International Energy Agency
Programme of Research and Development on
Wind Energy Conversion Systems

IEA R&D Wind Energy

ANNUAL REPORT 1990

Published by
National Energy Administration
Sweden, for the
IEA R&D WECS Executive Committee

Statens energiverk
1991:R1
IEA R&D Wind Energy

ANNUAL REPORT 1990

Published by
National Energy Administration
Sweden, for the
IEA R&D WECS Executive Committee
FOREWORD

This is the thirteenth Annual Report of the IEA Programme for Research and Development on Wind Energy Conversion Systems (IEA R&D WECS), reviewing the activities during 1990. The report is submitted to the Agency in accordance with the recommendations of the IEA Committee on Research and Development.

H J M Beurskens
Chairman of the Executive Committee

Bengt Pershagen
Secretary of the Executive Committee
CONTENTS

EXECUTIVE SUMMARY 7
THE IEA R&D WECS PROGRAMME 11
TASK VIII DECENTRALISED APPLICATIONS FOR WIND ENERGY 14
TASK IX INTENSIFIED STUDY OF WIND TURBINE WAKE EFFECTS 16
TASK XI BASE TECHNOLOGY INFORMATION EXCHANGE 21
TASK XII UNIVERSAL WIND TURBINE FOR EXPERIMENT (UNIWEX) 24
TASK XIII COOPERATION IN THE DEVELOPMENT OF LARGE SCALE WIND TURBINE SYSTEMS 34
PROPOSED NEW ACTION 35
THE EXECUTIVE COMMITTEE 36

APPENDIX 1 CUMULATED LIST OF TECHNICAL EXPERT MEETINGS
APPENDIX 2 LIST OF EXECUTIVE COMMITTEE MEMBERS AND ALTERNATE MEMBERS
EXECUTIVE SUMMARY

The IEA Programme for Research and Development on Wind Energy Conversion Systems (IEA R&D WECS) is one of two IEA programmes on wind energy, the companion one being the Co-operation in the Development of Large-Scale Wind Energy Conversion Systems (IEA LS WECS). IEA R&D WECS has sixteen Contracting Parties from fifteen countries: Austria, Belgium, Canada, Denmark, F R Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom and United States.

The IEA R&D WECS programme has twelve Tasks, seven of which have been successfully completed. Two additional Tasks are technically complete, but final reporting remains. The current Tasks include:

Task VIII Study of Decentralised Applications for Wind Energy
Operating Agent: National Engineering Laboratory, UK

Task IX Intensified Study of Wake Effects behind Single Turbines
and in Wind Turbine Parks
Operating Agent: Central Electricity Generating Board (UK)

Task XI Base Technology Information Exchange
Operating Agent: Department of Fluid Mechanics,
Technical University of Denmark

Task XII Universal Wind Turbine for Experiments (UNIWEX)
Operating Agent: Institute for Computer Applications,
University of Stuttgart, F R Germany

A new Annex XIII on Co-Operation in the Development of Large Wind Turbine Systems has been adopted. The Task, which will commence 1 January 1991 and continue for an initial period of three years, incorporates the activities of the IEA LS WECS Agreement which is terminated by 31 December 1990.
Tasks VIII, IX and XI are task-sharing projects, whilst Tasks XII and XIII are mixed task- and cost-sharing. In the task-sharing projects the participants are committed to in-kind contributions to a joint programme, managed by the Operating Agent.

Ten countries are participating in Task VIII, which has two Subtasks: Site Assessment Techniques and Wind-Diesel Systems. A draft manuscript of the final report, called the Wind-Diesel Guidebook, was nearly completed during the year. The book will be published on the open market.

Eight countries are participating in Task IX Intensified Study of Wind Turbine Wake Effects. A substantial amount of experimental data was collected from operating wind turbines and windfarms and compared with predictions from theoretical models. A benchmark exercise for the evaluation of both single wakes and windfarm models has been completed. A draft final report has been submitted to the Executive Committee. It is concluded that, whilst numerical models of single wakes are now soundly based, further work is needed to better understand the interaction of wakes in a windfarm.

Task XI Base Technology Information Exchange has participants from nine countries. A main activity is the preparation and publication of Recommended Practices for Wind Turbine Testing and Evaluation. To date eight documents have been published. They are updated as experience and feedback from the users is accumulated. A second edition of Vol 1 Power Performance Testing was issued during the year, and a second edition of Vol 6 Structural Safety is being considered.

Joint Actions represent the second Subtask of Task XI. In the Joint Action on Aerodynamics the fourth symposium was arranged during the year. Proceedings from the third symposium, held in November 1989 has been published. In the Joint Action on Fatigue, an international group of experts have agreed on a reference load spectrum for wind turbine blade fatigue testing. A Joint Action on
Offshore WECS has been initiated, aiming at the exchange of experiences from the design, construction and operation of offshore wind turbines.

As a third activity within Task XI, topical expert meetings are arranged and documented. The 19th meeting took place in May 1990 on Wind Turbine Control Systems - Strategy and Problems. Proceedings of the 18th meeting on Noise Generating Mechanisms in November 1989 has been published.

Task XII Universal Wind Turbine for Experiments (UNIWEX) has seven participants from three countries. The project aims at experimental studies of aerodynamics, operational behaviour, load spectra and control strategies for various hub concepts as well as at the validation of computer codes. The main activities during 1990 included the development of software and numerical simulation, the development, testing and installation of hardware for the modified experimental wind turbine as well as experiments for the verification of the computer models for simulating the hardware and the aerodynamic behaviour. Measurement campaigns were carried out with constant rotor speed, constant tip speed, different yaw angle, high angles of attack and tilted power.

The Executive Committee met twice during the year to review the progress of the ongoing Tasks and discuss proposals for new cooperative action. The national wind energy research programmes were presented at the meetings and progress and planning reports were exchanged.

A new Annex for Extended Wake Effect Studies is being drafted for consideration at the Spring 1991 meeting.

The Executive Committee has decided to investigate the possibility of issuing a Newsletter twice a year. The Newsletter should inform the wind energy community of IEA wind energy activities, including the status of national wind energy programmes, the progress of the Tasks as well as summary performance data and incident/accidents for large wind turbine systems.
The main issue during the year was the merger of the two Implementing Agreements. At the Fall meeting the Executive Committees of the R&D and LS Agreements unanimously agreed to terminate the LS Agreement by 31 December 1990 and to incorporate the LS activities as Annex XIII of the R&D Agreement from 1 January 1991. The decision reflects the changed environment in which the Agreements operate when most wind energy research and development is directed to large systems.
THE IEA R&D WECS PROGRAMME

The Programme of Research and Development on Wind Energy Conversion Systems (IEA R&D WECS) was initiated in 1977. IEA R&D WECS is one of two IEA programmes in wind energy. The companion programme is the Co-operation in the Development of Large-Scale Wind Energy Conversion Systems (IEA LS WECS), which is reported separately.

The general objective of IEA R&D WECS is to undertake collaborative R&D Tasks, as defined in Annexes to the Implementing Agreement. To-date twelve Tasks have been initiated, nine of which 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 Models for Wind Energy Siting
Operating Agent: US Department of Energy - Battelle Pacific Northwest Laboratories
Completed in 1983.

Task III  Integration of Wind Power into National Electricity Supply Systems
Operating Agent: Kernforschungsanlage Jülich GmbH
Completed in 1983.

Task IV  Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems
Operating Agent: Kernforschungsanlage Jülich GmbH
Completed in 1980.

Task V  Study of Wake Effects behind Single Turbines and in Wind Turbine Parks
Operating Agent: Netherlands Energy Research Foundation
Completed in 1984.

Task VI  Study of Local Wind Flow at Potential WECS Hill Sites
Operating Agent: National Research Council of Canada
Task VII  Study of Offshore WECS  
Operating Agent: UK Central Electricity Generating Board  

Task VIII  Study of Decentralised Applications for Wind Energy  
Operating Agent: UK National Engineering Laboratory  
Technically completed in 1989.

Task IX  Intensified Study of Wind Turbine Wake Effects  
Operating Agent: UK Central Electricity Generating Board.  
Technically completed in 1990.

Task XI  Base Technology Information Exchange  
Operating Agent: Department of Fluid Mechanics,  
Technical University of Denmark  
To be completed in 1991.

Task XII  Universal Wind Turbine for Experiments (UNIWEX)  
Operating Agent: Institute for Computer Applications,  
University of Stuttgart, F R Germany  
To be completed in 1991.

Task XIII  Cooperation in the Development of Large Wind Turbine Systems  
Operating Agent: Solar Energy Research Institute, USA  
To be completed in 1993

There are 16 Contracting Parties to the Implementing Agreement, representing 15 countries. The participation in the current Tasks is shown in Table 1. The Belgian and Swiss Contracting Parties have decided to withdraw from the Agreement, effective 31 December 1990.

In Tasks VIII, IX and XI, the Participants contribute manpower and work - usually in their home countries - to a joint programme coordinated by the Operating Agent. The total level of effort is typically about 10 manyears per Task. Tasks XII and XIII are mixed cost- and task-shared.

During the year the Executive Committee of IEA LS WECS agreed to terminate the IEA LS WECS Implementing Agreement, effective 31 December 1990. Simultaneously, the IEA R&D WECS Executive Committee decided to amend the IEA R&D WECS Implementing Agreement to include LS WECS activities in its scope as of 1 January
1991 and to adopt a new Annex for Co-Operation in the Development of Large Wind Turbine Systems (see below). At the same time, ENEL of Italy and Scottish Hydro-Electric plc of the United Kingdom, being the only Contracting Parties to the LS Agreement not already Parties to the R&D Agreement, joined the IEA R&D WECS Agreement.

Table 1 Participation per country in the current Tasks. OA indicates country of Operating Agent.

<table>
<thead>
<tr>
<th>Country</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VIII</td>
</tr>
<tr>
<td>Austria</td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>x</td>
</tr>
<tr>
<td>Denmark</td>
<td>x</td>
</tr>
<tr>
<td>Germany</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>x</td>
</tr>
<tr>
<td>New Zealand</td>
<td></td>
</tr>
<tr>
<td>Norway</td>
<td>x</td>
</tr>
<tr>
<td>Spain</td>
<td>x</td>
</tr>
<tr>
<td>Sweden</td>
<td>x</td>
</tr>
<tr>
<td>Switzerland</td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>OA</td>
</tr>
<tr>
<td>United States</td>
<td>x</td>
</tr>
</tbody>
</table>
TASK VIII DECENTRALISED APPLICATIONS FOR WIND ENERGY

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

- define cost effective models and techniques suitable for obtaining wind and load data necessary for planning and specifying decentralised wind energy conversion system installations; and

- apply and further develop models suitable for analysing the performance of wind-diesel systems.

Nine technical meetings were held during 1985-1989, involving 28 experts from the participating countries. At an early stage a desire was expressed to produce a work of reference which would convey to a wider engineering community the potential difficulties and stage of development of wind-diesel technology. The final report of the Task should therefore take the form of a handbook on the siting and implementation of wind-diesel systems.

A draft manuscript of the final report, called the Wind-Diesel Guide Book, was distributed to the Executive Committee Members and Task Participants in March. The manuscript was complete except for a chapter on economic issues. Writing of the remaining chapter and further editorial work are in progress to be completed in early 1991.

The authors comprise the foremost experts from the participating countries, who by discussion and information exchange have agreed upon the contents, which include:
Introduction

Wind-Diesel Options and Their Applicability

Consumer Demand Assessment

Wind Resource Assessment

Environmental and Other Factors

Design Considerations

Modelling Techniques

Installation and Operation of Wind-Diesel Systems

System Testing, Commissioning and Monitoring

Economics of Wind-Diesel Systems

The Executive Committee has agreed to have the book published on the open market. Two publishing houses have expressed willingness to publish the book, and a contract proposal has been obtained from one of them.

Participating Organisations

Canada National Research Council
Denmark Risø National Laboratory
Netherlands ECN Research Centre
New Zealand NZ Meteorological Service
Norway Research Institute of Electricity Supply
Spain Instituto de Energias Renovables, CIEMAT
Sweden State Power Board
Switzerland Federal Office of Energy
       Oekozentrum Langenbruck
       Alpha Real AG
United Kingdom Rutherford Appleton Laboratory
United States Department of Energy
       Solar Energy Research Institute
       University of Massachusetts
       Atlantic Orient Corporation

Operating Agent

United Kingdom National Engineering Laboratory
TASK IX  INTENSIFIED STUDY OF WIND TURBINE WAKE EFFECTS

The Task was set up in 1985 as a follow-on from the earlier Task V study of wake and cluster effects. The study has involved eight countries in a task-sharing arrangement, coordinated by the CEBG (UK) as Operating Agent. The overall objective has been to improve the knowledge of aerodynamic interactions between wind turbines operating in windfarms.

The Task has seen the development of more reliable wake models, and the acquisition of considerable amounts of data from single turbines, pairs of interacting turbines and from full size windfarms. Four technical meetings have been held, in which data were exchanged and models compared. The experimental data and theoretical techniques were brought together in benchmark exercises based around Näsudden (for the evaluation of single wakes) and Tændpipe (for the evaluation of windfarm models).

The final technical review meeting was held 11-12 June in London at which specialists from the participating countries reported progress from measurements and modelling. Discussions took place on the single wake and Tændpipe benchmark exercises in which predictions were compared with experimental results.

The draft final report was submitted to the Executive Committee in September. The report outlines the national contributions to the Task and summarises the work completed. It then highlights the principal results and conclusions from the studies and assesses those areas where further work may be required.

It is concluded that, whereas numerical models of a single wake are now soundly based on the physics of the wake mixing process, the windfarm codes currently available are "first generation" models. For more reliable predictions of the flowfield (both mean flow and turbulence models) within a windfarm to be made, further work will
be required to better understand and quantify the physical processes taking place when wakes interact within a windfarm.

**Participating Organisations**

<table>
<thead>
<tr>
<th>Country</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>RUCA Antwerp</td>
</tr>
<tr>
<td>Denmark</td>
<td>Risø National Laboratory</td>
</tr>
<tr>
<td>Italy</td>
<td>ENEL</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>TNO</td>
</tr>
<tr>
<td>Spain</td>
<td>Universidad Politecnica de Madrid (UPM)</td>
</tr>
<tr>
<td>Sweden</td>
<td>University of Uppsala</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Central Electricity Generating Board</td>
</tr>
<tr>
<td></td>
<td>ETSU for the UK Department of Energy</td>
</tr>
<tr>
<td></td>
<td>Garrad-Hassan Consultants</td>
</tr>
<tr>
<td>United States</td>
<td>US Department of Energy</td>
</tr>
</tbody>
</table>

**Operating Agent**

United Kingdom Central Electricity Generating Board

**Technical Reports and Papers**

<table>
<thead>
<tr>
<th>Country</th>
<th>Ref</th>
<th>Date</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BM-3</td>
<td>7/89</td>
<td>Wind and Power Measurements in the Wind Farm at Zeebrugge</td>
<td>J Van Leuven</td>
</tr>
<tr>
<td>Country</td>
<td>Code</td>
<td>Year</td>
<td>Title</td>
<td>Author(s)</td>
</tr>
<tr>
<td>-----------</td>
<td>------</td>
<td>------</td>
<td>----------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Denmark</td>
<td>D-01</td>
<td>5/89</td>
<td>Wake Interaction Measurements at the Masnedø wind farm</td>
<td>I Katic</td>
</tr>
<tr>
<td></td>
<td>D-02</td>
<td>7/89</td>
<td>Supervising and Measuring at Tændpipe Wind Farm - Progress Report</td>
<td>J Højstrup, I Katic, P Nørgard</td>
</tr>
<tr>
<td></td>
<td>D-03</td>
<td>6/90</td>
<td>A Summary of Tændpipe windfarm measurements</td>
<td>J Højstrup, P Nørgard</td>
</tr>
<tr>
<td></td>
<td>D-04</td>
<td>6/90</td>
<td>Danish Windfarm Measurements: IEA Annex IX</td>
<td>P Sanderhoff, J Højstrup</td>
</tr>
<tr>
<td>Italy</td>
<td>IT-01</td>
<td>7/88</td>
<td>Wind Turbulence Analysis in the Alta Nurra Wind Power Station Area</td>
<td>G Botta, R Castagna</td>
</tr>
<tr>
<td></td>
<td>IT-02</td>
<td>7/89</td>
<td>Preliminary Results of Wake Measurements at the Alta Nurra Wind Power Station</td>
<td>ENEL</td>
</tr>
<tr>
<td></td>
<td>IT-03</td>
<td>6/90</td>
<td>Results of Wake Measurements at the Alta Nurra Wind Power Station</td>
<td>G Botta, A Gilardi</td>
</tr>
<tr>
<td>Netherlands</td>
<td>NL-01</td>
<td>9/85</td>
<td>Wind Tunnel Measurements of the Wake of a Tipvane Rotor Model (Summary)</td>
<td>E Luken</td>
</tr>
<tr>
<td></td>
<td>NL-02</td>
<td>8/85</td>
<td>Wake of a Horizontal Axis Wind Turbine Model</td>
<td>A M Talmon</td>
</tr>
<tr>
<td></td>
<td>NL-03</td>
<td>1/86</td>
<td>Evaluation of Three Mathematical Wind Turbine Wake Models in Various Types of Flow</td>
<td>E Luken, A M Talmon, P E J Vermeulen</td>
</tr>
<tr>
<td></td>
<td>NL-04</td>
<td>11/86</td>
<td>Literature Data Base on Wind Turbine Wakes and Wake Effects</td>
<td>E Luken</td>
</tr>
<tr>
<td></td>
<td>NL-05</td>
<td>12/87</td>
<td>Comparison of Wind Tunnel and Full Scale Measurements of the Wake at the 25 m HAWT Site at ECN Petten</td>
<td>E Luken</td>
</tr>
<tr>
<td></td>
<td>NL-06</td>
<td>7/89</td>
<td>The Wind Load of Wind Turbines in Clusters - Literature Survey</td>
<td>E Luken</td>
</tr>
<tr>
<td>Code</td>
<td>Year</td>
<td>Description</td>
<td>Authors</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>-------------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>NL-07</td>
<td>1988</td>
<td>Nibe Wake Measurements Data Analysis and Model Validation</td>
<td>E Luken</td>
<td></td>
</tr>
<tr>
<td>NL-08</td>
<td>1989</td>
<td>Zeebrugge Windfarm Measurements - Model Validation</td>
<td>H van Oort</td>
<td></td>
</tr>
<tr>
<td>NL-09</td>
<td>1989</td>
<td>Tøndpiple Windfarm Measurements - Model Validation</td>
<td>H van Oort</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>SP-01</td>
<td>7/88</td>
<td>Validation of Turbulence Models of Wind Turbine Wakes</td>
<td>A Crespo, J Hernandez, E Luken</td>
</tr>
<tr>
<td>Spain</td>
<td>SP-02</td>
<td>7/89</td>
<td>Analysis of Wind Turbine Wakes</td>
<td>A Crespo, J Hernandez</td>
</tr>
<tr>
<td>Spain</td>
<td>SP-03</td>
<td>7/89</td>
<td>Wind Farms in Complex Terrain - Second Order Effects</td>
<td>A Crespo, J Hernandez, C Andreu</td>
</tr>
<tr>
<td>Spain</td>
<td>SP-04</td>
<td>1989</td>
<td>Numerical Modeling of the Flowfield in a Wind Turbine Wake</td>
<td>A Crespo, J Hernandez</td>
</tr>
<tr>
<td>Spain</td>
<td>SP-05</td>
<td>1990</td>
<td>Wind Turbine Wakes in the Atmospheric Surface Layer</td>
<td>J Hernandez, A Crespo</td>
</tr>
<tr>
<td>Sweden</td>
<td>SW-01</td>
<td>7/87</td>
<td>A Field Study of the Wake Behind a 2 MW Wind Turbine</td>
<td>U Högström, D N Asimakopoulos, A Smedman</td>
</tr>
<tr>
<td>Sweden</td>
<td>SW-02</td>
<td>1990</td>
<td>Some Additional Data on Full Scale Wind Turbine Wakes</td>
<td>U Högström, A-S Smedman</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>UK-01</td>
<td>7/87</td>
<td>Siting Guidelines for Wind Turbine Arrays</td>
<td>D J Milborrow, J S Holt</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>UK-02</td>
<td>7/87</td>
<td>Wake Modelling and the Prediction of Turbulence Properties</td>
<td>J F Ainslee</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>UK-03</td>
<td>7/87</td>
<td>Fluctuating Loads on a Wind Turbine Operating in a Wake</td>
<td>G J Taylor</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>UK-04</td>
<td>7/88</td>
<td>Near Wake Wind Tunnel Studies</td>
<td>D R Green</td>
</tr>
<tr>
<td>Code</td>
<td>Date</td>
<td>Title</td>
<td>Authors</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------</td>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>UK-05</td>
<td>7/88</td>
<td>Wake Interaction Studies on the HWP-300 and WEG MS-1 Wind Turbine Generators on Burgar Hill</td>
<td>A Scott</td>
<td></td>
</tr>
<tr>
<td>UK-06</td>
<td>7/88</td>
<td>The Impact of Wind Turbine Wakes on Machine Loads and Fatigue</td>
<td>U Hassan, G J Taylor, A D Garrad</td>
<td></td>
</tr>
<tr>
<td>UK-07</td>
<td>7/89</td>
<td>Comparison of NWAKE Model with Data from Nibe Wake Measurements Project</td>
<td>J F Ainslee</td>
<td></td>
</tr>
<tr>
<td>UK-08</td>
<td>10/89</td>
<td>Characterisation of Wind Turbine Wake Turbulence and Its Implication on Wind Farm Spacing</td>
<td>D Quarton</td>
<td></td>
</tr>
<tr>
<td>UK-09</td>
<td>1990</td>
<td>Wake Measurements on the Nibe Wind Turbines in Denmark Part 2: Data Collection and Analysis</td>
<td>G Taylor</td>
<td></td>
</tr>
<tr>
<td>UK-10</td>
<td>1990</td>
<td>Multiple Wake Measurements and Analysis</td>
<td>D Smith</td>
<td></td>
</tr>
<tr>
<td>US-01</td>
<td>4/88</td>
<td>An Examination of Wake Effects and Power Production for a Group of Large Wind Turbines (PNL-6528)</td>
<td>D Elliott, J Buck, J Barnard</td>
<td></td>
</tr>
</tbody>
</table>
TASK XI  BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote wind turbine technology by co-operative activities and information exchange on R&D topics of common interest. The Task has two Subtasks:

A  Development of Recommended Practices for Wind Turbine Testing and Evaluation
B  Joint Actions

In addition, topical expert meetings are arranged as agreed by the Participants, acting in the Executive Committee.

The Operating Agent is assisted by an advisory Standing Committee of technical experts. The Committee held its 12th meeting on 2-3 July in Norwich, Vermont, USA. The meeting reviewed updates of documents in the series of Recommended Practices, suggested topics for expert meetings and discussed priorities for wind energy R&D and standards.

In Subtask A, a second edition of Vol 1 Power Performance Testing was issued during the report period. A second edition of Vol 6 Structural Safety is being considered. A list of the published documents is shown in Table 2. The reports are available on request from the national representatives in the Executive Committee (see Appendix 2).

Subtask B currently has three activities:

- Joint Action on Aerodynamics
- Joint Action on Fatigue
- Joint Action on Offshore WECS

A fourth Joint Action on Wind-Diesel Systems is being considered as a continuation of the work in Task VIII which is technically completed.

In the Joint Action on Aerodynamics, the fourth symposium was held on 19-20 November at the ENEA Casaccia Centre in Rome, Italy.
Proceedings of the third symposium held in November 1989 at Harwell, England were published during the year.

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

<table>
<thead>
<tr>
<th>Vol</th>
<th>Title</th>
<th>1st Ed</th>
<th>2nd Ed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power Performance Testing</td>
<td>1982</td>
<td>1990</td>
</tr>
<tr>
<td>2</td>
<td>Estimation of Cost of Energy from Wind Energy Conversion Systems</td>
<td>1983</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Fatigue Characteristics</td>
<td>1984</td>
<td>1989</td>
</tr>
<tr>
<td>5</td>
<td>Electromagnetic Interference (Preparatory Information)</td>
<td>1986</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Structural Safety (Preparatory Information)</td>
<td>1988</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Quality of Power. Single Grid-Connected WECS</td>
<td>1984</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Glossary of Terms</td>
<td>1987</td>
<td></td>
</tr>
</tbody>
</table>

In the Joint Action on Fatigue, a group of experts have agreed on a reference load spectrum for wind turbine blade fatigue testing. The spectrum is known as WISPER (Wind turbine load SPECTrum Reference).

The first meeting in the Joint Action on Offshore WECS took place on 26 January in London with participation from Denmark, Germany, Italy and Sweden. It was found that interest in offshore siting is increasing. Practical experience from the operation of offshore wind turbines is accumulating from Sweden and will be available from Denmark shortly.
The 19th topical Expert Meeting was held 3-4 May in London on Wind Turbine Control Systems - Strategy and Problems. Proceedings from the 18th meeting in November 1989 in Petten, the Netherlands on Noise Generating Mechanisms for Wind Turbines were published during the year. The cumulated list of expert meetings arranged under the IEA Wind Energy Agreements is shown in Appendix 1.

**Participating Organisations**

- **Canada**
  - Department of Energy, Mines and Resources
- **Denmark**
  - Department of Fluid Mechanics, Technical University of Denmark
- **Germany**
  - KFA Jülich
- **Italy**
  - ENEA
- **Norway**
  - Directorate of Energy
- **Netherlands**
  - ECN
- **Spain**
  - IER/CIEMAT
- **Sweden**
  - FFA
- **United Kingdom**
  - ETSU for the Department of Energy National Engineering Laboratory
- **United States**
  - Department of Energy

**Operating Agent**

Department of Fluid Mechanics of the Technical University of Denmark

**Technical Reports and Papers**

  - Published by the IEA R&D WECS Executive Committee

  - Published by the Energy Technology Support Unit, UK

- **Noise Generating Mechanisms for Wind Turbines**
  - Proceedings of the 18th Expert Meeting held 27-28 November 1989 in Petten, the Netherlands.
  - Published by the Research Centre Jülich GmbH, Germany
TASK XII  UNIVERSAL WIND TURBINE FOR EXPERIMENTS (UNIWEX)

UNIWEX is a computer-controlled, two-bladed experimental wind turbine of 16 m rotor diameter installed at the Ulrich Hütter Wind Test Field near Schnittingen, Germany (see Figures 1 and 2). The main goals of the project are the experimental study of aerodynamics, operational behaviour, load spectra and control strategies for different hub concepts, as well as the validation of computer codes.

So far, seven organisations from three countries are participating:

**Participating Organisations**

<table>
<thead>
<tr>
<th>Country</th>
<th>Organizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Kernforschungsanlage Jülich GmbH (KFA), Institute for Computer Applications (ICA), University of Stuttgart</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Netherlands Energy Research Foundation (ECN), Delft University of Technology (DUT), Stork Product Engineering (SPE)</td>
</tr>
<tr>
<td>Sweden</td>
<td>National Energy Administration Sweden (NE), The Aeronautical Research Institute of Sweden (FFA)</td>
</tr>
</tbody>
</table>

**Operating Agent**

Institute for Computer Applications (ICA), University of Stuttgart

Representatives of the participants met on the following occasions:

- four technical meetings (2 April, 11-12 July, 7 September in Stuttgart and on the testfield, 31 July in Bromma)
- a measurement campaign (19-24 November on the testfield)
- an Executive Committee meeting (5 September in Santiago de Compostela)
- ECWEC '90 (10-14 September in Madrid)

As a consequence of the technical meetings, the work plan was updated with respect to priorities in the technical topics and the time schedule. Progress reports were given at the two EC meetings. At the Fall meeting the time schedule was extended from 1 April to 31 December 1991.
The main technical activities in 1989 are listed below:

**At ICA/University of Stuttgart**

1. **Software Development and Numerical Simulation**
   - **Simulation software**
     - Software development
     - *Studies of unsteady aeroelastic effects of horizontal-axis wind turbines using the program system ARLIS with a new implemented vortex ring model (see Figure 3)*
     - *Description of the windfield for upwind rotors using the potential flow around a plane half-body and around an infinite cylinder*
     - *Installation and tests of ARLIS on the workstation STELLAR*
   - Software applications
     - *Applications of the aeroelastic program system ARLIS to one-, two- and three-bladed horizontal-axis wind turbines*
   - **Modelling of the modified UNIWEX wind turbine**
     - *Re-analysis of the finite element model of the nacelle (new cardan shaft and new supports of the gearbox and the generator, see Figures 3 and 5)*
     - *Structural re-modelling of the rotor blade using the shell-beam conversion package ATACYT and the new measured rotor blade geometry*
     - *Re-analysis of the whole UNIWEX wind turbine with the finite element method*
   - **Identification of the simulation model by comparison with measurements**
     - *Eigenfrequencies of the rotor blade*
     - *Eigenfrequencies of the whole wind turbine*
     - *Comparison of \( c_p - \lambda \) - curves calculated by different institutions*
   - **Post-processing and animation**
     - *Development of new plot software for evaluation of results*
- Implementation of newly developed processors in the FE-package ASKA for displaying of steady state and transient response results (see Figure 6)
- Development of special graphic software for computer animation on IRIS and STELLAR work stations
- Computer animation of eigen modes, steady state and transient response behaviour for beam, shell and volume structures

• Compilation of wind turbine data for the other participants

2 Development of hard- and software for testing purposes

- Implementation of a system for the control of the rotor speed by "generator" torque, the option for the control by blade pitch being maintained
- Construction of a mobile telescope meteorological mast for wind measurements at hub height
- Improvement of all control algorithms, including the simulation of the flexible hub (free flapping and teetered hub)
- Development of the complete software for for the processing and post-processing of the measured data
  - Working-up of the measured raw data to bulk data
  - Display of raw and worked-up data
  - Interactive frequency analysis
  - Interactive selection, display and output of specific values and mean values
  - Elaboration of $c_p$-lambda curves with different methods
  - Plotting and display possibilities for all post-processing results (see Figure 7)

3 Experiments

- Comprehensive calibration of all sensors
- Measurements of geometry and eigenfrequencies, partly under direct assistance of the other participants
- Runs for the verification of the computer models for the simulation of the hardware and the aerodynamic behaviour
- Runs with constant rotor speed controlled by
  - blade pitch
  - "generator" torque
- Runs with constant tip speed
- Runs with different yaw angle (relative to the wind direction) and constant yaw rates. The results are used for investigations of power control by yawing strategies.
- Runs at high angles of attack
- Runs with tilted power

As most of these experiments have been undertaken upon the wishes of the Dutch and Swedish partners, the respective measurement recordings have been worked-up and distributed among these participants.

**At ECN, the Netherlands**

1 Analysis of measurements
With the results of measurements of the UNIWEX now coming in, analysis of the measurement signals was taken up by the Dutch participants. Some anomalies were detected and discussed at a technical meeting with the Operating Agent. Most have now been explained or, in some cases, given rise to adjustments in the measurements, the sensors. A discrepancy between the plane blade moments and the axial torque signals is still of some concern. A number of measurements were performed with the explicit aim of system identification, for the Delft University of Technology.

2 Calibration
In order to obtain a better idea of system geometry, eigenfrequencies and expected error ranges, an extensive programme of calibration tests was conducted together with the Operating Agent in the week of 19-24 November. Part of the measurements must still be interpreted. One important discovery was a slight unbalance in the blades, which explains some of the measured phenomena.

3 Numerical simulation
A number of calculations were done with the system identification methods used by the DUT. The blade moment signals measured by the load cells seem to indicate that a system of relatively high order is needed for a good simulation. At ECN and SPE the simulation software was readied for the inclusion of the results of a wind
generator. This will give a much more realistic behaviour of the excitations with frequency of nP (1P being the rotational frequency), due to the "vortex licing" effect.

At FFA, Sweden

1 Analysis of measurements
Three magnetic tapes with measurements have been received containing data from runs with constant rpm, according to request made earlier by the Swedish participant. The evaluation of the data and the interpretation of the results are not yet finished.

2 Studies of control strategies
During a meeting at the test field on 7 September the possibilities of studies of control strategies were discussed. It was found that the present hardware for UNIWEX is not suitable for an extension of the original work plan in this direction, i.e. for research on control strategies involving for example variable rotor speed coupled with yawing or stalling.

3 Numerical simulation
The planned modelling of the modified UNIWEX turbine has not yet started. The numerical simulation program GAROS has nonetheless been updated and used during the year for stability studies on other wind turbines. Hence the capability of the software has been increased, allowing for a more sophisticated analysis of the UNIWEX turbine. An agreement on a joint paper to be presented at the wind energy conference in Amsterdam 1991 has been made. The paper concerns the numerical simulation of the UNIWEX turbine in two different computer codes, ARLIS and GAROS, and a comparison of the differences in the theoretical background for the codes.
Technical Data of the UNIWEX test wind turbine:

Rotor:
- Number of blades: 2
- Diameter: 16 m
- Speed: variable (rated 70 r.p.m.)
- Tip speed ratio: 12 (rated)
- Hub type: variable (fully articulated)

Blade:
- Length: 7.80 m
- Chord length: 0.15 m ... 0.70 m
- Airfoils: FX 77-W-343, FX 77-W-270, FX 77-W-151 A
- Material: Composites
- Mass: 106 kg netto, 137 kg with ballast in 22 chambers

Tower:
- Type: supported steel tube, yawing
- Hub height: 15 m
- Diameter: 0.82 m
- Foundation: I-Steel-rig, ballast

Generator, Gear:
- Hydraulic motor-generator: 45 kW
- Planetary step up gear: 1:40

Control:
(by means of computer controlled servo hydraulics)
- Blade pitch
- Generator torque
- Rotor yawing

Figure 1: General view, characteristics and technical data of the UNIWEX wind turbine
Figure 2: UNIWEX wind turbine in operating position with opened installation platform

Figure 3: New implemented vortex ring model for analysis of unsteady aeroelastic effects
Figure 4: General view of the UNIWEX-nacelle

Figure 5: 1st eigenmode of the UNIWEX-nacelle with stiff horizontal rotor ($f_1 = 4.53\text{ Hz}$)
Figure 6: Computer animation and displaying of steady state and transient response results
This plot shows results of a run with fixed hub and rotor speed control by rotor torque. The mobile anemometers were placed 19 m upwind the rotor plane with a lateral distance of 3.5 m and the anemometer on the hub at 7.5 m upwind the rotor plane. It can easily be seen, that it is important for a good interpretation of the measurement data to have more than one anemometer. The plot shows that the load peaks in flap direction (mainly coming from the tower shadow) increase with the rotor power (rotor moment).

Figure 7: Plot of measuring results
TASK XIII  COOPERATION IN THE DEVELOPMENT OF LARGE-SCALE WIND TURBINE SYSTEMS

At the fall meeting the Executive Committee adopted a new Annex XIII, effective 1 January 1991. The Annex incorporates the activities of the LS WECS Implementing Agreement which will be discontinued as of 31 December 1990 by decision of the LS WECS Executive Committee. The Annex will be in force for an initial period of three years.

The objective of the Task is to further the development of Large Wind Turbine Systems (LWTS) by means of cooperative action and exchange of information on the planning and execution of national LWTS research, development and demonstration programmes. An LWTS is defined as a megawatt-sized wind turbine or windfarm.

The Task will involve ten countries in a cost-shared arrangement, coordinated by the Solar Energy Research Institute (USA). Information systems will be established for the exchange of information on LWTS design, testing, performance and incidents/accidents. Annual reports of LWTS activities in the participating countries will be prepared.

Participants

Canada    Department of Energy, Mines and Resources
Denmark   Ministry of Energy
Germany   Forschungszentrum Jülich GmbH
Italy     Ente Nazionale per l'Energia Elettrica
Netherlands  Stichting Energieonderzoek Nederland
Norway    Directorate of Energy
Spain     Instituto de Energías Renovables
Sweden    National Energy Administration
United Kingdom Scottish Hydro-Electric plc
United States  Department of Energy

Operating Agent

Solar Energy Research Institute (USA)
PROPOSED NEW ACTION

Systems Interaction

In view of the CEC grid integration study and existing bilateral agreements, the proposal for an IEA study has been withdrawn.

Extended Wake Effects Study

The Participants of Task IX, which is being finally reported (see above), have recommended that further work be considered in the following areas:

- Local flow effects and atmospheric stability
- Overlapping wakes and rules for superposition
- Prediction of turbulence within windfarms
- Windfarm performance in hilly terrain
- Wake-induced blade loads and rotor fatigue within windfarms.

The UK Contracting Party will draft an Annex for consideration at the Spring 1991 meeting of the Executive Committee.

Effect of Environment on Wind Turbine Safety and Performance

A proposal was introduced by the German Contracting Party for a cooperative study of the effects of icing conditions on wind turbines. A workshop will be arranged on the generalised subject of environmental effects on wind turbine safety and performance.

Wind Energy Newsletter

At the Fall meeting the Executive Committee decided to investigate the possibility of issuing a Newsletter twice a year. The Newsletter should inform the wind energy community of IEA wind energy activities, including the status of national wind energy programmes, Task progress reports, summary LWTS performance data and incident/accident reports, calendar of meetings and lists of technical reports and publications. A test issue will be prepared for consideration at the Spring 1991 meeting of the Executive Committee.
THE EXECUTIVE COMMITTEE

The 25th meeting of the Executive Committee took place on 19 April 1990 at the Sin-Osaka City Plaza Hotel, Osaka, Japan. The 26th meeting was held on 5 September 1990 at the Hotel De Los Reyes Catolicos, Santiago de Compostela, Spain. At the meetings the EC reviewed the progress of the ongoing Tasks and discussed proposals for future work.

Mr H J M Beurskens (the Netherlands) and Dr P Surman (UK) served as Chairman and Vice Chairman during the year. At the Fall meeting Mr Beurskens and Dr Surman were re-elected Chairman and Vice Chairman for 1991.

Some changes in membership were announced during the year. An updated list of EC Members and Alternate Members is attached as Appendix 2.

Following the completion of Tasks VIII and IX, the Swiss and Belgian Contracting Parties are withdrawing from the Implementing Agreement, effective 31 December 1990. In consequence of the merger of the R&D and LS Agreements, ENEL of Italy and Scottish Hydro-Electric plc are entering the R&D Agreement as of 1 January 1991.

At the Fall meeting the Executive Committees of the R&D and LS Agreements unanimously adopted a Resolution to the effect that the LS Agreement is terminated by 31 December 1990, that the LS activities are incorporated as Annex XIII of the R&D Agreement as of 1 January 1991.

A Conformed Copy of the Implementing Agreement including Annexes, taking into account changes and amendments, is being prepared by the IEA Secretariat.
## IEA Wind Energy Expert Meetings

<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Date</th>
<th>Venue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Seminar on Structural Dynamics</td>
<td>12 Oct 77</td>
<td>Munich, Germany</td>
</tr>
<tr>
<td>2</td>
<td>Control of LS WECS and Adaption of Wind Electricity to the Network</td>
<td>4 Apr 79</td>
<td>Copenhagen, Denmark</td>
</tr>
<tr>
<td>3</td>
<td>Data Acquisition and Analysis for LS WECS</td>
<td>26-27 Sep 79</td>
<td>Blowing Rock, North Carolina, USA</td>
</tr>
<tr>
<td>4</td>
<td>Rotor Blade Technology with Special Respect to Fatigue Design</td>
<td>21-22 Apr 80</td>
<td>Stockholm, Sweden</td>
</tr>
<tr>
<td>5</td>
<td>Environmental and Safety Aspects of the Present LS WECS</td>
<td>25-26 Sep 80</td>
<td>Munich, Germany</td>
</tr>
<tr>
<td>6</td>
<td>Reliability and Maintenance Problems of LS WECS</td>
<td>29-30 Apr 81</td>
<td>Aalborg, Denmark</td>
</tr>
<tr>
<td>7</td>
<td>Costing of Wind Turbines</td>
<td>18-19 Nov 81</td>
<td>Copenhagen, Denmark</td>
</tr>
<tr>
<td>8</td>
<td>Safety Assurance and Quality Control of LS WECS during Assembly, Erection and Acceptance Testing</td>
<td>26-27 May 82</td>
<td>Stockholm, Sweden</td>
</tr>
<tr>
<td>9</td>
<td>Structural Design Criteria for LS WECS</td>
<td>7-8 March 83</td>
<td>Greenford, UK</td>
</tr>
<tr>
<td>10</td>
<td>Utility and Operational Experience from Major Wind Installations</td>
<td>12-14 Oct 83</td>
<td>Palo Alto, California</td>
</tr>
<tr>
<td>11</td>
<td>General Environmental Aspects</td>
<td>7-9 May 84</td>
<td>Munich, Germany</td>
</tr>
<tr>
<td>12</td>
<td>Aerodynamic Calculation Methods for WECS</td>
<td>29-30 Oct 84</td>
<td>Copenhagen, Denmark</td>
</tr>
<tr>
<td>13</td>
<td>Economic Aspects of Wind Turbines</td>
<td>30-31 May 85</td>
<td>Petten, the Netherlands</td>
</tr>
<tr>
<td>14</td>
<td>Modelling of Atmospheric Turbulence for Use in WECS Rotor Loading Calculations</td>
<td>4-5 Dec 85</td>
<td>Stockholm, Sweden</td>
</tr>
<tr>
<td>15</td>
<td>General Planning and Environmental Issues of LS WECS Installations</td>
<td>2 Dec 87</td>
<td>Hamburg, Germany</td>
</tr>
</tbody>
</table>
### IEA Wind Energy Expert Meetings (continued)

<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Date</th>
<th>Venue</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Requirements for Safety Systems for LS WECS</td>
<td>17-18 Oct 88</td>
<td>Rome, Italy</td>
</tr>
<tr>
<td>17</td>
<td>Integrating Wind Turbines into Utility Power Systems</td>
<td>11-12 Apr 89</td>
<td>Herndon, Virginia USA</td>
</tr>
<tr>
<td>18</td>
<td>Noise Generating Mechanisms for Wind Turbines</td>
<td>27-28 Nov 89</td>
<td>Petten, the Netherlands</td>
</tr>
</tbody>
</table>
IEA R&D WECS EXECUTIVE COMMITTEE ADDRESS LIST

(M = Member, A = Alternate Member)

CHAIRMAN  Mr H J M BEURSKENS  Tel 2246 4184
ECN Research Centre  Tlx 572 11 REACP NL
P.O. Box 1  Fax 2246 3214
1755 ZG PETTEN

SECRETARY  Mr B PERSHAGEN  Tel 155 848 78
NUWEC energikonsult  Tlx 64013 STUDS S
Svanvågen 46  Fax 155 872 11
S-611 62 NYKÖPING

AUSTRIA  (M)  Prof Dr H DETTER  Tel 222 657 6410
Technische Universität Wien  Tlx 131 000 TVFAW
Institut für Strömungslehre  und Wärmeübertragung
Wiedner Hauptstrasse 7
A-1040 WIEN

(A)  Mr R HERDIN
   - same address -

BELGIUM  (M)  Prof J VAN LEUVEN  Tel 3 218 0756
University of Antwerp  Tlx RUCABI 33362
State University Centre  Fax 3 218 0217
Department of Energy Technology
Middelheimaan 1
B-2020 ANTWERP

CANADA  (M)  Vacant  Tel 613 993 9127

(A)  Mr R S RANGI  Tlx 053 3386
National Aeronautical Establishment
National Research Council Canada
OTTAWA K1A OR6

Fax 613 957 4309

DENMARK  (M)  Mr B MARIBO PEDERSEN  Tel 2 884 622
Technical University of Denmark  Tlx 375 29 DTH DIA
Lundtoftevej 100  Fax 2 882 239
DK-2800 LYNGBY

(A)  Mr B RASMUSSEN  Tel 45 556 2983
Overgade 14  DK-7000 FREDERICIA
GERMANY (M) Dr R WINDHEIM_
Porschungszentrum Jülich GmbH
Postfach 1913
D-5170 JÜLICH

(A) Mr G JOSWIG
- same address -

ITALY (M) Dr G GAUDIOSI
ENEA C.R.E. Casaccia
Casella Postale n. 2400
I-00100 ROMA A.D.

(A) Dr E SESTO
ENEL CREL
Via A Volta 1
I-20093 COLOGNO MONZÈSE MI

JAPAN (M) Mr KAWAMO
Sunshine Project H.Q.
AISI, MITI
Kasumigaseki, 1-3-1
Chiyoda-ku
TOKYO

(A) Dr H MATSUMIYA
Mechanical Engineering Laboratory
MITI
1-2 Namiki
TSUKUBA 305

NETHERLANDS (M) Mr H G DOUMA
NOVEM
P.O. Box 8242
3503 RE UTRECHT

(A) Vacant

NEW ZEALAND (M) Mr M A GRANT
New Zealand Meteorological Service
P.O. Box 722
WELLINGTON 1

(A) Mr J RICHARDSON
Ministry of Energy
P.O. Box 2337
WELLINGTON
NORWAY (M)  Mr E SOLBERG  
Norwegian Water Resources  
and Energy Administration  
Postbox 5091 Maj  
N-0301 OSLO 3  
Tel  2469 800  
Tlx  793 97 NVEO N  
(A)  Mr C GRORUD  
- same address -

SPAIN (M)  Mr E SORIA  
IER/CIEMAT  
Avda Complutense 22  
28040 MADRID  
Tel  1449 6200  
Tlx  235 55 JUVIG E  
Fax  1346 6005  
(A)  Mr F AVIA  
- same address -

SWEDEN (M)  Mr S ENGSTRÖM  
National Energy Administration  
S-117 87 STOCKHOLM  
Tel  8744 9730  
Tlx  12 870 Energy S  
Fax  8744 0980  
(A)  Mr O SANDBERG  
- same address -

SWITZERLAND  Dr L DUBAL  
Federal Office of Energy  
CH-3003 BERNE  
Tel  31615 644  
Tlx  911 570 bew ch  
Fax  31615 656

UNITED KINGDOM (M)  Dr P L SURMAN  
National Power  
Sudbury House  
15 Newgate Street  
LONDON EC1A 7AU  
Tel  16345 5200  
Tlx  883 141  
Fax  1634 5811

UNITED STATES (M)  Mr R L LOOSE  
Wind/Ocean Technologies Division  
United States Department of Energy  
1000 Independent Ave., S.W.  
WASHINGTON D C  20585  
Tel  202 586 1776  
Tlx  710 822 0176  
Fax  202 586 8134  
(A)  Mr D F ANCONA  
- same address -

IEA  Dr R SCHNEIDER  
International Energy Agency  
2, rue André Pascal  
F-75775 PARIS Cedex 16  
Tel  14524 9975  
Tlx  630 190 ENERG A  
Fax  14524 9988
CUMULATED LIST OF PUBLICATIONS ISSUED BY THE
NATIONAL ENERGY ADMINISTRATION SWEDEN

1984:R1  IEA Forestry Energy
          Annual Report 1983

1985:R1  IEA Forestry Energy Project
          A study of Biomass Liquefaction test Facility

1985:R2  IEA Forestry Energy
          Annual Report 1984

1985:R3  IEA Peat Production and Utilization Project
          Annual Report 1984

1985:R4  Demand for Commercial Energy in Developing Countries
          Phil O’Keefe, Beier Institute

1985:R5  Kommunal energiplanering
          Fem uppsatser

1986:R1  IEA Forestry Energy
          Annual Report 1985

1986:R2  Låga oljepriser?
          Effekter på svensk energiförsörjning

1986:R3  Elmarknaden 1985
          - En vändpunkt?

1986:R4  Förutsättningar för minskning av svavelhalten i oljeprodukter i
          Sverige
          Underlagsmaterial till Statens energiverks utredning om svavelhalten
          i oljeprodukter.
          Nils Elam, Atrax Energi AB

1986:R5  Reduction of sulphur contents in gasoil and heavy fuel oil
          Background material for the National Energy Administration’s study
          of the sulphur content in oil products.
          Prepared for the National Energy Administration by Purvin & Gertz,
          Inc.

1986:R6  Avsvalning av petroleumprodukter
          Tekn. lic. Arne Bergholm.
          Framställning av lågsvavliga eldningsoljor.
          Sveriges Tekniska Attachéer, Washington.
          Underlagsmaterial till Statens energiverks utredning om svavelhalten
          i oljeprodukter.
<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986:R8</td>
<td>Nedsättning av energiskatterna inom industrin</td>
</tr>
<tr>
<td>1986:R9</td>
<td>IEA District Heating Small-scale Combined Heat and Power Plants</td>
</tr>
<tr>
<td>1986:R10</td>
<td>IEA District Heating Cost Analysis of District Heating Networks</td>
</tr>
<tr>
<td>1986:R11</td>
<td>Efter Tjernobyl Elförbrukning för uppvärmning övrigsektorn</td>
</tr>
<tr>
<td></td>
<td>Eje Sandberg, Rolf Westerlund, K-Konsult</td>
</tr>
<tr>
<td>1986:R12</td>
<td>Efter Tjernobyl Ny elproduktion vid forcerad kärnkraftsavveckling, PFBC</td>
</tr>
<tr>
<td></td>
<td>ÅF-Energikonsult, Stockholm</td>
</tr>
<tr>
<td>1986:R13</td>
<td>Efter Tjernobyl Förgasning av inhemska bränslen för elproduktion i kraftvärmeverk</td>
</tr>
<tr>
<td></td>
<td>Jan Fors, Leif Magnusson, Teknikgruppen AB</td>
</tr>
<tr>
<td>1986:R14</td>
<td>Efter Tjernobyl Försörjningsmöjligheter för extremt lågsvålig olja till kraftverken i</td>
</tr>
<tr>
<td></td>
<td>Stenungsund och Karlshamn</td>
</tr>
<tr>
<td></td>
<td>Atrax Energi AB</td>
</tr>
<tr>
<td>1986:R15</td>
<td>Efter Tjernobyl Naturgasen - ett alternativ</td>
</tr>
<tr>
<td></td>
<td>Swedegas AB</td>
</tr>
<tr>
<td></td>
<td>Svensk elkraft från norsk naturgas</td>
</tr>
<tr>
<td></td>
<td>Norconsult och PPS AB</td>
</tr>
<tr>
<td>1986:R16</td>
<td>Efter Tjernobyl Ut ur återvändsgränderna</td>
</tr>
<tr>
<td></td>
<td>Olof Eriksson, Arne Mogren</td>
</tr>
<tr>
<td>1986:R17</td>
<td>After Chernobyl The Effect of a Phase Out Nuclear Power in OECD Countries on</td>
</tr>
<tr>
<td></td>
<td>Demand for Fossil Fuels and on Sulphur Precipitation in Sweden</td>
</tr>
<tr>
<td></td>
<td>Metra Consulting Group Limited</td>
</tr>
<tr>
<td>1986:R18</td>
<td>Efter Tjernobyl Katastrofisker i energisystemet</td>
</tr>
<tr>
<td></td>
<td>Lars Kristofersson, Björn Kjellström, Per Johan Svenningsson</td>
</tr>
<tr>
<td>1986:R19</td>
<td>Efter Tjernobyl Energimarknader och prisrelationer</td>
</tr>
<tr>
<td></td>
<td>Per Anders Bergendahl</td>
</tr>
</tbody>
</table>
1986:R20  Efter Tjernobyl  
Industrins elanvändning  
AF-Energikonsult, Stockholm

1986:R21  Efter Tjernobyl  
Analys av skogssektorn vid förändrade energipriser  
Göran Lönner, Sten Nilsson, Hans-Olof Nordvall

1986:R22  Efter Tjernobyl  
Ny elproduktion vid forcerad kärnkraftsavveckling  
AF-Energikonsult, Stockholm

1986:R23  Efter Tjernobyl  
Arbetsmiljö vid utvinning, beredning och transport av vissa bränslen för kraft- och värme中央er  
Yngve Hagerman

1987:R1  IEA Bioenergy  
Annual Report 1986

1987:R2  IEA Forestry Energy  
Summary Report for period 1978-86

1987:R3  Värmepumpar  
Aktuella förändringar och framtidsutsikter

1987:R4  IEA District Heating  
Temperature levels in district and local heating systems in Sweden

1987:R5  El- och värmeproduktion med naturgas

1987:R6  IEA District Heating  
Technical and economic assessment of new distribution technology

1988:R1  IEA Bioenergy  
Annual Report 1987

1988:R2  IEA R&D Wind Energy  
Annual Report 1987

1988:R3  IEA Large-Scale Wind Energy  
Annual Report 1987

1988:R4  Moms på energi  
Konsekvenser för svensk ekonomi och industri

1988:R5  Förändrad energibeskattning  
Tre rapporter
<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988:R6</td>
<td>Import av trädbränslen till Sverige</td>
</tr>
<tr>
<td></td>
<td>Potential på kort och lång sikt</td>
</tr>
<tr>
<td>1988:R7</td>
<td>Oljeberoende</td>
</tr>
<tr>
<td></td>
<td>Och alllokeringspolitik</td>
</tr>
<tr>
<td>1988:R8</td>
<td>Effekter på hushållens konsumtionsstandard av förändrad beskattnings</td>
</tr>
<tr>
<td></td>
<td>av energi</td>
</tr>
<tr>
<td></td>
<td>Effekter baserade på förslag om övergång till momsbeskattnings av</td>
</tr>
<tr>
<td></td>
<td>energi</td>
</tr>
<tr>
<td>1988:R9</td>
<td>Mål och medel</td>
</tr>
<tr>
<td></td>
<td>Vid beskattnings av energi</td>
</tr>
<tr>
<td>1988:R10</td>
<td>Beskattnings av energi i utlandet</td>
</tr>
<tr>
<td>1988:R11</td>
<td>IEA-PFBC Workshop 1986</td>
</tr>
<tr>
<td></td>
<td>PFBC-Facilities Status 1987</td>
</tr>
<tr>
<td>1988:R12</td>
<td>IEA District Heating Small Heat Meters</td>
</tr>
<tr>
<td>1988:R13</td>
<td>IEA District Heating</td>
</tr>
<tr>
<td></td>
<td>State-of-the-art reiew of coal combustors for small district heating</td>
</tr>
<tr>
<td></td>
<td>plants</td>
</tr>
<tr>
<td>1988:R14</td>
<td>Utvärdering av det svenska oljeprospekteringsstödet</td>
</tr>
<tr>
<td>1988:R15</td>
<td>Elmarknadsrapport 1988</td>
</tr>
<tr>
<td>1988:R16</td>
<td>IEA District Heating</td>
</tr>
<tr>
<td></td>
<td>Summary of Research Activities 1983-1987</td>
</tr>
<tr>
<td>1989:R1</td>
<td>IEA R&amp;D Wind Report</td>
</tr>
<tr>
<td></td>
<td>Annual Report 1988</td>
</tr>
<tr>
<td>1989:R2</td>
<td>Energi ur industriavfall</td>
</tr>
<tr>
<td></td>
<td>En fallstudie över hinder och drivkrafter</td>
</tr>
<tr>
<td>1989:R3</td>
<td>IEA Bioenergy</td>
</tr>
<tr>
<td></td>
<td>Annual Report 1988</td>
</tr>
<tr>
<td>1989:R4</td>
<td>IEA Large-Scale Wind Energy</td>
</tr>
<tr>
<td></td>
<td>Annual Report 1988</td>
</tr>
<tr>
<td>1989:R5</td>
<td>Petroleumbränslen</td>
</tr>
<tr>
<td></td>
<td>Kvalitetsutveckling från 1980 och framåt</td>
</tr>
<tr>
<td>1989:R6</td>
<td>Koldioxid från fossil förbränning</td>
</tr>
<tr>
<td></td>
<td>Möjligheter att reducera och deponera koldioxidinen</td>
</tr>
</tbody>
</table>
| 1989:R7 | Värme-produktion med gasol  
Föreskrifter och säkerhetsfrågor  
Teknik, Ekonomi, Miljökonsekvenser |
| 1989:R8 | Naturgasmarknaden i Västeuropa  
Historisk bakgrund och framtidsbedömningar |
| 1989:R9 | Ett miljöanpassat energisystem  
Bilder av energipolitikens framtida omvärld |
| 1989:R10 | Ett miljöanpassat energisystem  
Styrmedel för minskning av CO₂ under svensk kontroll |
| 1989:R11 | Ett miljöanpassat energisystem  
Miljöscenarier för torvanvändning fram till år 2015 |
| 1989:R12 | Ett miljöanpassat energisystem  
Miljöscenarier för energi ur avfall fram till år 2015 |
| 1989:R13 | Ett miljöanpassat energisystem  
Produktion och utbud av trädbränslen från sågverk och skivindustri i framtiden |
| 1989:R14 | Ett miljöanpassat energisystem  
Arbetsmiljö/energi |
| 1989:R15 | Ett miljöanpassat energisystem  
Energiskog, energigrödor och halm |
| 1989:R16 | Ett miljöanpassat energisystem  
Energin, makten och framtiden |
| 1989:R17 | Ett miljöanpassat energisystem  
Regionala bioenergibalanser |
| 1989:R18 | Ett miljöanpassat energisystem  
Konkurrenssituationen för kraftvärme och värmpumpar |
| 1989:R19 | Energy and Environmental  
The importance of greenhouse gases other than carbondioxide and other possible differences between various fuels |
| 1989:R20 | Energy and Environmental  
Methane losses from natural gas utilisation |
| 1989:R21 | Ett miljöanpassat energisystem  
Massa- och pappersindustrin  
Produktionsteknik och energibalanser |
<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
</tr>
</thead>
</table>
| 1989:R22 | Ett miljöanpassat energisystem  
Framtida energianvändning i bostäder och lokaler |
| 1989:R23 | Energy and Environmental  
East-West Cooperation in the Environment in Europe-Problems  
Strategies Perspektives |
| 1989:R24 | Ett miljöanpassat energisystem  
Småskalig förbrännning |
| 1989:R25 | Ett miljöanpassat energisystem  
Restprodukthantering |
| 1989:R26 | Ett miljöanpassat energisystem  
Kostnader och tillgänglighet för avveckling på lång sikt |
| 1989:R27 | Ett miljöanpassat energisystem  
Rökgaskondensering |
| 1990:R1 | IEA R&W Wind Report  
Annual Report 1989 |
| 1990:R2 | IEA Large-Scale Wind Energy  
Annual Report 1989 |
| 1990:R3 | IEA Bioenergy  
Annual Report 1989 |
| 1990:R4 | Erfarenheter från vindkraftsverken vid Maglarp och Näsudden |
| 1990:R5 | Kommunal energiberedskap  
Sammanfattnings av projektet Värmeförsörjning i kristid |
| 1990:R6 | Kväveoxider från transportsektorn |
| 1990:R7 | Om elsparandets samhällsekonominiska intäkter och kostnader |
| 1990:R8 | Elsparpotential till mitten av 1990-talet för offentlig förvaltning - lokaler |
| 1990:R9 | Estlands energi och miljö - en introduktion |
| 1990:R10 | Förutsättningar för naturgasintroduktion |
| 1990:R11 | Avvecklingen av två kärnkraftsreaktorer - kostnader och miljökonsekvenser |
| 1990:R12 | Natural Gas  
Distribution Industry Structure and Regulation |
1990:R13 De internationella bränslemarknadernas framtida utveckling Utblick år 1990

1990:R14 Energy and environment in Estonia - an introduction
IEA R&D Wind Energy

ANNUAL REPORT 1990

Published by
National Energy Administration

Mailing Address: S-117 87 STOCKHOLM, Sweden
Street Address: 30 Liljeholmsvägen, Stockholm
Telephone: +46 8-744 95 00
Telegram: Energyadmin
Telex: 128 70 ENERGY S
Telefax: +46 8-744 09 80

1991: R1
Statens energiverk