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Systems Analysis Department Annual Progress Report 1986

Edited by P.E. Grohnheit, H. Larsen, N.K. Vestergaard

Risø National Laboratory, DK-4000 Roskilde, Denmark
February 1987

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SYSTEMS ANALYSIS DEPARTMENT
Annual Progress Report 1986

Edited by
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Abstract. The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1986. The activities may be classified as energy systems analysis and risk and reliability analysis. The report includes a list of staff members.

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1. INTRODUCTION

The activities of the Systems Analysis Department in 1986 covered subjects such as development of risk and reliability models, and energy-economy models. A number of projects have been carried out dealing with risk assessment, energy planning and technology assessment. The research and development activities of the department are undertaken by the Energy Systems Group (ESG), and the Risk Analysis Group (RAG).

The various tasks undertaken are carried out either as basic R&D studies or under contract with different organisations in Denmark and abroad, or as consultants for industry. The majority of the studies undertaken by the department involves a close collaboration with Danish and foreign companies, consulting firms, ministries and international organisations, such as the Danish Ministry of Energy, the Danish Energy Agency, the National Agency of Environmental Protection, the Nordic Council of Ministers and the Commission of the European Communities.

The research and development activities in 1986 involved three postgraduate research projects: One ongoing project concerns energy planning and project assessment in developing countries. Another deals with unwanted chemical reactions in the chemical process industries. Finally, a project concerning the development of an energy rationing model for acute energy shortages has been completed.

The research and development activities of the Energy Systems Group have included work in connection with the energy-modelling programme of the Commission of the European Communities dealing with a macrosectoral model and a European version of the Danish Energy System model. Work has continued on the incorporation of uncertainties in the economic calculations for energy technologies. The Danish Energy Systems model DES, and the simulation model for combined collective energy systems are continuously being modified and improved. Work has been initiated concerning the development of technical and economic models in the oil and gas area to be used in connection with field developments in the North Sea. Finally, models have been developed and validated for developing countries.

The Energy Systems Group has been involved in Danish energy planning for many years. In 1986 this has involved preliminary work for a new Energy plan for Denmark, preparation of Energy Review 1986, running the DES-model, electricity demand forecasting, and participation in a number of working groups. A major study for the Ministry of Energy on the development of a technical-economic model for energy consumption by industry has been completed. The activities concerning wind energy have been continued. Finally, a new project dealing with absorption cooling has been initiated.

The research and development activities of the Risk Analysis Group have included a number of projects dealing with the development of tools and methods to be used in connection with risk analysis. Projects have been undertaken concerning risk management and the group has participated in three European benchmark exercises, concerning common cause failures, structural reliability, and human factors. Work has been carried out concerning improvement and updating of the RIKKE-package, which is an automatic fault-tree construction program, and work has been initiated for the development of a new improved version in collaboration with JRC-Ispra. Further, work has continued on the development of a consequence management program. Finally, work has continued on risk analysis within the research programme of the Nordic Liaison Committee for Atomic Energy.

A number of projects dealing with safety analyses of offshore oil and gas production installations have been carried out for Danish and foreign companies. Risk assessment studies have been carried out for a number of chemical industries in Denmark. The group also participated in a study dealing with tanker and pipeline accidents in Thai Waters. Finally, a study on the reliability of windmills has been initiated.

In conjunction with the modelling activities of the department an International Conference on Models and Uncertainty in the Energy Sector was organized. The conference was sponsored by the Nordic Council of Ministers, and took place at Risø 11-12 February 1986.

During the year four guest researchers have visited the department for one month or more. The guest researchers came from the Electric Power Research Institute of Mexico, Department of Energy, Lusaka, Zambia, University of Bradford, U.K., and University of Essen, Germany. Members of the department have participated in and presented papers at various international conferences.

2. RISK AND RELIABILITY MODELS

An important part of the work in the Risk Analysis Group is concerned with development of methods and tools for risk and reliability analysis. Probabilistic risk assessment, emergency control and human failures are among the subjects dealt with.

In collaboration with JRC-Ispra development of a new version of the RIKKE-package was started.

The general structure of the new consequence management programme was defined and a Ph.D. study within the area was initiated.

2.1. Risk management

The aim of safety improvements are to prevent or reduce material losses as well as damages to human life, health, and environment. Risk managers therefore have to evaluate:

- the risk
- the values at risk
- the cost of risk reduction.

The risk analysis group has started a review of the problem area "risk management" to select subareas suitable for further work.

A risk analysis is often carried out as a once-for-all study for design purpose or approval by authorities. Higher returns from the cost of a risk analysis can be obtained if the analysis is continued by the organization operating the study object.

Tools for continuous risk management could handle on-line risk analysis, and the economy of risk. This may involve a review of standard analyses, simple handrules for risk assessment involving several types of risk, and suitable expert systems and data banks.

The economics of risk management is developed in a few particular areas, e.g. design of traffic systems, where monetary equivalent values of human lives are utilized for comparing different solutions. In such cases it is feasible to relate the cost of risk reduction to the saved lives. The economics of rare accidents like the Chernobyl accident this year is more difficult to represent in a form suitable for every day risk management. The problem is stochastic, and the cost of disaster can be represented in only a very rough manner. Even then, society makes a choice where the inconvenience and costs of safety are outweighed against saved lives and losses avoided.

Like public safety decisions any risk manager's choice is mixed up of knowledge, feelings and politics, but the rational element may have a greater influence, when fast and reliable methods are available for the daily work process.

A group under The Danish Academy of Technical Sciences works on some of the problems described above. Two members of the Risk Analysis Group participate in this work.

2.2. European Reliability Benchmark Exercises

Within the European Community a number of Reliability Benchmark Exercises (RBE) have been initiated with the purpose of comparing and improving methods and tools for system reliability analysis.

2.2.1. Common cause failures

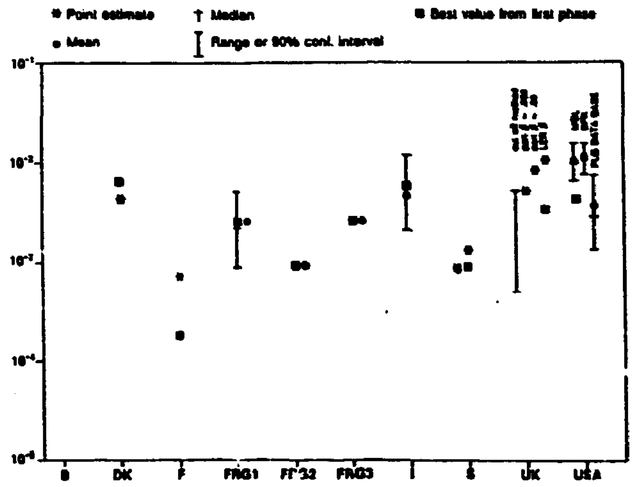
The Common Cause Failure Realibility Benchmark Exercise (CCF-RBE) was finished in 1986, and the final report will be published primo 1987.

The last phase of the analysis was completed in 1986. It comprised a part of the emergency feed water system in the Grohnde PWR power plant (West Germany) - the four x 100% redundant emergency feed water subsystems.

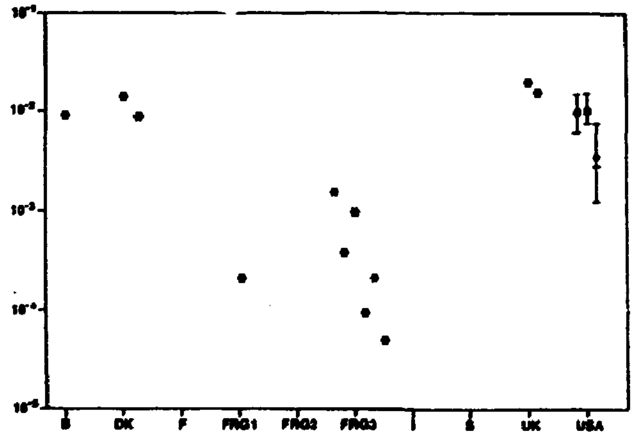
Risø used two different parametric models for the common cause failures, BFR - the binomial failure rate model - and MGL - the multiple Greek letter model. Risø used three different methods for calculating the influence upon the system unavailability, applying Risø's MOCARE and FAUNET computer programs. All Risø's results were acceptable; only one, based upon evaluation of the individual cutsets, gave an approximately 40% overestimate due to CCF's influencing more than one cutset.

The result of the second phase of the CCF-RBE is presented in Fig. 2.1, which shows the unavailability of the system, including CCFs using different data. According to Risø's calculations, the unavailability excluding CCFs is of the order 10^{-5}. The figure at the top is based upon the participant's own data and the centre figure on each participants own MGL parameters estimated on the basis of a common set of components failure event reports. The bottom figure is based upon common data.

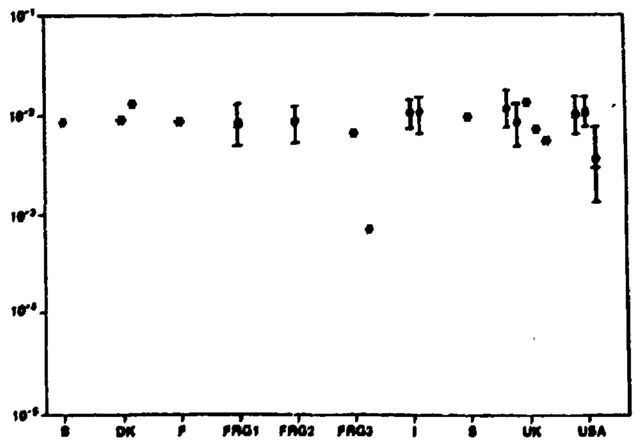
As can be seen from Fig. 2.1 a considerable spread on the result arises from differences in the data used and also from variations in the estimation of data from the component failure event reports. The calculational methods in themselves do not contribute significantly to the uncertainty of the result, however.



Phase II results (participants own data)



Results of quantification using estimated MGL parameters



Phase II results (data provided by PLG)

Figure 2.1. Results of the CCF-RBE for different sets of data.

In agreement with Fig. 2.1 there was a general consensus among the participants that the unavailability of the system analysed is caused namely by CCFs.

A series of important lessons learned will be presented in the final report concerning both the qualitative and quantitative part of the analysis. The CCF-RBE emphasized the importance of a systematic and well-structured qualitative analysis.

2.2.2. Human factors

The collaboration on benchmark exercises was continued in the Human Factors Reliability Benchmark Exercise (HF-RBE).

In total, nine teams from Belgium, Denmark, France, Germany, Italy, Netherlands, Sweden, UK and USA participate in the exercise. A decision will soon be made as to whether further teams will join the exercise. The teams from the EC countries participate under the cost-shared action programme of the Commission of the European Communities.

The exercise was started ultimo 1986 and is planned to be finished ultimo 1987. The exercise concerns human errors during testing and operation of the emergency feed-water system in the Grohnde PWR power plant, the same system as the one analysed in the CCF-RBE. Two different studies will be performed, one on a routine functional test and one on an operational transient.

Three different routine test procedures were studied:

- Test of the cut-in signal from the reactor protection system.
- Test of the cut-off signal from the reactor protection system.
- The minimum flow test of the redundant emergency feed water sub system.

Three different problems related to the test procedures were studied:

- Assessment of the unavailability of the system caused by human errors during the tests assuming a perfect system before the test.
- Assessment of the probability that a failure present in the emergency feed system will not be revealed by the test.
- Assessment of the likelihood of initiating an operational transient during the tests.

The qualitative part of the analysis comprised a task analysis, in which a list of all human actions performed was made, and in which the potential human errors were identified. Further, the resulting individual component failures contributing to the three different system failure conditions studied were identified.

The assessment of the probabilities of the human errors identified was done by two different methods. One of these is the method of Alan D. Swain and the other a special application of the Human Cognitive Reliability model. The two gave results that in most cases agreed fairly well.

2.2.3. Structural reliability benchmark exercise

A European benchmark exercise on structural integrity was started as a cost-shared action program. JRC-Ispra acts as coordinator, and the four participants are Framatome, France, Fraunhofer Institut, Darmstadt, FRG, The University of Karlsruhe, FRG, and Risø.

The object of the benchmark exercise is a 1/5-scale vessel located at Ispra. This vessel contains some artificial and some real defects. The vessel was subjected to pressure cycles and inspected by ultrasonics by 3 different teams. Furthermore, the material properties i.e. yield strength, fracture toughness and crack growth caracteristics were tested on several speciments.

The teams are supposed to set-up probabilistic models for the crack growth and subsequent failure of the vessel. This involves probability distribution functions for the material properties, of location and size defects and stresses. Finally, the predictions on the location of leaks and number of cycles will be compared with the experiment.

Crack growth experiments on the vessel material were performed by JRC-Ispra and reported as tables showing the crack lengths and number of cycles. A statistical analysis of the data and critical review of fatique crack growth models indicate that the crack growth can be modelled by a general continuous Markov process.

2.3. Computer-aided risk analysis

During the past decade Risø has developed a computer code for fault-tree construction, handling and unavailibility calculations. During the last years this program, called RIKKE, has been in commercial use in a number of European countries.

From the experience with this code and discussions with the constructor of another European fault-tree code, it was decided to start a new development project. The aim of this project will be to build up a new second generation system, which should be able to produce fault-trees on both detail and unit level.

The project was started in the autumn of 1986 and is a collaborative one which includes the Joint Research Centre Ispra. It is planned to last three years.

The code will be developed for an IBM/PC-AT with a UNIX (system V) operating system. The planned structure of the program is shown in Fig. 2.2.

2.4. Consequence management models

Major accidents in the industry almost exclusively involve the release of dangerous substances to the surroundings. To estimate the release rate the behaviour of the partially damaged process system must be investigated, and to evaluate the environmental impact the effects of fire, explosion and toxic release must be assessed.

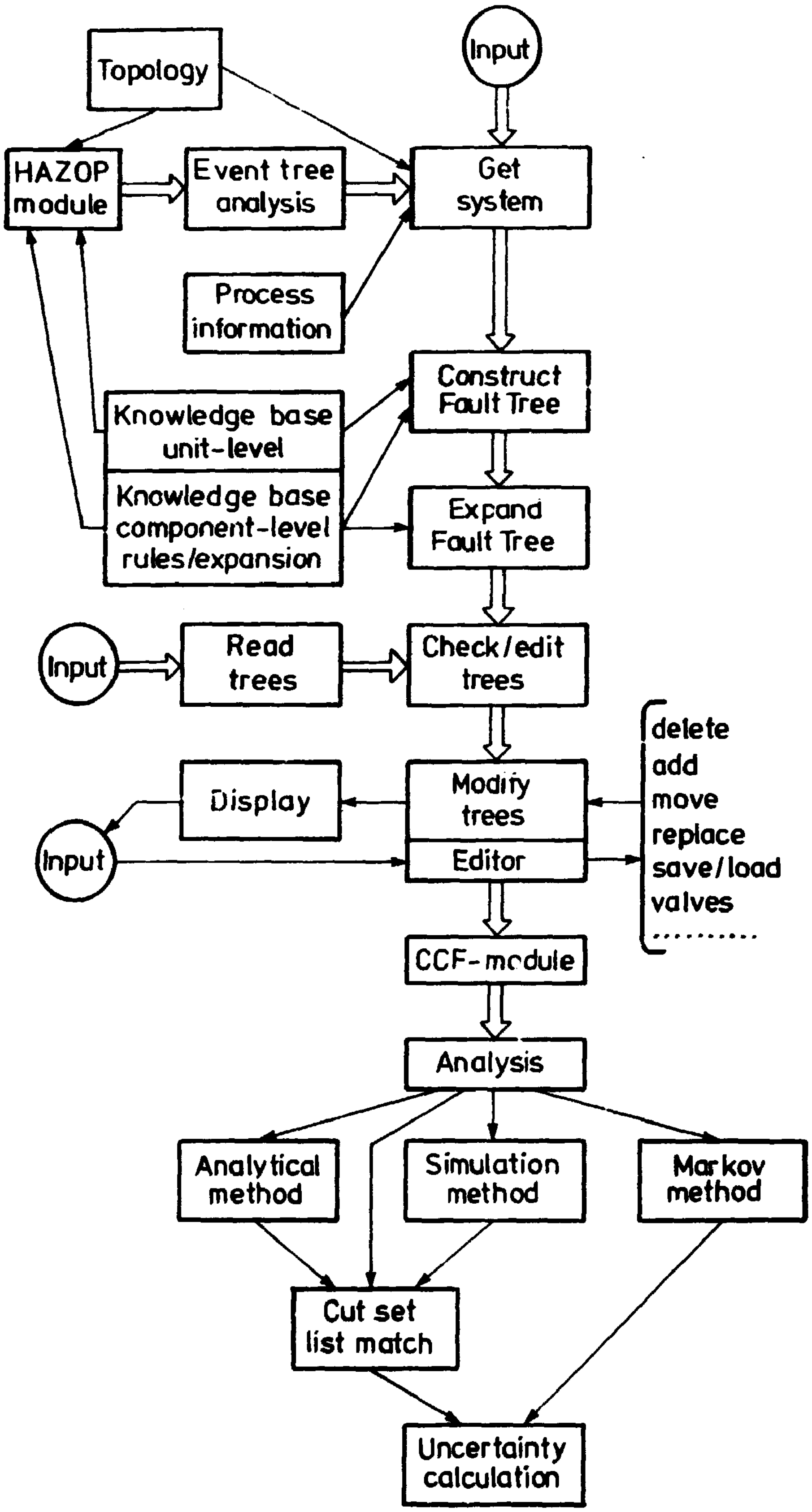


Figure 2.2. Program structure for the fault-tree constructing, handling and calculating code.

In order to carry out a consequence analysis a number of computer models are needed to describe the various aspects of the evolution of an accident scenario. Several such programs have been developed handling among other things: one- and two-phase discharge, spreading of evaporating (cryogenic) pool, pool fire, jet fire, heat radiation, heat impact on structural members, heat transfer, effect of deluge systems, effect of explosion, dense gas dispersion, and toxic effects. The programs are independent building blocks that can be combined to suit the purpose of the particular risk analysis in question. The program package is far from complete, however, and further work is needed to develop and implement new models and to improve existing ones.

A general computer framework for consequence models has been outlined (COMA). The idea is to represent the various submodels as possible coexisting processes influencing the "state" of the plant. Thus the user can set up a scenario by selecting appropriate processes (release, spreading pool, fire, etc.) along with criteria for their onset and termination. The systems should facilitate consequence calculations so that accident simulations could be performed in all stages of a risk analysis to ensure a proper identification of major potential hazards.

2.5. Unwanted chemical reactions in the chemical process industry

A Ph.D. study concerning unwanted and hazardous chemical reactions in the chemical process industry has been initiated in 1984. The project is carried out in collaboration with the Institute for Chemical Industries, at the Technical University of Denmark. The work will be completed in 1987.

The purpose of the study is to establish a basis on which the efficiency of risk analysis methods and laboratory tests can be assessed in order to identify unwanted chemical reactions. The main questions are:

- Are the methods used/known by the designers?
- Are the methods sufficient?
- How can the methods be improved?

The first part of the project was a study of accident case stories. In that way it was possible to quantify the role of unwanted chemical reactions in the chemical process industry. The intention was to collect information about why, how, and when the accidents occurred. In total 190 accident case stories were analysed. This part of the study is complete and a preliminary report has been written.

The second part of the project is a detailed investigation of an incident which occurred at a Danish process unit. The aim was to qualify advantages and limitations of existing methods. The incident was a runaway reaction in a vessel containing 1200 l jointfiller. The consequences involved the escape of HCl and Cl_2. The result of the analysis is:

- a hypothesis of the course of the incident (experimental and theoretical founded),
- a discussion of risk analysis methods and laboratory tests with respect to the possibility of identifying the potential hazard.

Part III will contain results and conclusions: a summary of the main conclusions from Parts I and II, a proposed method for identifying unwanted chemical reactions, a test of the method on one or two Danish chemical process units, and recommendations for future work.

2.6. Risk analysis, NKA

A project "Risk Analysis" within the Nordic Liaison Committee for Atomic Energy (NKA) research programme 1985-89 was started with the aim of studying treatment of common cause failures, human errors and uncertainties in risk analyses in order to cope with the completeness question. The first phase of the project concerned a review of failure reports contained in the Swedish ATV data base concerning motor-operated valves with the purpose of identifying common cause failures (CCF). In the next phase, quantifications of CCF contributions was performed.

Main findings of the Benchmark Exercise concern:

- recommendations on suitable procedures for searching for CCFs,
- suggestions for improving the current failure reporting system,
- merits and drawbacks of the classification systems,
- most sensitive elements in the process of CCF-quantification,
- evaluation of parametric models and use of direct assessment in the context of CCF-quantification.

The results will be presented in the spring of 1987 in a summary report.

It is found that the use of computers in the search procedures, based on e.g. datas of failure events and on codes for failure modes or causes, is highly recommended. This would save time, rationalize comparison of reports, allow more flexibility, and increase the degree of completeness. However, in view of rather frequently incorrect, imprecise or lacking codification, the computerized search must be followed by a manual analysis in order to achieve good quality and high degree of coverage. There is no substitute for the use of engineering judgement in interpreting failure reports.

The quantitative analysis has shown that direct assessment of CCF-contributions is possible, given comprehensive information containing system flowschemes for identifying redundancies and the number of actuations and failures of all relevant components. Single parametric methods such as MGL (Multiple Greek Letter) are still of interest; they are easy to apply and suitable for checking the impact of modified assumptions.

The agreement between the searches for CCFs performed by different groups in the exercise is satisfactory. The majority of observed discrepancies can be explained by differences in scope, boundary conditions and type of basic approach. Also the quantitative analyses have lead to reasonable agreement (with few exceptions). In most cases the identified differences are modeldependent to only a limited extent. The treatment of data, i.e. screening, use of impact vectors and weighting factors etc., is of decisive importance in this context.

3. ENERGY ECONOMY MODELS

Through the past decade the Energy Systems Group has gained extensive experience within the energy modelling field, and a variety of models has been developed to cover a wide range of applications.

The Energy Systems Group took part in the European Commission's Energy Modelling programmes for the first time in 1978, and are now working extensively in the third programme, developing the Detailed Energy System Simulation (DESS) model and implementing the macrosectoral model HERMES.

Method developments are taking place within probabilistic and uncertainty modelling. During the past years a model has been developed incorporating uncertainties into economic calculations for energy technologies.

In 1985 the Energy Systems Group collaborated with the Chr. Michelsen Institute in Norway on developing an optimization model on the sequencing of oil fields development in the North Sea.

3.1. European Commission energy-economy and environmental models

The Energy Systems Group is responsible for the Danish implementation of a number of models developed within the energy modelling programme of the Commission of the European Communities. The models presently under development are the macrosectoral model HERMES, the simulation model DESS, and an environmental module for the optimization model EFOM.

3.1.1. The macrosectoral model, HERMES

The HERMES-model is an econometric medium-term model determining the economic development with special emphasis on the energy-economy interactions. One of the main purposes of the project is to develop national models of equal structure for each of the EC countries and interlink these models to a multinational model.

Work on the model was started in 1981. The main objectives of the work in 1986 have been to complete the estimates and choose among them those equations that will enter the final model, and finally, to implement to the model into a simulation software. By the end of 1986 the complete set of model equations had been entered into the simulation software TROLL implemented on an extended IBM/PC-AT. The first simulation experiments should be obtained at the beginning of 1987. Concerning the future work the simulation experiments are expected to reveal areas where the model will have to be corrected and possibly some of the equations reformulated. Finally, the model has to be transferred to the central group of the project and interlinked with the national models of the other EC-countries.

3.1.2. The detailed energy systems simulation (DESS) model

The overall purpose of the DESS-Model is to develop a flexible and easily understandable tool for translating energy demand forecasts into their economic and environmental consequences. The aim of the project is to develop and extend a model that has been used so far in Denmark (The DES-Model) into a model which is able to simulate different national energy supply systems, in particular the power-generating and space heating systems. The model is for a beginning to be implemented for Denmark, The Federal Republic of Germany, and Italy. This project was started by the end of 1985, and it is to be finished in 1987.

In 1986 a transcription of the software to commonly used mainframe computers has been completed. The submodel for the power-generating system with combined heat and power (CHP), which was based on half-year load duration curves and heat demand levels, has been modified to deal with monthly data in order to model the German power system. The new software has been tested by implementing the detailed Danish model used so far for the Ministry of Energy.

A more rigorous modular structure of the model has been built up, which allows the same structure to be used for different countries and different levels of aggregation. The model consists of modules or submodels (see Fig. 3.1).

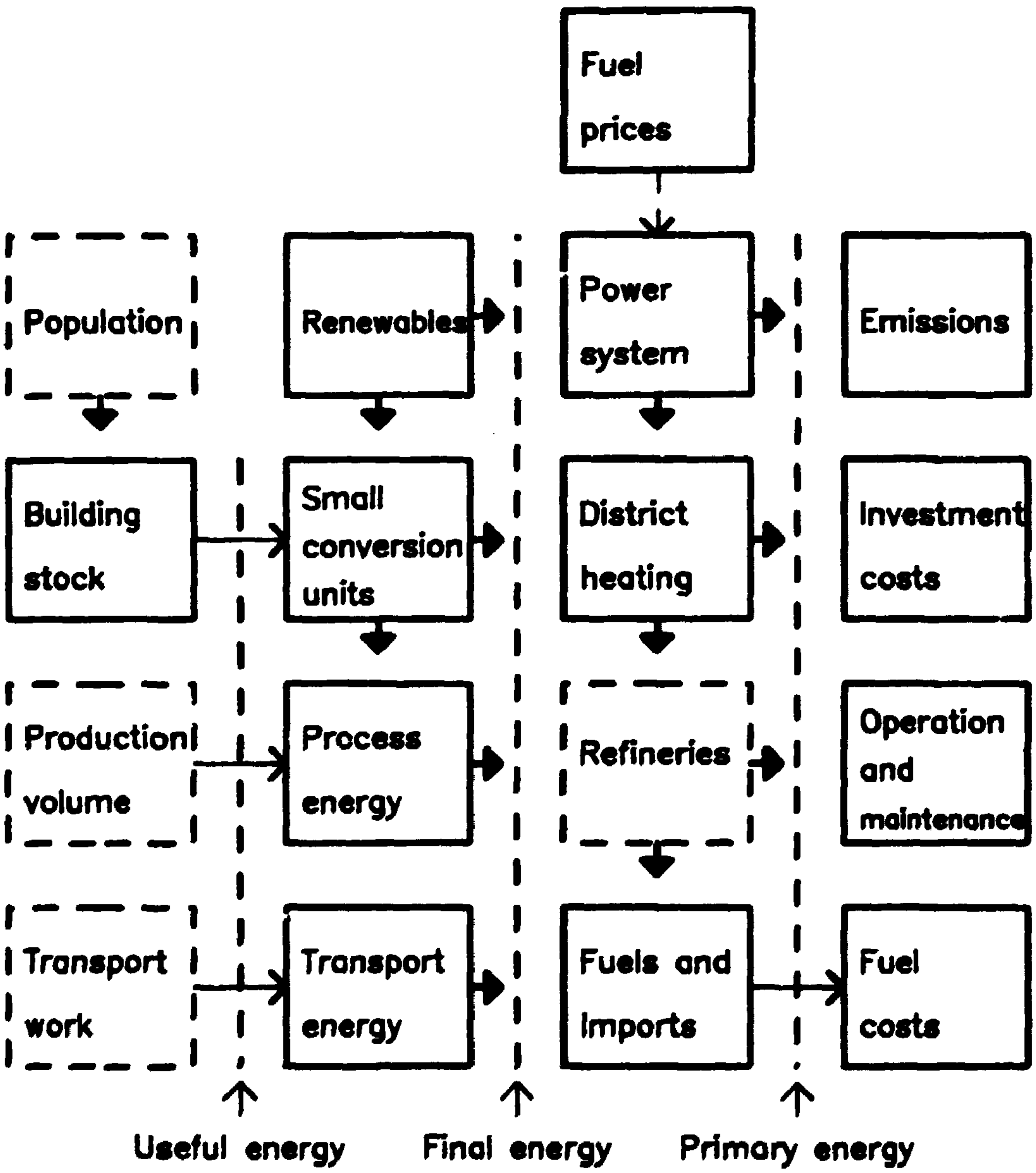


Figure 3.1. The DESS-Model information flows.

An aggregate version of the model based on the Commission's "Energy 2000" study (Ref. 2) is being built up, and contacts have been established with institutions in Germany and Italy for more detailed data collection.

The original Danish version of the model has been used for several years for the Danish national energy planning as well as partial studies of the energy system, e.g. the economic assessment of nuclear power, and the environmental consequences of energy system changes.

3.1.3. An environmental module for (EFOM)

The energy flow optimisation model EFOM is the supply part of the Commission's energy model complex. It uses the technique of linear programming to find the optimal energy supply structure that satisfies a given demand vector.

During 1986 work has started on the development of an extension of the EFOM model that includes emissions of pollutants as well as emission abatement techniques. The model development, which is performed by three German institutes, is a part of the research project "Optimal Control Strategies for Reducing Emissions from Energy production and Energy Use on a European level".

The effectiveness of this extended EFOM model will be demonstrated through an analysis of cost optimal strategies for sulphur dioxide (SO_2), nitrogen oxides (NO_x), and dust emission control for the countries of the European Community.

The main tasks of the project is to provide the appropriate data for the Danish version of the EFOM model, to analyse and evaluate the data obtained with the application of the model, and comparison of these results with those obtained with the DESS-Model.

3.2. Uncertainties in energy economic calculations

When handling uncertainties in energy economic models stochastic independency is mostly assumed. This assumption implies that a variation of one input variable in its range of uncertainty does not affect other input variables, an assumption that often does not hold. For example, a high investment cost is likely to correlate with long lifetime or high performance. Model flexibility, and often consistancy and accuracy of modelling, is reduced when input variables are restricted to stochastic independence.

Computer models have been developed that do allow stochastic dependencies among input variables. Facilities have been developed that provide access to the most commonly used distribution types for specifying uncertainties of input variables. Furthermore, a facility for stating assumptions on uncertainty of fuel price forecasts has been developed.

The models combine probabilistic calculations with sensitivity analyses based on specified uncertainties in input data. Sensitivity analyses describe the influence from individual data distributions on the calculated overall uncertainty, and thus point out major and minor risk contributing factors. Data and results from the models are presented graphically and provide a basis for applying various decision criteria.

A specific model has been constructed to perform comparative economic analyses of energy technologies. The model makes use of the above-mentioned facilities for probabilistic calculations. Calculations are based on detailed data for the various components and employment and import coefficients. Assumptions on overall shadow prices can enter the calculations. The model calculates probability distributions on present values and levellized costs of energy.

The work has been carried out under contract with the Nordic Council of Ministers and the Danish Ministry of Energy.

3.3. Simulation models for the Danish energy system

The DES-Model (Danish Energy System) is the origin of the DESS-Model, which is now being developed for the EC (see Section 3.1); it has been used for several years as the most comprehensive model for the Danish national energy planning to translate useful energy forecasts for the various demand sectors and exogenous development plans for conversion units into annual energy requirements as well as fuel, operation and maintenance, and investment costs.

In 1986 the model has been updated and used for the Energy Review 1986 issued by the Ministry of Energy.

A report describing the model and its application has been published. This report includes a comparison of scenarios for the Danish power generating system with combined heat and power (CHP) that are simulated both by the DES-Model using load duration curves to describe the load variation and the more detailed model for the power system SIMULACHRON (Ref. 3), in which the power and heat load variations are described by two-hour time steps.

The use of the model to analyse the effects of energy system changes on emissions of pollutants was presented at a conference on energy and cleaner air. Table 3.1 shows the planned changes in the Danish space heating system; the main features of this planning has been the introduction of natural gas, expansion of district heating systems supplied by CHP and waste heat, and zoning of areas most suitable for natural gas, district heating, or individual heating. Although the total building area is expected to increase, the primary energy requirement will remain nearly constant. The effects on the emissions are shown in Table 3.2. The SO_2 emissions from space heating will be reduced, and a much larger share will be emitted from power stations with high stacks. The NO_x emissions, on the other hand, will increase due to higher NO_x emission factors for power stations than for private oil burners. The emissions for year 2000 that are shown in the table will be reduced substantially by the abatement measures for SO_2 that were introduced in 1984 and those expected for NO_x.

Table 3.1. Space heating structure in Denmark 1982 and 2000, PJ

	Useful energy		Primary fuel requirement	
	1982	2000	1982	2000
High stack				
Electrical resistance heating	6	12	18	38
Electrical heat pumps	1	7	1	10
Combined heat and power (CHP)	23	62	16	42
Medium high stack				
District heating centrals, etc.	43	28	64	45
Waste incineration	4	9	7	14
Low stack				
Biomass and renewables	1	9	2	7
Private gas burners	2	29	4	40
Private oil burners	81	34	118	44
Total	161	190	230	240
Building floor area mill. m^2	314	399		

Table 3.2. Emissions from space heating in Denmark 1982 and 2000, 1000 t.

	SO_2		NO_x	
Stack height	1982	2000	1982	2000
High	28	67	13	36
Medium	73	26	10	12
Low	28	10	18	14
Total	129	103	41	62

3.4. Simulation model for collective combined energy systems

The simulation model, SIKKE, has been developed since 1984 for simulation of combined energy systems. SIKKE evaluates the economics of different system layouts and control strategies by a simulation over the year with time steps such as 10 minutes, or 1 hour.

In 1986 the program has been tested and a new option has been introduced in the operational strategy. It is now possible to define different time-intervals of the day in which different units are allowed to operate. This option has been used in simulation of wind/diesel systems in cases without electricity consumption at night with corresponding shutdown of the diesel generator.

The model includes 14 different technologies. In 1987 it is planned to expand the model with e.g. modules to handle electricity storage.

3.5. Technical/economic models for offshore oil and gas activities

During 1986 a new activity within the Energy Systems Group has emerged: development of technical/economic models for offshore activities. The work has been carried out in close cooperation with Chr. Michelsen Institute (CMI) in Bergen, Norway. The Danish participation is financed by the Ministry of Energy.

During 1986 two tasks have been covered by the project:

1) Formulation of a model for the Danish hydrocarbon and corporate taxation.
2) Development of a sequencing model for oil and gas fields.

A comprehensive cash-flow model MECCA developed at CMI has been transferred to the Danish energy authorities. In its basic version MECCA contains a model for the Norwegian system of taxation.

Before transferring the model Risø has studied and interpreted the Danish hydrocarbon and corporate taxation rules to make a description that fits into MECCA; whereafter, a Danish taxation model based on this study has been incorporated into MECCA by CMI in accordance with the specifications given by Risø.

A sequencing model for oil and gas fields is under development and is intended to be used in the planning of future oil and gas activities.

The model contains data describing each existing or potential field (investments, production, operating costs, transport system). From these data and those on product prices, maximum or minimum total productions, maximum capacities of process facilities and transport systems, and maximum consumption of several resources (e.g. investment) the model points out which fields or field alternatives should be developed - and when. This is done by maximizing the net present value. Moreover, the model may be used to assess the consequences of several userspecified solutions.

During 1986 the work on the sequencing model has been concentrated upon

- definition of the mathematical model,
- development and test of optimization methods,
- determination of the software requirements (what exactly should the model be able to do, and how would it be operated by the users), and
- feasibility test of a system for automatic creation of display terminal menues.

3.6. Models for developing countries

In the 9 member states of the Southern African Development Coordination Conference (SADCC) wood based fuels account for about 75 per cent of the regions energy requirements. Furthermore, there is strong evidence of growing scarcity in many areas. This situation is the background for a project entitled "Energy Development: Fuelwood" (Ref. 1). The project is carried out by an international team of individual experts and institutions headed by the Dutch consultant company ETC, and funding is provided by the EC and the Dutch government.

The Risø part of the work has been to evaluate existing woodfuel energy models. However, only a few models exist with the necessary emphasis on non-commercial fuels, and in particular woodfuels. Several international studies have concluded that the LEAP model, developed by ESRG in Boston is the most suitable model for countries concerned with these issues. In addition, LEAP has already been used in some SADCC member states. Consequently, it was decided to focus on LEAP in the evaluation.

LEAP is a chain of programs connecting population trends, land-use projections and economic activity with energy demand, transformation and resources; the final program calculates the costs of a given scenario. The general conclusion of the evaluation is that LEAP satisfies the special energy modelling needs for a developing country, where biomass fuels play a major role. It is a comprehensive, flexible and user-friendly model. Our recommendations for adaption of LEAP can be separated into three broad categories: 1) improvements in the costing programme; 2) the issue of scaling of variables; 3) changes which are predominantly concerned with the data input operations.

An additional recommendation was that no attempt should be made to enter a social cost/benefit analysis programme into the LEAP model itself; this would be inexpedient and accomplished more satisfactorily with a separate model. As a result of the evaluation, the LEAP group at ESRG in Boston is implementing the recommended improvements in LEAP before the system is installed in the individual SADCC countries.

4. RISK ASSESSMENT

During 1986 the Risk Analysis Group was engaged in several risk and safety analyses on a consultancy basis for Danish industry and authorities. The growing demand for such analyses in Denmark arises from the implementation of the EEC Directive on "Major Accidents Hazards of Certain Industrial Activities". Analyses were performed also for the offshore sector.

In addition, a number of analyses was carried out for foreign customers, including a comparative risk analysis of different locations of an oil and gas terminal in Norway, a chemical waste treatment plant and emergency planning for oil pollution in Thai Waters. Finally, a study of the reliability of smaller windmills was initiated.

4.1. Offshore oil and gas production

In 1986 RAG participated as subcontractor in three risk analyses dealing with the oil and gas industry: the Skjold platform safety evaluation, assessment of different alternative locations of a planned LPG terminal in Norway (Statoil), and a risk analysis of the crude oil terminal at Fredericia.

Skjold is a small, unmanned, remotely controlled platform in the Danish sector of the North Sea. The platform is of the steel jacket type. From Skjold, unstabilised oil is transported to the Gorm Complex. To increase oil production water injection is to be installed at Skjold with injection water supplied from facilities at Gorm. At Skjold new wells are drilled, new risers for oil and water are installed, and various pieces of equipment are changed.

The analysis was performed in collaboration with COWIconsult in accordance with the proposed regulations of the Norwegian Petroleum Directorace (NPD Guidelines). The NPD Guidelines emphasize the ability of the design of the installation to allow safe escape of personnel in case of an accident. In short, it is recommended in the guidelines that events causing violation of such safety criteria should not occur with an estimated frequency exceeding 10^{-4} per year. The probabilities and the consequences of accidents like blow-out, riser leaks and explosion of an oil/gas mist were estimated. Accidental events were identified using cause-consequence methodology.

An evaluation of the safety of nine proposed locations for a LPG terminal in Norway has been carried out for Statoil. The risks considered in the analyses were risk to third party and risk to the environment from marine operations, loading operations at the terminal, and processing and storage operations at the terminal. The work was done by COWI-consult A/S with Risø as a subcontractor, and resulted in a ranking of the sites based on evaluation of accidents in different consequence classes, and evaluation of consequences and probabilities for various accident scenarios.

Risø contributed with assessments of gas releases following rupture of a pressure vessel (on a gas carrier or onshore). The calculations included vaporization of a spreading cryogenic liquid on the sea surface and in a storage tank farm as well as dense gas plume modelling and calculations.

The risk analysis of the crude oil terminal at Fredericia was done in collaboration with Nielsen & Rauschenberger A/S. The terminal normally receives stabilized crude oil from the Gorm E production platform and condensate from Tyra in the North Sea. The oil is dewatered and stored in 4 storage tanks. In addition, the terminal has an emergency stabilisation unit. This insures continuation of gas production in case of shutdown of the Gorm C process facility.

Consequence analysis was performed in order to estimate the effects of fire and explosion in various accident scenarios. In the analysis domino effects were investigated with special emphasis on possible escalation of smaller fires to major storage tank fires.

4.2. Risk analysis for chemical industry

The EEC Directive on "Major Accidents Hazards of Certain Industrial Activities" has been implemented for Denmark. As a consequence there is a growing demand for risk analyses for the chemical industry. In addition, risk assessment is rapidly becoming a common contribution to the physical planning process in local government. As a result the Risk Analysis Group has taken part in or performed a large number of assessments for the chemical industry.

The assessments can be divided into two groups. Those where the assessments are performed on existing production plants as part of the basis for urban planning, and those where the assessments are performed on a plant in the design stage. The last-mentioned type is normally performed as a part of the documentation for an application.

Among others the assessments of existing plants have been performed for an ammonia unloading storage and transfer facility. The plants included spherical storage tanks, of 1100 and 3000 tons capacity, situated in the harbour area in the middle of a town with 20,000 inhabitants. Other assessments have included pesticide production.

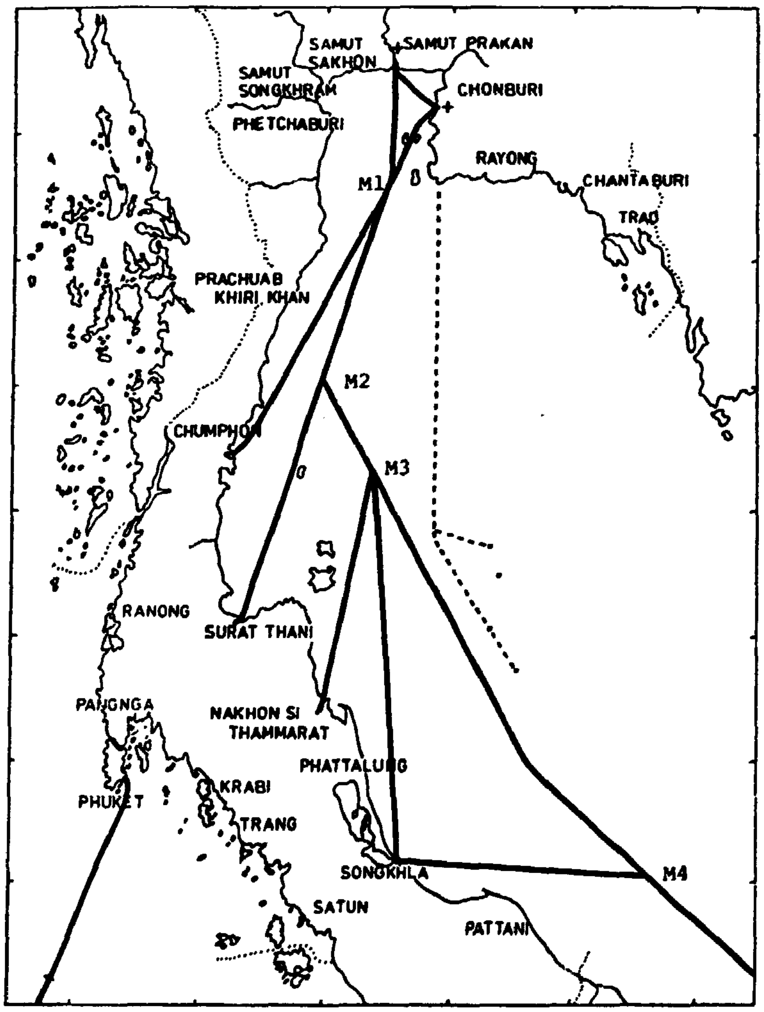
Design stage assessments have among others been performed on production and storage facilities for pesticide production and as a preliminary assessment for siting applications for a chemical waste treatment plant in New Jersey, USA.

4.3. Probabilistic assessment of oil pollution risk

As part ot a project between authorities in Thailand and Danish consulting engineers, Risø has made a probabilistic assessment of tanker accidents in Thai Waters. The assessment was made as subcontractor to Oilconsult A/S.

The main outcome of the project will be a better contingency plan for tanker and pipeline accidents in Thai Waters, and a better distribution of pollution fighting equipment.

The assessment was carried out utilising ship collisions and stranding theories. The known and verified collision theories are developed for channel navigation, and it was therefore a necessity to collect data for and construct a good description of the navigation in Thai Waters.



——— Shipping routes

-------- Gas pipeline & offshore installations

M1, M2, M3, M4 Route meeting/crossing points

\+ Refineries

Figure 4.1. Gulf of Thailand and Malacca Strait (left) with estimated sailing/shipping routes.

In Fig. 4.1 the major shipping routes are indicated for the Gulf of Thailand and part of the Malacca Strait.

The assessment included a comparison of the calculated results to statistics. The probabilistic results were found to be in good agreement with world-wide statistics on reported tanker casualties and the reported number of incidents for Thai Waters until now.

4.4. Reliability of smaller windmills and economic consequences

A project was started as part of the Danish Energy Research Programme 1986 (EFP86) with the aim of including reliability analysis in technical and economic assessments of smaller windmills.

It was inevitable that the first generation of windmills was to experience severe failures. The wind power industry learned much from them and later designs showed considerably improved reliability. However, a systematic utilization of the operating experience gained has not yet been made.

The project aims to meet this need. Through reliability analysis technical and economic consequences will be assessed from the existing material of operating experience. The work will be carried out in collaboration with the producers of windmills.

Results from the project will be suggestions for improved design, strategies for control and procedures for maintenance. Its main purpose is to reduce expenses on repairs and to increase the availability of the windmills.

In the first phase of the project the published operating experience is analyzed. The affected systems are identified and failure causes and failure consequences are assessed. The preliminary results show that no significant differences are identified in operating behaviour between different designs and sizes. This will be further evaluated in the next phase in addition to a detailed modelling of the systems with the purpose of making a subsequent reliability calculation.

5. ENERGY PLANNING AND TECHNOLOGY ASSESSMENT

The Energy Systems Group has a close collaboration with the Danish authorities, especially the Ministry of Energy and Energy Agency. This is the background for the participation in the Danish energy planning, preparation of the energy reviews, etc. A number of studies and technology assessments were carried out. ESG has been involved in the Staff Training and Institutional Strengthening programme (STIS) initiated by the Danish Energy Agency. A staff member took part in a study of the economic prospects of fusion power within the European Community.

5.1. Danish energy planning

ESG contributed to the preparation of the Energy Plan 81. Since then a number of revisions has been carried out, mainly in the form of energy reviews. In this context the role of ESG is threefold:

- performing the calculation for the various supply scenarios by applying the DES-model
- forecasting the industrial demand for energy using the technical-economic industry model
- forecasting the demand for electricity, especially for households.

A new Energy Review was published by the Ministry of Energy by the end of 1986.

Forecasts for electricity demand are important, as development plans for the utility companies have to comply with the official forecast for electricity consumption. For several years these forecasts have been made in collaboration with the Danish Energy Agency. A stock-vintage model for the household consumption of electricity has been developed; on the basis of economic assumptions the model forecasts the long-term demand for electricity for appliances.

In spite of its relative importance the commercial sector has been poorly treated in the existing energy plans. This is mostly due to its very heterogenous character, which makes it very difficult to forecast. In order to get a better understanding of what happens in this sector, a project is being carried out in collaboration with the Energy Agency. The aim of the project is to investigate the structure and development of electricity demand in the commercial and service sector. A preliminary report was published in 1986.

5.2. A technical-economic model for energy consumption by industry

The technical-economic model is developed for the Danish Ministry of Energy and is used as a forecasting tool in the national energy planning. Work on the model was started in January 1984 and the development of a first version was completed in 1986.

The model requires as input forecasts for the energy prices and the economic development. For the latter the projections are based on the macro-economic model ADAM used for planning purposes by the Ministry of Finance. The energy model converts forecasts for the economic - and the energy price development into forecasts for the energy consumption by each of the 14 industrial branches handled by the model and the four fuels: solid, fluid, electricity, and transport fuels.

The model is based on detailed technical and economic analyses of the development since 1966. The technical analysis is concentrated on the energy savings, the possibilities for future energy savings, changes in the production methods, and the composition of goods produced in each of the branches analysed. The economic analysis has focused on the effects of changing energy prices, the level and composition of production, employment and investments. In order to quantify these effects the model is estimated on data for the period 1966 to 1980. For the effects that are poorly captured by the estimations the technical analyses have proven to be very useful to evaluate the size of the effects.

Some of the more important conclusions from the analyses are that

- the production and price elasticities differ markedly from branch to branch and on average the production and price elasticities are 0.8 and -0.2, respectively,
- the easist and largest relative savings are obtained within the less energy-intensive branches,
- one-time changes, such as the closing-down or starting-up of specific productions have been very important in the period analysed, and
- changes in the production structure had a very limited importance before 1978 while from 1978 to 81 structural changes have saved about 8% of the total industrial energy consumption.

Finally, the analyses show that the recent increases in the energy consumption per unit of output are explained partly by a relatively large increase in the production in some of the more energy-intensive branches and partly by the decrease in the real energy price. Concerning the different fuels the analyses show a trendwise increase in the electricity consumption, a decrease in the share of oil and a consumption of solid fuels that has stabilised at a level somewhat higher than before the energy price increases.

5.3. Energy rationing model for acute energy shortages

In 1986 an economic Ph.D. project carried out in collaboration with the Institute of Economics at the University of Copenhagen concerning energy rationing in the event of an acute energy shortage was finished. The main objective of the project was to analyse the possibilities for an optimal allocation of scarce energy resources in the event of a short-term reduction in oil supply. The analysis involves the consideration of, e.g. strategic reserves, limitations on private energy consumption, and rationing. The result of the study is a model - LINRAT - which can be used to decide on the optimal allocation of scarce energy resources according to a set of criteria defined by the user.

If use is made of traditional economic theory about market equilibrium, an acute oil shortage can be explained as a sharp reduction in oil supply that brings the oil market to a temporary state of disequilibrium.

LINRAT (linear rationing model) assumes the existence of price control, so that the price of oil and other commodities remain constant during the disruption period. The aim of the model is then to allocate energy in an optimal way, i.e. to determine a rationing scheme.

LINRAT is an input-output model in which an object function is optimised under given constraints by the method of linear programming. As the oil disruption is assumed to last a short period; investments cannot be carried out; therefore the technical coefficients in the model can be assumed to remain constant.

To be useful as a planning tool, in practice an energy-rationing model has to operate on a highly disaggregated level, and therefore, detailed information is needed about the various sectors in the economy and the different demand categories. The official Danish input-output tables and energy matrices, which are published by the Danish Statistical Office, are used as main sources for this detailed data information.

The objective function in the model is flexible and, therefore, it is possible to specify alternative linear combinations of criteria in collaboration with the model user. In the present version of LINRAT the aggregated employment in the economy is maximised. The constraints in the model are incorporated in four modules: an input-output, refinery, substitution, and energy-rationing module.

The input-output module is a disaggregated account system for non-energy flows and total energy flow in the Danish economy. The import of non-energy is treated endogenously and import of energy exogenously. Final demand is split into private consumption, government consumption, investments, export, and changes in stocks. The refinery module handles two qualities of crude oil and four refined products. Cracking of crude oil represents a flexibility, so that the product mix is not fully determined by the quality of the crude oil. Substitution in the short run - on an existing production plant - between alternative energy products is possible in the substitution module, which further comprises the detailed energy balances. If the energy rationing scheme is not to be determined endogenously by LINRAT, a specific scheme can be implemented in the energy-rationing module

In its present state LINRAT comprises 14 non-energy sectors, 3 energy conversion sectors and 8 energy products. Unlike the official Danish 117 input-output sectors the non-energy sectors are aggregated, the energy conversion sectors are identical, and the energy products are disaggregated. The latter ones are based on the detailed energy matrices.

Two scenarios are presented in the report: the undisturbed economy and a crisis scenario. The first one reflects the economy without oil disruption and the second one reflects the consequences of a 20% reduction in the import of heavy crude oil and refined products. A realistic mix of policy instruments is specified for the crisis scenario. The main effects on some important macroeconomic variables is shown in Table 5.1.

The two scenarios are used as reference scales for a sensitivity analysis covering the different policy instruments and assumptions. The partial influence of the size and quality of the oil disruption is investigated. Further investigations concern the effects of cracking flexibility, energy savings, energy substitution, restrictions on private consumption, and a proportional rationing scheme. Finally, the practical implementation of the different policy instruments in a public planning context is discussed.

Table 5.1. Macroeconomic effects of a 20% reduction in the import of oil.

Total production	-74	billion	Dkr.
Export	0	"	"
Import	-27	"	"
Trade balance	+27	"	"
Private consumption	-13	"	"
Government consumption	0	"	"
Changes in stocks	-13	"	"
Investments	-35	"	"
Employment	-249,000	man years	

5.4. Energy planning and project assessment in developing countries

It is essential, especially in developing countries, that project assessment work is not regarded as an isolated activity, because it is closely related to the development strategy and aims of the country, the political and administrative realities, the donor interests, etc.

Based on these general aspects and the specific experiences from the ongoing collaboration with the Department of Energy (DOE) in Zambia, a PRoject Analysis Model (PRAM) is being developed as a part of the Ph.D. project concerning assessment methods applicable to rural energy projects. The main purpose with PRAM is to provide a flexible tool to assist in the preparation- and analysis phases of the assessment process.

Focus in the development of the model has been on user-friendliness, flexibility and simplicity, since it was found to be key aspects, if the model should be of use in DOE and similar institutions.

The basic options for the model was discussed with a staff member from DOE during his visit to Risø as a guest researcher early in 1986, and later a preliminary version of the model was discussed with DOE in Zambia. Development work continues based on the results and comments obtained during this visit.

Besides participating in the Ph.D. project the Zambian guest was engaged in the evaluation of the LEAP model (see Section 3.6). This participation provided good training possibilities, but it also contributed to the evaluation by adding the direct users point of view, since LEAP had been installed in DOE a few months earlier.

5.5. Wind energy

Since 1980 a rapid development of windpower has taken place in Denmark. In 1985 about 1600 windmills were in operation in Denmark. In 1986 a project to analyse the economics of windpower was initiated by the Energy Systems Group in collaboration with the Test Station for Windmills at Risø.

The project has two main purposes:

- to give the state-of-the-art of the economics of windmills,
- to estimate the future development in the production costs of a windmill.

Concerning the state-of-the-art a survey is performed to give the real figures for repair and maintenance, investment costs, the yearly electricity production of the windturbine, etc. The survey is coordinated with already existing data for windmills, e.g. the renewable energy data base. The collected data will be used to calculate the costs of different categories of windmills, and the impact of windmill sizes upon the costs will be evaluated.

Concerning the future development, the main attention will be given to the development in construction, optimizing the size of the windturbine, and possibilities to rationalize the production process, and finally the economic consequences will be evaluated.

The growing interests in wind/diesel systems has increased the demand for knowledge about the structure of the electricity consumption in small communities without grid connections. On the island of Anholt (in Kattegat) the load is logged using a mechanical chart recorder. The 1984 data was digitised with a timestep of 10 minutes. These data has been analysed on the computer together with a series of measurements of the load with timesteps of one second taken by the Test Station for Windmills at Anholt the 2nd week in March 1985.

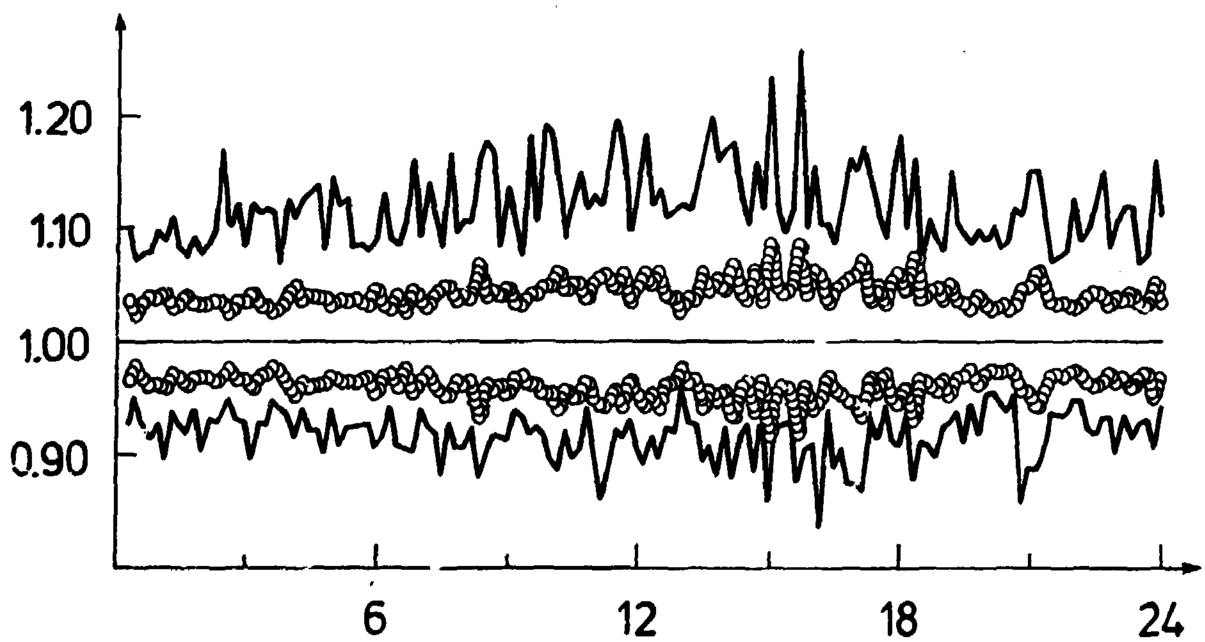


Figure 5.1. Power demand relative to mean. Saturday 16 March 1985.

In Fig. 5.1 the one-second data from one day is shown. The 10-minutes mean value of the power demand one standard deviation, the maximum and minimum values in the 10 minutes are plotted relative to the mean value.

5.6. Absorption cooling

Of the total Danish electricity consumption 20% is used for cooling purposes. Refrigeration and freezing of food account for 85% of this, and the rest is used for air conditioning of computer installations, banks, department stores, hotels, hospitals, etc.

Almost all cooling is provided by electricity-driven compressor units but there are a few installations with absorption machines. Such machines can utilize surplus heat from CHP power plants, incinerators, and industry as energy source. A part of this surplus heat is used for district heating but during the summer months, where the need for space heating is very low, the heat is unused and the CHP power plants must operate almost exclusively as electricity-producing condensing plants with corresponding large losses.

A substitution of compressor units with absorption units will result in a lower electricity consumption, especially in the summer, and a levelling off of the heat consumption.

With participation from the Engineering Department at Risø, Copenhagen County Hospital at Herlev, and Sabroe A/S a project has been initiated that will give a mapping of the potential use of absorption cooling and a quantitive estimation of the profitability. The value of the surplus heat for this purpose will be calculated. The project is funded by the Danish Ministry of Energy.

6. PUBLICATIONS, LECTURES AND CONFERENCES

6.1. Risø International Conference on Models and Uncertainty in the Energy Sector

On 11-12 February 1986 an international conference on models and uncertainty in the energy sector took place at Risø. The conference was sponsored by the Nordic Council of Ministers.

Computer models play an important role in the energy sector. Models are used at many levels from detailed assessments of single units with respect to performance, reliability, economy, to systems analyses of complex systems. Furthermore, technical and economic models are used in planning i.e. forecasting, scenario analyses, development plans and overall risk assessments. Such calculations are always subject to uncertainties at different levels.

The aim of the conference was to bring together scientists, economists, manufacturers, energy planners, and decision makers in order to discuss what can or should be done with respect to including the uncertainties into the model calculations.

The conference was organized with 15 papers grouped into 4 sessions dealing with energy and economy, reliability, methods, and planning. The conference attracted wide interest, the 100 participants represented 12 different countries. The closing session took the form of a panel discussion among the four session chairmen followed by a general discussion. A summary of the chairmen's remarks are included in the proceedings published after the conference.

6.2. Publications

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GROHNHEIT, P.E. (1986), Effects of energy system changes on the reduction of SO_2 and NO_x. Paper presented at ENCLAIR 86 International Symposium on Energy and Cleaner Air: Costs of Reducing Emissions. Organized by OECD and ENEA 28-31 October 1986, Taormina, Italy.

LARSEN, H. (1986), Models and Uncertainty, [In:] Risø International Conference on Models and Uncertainty in the Energy Sector, 11-12 February 1986, Risø, Denmark. (Risø National Laboratory, Roskilde) p. 13-18.

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VESTERGAARD, N.K., and TAYLOR, J.R., Tanker Incident Probability as a Basis for Environmental Emergency Planning. [In:] SRE-Symposium '86, Otaniemi, Finland, October 14-16, 1986.

6.3. Lectures

FENHANN, J., and CHRISTENSEN, J.M., Energy Systems Investigations. Report of the 1986 workshop of the European cooperative networks on rural energy on wind energy applications for rural areas, 14-16 May 1986. FAO.

GROHNHEIT, P.E., National energy planning in Denmark, 7 Februar 1986. Universiteit Antwerpen, Studiecentrum voor economisch en sociaal Onderzoek.

7. STAFF

Hans Larsen, M.Sc. Elec. Eng., Ph.D. in Reactor Physics in 1973. From 1973 to 1976 at Dragon project at AEE Winfrith, U.K. Risø from 1976. Energy Technology Department 1976-1980, working with systems reliability. Head of Energy Systems Group 1980-1984. Head of Systems Analysis Department from 1985.

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The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1986. The activities may be classified as energy systems analysis and risk and reliability analysis. The report includes a list of staff members.

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