

INTERNATIONAL ENERGY AGENCY
Programme of Research and Development
on Wind Energy Conversion Systems
(IEA R&D WECS)

ANNUAL REPORT 1983

A report by the IEA R&D WECS Executive Committee

January 1984

INTERNATIONAL ENERGY AGENCY

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FOREWORD

This is the sixth Annual Report of the IEA Programme for Research and Development on Wind Energy Conversion Systems (IEA R&D WECS) reviewing the progress during 1983. It is submitted to the IEA in accordance with the recommendations of the IEA Committee on Research and Development. The report was compiled by the Secretary of the Executive Committee with contributions from the Operating Agents.

E Kinsella

Chairman of the Executive Committee

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EXECUTIVE SUMMARY

The programme of work includes the following Tasks:

- I Environmental and meteorological aspects of WECS
(Completed in 1981)
- II Evaluation of wind models for WECS siting
(Completed in 1982)
- III Integration of wind power into national electricity supply systems
(Phase 1 completed in 1979, Phase 2 in 1982)
- IV Investigation of rotor stressing and smoothness of operation of large-scale WECS
(Completed in 1979)
- V Study of wake effects behind single turbines and in wind turbine parks
(Technical work completed in 1983)
- VI Study of local wind flow at potential WECS hill sites
(To be completed in 1985)
- VII Study of offshore WECS
(To be completed in 1985)

A final workshop of Task V was held in September 1983. A large amount of experimental wind tunnel data and small-scale clusters has been obtained. The data compare well with predictive models. For full validation of the models, large-scale data are needed. An extension of Task V to cover full-scale measurements has therefore been proposed.

Task VI is proceeding according to plan. The main experiment was successfully conducted between September 14 and October 9 at the Askervein site on the Outer Hebrides. Analysis of the results and comparison with predictive models are in progress.

Task VII was formally started on May 1, 1983. Work plans have been agreed for four Sub-Tasks including collection of meteorological data, conceptual design of an offshore wind power plant, technical specifications for an offshore WECS prototype, and generic studies.

A draft Annex has been submitted for a "Study of decentralized uses of wind energy", directed to the identification of predictive models and measurement techniques for the planning and specification of a decentralized WECS installation and to the study of wind/diesel systems for comparing their performance with predictions.

The expert group on "Recommended practices for wind turbine testing and evaluation" has continued its work. A document on "Estimation of the cost of energy from wind energy conversion systems" was published during the report period. Additional documents are nearing completion. The documents will be continuously updated as needed when experience from their application accumulates.

Participating Countries: Austria, Canada, Denmark, Germany, Ireland, Japan, Netherlands, New Zealand, Norway, Sweden, United Kingdom, United States.

Operating Agents: National Research Council of Canada (Task VI), Kernforschungsanlage Jülich GmbH (Task III and IV), Stichting Energionderzoek Centrum Nederland (Task V), National Swedish Board for Energy Source Development (Task I), Central Electricity Generating Board, United Kingdom (Task VII), United States Department of Energy (Task II).

1 THE IEA R&D WECS PROGRAMME

This report reviews the progress during 1983 of the Programme of Research and Development on Wind Energy Conversion Systems (IEA R&D WECS) initiated in 1977 under the auspices of the International Energy Agency. IEA R&D WECS is one of two IEA projects in wind energy. The companion programme is directed to Co-operation in the Development of Large-Scale Wind Energy Conversion Systems (IEA LS WECS) and is reported separately.

The general objective of IEA R&D WECS is to undertake collaborative research and development Tasks as defined in Annexes to the Implementing Agreement. To-date seven Tasks have been initiated, four of which have been completed:

- Task I Environmental and Meteorological Aspects of Wind Energy Conversion Systems
Operating Agent: National Swedish Board for Energy Source Development
Completed in 1981
- TaskII Evaluation of Models for Wind Energy Siting
Operating Agent: U.S. Department of Energy
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: Stichting Energionderzoek Centrum Nederland
Initiated in 1980
- Task VI Study of Local Wind Flow at Potential WECS Hill Sites
Operating Agent: National Research Council of Canada
Initiated in 1982
- Task VII Study of Offshore WECS
Operating Agent: Central Electricity Generating Board, United Kingdom
Initiated in 1983

There are 13 Contracting Parties to the Implementing Agreement from 12 countries. The countrywise participation in the Tasks which were in force during 1983 is shown in Table 1.

Tasks II and VII are task-sharing projects while Task III is a cost-sharing one. The remaining Tasks are mixed cost-sharing and task-sharing undertakings. The level of effort is generally about 10-20 manyears per Task.

Table 1 Participation in current Tasks

Country	Task II	Task III	Task V	Task VI	Task VII
Austria					
Canada	x		x	x	
Denmark	x		x	x	x
Germany	x	x		x	
Ireland			x		
Japan	x	x	x		
Netherlands		x	x		x
New Zealand				x	
Norway	x				
Sweden	x	x	x		x
United Kingdom	x		x	x	x
United States	x	x	x		

A special study of Recommended Practices for Wind Turbine Testing and Evaluation is being conducted for the Executive Committee by an expert group under the direction of Denmark

During 1983 a draft Annex VIII for a new Task on Decentralized Uses of Wind Energy has been elaborated by the United Kingdom.

The status of the current Tasks is summarized in the following sections.

2 Task II. EVALUATION OF WIND MODELS FOR
WECS SITING

The objectives of this Task are to verify selected atmospheric boundary layer numerical models by comparison with each other and with observed data, and to evaluate the usefulness of such models for wind turbine siting.

Three data sets were chosen from the island of Oahu, the state of Nevada and the island of Gotland. Five numerical models of varying complexity were used. The models were tested by comparing their predictions of surface wind flow with the sets of wind observations.

A summary report of the study was published in the end of 1982. During 1983 the detailed results were published as follows:

W T Pennell (Ed.)
An Evaluation of the Role of Numerical Wind
Field Models in Wind Turbine Siting: Appendices.
Pacific Northwest Laboratory Report PNL-SA-11129
March 1983
901 pp

The general conclusion from this multiyear study is that numerical wind field modeling can be useful in the initial stage of siting where a relatively large area is screened for those portions having the greatest wind energy potential, but that the accuracy of modeling results are low. No correlation was found between model complexity and ability to simulate the surface wind flow. This means that including more physics in a model does not guarantee improved performance, if many of the crucial data needed to run the more sophisticated models are not available.

3 Task IIIa. INTEGRATION OF WIND POWER
 INTO NATIONAL ELECTRICITY SUPPLY
 SYSTEMS

Task IIIa is a continuation of Task III, in which a computer model for determining the economic value of wind energy to a large electric utility was developed and applied to the case of Germany. In Task IIIa the model is adapted and used to the cases of Japan, the Netherlands, Sweden and the U.S.A. The model requires wind and WECS cost data as well as utility system plant mix and load data as input. Because of the present uncertainty in WECS costs the approach was taken to calculate the break-even wind turbine cost for displacing conventional fossil-fired units. The benefit of introducing wind power is mainly in fuel savings and to a lesser extent in displacing power capacity.

The Task was carried out by the Wind Energy Group of the University of Regensburg with Kernforschungsanlage Jülich as Operating Agent. The technical work was completed in 1982 with the publication of case reports for the participating countries. A final summary report was published in 1983:

W Dub, H Pape
Integration of Wind Power into National
Electricity Supply Systems
Special KFA Report
Restricted distribution

The study was made with 1985 as the year of reference and included different levels of wind turbine penetration in main electricity generating systems in the countries concerned.

The effects of turbine output and lifetime were studied. Economic parameters for fossil-fuelled units appropriate to the conditions in the different countries were assumed. The results indicate breakeven values from 2000 to 8000 1985 dollars per kilowatt rated wind power output depending on the particular case. The results were very sensitive to the assumed escalation rate of fuel prices. The higher breakeven values are associated with a low penetration level, a high fuel price escalation rate, a high unit output and a long operating lifetime. As a general conclusion, the results indicate that wind power is likely to become cost-effective for utilities with good wind regimes and high electricity generation.

4 Task V. STUDY OF WAKE EFFECTS BEHIND
SINGLE TURBINES AND IN WIND TURBINE
PARKS

This Task was initiated in 1980 with the objective of producing estimates of the performance of arrays of wind turbines. Work is performed jointly in the Netherlands and the United Kingdom in three major areas:

- Measurements of individual wake structure and decay
- Measurements of machine performance in velocity fields of the type that may be encountered in a wake
- Theoretical and experimental modeling of machine cluster performance by combining information on individual wakes with knowledge of machine performance in wake-type flows

The Dutch part of the work was finished in 1982 and the UK part in 1983. A final workshop was held in Petten, September 5-6, 1983.

The activities during the report period are summarized as follows.

The turbulence measurements in simulated wind turbine clusters (wind tunnel studies carried out in 1981) have been analyzed and empirical correlations derived. Thus, a data base is available for design purposes.

Wake measurements on a 3 m diameter, horizontal-axis rotor have indicated the validity of simulators for wind tunnel tests of clusters, and also shown the effects of changes in machine

performance on wake characteristics. Analysis of the data from a 17 m diameter horizontal-axis wind turbine has also confirmed the similarity between rotor and wire gauze simulators.

A programme of outdoor measurements is carried out at Alresford, Hants (U.K.) on a mini-array of three vertical-axis rotors. The machines are three-bladed, Musgrove type, with inclined self-furling interconnected blades. Rotor diameter is 6 m, rotor height 7 m, and blade lengths 3 m. The machine array is triangular with spacings of 3, 5 and 7 machine diameters. In addition to the three turbines, three 6 m x 3 m perforated screens, suitably mounted at hub height, are also available to act as wake simulators.

A comparison has been made between different predictive models using a similar technique for calculating the cluster efficiency for clusters of a specified geometry. The effective differences between the models lie in the equations used to describe the decay of a single wake. Comparison of the models with experimental data from wind tunnel cluster studies shows reasonable agreement, but large differences can occur and none of the models gives consistently good agreement.

The major uncertainties in the wake decay equations occur in the treatment of the near wake, where equations are known to be unrealistically simple, and in the far wake where the experimental data is sparse and of limited accuracy. The comparison of the models indicated that the far wake behaviour does have a significant influence on the performance of a cluster.

In September 1983 a final workshop was arranged in Petten, the Netherlands. The following conclusions were reached:

- The Task V programme has resulted in a wealth of experimental data obtained in wind tunnel tests or as small scale field experiments
- Predictive methods have been developed for single wakes, small clusters and large clusters
- Decisive evaluation of these methods is not yet possible because of a shortage of reliable full scale data
- Full scale experiments are therefore first on the list of further work. Other areas where further information is required include the effects of complex terrain, the change of turbulence within clusters and the effect of flow structure on performance

References

Vermeulen P E J
Report of the IEA Technical Meeting on Wakes and Clusters, held at Leatherhead, February 2-3, 1981. MT-TNO 81-04676

Clayton B R, Filby P
Wind turbine wake studies. Proc. Third BWEA Wind Energy Conference, April 9-10, 1981

Taylor G J, Turner J D, Fordham J
Preliminary performance measurements on the 5 m horizontal axis wind turbine at University College, Swansea. IEA Annex V Technical Meeting, Leatherhead, February 2-3, 1981

Milborrow D J
Measurement and interpretation of wind turbine wake data. Proc. Third BWEA Conference, April 9-10, 1981

Ross J N, Ainslie J F
Wake measurements in clusters of model wind turbines using Laser Doppler Anemometry. Proc. Third BWEA conference, April 9-10, 1981

Vermeulen P E J, Heijke R C
Measurements of the drag coefficient of the CERL Wind turbine simulator. MT-TNO Report 81-02840

Ainslee J F

Computer modeling of wake effects in clusters of wind turbines. IEA Annex V Technical Meeting, Leatherhead, February 2-3, 1981

Vermeulen, P E J, Builtjes P J H, Vijge J B A
Mathematical modeling of wake interaction in wind turbine arrays. MT-NTO Report 81-01473. Part I and II

Vermeulen P E J

Definition of turbulence concept in relation to wind turbine design. MT-NTO Report 81-09061

Vermeulen P E J, Builtjes P J H

Turbulence measurements in simulated wind turbine clusters. MT-NTO Report 82-03003

For completeness, the following publications from 1980 and earlier are also listed since they have bearing on the Task V programme.

Vermeulen P E J

A wind tunnel study of the wake of a horizontal axis wind turbine. MT-NTO Report 78-096/4, September 1978

Vermeulen P E J et al.

An experimental study of the wake behind a full scale vertical-axis wind turbine. MT-NTO Report 79-06118, June 1979

Vermeulen P E J

Mixing of simulated wind turbine wakes in turbulent shear flow. MT-NTO Report 79-09974, September 1979

Vermeulen P E J

Studies of the wake structure of model wind turbine generators. MT-NTO Report 79-012904, November 1979

Builtjes P J H, Milborrow D J

Modelling of Wind Turbine Arrays. Proc. Third Int. Symp. Wind Energy Systems, Copenhagen, August 1980

Vermeulen P E J

An experimental analysis of wind turbine wakes. Proc. Third Int. Symp. Wind Energy Systems, Copenhagen, August 1980

5 Task VI. STUDY OF LOCAL WIND FLOW AT
POTENTIAL WECS SITES

This Task is basically a project for a major cooperative field experiment to measure details of the spatial variations of mean wind and turbulence over a typical WECS hill site. The site selected is Askervein, a 125 m hill on the island of South Uist, Scotland, Figure 1.

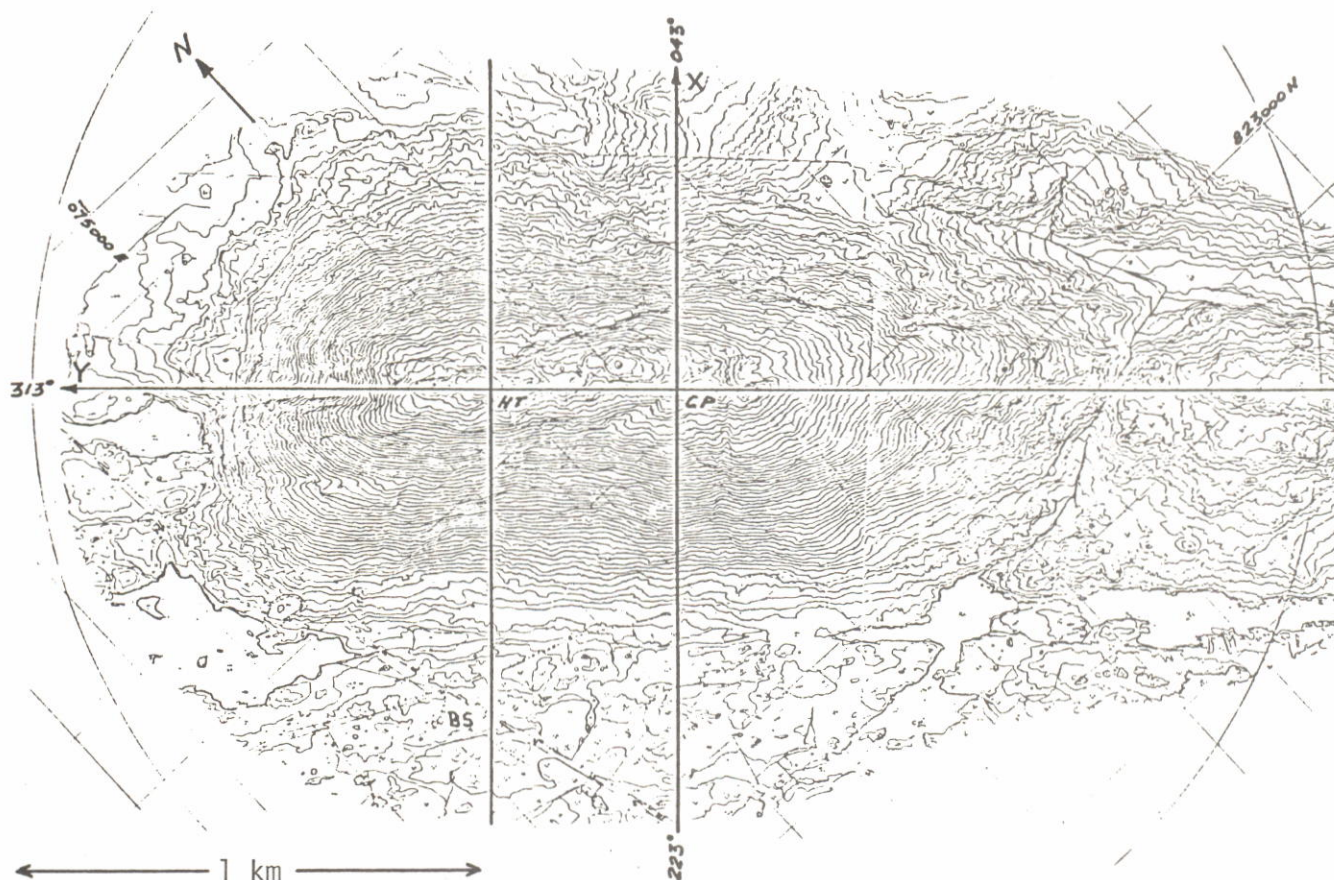


Figure 1 High resolution contour map of
Askervein. Original was drawn at
1:2000 scale with 2 m contour interval

Data from the September 1982 preliminary experiment were analyzed during 1983 and a report on that experiment is being prepared for submission to the Executive Committee. The data include mean winds at 10 m elevation above ground along two radial lines through the hilltop, profiles of wind speed to 50 m above the hilltop and at an upwind reference site, and some preliminary turbulence measurements.

The main experiment was conducted between 14 September and 17 October 1983. During the core observing period (25 Sep - 9 Oct) weather and wind were cooperative and good data were obtained in moderate to strong SW, S and W winds. A large number of instruments were deployed including 7 sonic anemometer systems, one of which could handle up to 7 kites. Two 50 m towers, Figure 2, one 30 mast and two 17 m towers were used for instrumentation at key locations, while another fifty 10 m towers and posts were used to make measurements with good spatial resolutions on the hill. Preliminary on site analyses indicated that most of the systems operated satisfactorily and reliably. Comprehensive data sets will be forthcoming, including mean flow profiles to approximately 200 m above the hilltop (measured with kite anemometers) and extensive turbulence measurements both on and upstream of the hill.

Wind tunnel and numerical modelling studies were initiated during 1983. Preliminary results show good agreement with the mean flow field data from the 1982 experiment.

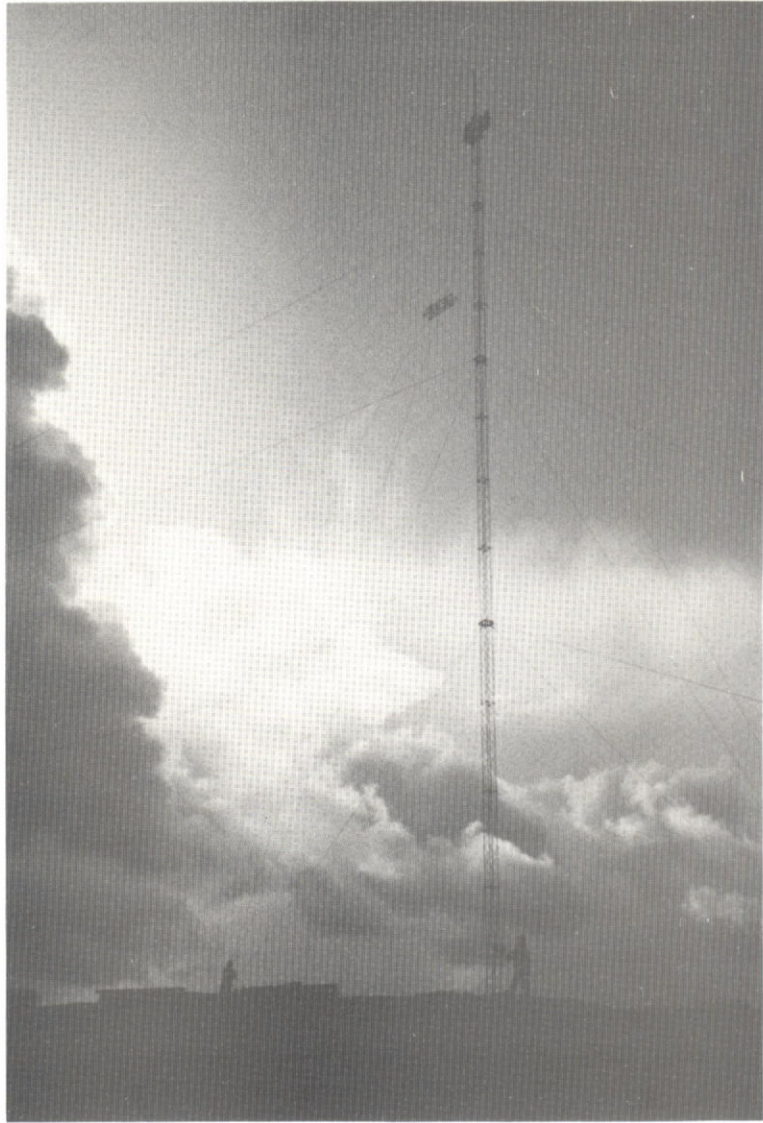


Figure 2 Erecting the hilltop 50 m tower

6 Task VII. STUDY OF OFFSHORE WECS

This Task started formally on May 1, 1983. The objectives are to assess the economic viability of offshore wind power, to define design criteria for an offshore WECS prototype, and to outline a plan for the design, construction and operation of a joint prototype. This will be achieved in a task-sharing effort over a two-year period involving about 25 man-years from four countries (Denmark, the Netherlands, Sweden and the U.K.) with the Central Electricity Generating Board (U.K.) acting as Operating Agent.

The Task is divided into four Sub-Tasks each of which is managed by a Responsible Participant:

- A Meteorological data collection and compilation (U.K.)
- B Conceptual design study of an offshore wind power plant (NL)
- C Technical specifications for an offshore WECS prototype (S)
- D Generic studies (DK)

Major study areas in the Sub-Tasks have been agreed and work plans drafted. For example, Sub-Task A will include the following areas:

- Review and analysis of existing data. Target completion date September 1984
- Sensitivity of WECS structures and systems to meteorological parameters. Target date September 1985
- Measurements of offshore wind data and waves. Target date September 1984

- Investigations of land to sea wind speed recovery.
Target data September 1985
- Investigation of the prediction of local wind velocities.
Target data January 1985

Sub-Task definition meetings were held in Stockholm May 31- June 1 and Leatherhead July 22 and a progress meeting in Copenhagen October 3-4, 1983.

The Task is open for participation by other countries and interest has been expressed from Norway and the U.S.A.

7 RECOMMENDED PRACTICES FOR WIND TURBINE
TESTING AND EVALUATION

In 1980 the Executive Committee organized an expert group for recommending procedures for testing and evaluating WECS performance. The group identified the following study areas:

- Power performance testing
- Costing of WECS
- Determination of power quality
- Acoustic noise measurement
- Fatigue life evaluation
- Electromagnetic interference
- Safety and reliability

To-date two documents have been published:

S Frandsen, A R Trenka, B Maribo Pedersen (Eds)
Recommended Practices for Wind Turbine Testing
Vol 1, Power Performance Testing
1. Edition 1982

J Nitteberg (Ed)
Recommended Practices for Wind Turbine Testing
Vol 2, Estimation of Cost of Energy from Wind
Energy Conversion Systems
1. Edition 1983

The reports are available through members of the Executive Committee.

Other documents are in various stages of preparation.

The Executive Committee has agreed to establish a standing committee of five experts for continuously keeping the documents up-to-date. Specific working parties will be set up as the need arises.

8 DECENTRALIZED USES OF WIND ENERGY

Decentralized uses of wind energy involves the use of small and medium WECS for either autonomous (non-grid-connected) applications or in combination with diesel generators to supply electricity for local networks in remote areas. In view of the growing interest in these applications, a draft Annex for a cooperative research programme was submitted to the Executive Committee. The draft Annex suggests a task-sharing project with two Sub-Tasks:

- Site evaluation techniques for small autonomous systems
- Analysis of wind/diesel systems

The first Sub-Task will identify predictive models and measurement techniques appropriate to the planning and specification of a decentralized WECS installation. The second Sub-Task will select options of wind/diesel systems for comparing their performance with predictions. A demonstration project might be included at a later stage.

The proposed Annex is being considered for approval at the 1984 spring meeting of the Executive Committee.

9 ACTIVITIES OF THE EXECUTIVE COMMITTEE

The Executive Committee held its eleventh meeting on March 21, 1983 at ECN, Petten. The twelfth meeting took place on September 27, 1983 at the Technical University of Denmark, Lyngby. At this meeting Mr B Maribo Pedersen (Denmark) and Mr P F Sens (the Netherlands) were elected Chairman and Vice-Chairman for 1984.

At the 11th meeting representatives of Italy and Spain were invited as observers. They reported of wind energy activities in their countries. At the 12th meeting it was agreed to invite observers from the European Communities' Directorate General for Science Research and Education (DG 12) and Directorate General for Energy (DG 12) to the next Executive Committee meeting with a view to coordinating wind energy activities.

The relationship between the newly created Renewable Energy Working Party of the IEA Committee on Research and Development and the Executive Committee was clarified during the year.

The technical and financial status of the Tasks were reviewed at the Executive Committee meetings. Proposals for new Tasks were discussed, including:

- Decentralized uses of wind energy
- Fast time response of wind turbines and arrays
- Comparison of test facilities
- Large-scale wake effect studies

A topical meeting on "Electrical Conversion Systems for Wind Turbines" was arranged in Petten on Jan 26-27, 1983. An overview was presented of various electrical conversion systems with their attendant advantages and disadvantages. Some areas were identified requiring further study, possibly in international cooperation. Proceedings of the meeting were published by the Netherlands Energy Research Foundation (ECN).

The Executive Committee agreed to establish a common fund for Secretariat expenses, printing of reports etc.

A list of Executive Committee members is attached.

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