INTERNATIONAL ENERGY AGENCY

Programme of Research and Development

on Wind Energy Conversion Systems

(IEA R&D WECS)

IEA R&D WECS ANNUAL REPORT 1980

A report of the Executive Committee

of the IEA Implementing Agreement for

a Programme of Research and Development

on Wind Energy Conversion Systems

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FOREWORD

This report, summarizing the progress during 1980 of the IEA R&D WECS project, is submitted to the IEA Secretariat by the IEA R&D WECS Executive Committee.

The report is intended to meet the requirements of Level 2 type information as set forth by the IEA Committee on Energy Research and Development.

Louis V. Divone
Chairman

Bengt Pershagen
Secretary

Executive Summary

The objective of this program is to perform co-operative research, development and demonstration, and to exchange information in the area of wind energy utilization and associated problems. Four Tasks were initiated in 1977:

_____ Environmental and meteorological aspects of WECS
_____ Evaluation of numerical models for siting of WECS
_____ Integration of wind power into national electricity supply systems
_____ Investigation of rotor stressing and smoothness of operation of large-scale WECS

The first Task has a number of separate and rather diverse sub-tasks. Considerable progress was made during 1980, and four sub-tasks have been completed.

The visual impact of large scale WECS units and arrays was analyzed by means of perception theory, field observations, case studies and visualization techniques. Various ways of reducing the visual interference were suggested. Results were presented in artist's sketches and pictures, and films were taken of rotating model WECS against the background of real landscapes.

In a study of wind forecasting for the day-to-day operation of WECS, it was found that short-range wind forecasts lack in overall quality and don't meet the demands for accuracy required in wind power forecasting at the present time. Subjective methods were better than numerical/statistical methods for the first 18 hours, while objective methods performed better for extended 1-3 days prognoses.

Studies of the design of WECS were undertaken in another sub-task which was completed during 1980. General design principles and safety requirements were reviewed as a basis for defining load cases. Load cases were selected and evaluation methods and techniques recommended for both horizontal and vertical axis WECS.

The potential savings by co-siting a WECS farm and a short rotation forestry plantation were analyzed. The results show that in this particular case, the disadvantages of a biomass production system outweigh the advantages of co-siting, although there may be exceptional sites or circumstances where the two systems could be favorably combined.

It is expected that this part of the program will be completed in early 1981.

The second Task of evaluating numerical models for the siting of WECS proceeded according to plan. Three data sets were chosen for the comparison and evaluation of five numercial models. Processed data were delivered to the modeling groups. Initial results from the simpler models have been compared. Some difficulties were experienced in getting the more complicated models to run, but these problems have been solved. This Task is scheduled to be completed in December 1981.

The research performed under the last two Tasks was completed in 1979 with final reports available in 1979 and 1980 for Task III and IV, respectively. A second phase of Task III started in late 1979, comprising assessment of the potential of integrating wind power into electricity networks in Japan, the Netherlands, Sweden and the USA. The work during 1980 involved data acquisition and analysis, and application of the computer model, developed during the first phase.

A fifth Task WECS Wake Effects, commenced in 1980 as a continuation in more depth of similar work performed earlier in a sub-task under Task I. Wind tunnel measurements of individual wake structures and of cluster performance were made, as well as some limited field measurements behind a 5m diameter experimental WECS.

The Executive Committee initiated a study project on offshore siting of WECS for the purpose of comparing and evaluating initial feasibility studies carried out in the Netherlands, Sweden, United Kingdom and United States of America, and investigating the potential for significant cooperative research on offshore systems.

The countries participating in the R&D WECS projects are: Austria, Canada, Denmark, Germany, Ireland, Japan, Netherlands, New Zealand, Norway, Sweden, United Kingdom, and United States. However, not all countries participate in all Tasks.

Operating Agents: Kernforschungsanlage Julich GmbH (Germany), Stichting Energionderzoek Centrum Nederland (Netherlands), National Swedish Board for Energy Sources Development, United States Department of Energy.

1. IEA R&D WECS PROGRAM

This report reviews the progress during 1980 of the Programme of Research and Development on Wind Energy Conversion Systems (R&D WECS) operated under the auspices of the International Energy Agency (IEA).

IEA R&D WECS is one of two IEA projects on wind energy. The other project concerns cooperation in the development of large-scale WECS. Both projects have been in effect since October 6, 1977 when the Implementing Agreements were signed.

The overall objective IEA R&D WECS is to perform cooperative research, development and demonstrations, and to exchange information within the framework of the Implementing Agreement. As described in Annexes I-IV to the Implementing Agreement, the original programme of work had four Tasks:

Task I Environmental and Meteorological Aspects of Wind Energy Conversion Systems
Operating Agent: National Swedish Board for Energy Source Development

Task II Evaluation of Models for Wind Energy Siting
Operating Agent: Department of Energy, USA

Task III Integration of Wind Power into National Electricity Supply Systems
Operating Agent: Kernforschungsanlage Julich GmbH

Task IV Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems
Operating Agent: Kernforschungsanlage Julich

The first phase of Task III was completed in 1979, and a second phase, Task IIIa, was initiated in late 1979.

The technical work of Task IV was completed in 1979; the final report is being prepared for printing.

A new Task V on Study of Wake Effects behind Single Turbines and in Wind Turbine Parks was initiated during 1980 with the Stichting Energieonderzoek Centrum Nederland as Operating Agent.

The participation in the Tasks is as follows:

Country	Task I,	II,	III and IIIa,	IV,	V
Austria	x				
Canada	x	x			x
Denmark	x			x	x
Germany	x	x	x	x	
Ireland	x				
Japan	x	x	x	x	x
Netherlands	x		x	x	x
New Zealand	x				
Norway	x	x			
Sweden	x	x	x	x	x
United Kingdom		x			x
United States	x	x	x	x	x

Tasks I, III, IIIa and IV are commonly funded which means that the costs are shared by the contracting parties in pre-determined proportions. Task II is a task-sharing project where each participant carries his own cost. Task V is a mixed cost-sharing and task-sharing effort.

2. TASK I ENVIRONMENTAL AND METEOROLOGICAL ASPECTS OF WIND ENERGY CONVERSION SYSTEMS

The objectives of this Task are:

- to study the environmental impact and operational safety of large-scale WECS
- to investigate the uncertainty in wind forecasting appropriate for day-to-day operation of WECS
- to recommend design methods for selected load cases

The Task is subdivided in eight sub-tasks carried out in three different countries, acting as Responsible Participants, as follows:

Sub-Task	Title	Responsible Participant
A 1	Study of WECS farm area and WECS safety limit requirements	Sweden
A 2	Study of combined wind-biomass energy systems	Ireland
A 3	Study of wind wake effects	Netherlands
A 4	Study of the impacts of large-scale WECS on the performance of electromagnetic wave systems	Netherlands
A 5	Study of aesthetic factors and visual effects of large-scale WECS	Sweden
A 6	Reporting	Sweden

B 1	Investigation of the uncertainty in wind forecasting for wind power networks	Sweden
C 1	Load case recommendations	Sweden

Sub-task A 4 on wake effect studies was completed in 1979 and the main results were summarized in the previous Annual Report.

Sub-tasks A 2, A 5, B 1 and C 1 were completed during 1980. Sub-tasks A 1 and A 4 are delayed and are expected to be finished during early 1981. The status and main technical results obtained during the report period are summarized below for each sub-task.

2.1 Sub-Task A 1. Study of WECS farm area and WECS safety limit requirements

The first phase of this sub-task resulted in a preliminary manual for the analysis of risks associated with the potential structural failure of WECS, published in 1979 by the Aeronautical Research Institute of Sweden being the responsible organization for performing the work.

In February 1980 an expert meeting was held in Stockholm on the subject of safety analysis of WECS. The meeting was attended by 42 participants from seven countries. The discussion after the prepared contributions mainly dealt with the problem of fractured parts and sheets or lumps of ice separating from a WECS rotor. It was suggested that an international collection of information on abnormal events occurring during future operation of large-scale WECS would be very useful.

The second phase of this sub-task includes an update of the manual for safety analysis and numerical application to the two Swedish prototypes under construction. This work has been delayed and is expected to be reported in March 1981.

2.2 Sub-Task A 2. Study of combined wind-biomass energy systems

The objective of this sub-task was to study the co-siting of a WECS farm and a short rotation forestry (SRF) plantation, the latter supplying a thermal electricity station. Potential capital and operating cost reductions were of particular interest. The study was started in September 1979 and completed in June 1980, under the co-ordination of Energy Division of the National Board for Science and Technology, Dublin, Ireland.

The study examined a combined WECS-SRF installation in a general way. No particular site was chosen. The SRF plant covered an area of 10 000 ha with the power station of 70 MW situated centrally. The trees which are coppicing trees, i.e. they can grow again from a stump, are planted initially in consecutive sections and harvested in rotation every 4-5 years. The WECS farm consisted of 50 machines producing 1 MW each at rated speed, 12 m/s.

The results may be summarized as follows:

(i) Capital savings on the joint electrical installation amount to 4.2 % of that portion affected by the co-siting i.e. transformers and switchgear.

(ii) Staffing requirements for operation and maintenance are reduced by 4 % of that required for separate operation.

(iii) Biomass production rates will be directly reduced by increased wind regimes and indirectly by the soil type to an extent which will be site specific.

(iv) Cost savings on access road construction are real but very small.

In general, the disadvantages of the biomass production outweigh the advantages of co-siting with a WECS farm, though there may be exceptional sites or circumstances when the two systems could be favourably combined.

2.3 Sub-Task A 3. Study of wind wake effects

This sub-task was completed in 1979. The main findings were summarized in the previous Annual Report.

The wake effect studies have continued as a separate Task under the IEA R&D WECS agreement. The progress of the new Task is reported in Section 8 below.

2.4 Sub-Task A 4. Study of the impact of large-scale WECS on the performance of electromagnetic wave systems

The objective of this sub-task is to study the effects of rotating and parked large-scale wind turbines on broadcasting systems, telecommunication systems, and radar position finding and direction finding systems. The work is carried out at the Dr Neher Laboratory of the Dutch PTT and includes calculation of biostatic cross sections of planar and cylindrical bodies having similar scattering properties as an actual windmill, and calculation of the reduction of scattering properties by coating. Due to delays in the performance of work, measurements on actual windmills have been abandoned.

A workshop on telecommunication interference was held in Copenhagen on August 29, 1980.

2.5 Sub-Task A 5. Study of aesthetic factors and visual effects of large-scale WECS

This sub-task was completed in 1980 and a final report was published by the National Swedish Board for Energy Source Development.

The visual effects of WECS units and arrays were studied by means of perception theory and field observations. In a case study of siting a WECS group station in an agricultural area in southern Sweden, different principles of grouping were examined. The effects of unit size (50 and 100 m turbines) on the visibility and the character of the landscape were analyzed.

Different methods of visualizing WECS in the landscape by means of pictures and films were tried. The best results for close-up photos and film sequences (of rotating WECS) were obtained by using WECS models (scale 1:100) standing in a modelled foreground of the real landscape. For distant photos and films, where motion is not essential, a photo montage technique proved advantageous. The chroma-key method also gave good results but was found more expensive.

2.6 Sub-Task B 1. Investigation of the uncertainty in wind forecasting for wind power networks

Accurate forecasting of wind speed is of great importance for day-to-day operation of WECS when integrated in a power grid. The objective of this sub-task is to examine the uncertainty in present methods of wind prediction for levels up to 100 m above ground from 1 to 72 hours ahead. The work started in 1979 with active participation from Austria, Germany, New Zealand, Sweden and USA. A draft version of the final report was completed in December 1980 by the Swedish Meteorological and Hydrological Institute.

Criteria for an objective wind forecast verification scheme were defined. The requirements on forecasting accuracy from the aspect of power generation were determined. Observational data were supplied from four countries and used to test different forecasting techniques by means of a specially developed computer code. Due to time limitations, the programme of work had to be revised and the data and analysis were not as complete as originally anticipated.

The main results may be summarized as follows:

- The overall quality of wind forecasts is not sufficient for wind power forecasting to a desirable uncertainty level at the present time.

- Subjective methods are better for short-range forecasts of less than 18 hours, but deteriorate faster than numerical/statistical methods which become better than subjective methods after 18 hours.

- There is a definite need for developing forecast methods for very short range forecasts, i.e. 0-6 hours ahead.

- It is recommended that national weather services improve their basic subjective and objective guidance, especially for the range 3-12 hours.

2.7 Sub-Task C 1. Load case recommendations

A wind turbine will be subject to various static and dynamic loads due to wind, gravity, malfunction of control and safety systems, etc. Excessive loads may give rise to failures of blades and attachments, control mechanisms and tower structure. A WECS must be designed to meet the requirements of all anticipated load cases. The requirements can be stated in general terms or be expressed as specified load cases.

The objective of sub-task C 1 was to review design principles and requirements of WECS as a basis for recommended load cases. The work started in 1978 at the Aerospace Division of SAAB-SCANIA, Linkoping, Sweden and was completed in 1980. Both horizontal and vertical axis WECS were studied. In the analysis of the vertical axis WECS to the German firm ERNO acted as subcontractor.

The work included a review of environmental conditions applicable to the design of WECS, particularly wind characteristics such as wind speed duration, extreme wind speed, wind shear, wind direction and turbulence. Basic principles for the selection of load cases and safety factors and/or allowable strains were studied and used to define load cases and recommend methods of load calculations for horizontal and vertical axis WECS.

The results are contained in three reports, draft versions of which were distributed to the Participants in December 1980. The reports have the following titles:

Basic design recommendations for wind energy converters

Design recommendations for wind energy converters with horizontal rotor axis

Design recommendations for wind energy converters with vertical rotor axis

3. TASK II. EVALUATION OF WIND MODELS FOR WECS SITING

The objective of Task II is to evaluate the role of numerical wind models in the siting of WECS. The verification program has been subdivided into three sub-tasks. Sub-task 1 provides for the preparation of a detailed verification plan. In sub-task 2, model verification will be carried out by the various participants. Sub-task 3 covers reporting the final results.

Sub-task 1 was completed in 1979. Three data sets were chosen for evaluation of the numerical models. The data sets were for Oahu, Nevada and Gotland. Four methods were selected originally:

- a simple, mass-consistent, wind interpolation code (the NOABL code developed by Science Applications, Inc., U.S.A.)

- a one-level, primitive equation model (SAM, developed by the Atmospheric Environment Service of Canada)

- a multi-level, time-dependent, hydrostatic model (the University of Virginia mesoscale model)

- a multi-level, time-dependent, non-hydrostatic model (the Tapp and White model of the UK Meteorological Office)

An additional model has been added to the program:
the multi-level, time-dependent, hydrostatic model developed by Science Applications, Inc., called SIGMET. SIGMET has a different turbulence model than the other hydrostatic model, and it uses numerical procedures in solving the equations of motion. The purpose of including SIGMET was to see if its modeling differences would make significant differences in the simulated windfields.

Processed data were delivered to the various modeling groups in early 1980. In June 1980 a meeting was held in Leatherhead, U.K. to compare initial results and to iron out any problems in the work plan for the Task. By

the time of the Leatherhead meeting, the initial cases had been completed by the simpler models (NOABL and SAM). However, the more complicated models (SIGMET, the University of Virginia model and the U.K. Meteorological Office model) had not completed these cases. The modelers were having more difficulty getting their simulations under way than they had anticipated.

Because of these problems an additional meeting will be held before the meeting on final results, which is scheduled for April 1981. This additional meeting will help ensure that all participants will arrive at the April 1981 meeting with comparable products that can be quickly integrated into a final report.

4. Tasks III and IIIa. INTEGRATION OF WIND POWER INTO NATIONAL SUPPLY SYSTEMS

The objective of this Task is to analyze the technical and economic possibilities of integrating large-scale WECS into national electricity grids, with special attention to power regulation capacity including storage and peaking devices.

In the first phase (Task III), a computer model was developed and applied to the case of Germany. Task III was completed in 1979 and the final report published in September 1979. The results were summarized in the previous Annual Report.

The second phase (Task IIIa) started in late 1979, and includes application of the computer model to conditions in Japan, Netherlands, Sweden and USA. This involves acquisition of wind data, estimation of wind energy potential with varying technical parameters for different wind turbines, and integration of wind power into the electricity grid. By the end of 1980 the case of the Netherlands was nearly completed, Sweden was well under way, and data acquisition for Japan and USA had started.

5. Task IV. INVESTIGATION OF ROTOR STRESSING AND SMOOTHNESS OF OPERATION OF LARGE-SCALE WECS

This Task was technically completed in 1979 but has not yet been fully reported. The results were summarized in the previous Annual Report.

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

This Task was initiated in 1980 with the Stichting Energieonderzoek Centrum Nederland as Operating Agent. The objective of this Task, which is an extension of Sub-Task A 3 of Task I, is to produce estimates of the performance of arrays of wind turbine generators including:

a) power output efficiency as a function of spacing, disposition and number of machines and machine types

b) turbulence levels generated and associated dynamic effects

Work is performed 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 progress during 1980 includes:

- wind tunnel studies of the wake structure behind a turning model of a horizontal axis wind turbine
- wake studies behind a 5 m diameter vertical axis turbine at Fokker-Schiphol and a 5 m dia horizontal axis turbine at Swansea
- extensive measurements in U.K. and Dutch wind tunnels of cluster performance as a function of array size, shape and mutual distance between turbines

- development of a computer model based on the experimental results and capable of calculating the power output of each individual turbine in an array of any arbitrary configuration.

Task V is expected to cost about Hfl 825 000 and last for a period of three years.

7. COMPARISON OF FEASIBILITY STUDIES FOR OFFSHORE WECS

If wind energy is going to contribute significantly to power generation in the future, a large number of wind power plants is required. The problem of siting will not be easily solved. The most favourable wind conditions are often to be found in coastal areas where competition for land is already great. It is therefore natural to seriously consider locating wind power plants offshore.

Noting that initial feasibility studies for offshore siting had been carried out in the Netherlands, Sweden, United Kingdom and United States, the IEA R&D WECS Executive Committee initiated a study project with the following objectives:

- to compare and evaluate the existing studies
- to specify areas for which there is agreement that no further work is necessary
- to identify areas requiring further investigations
- to put forward proposals for collaborative efforts

The study project started in mid-1980 and a final report is expected in April 1981. The work is performed as a task-sharing effort, each participating country being responsible for reviewing a certain technical area. A planning meeting was held in Copenhagen on August 25, 1980. A workshop for discussion of the contributions from the participating countries took place at Southall on November 10-11, 1980.

8. ACTIVITIES OF THE EXECUTIVE COMMITTEE

The Executive Committee held its fifth meeting on April 14, 1980 in Dublin, and its sixth meeting on September 23, 1980 in London. At the Dublin meeting, Mr. Divone (U.S.A.) and Mr. Sens (Netherlands) were elected Chairman and Vice-Chairman for 1980.

During the year, the United Kingdom entered as a participating country in Annex II and designated ERA Technology Limited as a Contracting Party to the Implementing Agreement.

The technical and financial status of the Tasks were reviewed at the EC Meetings, and the appropriate decisions taken. A new Task V Study of wake effects behind single turbines and in wind turbine parks was started. A study project on the feasibility of offshore siting of WECS was initiated. Proposals for new Tasks on Local wind measurements (Canada), Recommended practices for wind turbine performance testing (Denmark), and Extended wake effect measurements (U.K.) were discussed.