ne National Swedish Board for Energy Source Development

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acting for

IEA/WECS/Executive Committee
and as
IEA/WECS/Task I/Operating Agent

IEA/WECS/EC + TASK I ANNUAL REPORT 1979

International Energy Agency (IEA)
Programme of Research and Development
on Wind Energy Conversion Systems (WECS)

Information

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1980-01-30 IEA/RDWECS/AR79

To IEA

R&D WECS Annual Report 1979

As agreed in the CRD annual report should be worked out for each of the IEA projects and submitted to the IEA before the end of January of the following year.

By decision of the Executive Committee separate Annual Reports for each Task are submitted by the Operating Agents and in addition to this a Executive Committee Report is presented.

This document contains the Report of the Executive Committee and the Task I Annual Report.

Lars Rey
Chairman

Bengt Pershagen
Secretary

Leif Brandels
Task I Operating Agent

EXECUTIVE COMMITTEE REPORT 1979

1. IEA/RDWECS PROGRAM

This Summary reports on the progress during 1979 of the Programme of Research and Development on Wind Energy Conversion Systems (IEA/RDWECS) operated under the auspices of the International Energy Agency.

IEA/RDWECS is one of two IEA programmes on wind energy. The other programme concerns cooperation in the development of large-scale WECS. Both programmes are in effect since October 6, 1977, when the Implementing Agreements were signed.

The overall objective of IEA/RDWECS is to perform cooperative research, development, demonstrations and exchanges of information within the framework of the Implementing Agreement. As described in Annexes I-IV to the Implementing Agreement the programme of work consists of four Tasks:

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

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

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

Task IV Investigation of Rotor Stressing and Smothness of Operation of Large-Scale Wind Energy Conversion Systems
Operating Agent: Kernforschungsanlage Jülich GmbH

The participating countries in the various Tasks are:

Country	Task I	Task II	Task III	Task IV
Austria	X			
Canada	X	X		
Denmark	X			X
Germany	X	X	X	X
Ireland	X			
Japan	X	X	X	X
The Netherlands	X		X	X
New Zealand	X			
Norway	X	X		
Sweden	X	X	X	X
United States of America	X	X	X	X

Tasks I, III and IV are commonly funded which means that the costs are shared by the participating countries in pre-determined proportions. Task II is a task-sharing effort where each participant carries its own cost.

Task I Environmental and Meteorogical Aspects of Wind Energy Conversion Systems

The purpose of this Task is to provide information on:

- wind characteristics for the design and operation of large-scale WECS
- risks associated with the potential structural failure of WECS
- visual perception of large-scale WECS
- impact of WECS on telecommunication systems

There are eight Sub-Tasks carried out in Ireland (1), the Netherlands (2) and Sweden (5). One Sub-Task started in 1977, two in 1978 and four in 1979. Due to the slow start the programme is delayed for about a year and is expected to be completed during 1980.

One Sub-Task on wake effekt studies on vertical axis Darrieus type WECS was completed in 1979. By model scale experiments in a wind tunnel it was found that an economically acceptable optimum power output from an array of wind turbines could be reached at about 6 diameters mutual distance, and could give about 9 W/m^2 power output per unit ground area.

The first part of a study of methods for the safety analysis of WECS was completed and published. The study focused on Lazards imposed by WECS in operation due to complete collapse or separation of fractured parts. In another Sub-Task engineering wind models for calculating loads and specification of load cases were studied and documented in a report.

In a Sub-Task on the visual impression of WECS films of rotating models of prototype WECS in natural environments were produced as a means of visualizing the effects of single and multiple WECS in the landscape. A study of the uncertainty in wind forecasting for the day-to-day operation of WECS was initiated.

Four expert meetings were held during the year on wake effect studies, wind forecasting for WECS operation, and load case recommendations.

Technical reports were published on

- Safety of wind energy conversion systems
- Wind turbine wake effects
- Load case definitions and wind models for the design of WECS

The National Swedish Board for Energy Source Development acted as Operating Agent for the Task. Some difficulties in administering the Task were experienced due to the rather complex organisation with eight Sub-Tasks in three different countries.

Because of the delayed start the expenditures during 1979 were less than projected. The common fund maintained by the Operating Agent was more than adequate for covering the costs. The decision of the United Kingdom not to participate in Task I necessitated a revision of the scheme for distribution of costs among the participants.

Task II Evaluation of Wind Models for Wind Energy Siting

The objective of Task II is to evaluate the role of numerical models in the siting of WECS. The verification program has been devided 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.

Three meetings were held during 1979 in Paris February 1, Norrköping July 4 and 5, and Seattle October 3 and 4. Sub-Task 1 has been completed. Four models were selected for verification, and five data sets were proposed. The data needed to run the models, and the products to be generated have been specified.

The schedule for the implementation of Task II calls for completion in November 1981.

Task III Integration of Wind Power into National Electricity Supply Systems

The objective of this Task is to analyze the engineering and economic possibilities of large-scale WECS with special attention to complementary power regulation capacity including storage and peaking devices.

The first phase of the investigation, comprising development and testing of a computer model and application of the model to a reference case, has been completed. The final report was published in September 1979 with the title Large-Scale Wind Power Utilization: An Assessment of the Technical and Economical Potential for the Federal Republic of Germany.

The reference case was a compound of wind power plants in the North German coast region feeding into the entire national grid of the FRG. At a wind power penetration of 5, 10 and 15% the fuel savings amounted to 4.2, 8.8 and 13.9% of the fuel spent without wind utilization. The displaceable conventional capacity amounted to only 1/3, 1/4 and 1/5 of the installed wind capacity. An enlargement of the general storage capacity of at most one to two kilowatthours per installed kilowatt wind capacity was found to be appropriate. Dedicated storage systems for wind power systems are not suitable in a national electricity supply system.

Kernforschungsanlage Jülich acted as Operating Agent for the Task. The work was carried out at the University of Regensburg. The time schedule and expenditures were as originally projected.

The second phase of the investigation, comprising application of the methods developed in the first phase for the Netherlands, Sweden, The United States, and presumably Japan, was adopted by the Executive Committee as Task IIIa to be carried out in 1980/81.

Task IV Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems

The objective of this Task is to investigate possibilities for low rotor stressing, high operational smoothness and system vibration control of a 3 MW wind power system. This involves controlling the rotor blades in order to reduce additional loads resulting from wind profiles, gusts and gravity.

By means of improved design, accurate calculations and experiments using a wind tunnel, an extremely light but durable design of a 3 MW plant was prepared. A hub concept was developed which minimizes stressing of the structure and disturbances to the operational smoothness by external influences. A dynamic analysis of the whole system was carried out to avoid damage due to unacceptable vibrations. The computational methods were verified by wind tunnel experiments.

The Task has been finished and a final report is being prepared. The work was carried out at two institutes of the University of Stuttgart. The Kernforschungsanlage Jülich acted as Operating Agent.

2. ACTIVITIES OF THE EXECUTIVE COMMITTEE

The Executive Committee held two meetings during the year in Copenhagen April 2, and in Washington D C November 1. At the Copenhagen meeting Mr Rey (Sweden) and Mr Sens (the Netherlands) were re-elected as Chairman and Vice-Chairman for 1979. Rules of Procedure and Financial Rules were adopted as guidelines.

During the year it became apparent that the United Kingdom had not signed the Implementing Agreement and thus was not a Contracting Party as had previously been assumed. At the Washington meeting the Executive Committee was informed that the UK is proceeding to sign the Agreement with respect to Annex II.

The technical and financial status of the Tasks were reviewed at the EC meetings, and the appropriate decisions were taken. Tasks III and IV were completed during the year. The schedule and budget for completion of Task I during 1980 was approved at the Washington meeting.

Several new Tasks were proposed. A new Task IIIa on a second phase of Task III with Kernforschungsanlage Jülich as Operating Agent was adopted at the Copenhagen meeting. Similarly, a new Task V on continued wake effect studies was adopted at the Washington meeting with the Stichting Energionderzoek Centrum Nederland as Operating Agent. Proposals for new Tasks on measurements for wind power output, off-shore siting of WECS, and local wind flow measurements will be further discussed.

TASK I ANNUAL REPORT 1979

1. INTRODUCTION

The Programme of Research and Development on Wind Energy Conversion Systems (IEA/RDWECS) is one of two cooperative programmes in the field of wind energy operated under the auspices of the International Energy Agency. The other programme concerns co-operation in the development of Large-Scale WECS. Both programmes are effective since October 6, 1977, when the Implementing Agreements were signed.

The overall objective of IEA/RDWECS is to carry out cooperative research, development, demonstrations and exchanges of information within the framework of the Implementing Agreement the programme of work consists of four Tasks:

Task I	Environmental and Meteorological Aspects of Wind Energy Conversion Systems
Task II	Evaluation of Models for Wind Energy Siting
Task III	Integration of Wind Power into National Electricity Supply Systems
Task IV	Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale wind Energy Conversion Systems.

This report describes the progress during 1979 of Task I and is the second annual report. The first annual report was a part of the Annual Report 1978 for the whole IEA/RDWECS Programme.

The participants in Task I, i.e. the contracting parties to Annex I of the Implementing Agreement, are:

Austria	
Canada	National Government of Research Council of Canada
Denmark	Ministry of Trade and Industry
Germany	Kernforschungsanlage Jülich
Japan	
the Netherlands	Stichting Energieonderzoek Centrum Nederland
New Zealand	New Zealand Meteorological Service
Norway	Institutt for Atomenergi
Sweden	National Board for Energy Source Development
USA	Department of Energy

Task I is a cost-sharing effort with a total budget of approximately 1.5 million Swedish Kronor. The cost is shared among the participants in pre-determined proportions as set forth in Annex I of the Implementing Agreement.

2. PROGRAM DESCRIPTION

The objectives of Task I 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 WECS operation
- to examine wind models and recommend load case definitions for the structural design of WECS.

The Task has eight Sub-Tasks carried out in four different countries as shown in the following table.

Sub-Task	Title	Responsible Participant
A1	Study of WECS farm area and WECS safety limit requirements	Sweden
A2	Study of combined wind-biomass energy systems	Ireland
A3	Study of wind wake effects	Netherlands
A4	Study of the impacts of large-scale WECS on the performance of electro-magnetic wave systems	Netherlands
A5	Study of aesthetic factors and visual effects of large-scale WECS	Sweden
A6	Reporting	Sweden
B1	Investigation of uncertainty in wind forecasting for wind power networks	Sweden
C1	Load case recommendations	Sweden

Sub-Task A1-A4 focuse on safety on environmental aspects of importance for the large-scale deployment of wind energy. Sub-Tasks B1 and C1 address wind characteristics for WECS operation and the specification of load cases for WECS design. Wind models for resource assessment purposes are studied in Task II of the IEA/RDWECS programme.

3. SUB-TASK A1. STUDY OF WECS FARM AREA AND WECS SAFETY LIMIT REQUIREMENTS

The purpose of this Sub-Task is to study methods for the safety evaluation of WECS appropriate for the analysis of structural failures which would result in risk to life or serious injury to operation staff or general public.

The first part of the work has been completed and documented in a report. The study has focused on hazards imposed by WECS operation due to complete collapse or separation of fractured parts or pieces of ice acting as missilies. The study considers land-based large-scale WECS with horizontal axis located in a sparsely populated area. The blade material is assumed to be steel, aluminium or fiber-reinforced plastics, the tower being built of steel or reinforced concrete.

In the first part of the work critical structures and failure modes were identified. Statistical information on loads and strength of materials were compiled. A simplified method of risk analysis was defined. A dynamic study of objects separating from the turbine was performed. Some critical chains of events with regard to safety systems, inspection and repair were identified.

In the second part of the work a numerical safety analysis of a large-scale WECS prototype under construction in Sweden will be performed. An expert meeting will be arranged in February 1980 to discuss the results of the first part and plans for further work. The final result aimed for is a manual for safety evaluation.

4. SUB-TASK A2. STUDY OF COMBINED WIND-BIOMASS ENERGY SYSTEMS

This Sub-Task, which is coordinated by the Energy Divison of the National Board for Sciense and Technology in Dublin, was started in September 1979 and is expected to be completed in May 1980.

The objectives are to study the potential of co-siting wind energy conversion systems and short rotation forestry (SRF) farms. In particular, the advantages and disadvantages of combined operation will be identified with special emphasis on potential capital and operation cost reduction resulting from a joint use of construction roads, electrical transmission system operation and maintenance facilities.

The study is broken down into a number of sections to be dealt with by the appropriate authorities as follows:

1. Electrical system design and costing for WECS facilities shared with SRF thermal plant; relative optimum sizes and operating modes; operating and maintenance staff (Electricity Supply Board)
2. Soil suitability for SRF in high wind speed areas and affects of wind on SRF growth (An Foras Taluntais)
3. Suitability of forestry road for WECS construction and maintenance, cost savings; soil suitability for WECS foundations (Department of Forestry).

Because of the late start no results are as yet available from this study.

5. SUB-TASK A3. STUDY OF WIND WAKE EFFECTS

Large wind power stations will involve groups of 20-100 wind turbines. Since wind velocity is decreased in the wake behind a turbine the power output from an array of turbines will be reduced if the turbines are placed close together. The optimum mutual distance is an important consideration especially in densely populated countries where only very little area is available for locating large groups of wind turbines.

The purpose of Sub-Task A3 was to study wind wake effects by model scale experiments in a wind tunnel. A small scale rotating model of a vertical axis Darrieus type turbine was constructed to simulate in the homogeneous flow field of a wind tunnel a full scale turbine in the real atmospheric boundary layer. The velocity deficit was measured as a function of distance behind the turbine for different turbulence intensities in the flow field.

In order to investigate interaction effects between turbines in an array, a stationary object consisting of a guaze with a diffusor was developed to simulate the wake of the rotating turbine. Groups of upp to 100 gauzes were placed on a circular turn-table in the wind tunnel. By measuring the force on the different gauzes in a group an estimate can be made of the energy output from such a group of turbines.

The conclusions from the studies were summarized as follows

- The centerline velocity deficit behind a Darrieus turbine decays with distance, after an initial stage, according to a - 1,25 power law
- the wake of a Darrieus turbine can be simulated by a stationary object consisting of a gauze with a diffusor
- the available wind energy in an atmospheric boundary layer above grassland in a straight line at distances behind a turbine of 10 and 20 diameters is about 60 and 85 %, respectively, of the full power

- the power output of different turbines placed on a straight line reaches an equilibrium situation already at about the 4th turbine
- an economically acceptable optimum power output of a limited array coult be reached at about 6 diameters mutual distance and could give about 9 W/m^2 power output per unit ground area
- the maximum power output per unit ground area for an infinite array is about 8 W/m^2 at a mutual distance of 5 diameters.

This Sub-Task has been completed. The results were documented in a conference report and a final report. An expert meeting took place at Apeldoorn on September 9, 1979, to discuss the final report.

The wake effect work at Apeldoorn is continuing with studies on horizontal axis turbines and field measurements. It is highly probable that a new Task will be adopted for the extended wake effect studies.

6. SUB-TASK A4. STUDY OF THE IMPACT OF LARGE-SCALE WECS ON THE PERFORMANCE OF ELECTRO-MAGNETIC WAVE SYSTEMS

The Responsible Participant for this Sub-Task is the Netherlands' Energy Research Foundation. The work is performed at the Dr Neher Laboratory of the Dutch PTT. The objective 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 research program includes

- an inventory of possible effects and restrictions to be placed on the location of large-scale WECS with respect to telecommunication links
- measurements of bi-static radar cross sections using scale models
- calculations on arrays of wind turbines.

The inventory has been completed and documented in a draft report. The inventory indicates that - without further investigations - limitations regarding the siting of WECS can only be given in three cases:

- a certain area surrounding a radio link. The boundaries of the area is determined by the bi-static radar cross section depending on the polarisation and frequency of the electromagnetic wave and on the geometrical shape of teh obstacle
- depending on their height WECS may not be located within a certain range of a satellite receiving station
- WECS may not be located within a range of 6 km of broadcasting transmitting antennas.

To what extent WECS will disturb orher telecommunication systems can only be established after measurements of the bi-static radar cross sections.

7. SUB-TASK A5. STUDY OF AESTHETIC FACTORS AND VISUAL EFFECTS OF LARGE-SCALE WECS

The visual impression of large-scale WECS depends on a number of factors, for example the distance from the observer to the turbine, the topography and weather, the size, height, material, colour and movement of the turbine. There are also subjective factors depending on how the observer interprets a WECS in terms of functional, social and aesthetic aspects. The visual effects of an array of WECS in a wind power station will be more pronounced than those of a single turbine.

The objective of Sub-Task A5 is to study the visual effects of WECS by means of pictures and films using models of large-scale WECS. Three different methods of producing films of rotating WECS in a natural environment were tried. Good results were obtained with the chroma-key method mixing background landscape films on videotape with studio pictures of turning wind turbine models. A second method using front projection on 35 mm film gave less satisfactory results.

Because of the rather expensive studio work necessary in the chroma-key method another method was tried. The turning model was placed in the natural environment with an artificial near-landscape and the real sky as background. Two models or designs selected for the Swedish large-scale prototype WECS were used. The films gave a very realistic impression. A sequence was shown at Fourth Biennial Conference and Workshop on Wind Energy Conversion Systems in Washington D.D. October 23-31, 1979.

Colour slides and black/white paper copies with close-up and distant views of single wind turbines have also been produced. Planned work includes pictures of landscapes with a full group of wind turbines.

8. SUB-TASK B1. INVESTIGATION OF UNCERTAINTY IN WIND FORECASTING FOR WIND POWER NETWORKS

Accurate predictions of wind velocity on an hourly to daily time scale is of great importance for the operational planning of WECS. The objective of this Sub-Task is to determine the uncertainties in forecasting wind speed at specified locations and generally at hub height from 1 to 72 hours ahead. This is achieved by developing a computer program that accepts wind forecasts and wind observations as input and produces a complete set of verification scores as output. The participating countries will supply date to the Swedish Meteorological and Hydrological Institute where the computer program is developed and run.

The work started in March 1979. A revised work plan and time schedule aiming for project completion in July 1980 was adopted at a specialist meeting in May 1979. The meeting agreed on verification criteria and computer code specifications. Both subjective and objective, statistical forecasts for specified sites in various countries will be used. However, due to compressed project time schedule a full year of data will not be available making it impossible to study seasonal variations of forecasting performance.

The computer program has been coded and tested. Data will be supplied by January 31, 1980. The first verification data will be available for interpretation in April 1980 when an meeting will be arranged to discuss the results.

9. SUB-TASK C1. 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. Obviously, 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 av specified load cases.

The objectives of Sub-Task C1 are to review existing load case definitions and wind models used to calculate loads, to study common principles for the application of wind data to WECS design, and to suggest redommendations for load case data for different types of WECS.

The work is carried out by SAAB-SCANIA, Linköping, for the initial review and the methods and load case recommendations for horizontal axis WECS with ERNO, Bremen, as a subcontractor for vertical axis Darrieus type WECS.

The review of existing wind models and load case definitions has been completed and documented in a report. Some of the findings were that certain areas are reasonably well covered in theory, for example

- main load cases for a fault-free WECS
- a few load cases for obvious faults
- wind speed duration.

Areas which require further analysis to an important extent are

- total risk of failure due to simultaneous malfunction and extreme winds
- spatial averaging of extreme winds
- spatial effects of turbulence
- spatial averaging of wind direction.

10. EXPERT MEETINGS

One of the most important means of encouraging cooperation among the participants is to arrange meetings of experts to discuss the progress and results of the various Sub-Tasks. During 1979 four meetings have been held:

Sub-Task	Date	Place
A3	September 6	Apeldoorn
B1	May 31 - June 1	Norrköping
C1	September 12	Linköping
	December 12	Bremen

Minutes from the meetings including papers and handouts were distributed to meeting participants and members of the Executive Committee.

11. REPORTS

The following technical reports have been issued during the period

A1 S EGGWERTZ, I CARLSSON, A GUSTAFSSON, C LUNDEMO, B MONTGOMERIE, S-E THOR
Safety of wind energy conversion systems (WECS)
Preliminary Study
FFA Report HU-2126

A3 P J H BUILTJES
Windturne wake effects
TNO Report 79-08375

C1 G TÖRNKVIST
A review of load case definitions and wind models for the design of wind energy conversion systems
Saab-Scania Report TPES-79.37

A Draft report on the first part of Sub-Task A4 has also been prepared and was attached to the minutes of the third meeting of the Executive Committee.

12. ORGANIZATION

The program of work and budget for this Task is determined by the IEA/RDWECS Executive Committee. During 1979 the Executive Committee held two meetings, when the technical and financial status of the Task was reviewed.

The Operating Agent for the Task is the National Swedish Board for Energy Source Development. The Operating Agent provides coordination and supervision of the Sub-Tasks and prepares semiannual and annual progress reports.

The execution of the Sub-Tasks is contracted to various organizations in the countries of the Responsible Participants. The Sub-Task managers are the following

Sub-Task	Project Manager	Organisation
A1	S Lundgren	Aeronautical Research Institute Stockholm
A2	E Kinsella	National Board for Science and Technology, Dublin
A3	P J H Builtjes	TNO, Apeldoorn
A4	J M G A Ouderling	PTT, Leidschendam
A5	S Engström	National Swedish Board for Energy Source Development
A6	L Brandels	National Swedish Board för Energy Source Development
B1	S Bodin	Swedish Meteorological and Hydrological Institute, Norrköping
C1	G Törnkvist	Saab-Scania, Linköping

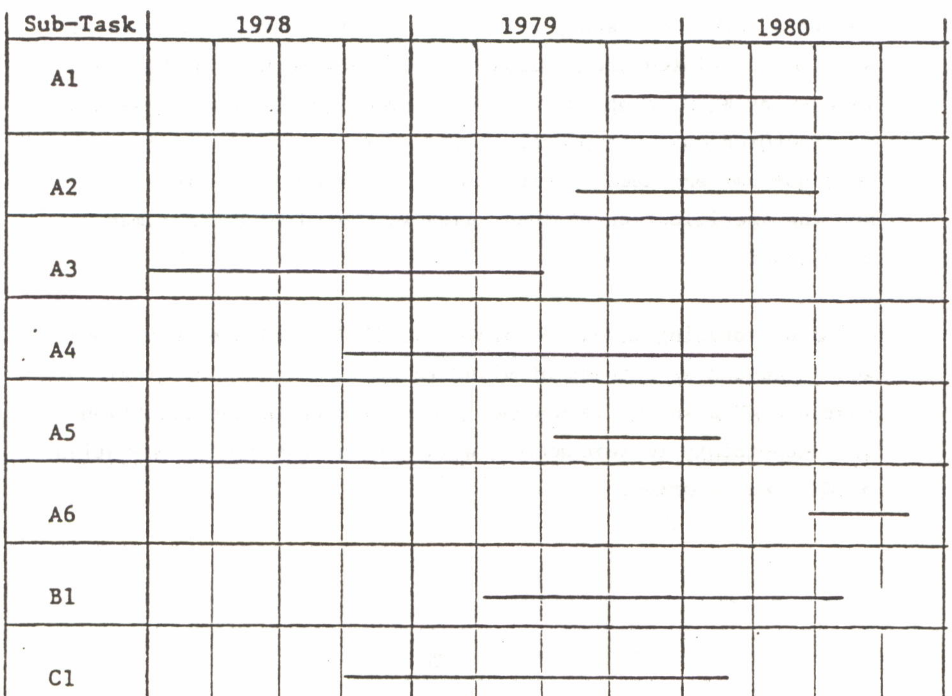
13. PLANNED WORK EFFORT FOR 1980

Task I is planned to be completed during 1980. The following work will be carried out as reflected in the schedule.

Sub-Task	Planned work
A1	Complete numerical safety analysis of large-scale WECS
A2	Complete study of electrical system, soil suitability and effects of high wind speed on SRF growth rates
A4	Complete measurements on scale models and calculations on arrays of wind turbines
A5	Complete final report

Sub-Task	Planned work
A6	Prepare Task I final report
B1	Submit data and perform verification
C1	Complete second editions of reports on load case recommendations for horizontal and vertical axis WECS.

Summary schedule



14. EXECUTIVE SUMMARY

The overall purpose of this Task is to provide information on wind characteristics for the design and operation of large-scale wind energy conversion systems (WECS) and on their environmental effects, in particular the safety limit requirements due to the potential structural failure of WECS, the visual perception of WECS, and the impact of WECS on the performance of telecommunication systems. 1111 countries are participating in the programme, which consists of 8 Sub-Tasks, carried out at various organizations in 3 countries. The program started in 1977 and is planned to be completed in 1980.

One Sub-Task on wake effect studies on vertical axis Darrieus type WECS was completed in 1979. By model scale experiments in a wind tunnel it was found that an economically acceptable optimum power output of an array of wind turbines could be reached at about 6 diameters mutual distance, and could give about 9 W/m^2 power output per unit ground area.

The first part of a study of methods for the safety analysis of WECS was completed and published. The study focused on hazards imposed by WECS in operation due to complete collapse or separation of fractured parts or pieces of ice acting as missiles. In another Sub-Task engineering wind models for the calculation of loads and the specification of load cases were studied and documented in a report.

Films or rotating models of prototype WECS in natural environments were produced as a means of visualizing the effects of single and multiple WECS in the landscape. A Sub-Task on the verification of the uncertainty in forecasting wind for the day-to-day operation of WECS was started.

National Swedish Board for Energy Source Development

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