA. Sweden participated in a number of Joule II and III projects during 1996. The experiences from this type of projects are very positive—they give possibilities to exchange and develop knowledge in a structured way. The joint financing also gives the possibility to run projects which otherwise would not have been possible to carry out. Swedish researchers and companies are therefore looking forward to continue the work within IEA and the next phase of the JOULE/THERMIE programs.

The European Union Wind Energy Conference and Exhibition, EUWEC '96, was held in Gothenburg 20–24 May, 1996. The conference is held every third year and attracted this time 600 participants from all parts of the world. The successful result of the conference was mainly due to the suitable conference facilities and the support from the European Commission and the Swedish sponsors— Göteborg Energy AB, Vattenfall AB, NUTEK, Elforsk AB, Kvaerner Turbine AB, Teknikgruppen AB, Nordic Windpower AB, and The Aeronautical Research Institute of Sweden. The next wind energy conference in Europe (EWEC '97) will be held in Dublin in 1997.

FFA arranged the IEA 9th Symposium on Aerodynamics of Wind Turbines in December 1996. The conference was attended by 23 persons and was chaired by Maribo Pedersen from Denmark.

UNITED KINGDOM

1. NATIONAL OVERVIEW

1.1. Government Aims, Objectives and Strategy

Policy

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

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

Strategy

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

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

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

1.2. Targets

The government has no specific target for wind energy but it has been announced that it is working towards the installation of 1500 MW DNC* of new electricity generating capacity from renewable sources for the UK by 2000.

1.3. Market Stimulation

There is a requirement on the electricity supply companies in the UK to provide a proportion of their supply from renewable energy sources; the requirement is set out in the government's Renewable Energy Obligations. There are separate obligations for England and Wales (the Non-Fossil Fuel Obligation—NFFO), Scotland (the Scottish Renewables Obligation—SRO) and Northern Ireland (the Northern Ireland Renewables Obligation—NIRO). The additional costs incurred by the companies in buying non-fossil fuel power to meet their obligation is passed on to the consumers. This part of the obligation is implemented through a series of tranches, set periodically by the government. The total for all the obligations is planned to be 1500 MW DNC, to be filled competitively by 2000.

1.4. Progress during 1996

During 1996 the following progress was made in each of the Renewables Orders:

NFFO (England & Wales)

Five of the projects awarded contracts under NFFO-3 were commissioned with a

* 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.

total rated capacity of 48.8 MW, while 176 tenders for wind energy contracts were made under NFFO-4. The NFFO-4 Order is expected to be announced during the first quarter of 1997 with the Order commencing in May 1997 (References 2, 3).

Northern Ireland Renewable Energy Order (NIRO)

Construction began on the sixth and final wind power plant of 5 MW rated capacity to be awarded a contract under NIRO-1. The total installed capacity under NIRO-1 will then be 30 MW. Two contracts under NIRO-2 were awarded in September to wind energy projects rated at 1MW and 5MW. A total of 31.87 MW DNC for all renewables have now been contracted in Northern Ireland, which represents a significant step towards the government's target of 45 MW DNC by 2005.

Scottish Renewable Energy Order (SRO)

Two adjoining wind power plants, totalling 21.6 MW, were commissioned under SRO-1, bringing the total installed capacity to 37.2 MW. Preparations for SRO-2 continued on a similar time-scale to NFFO-4.

1.5. Government Support for Research, Development, and Demonstration

The government (through its Department of Trade and Industry—DTI) supports a program aimed at helping industry to improve its market share both at home and abroad and nearly all expenditure is now on the development, demonstration and monitoring of projects to help reduce the cost of wind energy and improve competitiveness. Industry is expected to take full responsibility for addressing issues such as public acceptability, electrical integration and environmental impact. As wind energy becomes more commercially attractive and industry becomes self-sustaining, support is expected to decrease. An essential adjunct is dissemination of information arising from both directly funded work and from projects in the Renewable Energy Orders.

Table 1. Size and Timing of the Renewable Energy Obligations.

Order	Effective Start Date	Contract Length (max yrs.)	Number of Projects		Contracted Capacity MW DNC/ (Rated MW)
			Contracted	Built	
NFFO-1	1990	8*	9	9	12.21/(28)
NFFO-2	1992	6*	49	26	82.43/(192)
NFFO-3 (>1.6 MW)	1995	15	31	5	145.92/(339)
NFFO-3 (<1.6 MW)	1995	15	24	—	19.71/(46)
NFFO-4	1997	15	—	—	—
SRO-1	1995	15	20	4	45.60/(106)
SRO-2	1997	15	—	—	—
NIRO-1	1994	15	6	5	12.66/(29)
NIRO-2	1996	15	2	—	2.57/6

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

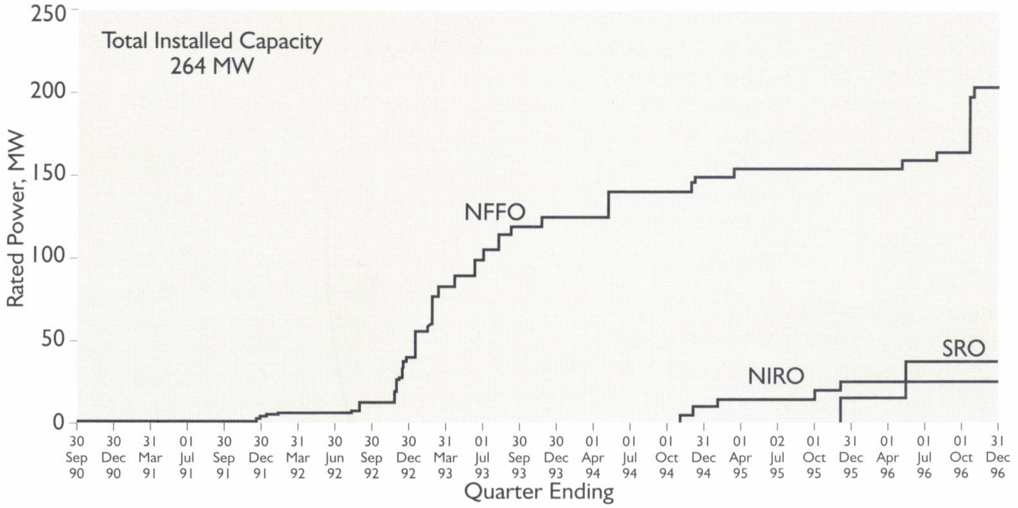

Figure 1. Rate of installation of wind energy capacity under the NFFO, NIRO, and SRO.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

2.1. Installed Capacity

A total of 70.4 MW of rated capacity was installed in the UK during the year. This brought the total installed capacity under the Renewable Energy Orders at the end of 1996 to 264 MW (639 turbines). Figure 1 shows the growth of this capacity with time.

2.2. Plant Type

The capacity installed during 1996 consisted of 122 machines, all of Danish manufacture, 14 of 400-kW rated capacity and 108 of 600 kW. This is to be compared to the average rated capacity of 380 kW for all 527 machines in NFFO-1 and NFFO-2. The machines were installed in seven wind power plants, five in England (14x400 kW; 7, 9, 28 and 28x600 kW, the last two being operated as a single wind power plant) and two in Scotland, each of 10.8 MW rated capacity (18x600 kW turbines).

2.3. Market Development

Forms of Ownership

The major UK electricity generators continue to take ownership of most of the new installations. This confirms the trend that as the reliability and performance of wind power plants becomes proven, corporate investment is increasing from, in particular, the electricity generating and distribution companies. During the year construction began on the first UK wind power plant attracting community funding. The Bay Wind community co-operative was formed in March 1996 and has so far raised sufficient funds to buy one of the five turbines at Harlock Hill in Cumbria.

Operators

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

2.4. Energy Output

During 1996 projects in the NIRO and SRO began to make substantial contributions to energy production statistics. Detailed returns are not yet available for the last few months of 1996 but for the year from 1 January to 31 December , the total energy output from projects in NFFO, NIRO, and SRO were 356 GWh, 81 GWh, and 46 GWh, respectively, bringing the national cumulative total to more than 1400 GWh.

The quarter by quarter output from the projects is shown in Figure 2.

2.5. Technical Performance

The technical performance was good with high availabilities (>95%) and good load factors (usually >0.3) being reported from the wind power plants. The wind power plants in Northern Ireland and Scotland performed particularly well with load factors approaching 0.50 in some months due to the good wind regimes.

2.6. Operational Experience

No operational difficulties were reported although wind speeds during the winter of 1995/96 were thought to be lower than average. Studies continued of the potential advantages and problems of increased penetration levels by renewable energy generators (Reference 4, 5, 6).

3. MANUFACTURING INDUSTRY

3.1. Wind Turbine Manufacturers

The year 1996 brought mixed fortunes to the three UK wind turbine manufactures which existed at the end of 1995:

- The joint venture company set up by WEG in India entered the market there by erecting six 400-kW turbines. Future development plans depend on inclusion of the company's machines on the Ministry of Non-conventional Energy Sources approved list.
- The technology rights to Markhams wind turbines were sold to Windmaster Development (UK) Ltd following a corporate decision, made during the restructuring of the Markhams parent company, to abandon the manufacture of wind turbines.
- Following a period of ownership and management difficulties, Carter Technology Ltd. ceased trading during 1996. It is hoped the technology can be revived under new management.

3.2. Other Industries

Component Suppliers

The drive for industrial expansion in the components industry strengthened during 1996 with reports of increased sales of UK manufactured components to foreign manufacturers. Two tower manufacturing facilities were established and British foundries began supplying castings overseas in a competitive market. The blade manufacturing facility set up by WEG (Aerolam) continued to expand its business while a competitor blade

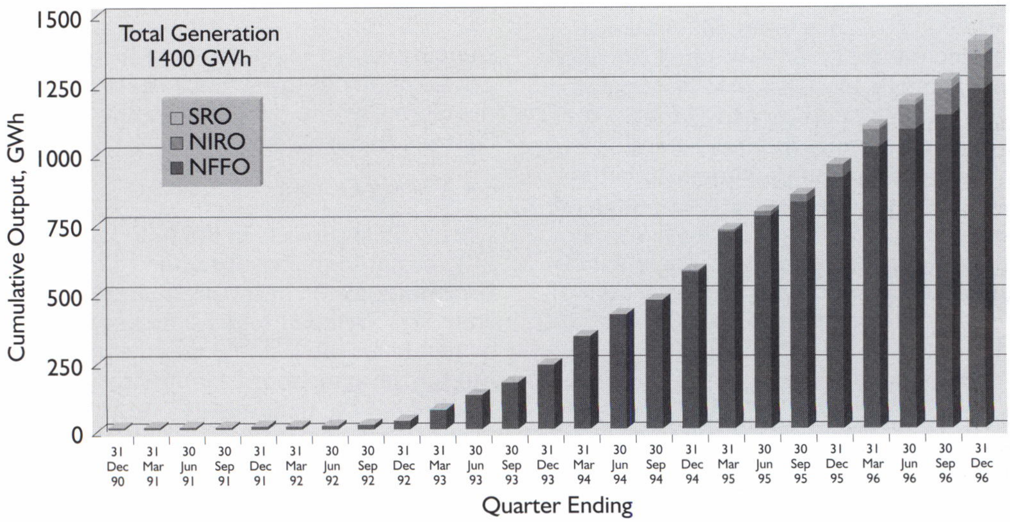

Figure 2. Cumulative installed wind energy production from NFFO, NIRO, and SRO projects.

company (Aerpac) established a manufacturing plant in Scotland.

Consultants

There is a continuing but uneven demand for consultants in site exploration, performance and financial evaluation, planning applications, and environmental impact statements as successive tranches of the Renewable Energy Obligations are announced.

3.3. Trade Association

During the year the British Wind Energy Association issued a policy statement, "Wind Energy—Power for a Sustainable Future" (Reference 7). The booklet describes the benefits and current status of wind energy and presents the BWEA's proposals to exploit its potential both in the UK and overseas.

4. ECONOMICS

4.1. Value

Total Invested Capital

On the assumption that the average installed cost of the wind plant already installed was GBP 1000/kW of rated power, the total invested capital is circa GBP 264M. On the assumption that the average cost of the wind plant installed during 1996 was GBP 800/kW, the capital invested during past year was circa GBP 56M.

Production

To the end of 1996, it is estimated that wind projects in the UK had generated around 1400 GWh of electricity. Assuming a conservative generation price for conventionally generated electricity (the "pool" price) of GBP 0.026/kWh, this is valued at GBP 36M. During 1996, 418 GWh of electricity were generated, valued at GBP 11 M.

4.2. Turbine and Project Costs

Based on data from manufacturers, the ex-factory cost of wind turbines is around GBP 500–600 per kW of rated power. For current projects, the total project cost for wind power plant developments was estimated to be about GBP 800–900 per installed kW. A significant factor in cost fluctuations has been the variation in exchange rates.

4.3. Generation Costs

The government introduced the NFFO to encourage renewable technologies to develop to the point where they can compete with conventional technologies. To show their progress, the government is looking for evidence of price convergence. For NFFO-3 contracts (awarded in 1995, up to 15 years in duration), the average bid-in price of large projects (>1.6 MW DNC) was GBP 0.0432/kWh (lowest GBP 0.0398/kWh, highest GBP 0.0480/kWh) while for SRO projects, the bid-in prices averaged GBP 0.0399/kWh (lowest GBP 0.0379/kWh, highest GBP 0.0417/kWh). These prices were substantially less than the strike price for NFFO-2 which would be GBP 0.0865/kWh after allowing for the increase in contract period and for inflation. The government is looking for further evidence of price convergence in future rounds of the Renewable Energy Orders. This may be achieved, in part, by the use of larger turbines with a rated capacity of at least 600 MW each and the more vigorous wind regimes in Northern Ireland and Scotland compared to England and Wales.

4.4. Benefits

Employment

A study undertaken jointly by the BWEA and DTI reported that 1300 jobs have been created in the UK by the wind industry and that this number is expected to increase by 30% over the next two years (Reference 8).

Avoided Emissions

If wind power displaces electricity that otherwise would have been produced by fossil fuel, the 361 GWh generated during the past year has avoided the emission of approximately 335 million tons of CO_2, 4.6 million tons of SO_x and 2.1 million tons of NO_x.

5. CONSTRAINTS ON MARKET DEVELOPMENT

5.1. Environmental Impact

Visual Intrusion

The visual impact of turbines continues to be one of the two prime concerns in the development of UK wind power plants due to developers seeking the best wind speed sites on high ground, which are often in areas of scenic beauty. The conflict between the environmental benefits of wind energy and loss of landscape value continues to be a major factor in obtaining planning consent for a wind power plant development

Noise

The second concern is that of the noise generated by wind turbines largely because of the high population density of the UK and dispersed settlement patterns. A noise working group was set up by the DTI 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. It has concluded its work and published its recommendations (Reference 9). The work of the group was supported by R&D studies in the government's program (References 10, 11, 12).

Ecology

A one-day seminar on "Birds and Wind Turbines" involving representatives of the wind industry, planning authorities, and environmental bodies proved a timely event with some wind power plant proposals raising concerns over the effects on bird life. The general conclusion was that the effect of wind power plants on birds was not a major environmental concern but it was important to have such meetings to put issues relating to birds into perspective in the wider picture of UK wind power plant development and a need was identified for a central data bank of the results of surveys of wind power plants (Reference 13).

Public Attitudes

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

Electromagnetic Interference

A working group was set up with the support of the DTI and BWEA to produce guidelines on the siting of wind energy developments in areas where their presence may cause electromagnetic interference. A report on the development and testing of modelling techniques and siting guidance for specific radio systems was published (Reference 14).

5.2. Institutional Aspects

Planning

The government continued to encourage local authorities to establish local structure plans which include renewable energy developments. The government is now monitoring the local authority structure plans to review how national renewable energy policies are being incorporated into local plans. The success of applications for planning permission for renewable energy projects is also being monitored.

Certification

Wind turbine standards and certification continue to receive increased attention. The BWEA, with the support of the DTI, continues to be increasingly involved in national and international activities in these areas, especially with the work ongoing in the European Union.

6. PROJECT REALIZATION

Type of Funding Available

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

Typical Financial Interest Rates

Interest rates asked by banks are typically 1.5% above the London Inter Bank Offered Rate (LIBOR). Equity/debt ratios are typically 25/75, with investors requiring a post tax return on equity of typically 15% to 25%. Clearly these figures can vary considerably from project to project. Alternatively larger companies will often finance a project themselves off the balance sheet and will expect a real rate of return of 8% to 12%, dependent on the associated risk.

Machine Certification Requirements

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

Insurance

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

Warranties

Machine warranties for two to five 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. R&D

Government R&D Funds versus Invested Capital

The government continues to work in a cost-shared program with industry but as the technology achieves maturity, the trend is towards decreasing contributions from government. Reference 1 discusses the forward strategy in greater detail. Funding for the wind program during 1996 amounted to GBP 2.5 million, which is to be compared to the estimate capital investment of GBP 56 million by developers in the same period. To date the government has spent in excess of GBP 63 million in sponsoring R&D work which should be compared to the estimated GBP 264 million invested in UK wind power plants (Section 4.1).

New Concepts under Development

A major trend in machine development in the UK is towards light, flexible machines to reduce machine loads and thus component weights and capital costs. WEG plan to demonstrate its MS4 turbine early in 1997. This 600-kW turbine has a flexible, three-bladed, downwind rotor mounted on a tilting as well as free-yawing nacelle. It is designed to be cost competitive in Europe but its low erection and reduced craneage costs are also seen as addressing the requirements of developing countries. It is intended to produce a version with a two-bladed, larger diameter rotor to further reduce costs. Another concept which has been investigated during the year is that of the coning rotor in which increasing loads are shed by the coning action of the blades (Reference 15).

MW-Size Machines under Development

The three-bladed, 1-MW turbine designed by Renewable Energy Systems Ltd with support from the EU and the DTI has obtained planning consent for construction in Northern Ireland and it is planned to build the demonstration machine in the near future.

Offshore

There is continued interest by some developers in the offshore siting of turbines, prompted in part by the difficulty of finding acceptable sites onshore. One developer has obtained support from the European Union to site two wind turbines offshore, while a major generator and a turbine manufacturer have erected an anemometer off the east coast of England with the expectation of building a commercial wind power plant of 25 turbines, each rated at 1.5 MW.

8. INTERNATIONAL COLLABORATION

Formal international collaboration in the DTI's wind energy program is through the IEA and the European Union (EU) programs. The DTI encourage UK contractors to participate in EU funded projects and the DTI and the EU programs are considered to be complementary. UK contractors can receive supplementary funding from the DTI if the work is relevant to the DTI program and there were 15 such collaborative projects. These had a total value GBP 9.38 million and attracted GBP 3.41 million of EU funds, complemented by GBP 2.22 million of DTI funds.

REFERENCES

A complete list of reports of work undertaken in the DTI's wind energy program can be obtained from the ETSU Enquiries Bureau, Building 168, ETSU, Harwell, OX11 0RA.

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

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(4) The AEP Guide: Electricity Production Connected to the Local Network (AEP, 1996)

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(8) Survey of Employment in the UK Wind Industry 1993-95. ETSU Report W/13/00354/47/REP (ETSU, 1996)

(9) The Assessment and Rating of Noise from Wind Farms. ETSU Report R-97 (ETSU 1996)

(10) Objective and Subjective Rating of Tonal Noise radiated from UK Wind Farms. ETSU Report W/13/00354/44/REP (ETSU 1996)

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(12) Noise Measurements in Windy Conditions. ETSU Report W/13/00386/REP (ETSU 1996)

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(14) Investigation of the Interactions Between Wind Turbines and Radio Systems Aimed at Establishing Co-siting Guidelines - Phase 1: Introduction and Modelling of Wind Turbine Scatter. ETSU Report W/13/00477/REP (ETSU 1996)

(15) Evaluation of the Coning Rotor Concept. ETSU Report W/45/00307/REP/1&2 (ETSU 1996)

UNITED STATES

1. GOVERNMENT PROGRAMS

The United States has supported wind energy along with other renewable technologies with a variety of programs by the Department of Energy (DOE) or its predecessor agencies since 1974. The current program strategy includes a comprehensive research and development effort aimed at improving wind technologies and enhancing cost-competitiveness. In addition, the Energy Policy Act of 1992 continues to encourage commercial wind systems and other renewable technology deployment by providing financial incentives that continue through 1999.

The goal of the DOE Wind Program is to establish wind energy as a regionally diversified, cost-effective power generation technology, through a coordinated research effort with industry, electric utilities, universities, and other researchers. The underlying assumption is that by minimizing the technical, economic, and institutional risks for U.S. companies developing advanced turbine technologies, the DOE program can offer the greatest benefit when competing in domestic and international markets. Cost goals are also important in keeping DOE and the wind industry focused on continually improving the cost and performance characteristics of U.S.-built turbines.

2. COMMERCIAL IMPLEMENTATION OF WIND POWER

The new wind generating capacity added in the United States in 1996 was composed of smaller projects and increments of capacity and at a slower rate than in recent years, but the total still reached about 1794 MW by the end of 1996. Vermont has become one of the latest states with a utility-scale wind installation, with a 6-MW wind power plant located near Searsberg, Vermont. The project is owned by Green Mountain Power Company and is part of the Utility Wind Turbine Verification Program supported by DOE and the Electric Power Research Institute (EPRI). The plant, Figure 1, came on line in July 1997 and consists of eleven, 550-kW, Zond Z-40 turbines designed for cold-weather operations. A summary of installed and planned installations in the U.S. is shown in Figure 2. The estimated energy production from the installed wind capacity in the United States was about 3.7 terawatt-hours during 1996.

3. MANUFACTURING INDUSTRY

The United States wind turbine manufacturing industry is expanding with 17 electrical and mechanical turbine manufacturers having produced about $3.5 billion worth of goods and services since 1980. Many of these firms are developing new turbines for both domestic and international markets. In addition to the turbines being developed in cooperation with DOE (see Wind Turbine Development section later), several larger turbines are being developed by United States companies.

Several United States turbine manufacturers are proceeding to obtain type certification of their turbines for exporting to countries with certification requirements.

4. ECONOMICS

The DOE program has been very successful in reducing the levelized cost of wind-generated electricity from USD 0.35/kWh in 1980, to USD 0.07/kWh in 1990, and to less than USD 0.05/kWh today at sites with moderate, 5.8 m/s (13 mph) winds. At current costs and in

Figure 1. Green Mountain Power 6-MW wind power plant near Searsberg, Vermont. Twelve 550-kW Z-40 wind turbines were installed.

selective markets, wind energy can compete with conventional energy sources on a life-cycle basis. Ultimately, wind energy is expected to compete favorably with gas- and coal-fired power plants, which dominate the generation mix in the midwestern United States where the majority of the best wind resources are located. To tap this vast resource base, and to allow wind to compete in an era of utility restructuring that emphasizes low cost and independent power projects, significant improvements to the technology are still needed to reach the DOE Program's target of USD 0.025/kWh in good winds by 2000. For turbine installation in the United States, certification is not required because the wind turbines developed in the United States are designed to meet or exceed current standards for reliability and maintainability. This free market approach, with commercial warranties, has encouraged the successful deployment of over 17,000 wind turbines domestically and additional units overseas.

5. MARKET DEVELOPMENT

There are several categories of federal financial incentives available for wind power plant developers.

The two primary incentives are contained in the Energy Policy Act of 1992 (EPAct). One section enacted the USD 0.015/kWh production incentive for electricity sold to an unrelated party from eligible wind and closed-loop biomass facilities. The eligibility period is January 1, 1994, through June 30, 1999. For investor-owned (tax paying) utilities, the production incentive is taken as a tax credit. For non-profit electricity generators that are tax

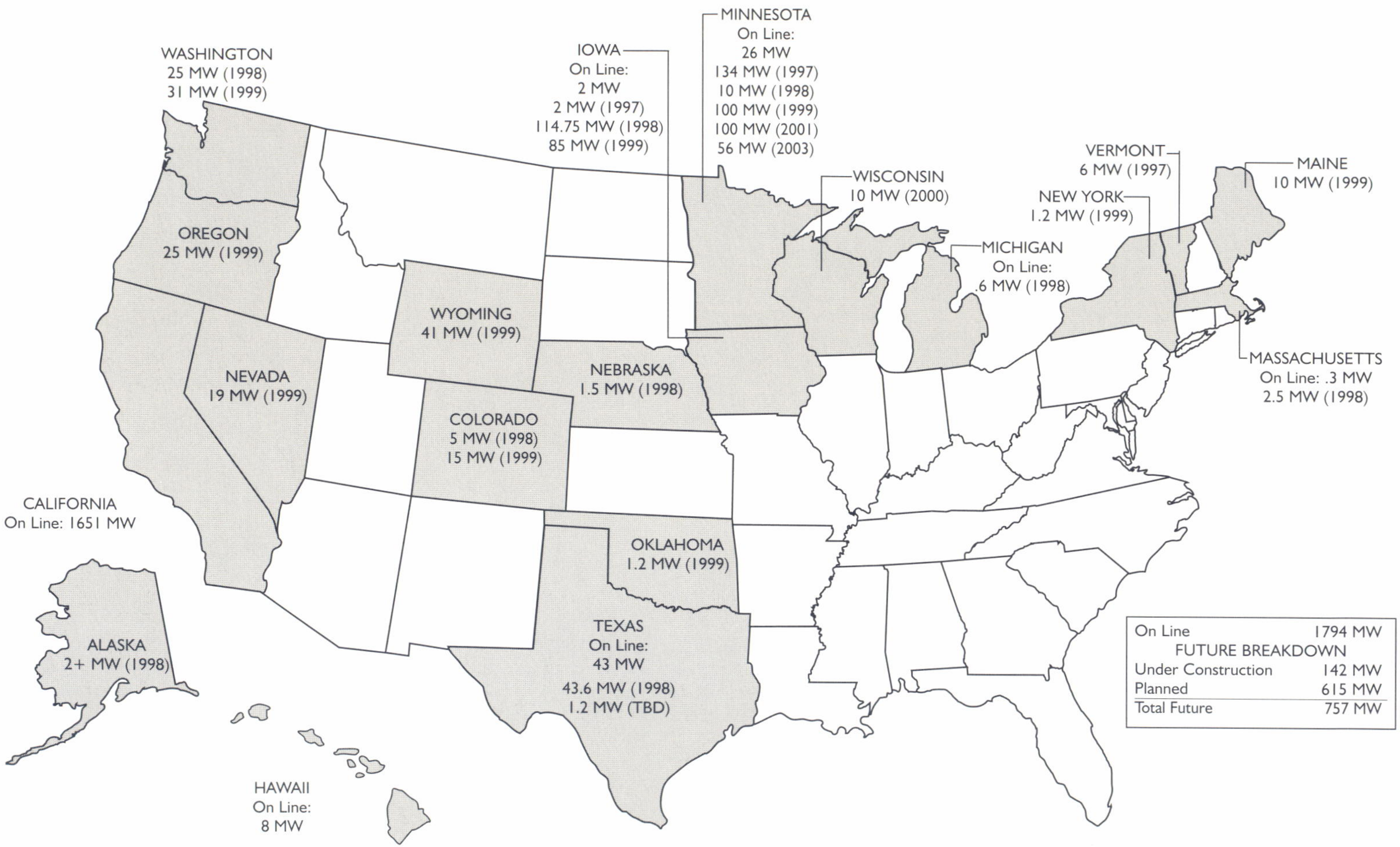

Figure 2. Map of grid connected wind power plants planned, under construction and operating in the United States at the end of 1996.

exempt, such as municipal or cooperative electric agencies, the Renewable Energy Production Incentive is available under another section of the EPAct, as an incentive payment from DOE, but is subject to annual funding by Congress. The incentive payments for 1996 energy production from solar, wind, and biomass plants were 2.5 million USD. Wind projects received payments totaling USD 167,348 for the year.

Incentives are also included for other renewable technologies. One section of EPAct made permanent a 10% business energy credit for qualified investments in new solar and geothermal properties.

Environment studies are an important part of planning a wind project in the United States. Environmental assessments are required on all planned wind power plants and when potential problems are discovered, a more comprehensive environmental impact statement may be required. There is continuing concern over potential negative impacts wind plants may have on local bird populations. A significant amount of research has been focused on a Golden Eagle population and one principle learned is that better siting techniques can reduce or eliminate avian impacts. Designing turbines to minimize bird perching is also reducing concern.

6. DOE WIND ENERGY PROGRAM

The objective of the DOE Wind Energy Program is to develop new technology and assist utilities and industry in its introduction into new markets and applications for wind systems. The underlying objective is to develop wind turbine technology that is economically competitive as an energy source. The DOE Wind Energy Program works with industry on the following activities:

- applied research
- turbine research
- cooperative research and testing.

The program's funding was USD 31.4 million in 1996 and USD 29.0 million in 1997.

The Wind Program's R&D activities are focused at National Renewable Energy Laboratory's National Wind Technology Center (NWTC), located on a 280 acre site near Boulder, Colorado. The NWTC conducts a wide range of wind energy research, component development, and testing to complete system verification. The NWTC includes several test turbines for the study of unsteady aerodynamics and variable-speed operation, a structural test facility, and a main research building. Construction was completed in 1996 on a 10,000-square-foot (930-square-meter) Industrial User Facility to be used for industry research and to support wind turbine certification testing. In addition to housing the largest indoor blade-testing area in the world, where researchers can analyze the performance and structural stability of individual wind turbine blades more than 85 feet (26 meters) long, the facility includes office space for industry researchers working with wind program technical staff, experimental laboratories, computer facilities for analytical work, and space for assembling components and turbines for atmospheric testing. A 600-kW advanced research turbine, designed for use in testing and evaluating a wide range of turbine components, became operational in 1997.

The NWTC has become one of the most comprehensive wind energy research facilities in the world.

6.1. Applied Research Program

Industry-driven, applied research continues at about USD 10 million per year ensuring that fundamental analysis and design tools are available for industry to perform detailed designs of future advanced wind turbines. Research includes computer models for aerodynamic performance, structural dynamics, and yaw dynamics. Key research activities support the wind industry's needs for turbines, components, and subsystems with more innovative and risky designs but which could yield major improvements in turbine performance, reliability, and cost. These activities are difficult for industry to support because of the long-term payback on research investments. Projects include the 10-meter diameter unsteady aerodynamics research test bed, wind characterization, aerodynamics, structural dynamics and fatigue, and power subsystems.

6.2. Wind Turbine Research Program

The development of technologically advanced wind turbines is one of DOE's and industry's highest priorities. The overall goal of the wind program is to develop systems that, at excellent wind sites, can compete with the costs of conventional electric generation. This goal will be achieved through a number of coordinated turbine research and development efforts with the United States wind industry.

The Turbine Research Program uses a dual-path technology development approach, supporting both near-term and next-generation development. Near-term efforts have supported the development, fabrication, and field testing of several new turbines (see Table 1). The near-term cost-of-energy goal of USD 0.05/kWh or less at 5.8 m/s sites by the mid-1990s has been met. These machines help bridge the gap between earlier first generation technology and the next-generation of utility-grade wind turbines under development.

Next-generation turbine development will employ advanced technology and innovative designs to reach the target levelized costs of electricity of USD 0.04/kWh or less (at 5.8 m/s) and

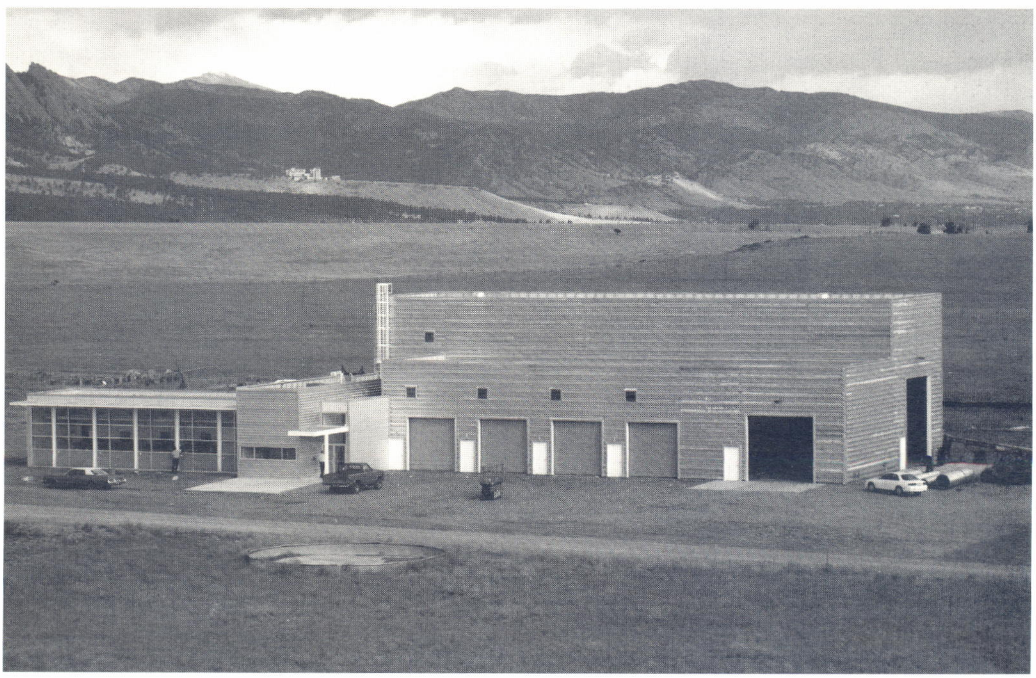

Figure 3. The new Industrial User Facility at the National Wind Technology Center near Boulder, Colorado.

USD 0.025/kWh (at 6.7 m/s) after 2000. These machines will compete directly for bulk electric power markets without the need for subsidies. In 1997, two subcontracts were signed with industry to develop next-generation turbines. Zond Systems, Incorporated, Tehachapi, California, a subsidiary of Enron Wind Corporation, and The Wind Turbine Company, Bellevue, Washington, signed subcontracts by NREL to design and test a new generation of wind turbines that will use the most recent technology in all aspects of wind turbine engineering. The two companies will cost-share 30% of the two $20 million contracts. The companies were among 10 selected for the first phase of the project, a Concept Definition Study. In the second phase, Prototype Development, each company will design, fabricate, and test a proof-of-concept turbine to demonstrate new components and subsystems, confirm aerodynamic performance, and validate computer models. Test results will be used by engineers to develop design improvements for engineering prototype turbines to be constructed by each company. An innovative subsystems development activity, currently under

Table 1. Characteristics and Status of Advanced Wind Turbines Developed under the U.S. Department of Energy Wind Energy Program.

COMPANY NAME	MACHINE NAME	ROTOR DIAMETER	POWER	INSTALLED OR PLANNED
Advanced Wind Turbines, Inc.†	AWT-26 AWT-27	26 m 27 m	275 kW	25 MW planned, U.S. 20 MW installed, India 30 MW planned, India 2 turbines installed, China
Atlantic Orient Wind Systems, Inc.†	AOC 15/50	15 m	50 kW	4 turbines installed, continental U.S. 1 turbine installed, Canada 3 turbines installed, Alaska 10 turbines planned, Alaska 20 turbines planned, Morocco
Cannon Wind Eagle	CWE 300	29 m	300 kW	2 turbines installed, U.S. 7 turbines planned, U.S.
New World Power Technologies Co.*	North Wind 250	25 m	250 kW	Prototype
Zond Systems, Inc.	Z-40*	40 m	550 kW	12 MW installed, U.S. 12 MW installed, U.K. 30 MW planned, China 60 MW planned, India
	Z-46, Z-50	46–50m	750 kW	Prototype, 500 MW planned in U.S. and overseas
FloWind Corporation*	EHD-17	17 m	300 kW	Prototype

* Shown in *IEA Wind Energy Annual Report 1994*
† Shown in *IEA Wind Energy Annual Report 1995*

way, also supports the next-generation path by exploring advanced generators, rotors, and control systems.

6.3. Cooperative Research and Testing Program

DOE has sponsored several efforts aimed at encouraging the deployment of wind energy technology. In 1992, DOE and EPRI initiated a joint Utility Wind Turbine Verification Program to evaluate the performance of new wind turbines and to demonstrate the value of wind energy to utilities. DOE and EPRI believe that experience operating a small wind power plant will allow utilities to make informed decisions about adding new wind generation in the future. Under this program, Green Mountain Power Corporation from Burlington, Vermont, and Central and South West Services, Inc., of Dallas, Texas, each built new cost-shared 6-MW wind power plants. Both plants use different configurations of the Z-40 turbines developed by Zond Systems, Incorporated.

DOE and EPRI issued a new Turbine Verification Program solicitation called the Distributed Wind Generation Project, targeted at utilities or independent power producers interested in building smaller, dispersed wind generation facilities connected directly to a distribution line. The sites selected in 1997 will help utilities reduce the risk of introducing a new and unfamiliar technology and to evaluate issues and benefits of wind power generation under utility control but at disbursed locations.

DOE will contribute funds towards the cost of deploying two other wind power plants, one in northwestern Iowa, and the other in southwestern Minnesota. Waverly Light and Power plans to install two Zond Z-46 turbines in Iowa in 1997. Zond Systems plans to develop an 11.5 MW wind power plant in late 1997 near Lake Benton, Minnesota, in cooperation with Northern States Power Company.

Isolated communities that rely on diesel electric generation are another important application for wind power. Under a cost-shared project, DOE is working with the Kotzebue Electric Association in Kotzebue, Alaska, to install ten 50-kW Atlantic Orient turbines connected to the local power grid and operated in conjunction with diesels totaling 11.2 MW. This wind plant will begin operation in 1997. In the nearby village of Wales, Alaska, a second project with an additional three 50-kW turbines will be operated in a high penetration mode, where the diesel can be shut down and the full load is met with wind turbines and a battery bank. Hundreds of other communities in Alaska are considering similar installations.

7. INTERNATIONAL PROGRAMS

The DOE Wind Program provides technical assistance to governments and utilities in countries planning wind projects in Central and South America, Asia, Africa, and elsewhere. An example is a bilateral agreement signed with the Ministry of Electric Power in China that will allow the exchange of scientists and assistance in planning large scale grid-connected and village power wind projects.

DOE is leading the Committee on Renewable Energy Commerce and Trade (CORECT), a working group of United States government agencies whose objective is to promote increased international use of renewable energy technologies. CORECT activities include assessing opportunities for renewables use overseas, supporting wind/photovoltaic hybrid pilot projects and feasibility studies, increasing access to project financing, and supporting renewable energy education efforts.

Recent CORECT accomplishments have included implementation of financing mechanisms that bundle loans for small scale renewable energy projects with larger development bank loans with emphasis on support for renewable energy projects in the western hemisphere. Ongoing activities include support of several wind hybrid power system and water pumping installations in Mexico, Brazil, Chile, Argentina, and other countries. Under the related U.S./Brazilian Rural Electrification Pilot Project, the National Renewable Energy Laboratory is expanding on the previous photovoltaics installations, with demonstrations of hybrid wind-photovoltaic systems at two sites in northern Brazil.

In cooperation with the United States Agency for International Development, DOE and its laboratories are involved in the support of wind resource assessment and renewable project evaluation and implementation in Mexico. Several wind-hybrid systems are being deployed there. In a related project in Indonesia, wind and wind-hybrid projects for electricity supply and irrigation water pumping are being installed through local Indonesian communities and non-governmental organizations.

Other international activities include such work as aiding in pilot projects and wind assessment efforts in eastern Europe and the former Soviet Union. DOE, working with the governments of Ukraine and Georgia, developed a plan to replace aging nuclear and fossil-fueled plants with energy conservation measures and a variety of new generating facilities, including wind power plants. Under a private commercial venture, the United States company PHB, Inc., (previously with Kenetech Windpower) has begun manufacturing 110-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. Installation of four of the turbines in the Republic of Georgia is planned for 1998. Additionally, Bergey Windpower was recently awarded a USD 1.78 million contract from the United States Agency for International Development for 40 village power systems in the former Soviet Union.

Currency conversion as of the end of December 1996

		AUD	CAD	DKK	ECU	FIM	DEM	GDR	ITL	JPY	NLG	NZD	NOK	ESP	SEK	GBP	USD
Australian Dollar	AUD	--	0.921	0.211	1.563	0.271	0.809	0.005	0.0008	0.011	0.721	0.883	0.194	0.010	0.167	2.089	1.255
Canadian Dollar	CAD	1.085	--	0.229	1.696	0.294	0.878	0.006	0.0009	0.012	0.782	0.958	0.211	0.010	0.181	2.267	1.362
Danish Krone	DKK	4.734	4.362	--	7.399	1.281	3.829	0.024	0.0039	0.052	3.412	4.178	0.919	0.045	0.789	9.889	5.943
European Currency Unit	ECU	0.640	0.590	0.135	--	0.173	0.518	0.003	0.0005	0.007	0.461	0.565	0.124	0.006	0.107	1.337	0.803
Finnish Markka	FIM	3.696	3.406	0.781	5.777	--	2.990	0.019	0.0030	0.041	2.664	3.262	0.717	0.036	0.616	7.721	4.640
German Mark	DEM	1.236	1.139	0.261	1.932	0.334	--	0.006	0.0010	0.014	0.891	1.091	0.240	0.012	0.206	2.583	1.552
Greek Drachma	GDR	195.72	180.3	41.343	305.90	52.953	158.3	--	0.1608	2.1556	141.04	172.73	37.993	1.8800	32.623	408.84	245.70
Italian Lire	ITL	1,217.5	1,121.8	257.18	1,902.9	329.40	984.8	6.2	--	13.409	877.38	1,074.47	236.34	11.695	202.93	2,543.3	1,528.4
Japanese Yen	JPY	90.796	83.661	19.179	141.91	24.565	73.441	0.464	0.0746	--	65.431	80.128	17.625	0.872	15.134	189.66	113.98
Netherlands Guilder	NLG	1.388	1.279	0.293	2.169	0.375	1.122	0.007	0.0011	0.015	--	1.225	0.269	0.013	0.231	2.899	1.742
New Zealand Dollar	NZD	1.133	1.044	0.239	1.771	0.307	0.917	0.006	0.0009	0.012	0.817	--	0.220	0.011	0.189	2.367	1.422
Norwegian Krone	NOK	5.152	4.747	1.088	8.051	1.394	4.167	0.026	0.0042	0.057	3.712	4.546	--	0.049	0.859	10.761	6.467
Spanish Peseta	ESP	104.108	95.926	21.991	162.71	28.166	84.207	0.532	0.0855	1.147	75.023	91.875	20.209	--	17.352	217.47	130.69
Swedish Krone	SEK	6.000	5.528	1.267	9.377	1.623	4.853	0.031	0.0049	0.066	4.324	5.295	1.165	0.058	--	12.533	7.532
U.K. British Pound	GBP	0.479	0.441	0.101	0.748	0.130	0.387	0.0024	0.0004	0.005	0.345	0.422	0.093	0.005	0.080	--	0.601
U.S. Dollar	USD	0.797	0.734	0.168	1.245	0.216	0.644	0.0041	0.0007	0.009	0.574	0.703	0.155	0.008	0.133	1.664	--

Source: International Monetary Fund Internet Web site, average of daily rates in December 1996.

The 38th Executive Committee meeting in Emden, Germany, on October 29/30, 1996. First row from left to right: E. Solberg, Norway, H. Ohlsson, Sweden, J. Templin, Canada, J. 't Hooft, the Netherlands, K. Steer-Diederen, U.S., R. Rangi, Canada, D. Ancona, U.S., K. Diamantaras, European Commission, J. Beurskens, the Netherlands, R. Windheim, Germany, R. Thresher, U.S., F. Avia, Spain. Second row from left to right: K. Averstad, Sweden, N. Stump, Germany, E. Sesto, Italy, B. Maribo Pedersen, Denmark, D. Chand, New Zealand, A. Adamantiades, World Bank, U.S., M. Legerton, U.K., P. Nielsen, Denmark, L. Barra, Italy, P. Vionis, Greece, H. Matsumiya, Japan.

APPENDIX II

APPENDIX III

IEA R&D EXECUTIVE COMMITTEE 1996
M = Member A = Alternate Member

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IEA WIND ENERGY
ANNUAL REPORT 1996

Wind energy stands out as one of the most promising renewable energy sources in the near term. The deployment of wind energy is promoted by national programs for advanced technology research and market incentives in many countries.

Parties from 16 countries and the European Union collaborate in wind energy research and development under the auspices of the International Energy Agency. The program includes joint research projects and information exchange on wind systems development and deployment.

The report reviews the progress of the joint projects during 1996 and highlights the national wind energy activities in the member countries.

By the end of the report period more than 28,000 grid-connected wind turbines were operational in the member countries, representing a rated power of around 5152 MW, bringing the world-wide total to about 6200 MW. Collectively, these turbines produced about 11 TWh during the year.

There has been a trend towards larger commercial turbines (now up to 500-750 kW, corresponding to rotor diameters of up to 40-45 m). Prototype megawatt-sized turbines (up to 3 MW) are in operation in nine member countries.

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