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# Energy Systems Group. Annual Progress Report 1984

**Grohnheit, Poul Erik; Larsen, Hans Hvidtfeldt; Villadsen, B.**

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# Energy Systems Group Annual Progress Report 1984

Edited by
P. E. Grohnheit, H. Larsen and B. Villadsen

Risø National Laboratory, DK-4000 Roskilde, Denmark
February 1985

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# ENERGY SYSTEMS GROUP

# Annual Progress Report 1984

Edited by
P.F. Grohnheit
H. Larsen
B. Villadsen

Abstract. The report describes the work of the Energy Systems Group at Risø National Laboratory during 1984. The activities may be roughly classified as development and use of energy-economy models, energy systems analysis, energy technology assessment and energy planning. The report includes a list of staff members.

INIS Descriptors: DENMARK; ECONOMIC ANALYSIS; ENERGY ANALYSIS; ENERGY SOURCES; PLANNING; POWER DEMAND; RESEARCH PROGRAMS; RISOE NATIONAL LABORATORY; INDUSTRY; POWER GENERATION

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## 1. INTRODUCTION

The activities of the Energy Systems Group (ESG) in 1984 covered a wide range of subjects such as the development of energy-economy models, technical and economic assessments of energy technologies and systems, and energy planning. The various tasks undertaken are carried out either as basic R&D studies or under contract with different organisations in Denmark and abroad.

The majority of the studies undertaken by the group involves a close collaboration with companies, consulting firms, ministries and international organisations, such as the Danish Ministry of Energy, the Danish Energy Agency, the National Agency of Environmental Protection and the Commission of the European Communities.

The research and development activities in 1984 involved three postgraduate research projects: One concerns the development of a model for the simulation of combined heat and power was completed. An ongoing project deals with the development of an energy-rationing model for acute energy shortages. Furthermore, a new post-graduate research project dealing with energy supply technologies for developing countries was initiated.

The Danish Energy System model DES, which has been used extensively in connection with Danish energy planning over many years, has been subject to major modifications, e.g. introduction of an environmental consequence module. The work on the development of a method to incorporate uncertainties in the economic calculations for energy technologies was continued. The work on the macrosectoral model HERMES carried out in connection with the energy-modelling programme of the Commission of the European Communities, was continued at a low level due to lack of funding. Work on the European long-term energy demand model MEDEE3 has been resumed.

A number of new model activities has been initiated. The effects of structural changes on the energy consumption are analysed within the framework of an input-output model. The study is carried out for the Danish Ministry of Energy. Two studies are carried out for the Danish Energy Agency. A simulation model is being developed for the simulation of combined collective energy systems. Work has been started on a project with the purpose of improving methods for electricity demand forecasts.

The work on the comprehensive study on the long-term prospects of energy technologies was completed in 1984. The study was carried out for the Danish Ministry of Energy. The study deals with the period 2000 to 2030. The official Danish projections for 2000 have been used as the starting point. A new major study has been initiated for the Danish Ministry of Energy on the development of a technical-economic model for energy consumption in industry. The main objectives of building the model are to analyse the development of the industrial energy consumption over the past 15 years, and to formulate a model that converts economic forecasts into industrial energy consumption forecasts.

The Energy Systems Group has been deeply involved in Danish energy planning for many years. In 1984 the activities in this area have covered economic calculations for energy technologies to be used in the areas scheduled to receive neither natural gas nor CHP-generated district heating. The work for the Ministry of Energy has, in addition, included contributions to the assessment study of power plant economy which compares nuclear with coal.

A number of assessment studies carried out under contract have been completed. A model to calculate the duration of energy stocks during an energy supply crisis has been developed for the Danish Energy Agency. A study of the cost effectiveness of various measures to reduce $SO_2$ and $NO_x$ emissions has been carried out for the National Agency of Environmental Protection. Finally, a study on employment effects of energy conservation measures has been carried out in collaboration with the Fraunhofer Institute in Germany for the Commission of the European Communities.

During the year an IAESTE-student from Egypt has visited the group for three months. One member of the ESG has visited the

Energy Systems Research Group at University of Stockholm for two months. Members of the group have participated in and presented papers at various conferences around the world. Moreover, the group has participated in a Danish energy symposium in the World Bank, together with 20 Danish companies and consulting firms.

Finally, it can be mentioned that the Energy Systems Group and the Risk Analysis Group at Risø from January 1985 jointly will form a new Systems Analysis Department. The present activities of the two groups will continue within the new department.

## 2. ENERGY-ECONOMY MODELS

The modelling activities of the Energy Systems Group cover a wide variety of model developments. It covers models able to handle multinational calculations. Simulation models have been developed for calculations on national or local levels. Methods to incorporate uncertainties in economic calculations are being developed. Furthermore, the effects of structural changes on the energy consumption are analysed within the framework of an input-output model. Finally, demand forecast models are being developed and the empirical performance of theoretical demand systems have been analysed using econometric methods.

The models are intended to complement each other and thus more models have been used in combination in a specific study e.g. DES and SIMULACHRON in the assessment of nuclear power. An aim of the group is the development of a span of models covering the sectors and technologies of the Danish energy system.

An important task in most energy modelling and planning is the collection and processing of statistical data. ESG has direct access to a number of databases from the Danish Statistical Office and other relevant institutions. The available databases include the input-output tables, energy balances, investment figures, employment data, and detailed data on buildings and the space heating system.

## 2.1. The Danish Energy System Model - DES

The DES-Model was developed to calculate the total Danish energy requirements and the associated costs. The model has been operated for several years by ESG and used as the most comprehensive model for national energy planning, which is carried out by the Danish Ministry of Energy. It is also used for partial studies of the energy system, e.g. the economic assessment of nuclear power and the environmental consequences of energy production (see Sections 4.2 and 4.3).

The DES-Model is composed of modules for energy subsystems with suitable interface variables; each module consists of energy data and submodels of varying complexity, ranging from simple accountancy assignments to a simulation model for the electricity generating system with combined heat and power production (CHP), see Fig. 2.1.

Given a set of forecasts for the demand for useful energy and a development plan for the conversion and distribution system, the model produces detailed results relating to the future energy supply system. The results consist of the primary energy requirements, the costs of the energy systems, and selected environmental consequences, e.g. $SO_2$ and $NO_x$ emissions. The model can be used for a period of up to 40 years, covering the lifetime of large technical equipment.

The simulation of the electricity generating system, including CHP is a central part of the model. The demand for electricity is described by load duration curves, and generating units are scheduled in merit order.

Other energy conversion technologies are described by a set of efficiency factors for any relevant fuel type and end use together with the associated cost.

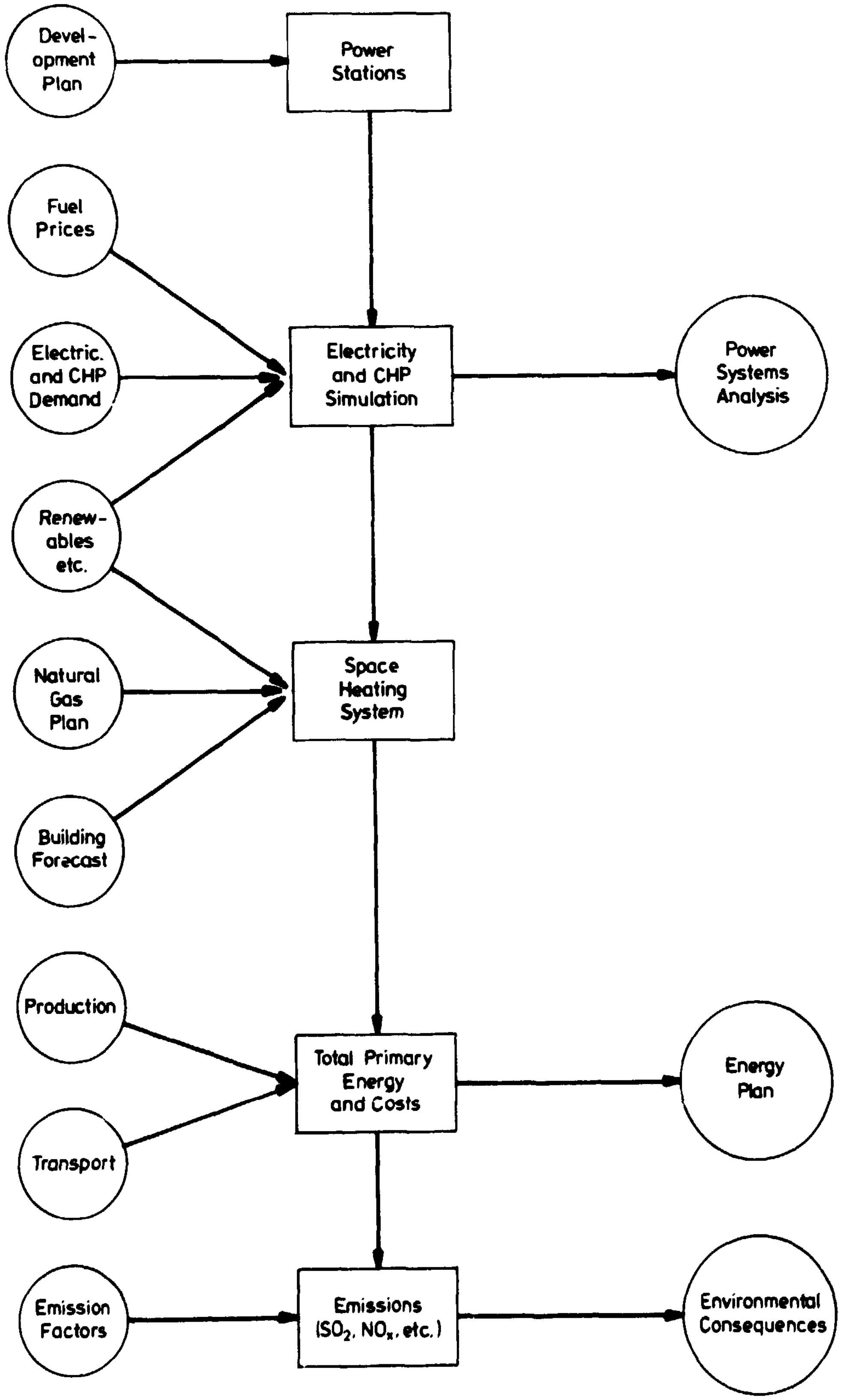



Fig. 2.1. The DES-Model.

The principal input data consist of:

- Energy demand forecasts for the period under consideration.
- Technical specification of existing and planned power stations (e.g. size, efficiency and availability).
- Technical specifications of other energy conversion technologies, e.g. oil furnaces, district heating plants, and renewable energy installations.
- Economic data such as fuel prices, investments, and operation and maintenance cost.
- Emission factors for air pollutants.

The output includes, for example:

- Annual primary energy requirements by sector and fuel type.
- Annual costs by sector and technology.

During 1984 the modular structure of the model has been improved, and historical data and model results (since 1980) are being checked off with the official statistics.

The software has been improved by the introduction of a facility which enables the user to modify data and assignments interactively. A transcription of the program, which is written in FORTRAN 66, to FORTRAN 77 has been initiated. This will facilitate the transference of the model to other computers.

## 2.2. SIMULACHRON - a simulation model for CHP-production systems

The SIMULACHRON is a new simulation model developed within the last few years as a tool for evaluation of expansion plans for the CHP production system on a national level. However, the model can also be used to model the CHP-system of a single town and for evaluation of single technologies (e.g. wind power).

The model describes in a very detailed way technical and economic aspects of a national CHP-production system including condensing, extraction, and back-pressure power plants, district heating boilers, and day-to-day heat storage facilities.

A time period of arbitrary length divided into an arbitrary number of time steps can be simulated (typically of length one to two hours). This time period is assumed to be cyclic in the way that the first time step follows the last one. By doing so it is unnecessary to specify the situation at the beginning or at the end of the period in question.

When simulating the operation of a CHP-system over a long time, say a whole year, each week is considered separately to keep down the number of variables that have to be optimized simultaneously. Because the heat and power load profiles change very little from week to week, and because a week, as mentioned, is considered to be cyclic, the error introduced by subdividing the year into independent weeks is small.

When operating a production system comprising condensing power plants and CHP plants the combined production has a priority over the production at the condensing power plants. This follows from the economic savings that are brought about by producing as much heat and electricity as possible in combined production. In the computer model the same philosophy is followed.

In an evaluation of development plans for the national CHP production system the SIMULACHRON model is intended to be used as a supplement to the DES-model (see Section 2.1). The modelling of the CHP-system in SIMULACHRON is very different from DES: In DES the simulations are based on half-year load-duration curves for the power demand, whereas SIMULACHRON as mentioned above is based on time series. Due to this difference the DES-Model is normally used to simulate the system operation for a few decades ahead, whereas the SIMULACHRON model is used in a more thorough simulation of selected weeks within this span of years.

In the work described in Section 4.2 (Assessment of nuclear energy) the SIMULACHRON model was used to find to which extent the co-production is reduced when nuclear condensing power plants are introduced. Likewise the results of the SIMULACHRON model has been used to give an estimate of how the operation of conventional base load and peak load power plants are affected by the introduction of nuclear plants.

## 2.3. European Commission energy-economy models

The Energy Systems Group is responsible for the Danish implementation of a number of energy models developed within the energy-modelling programme of the Commission of the European Communities. During 1984 the work was concentrated on the macrosectoral model HERMES, and the long-term energy demand model, MEDEE3. Primarily, the work on the MEDEE model was devoted to an application of the model to Danish conditions.

### HERMES

During 1984 work on the macro-sectoral model HERMES was continued at a reduced level, due to lack of fund ng. In March a final report containing the first estimation results for most of the model's relations was issued. Since then work has been limited to a few additional estimation experiments, and some updating of the database. Further work to obtain the first simulation experiments with the model includes estimation of import and export relations, formulation of identities and implementation of a simulation software. In addition, a disaggregated treatment of the energy branch remains to be implemented and an updating and reestimation of the relations is desirable.

### MEDEE3

Work on the European long-term energy demand model MEDEE3, which simulates the evolution of energy demand over a period of 25 to 30 years, has been resumed. The model calculates the energy demand of three consumption sectors: households & tertiary sector, production sector, and transportation sector. The model is highly disaggregated and thus requires a large amount of economic, demographic and technical data. The MEDEE3 model is a calculational tool used to translate particular scenarios for the development of the socio-economic system into energy demand terms.

In 1984 work on the model consisted mainly of database updating, error correction, and a run of three scenarios for Denmark. The scenarios were chosen comparable with those of the latest Danish energy plan (ref. 1) and hence could be characterized as neutral (in economic growth and energy control), strongly controlled and low growth. (N, SC and L, respectively). The scenarios revealed that MEDEE3 with some minor changes is applicable to Denmark and confirmed that industry and transportation in the future will take up a growing part of the energy consumption as shown in Figs. 2.2 and 2.3.

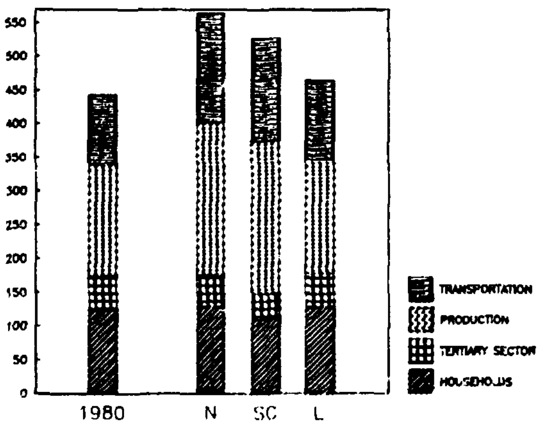



Fig. 2.2. The demand for fossil fuels by sectors in 1980 and 2000 (PJ).

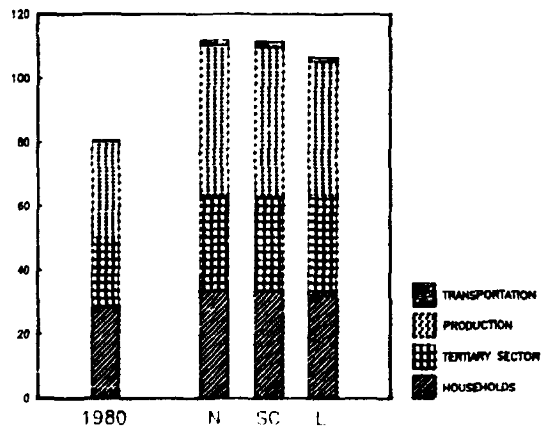



Fig. 2.3. The demand for electricity by sectors (PJ) in 1980 and 2000 (PJ).

Further work on the model consists of finally updating the database and elaboration of the model formulation with special emphasis on energy demand in industry.

## 2.4. Uncertainties in energy/economic calculations

The aim of this ongoing project is to develop methods that allow uncertainties to be incorporated in the economic calculations for energy technologies.

When new technologies are compared to well-known technologies, uncertainties in data, particular for the new technology can be of considerable importance.

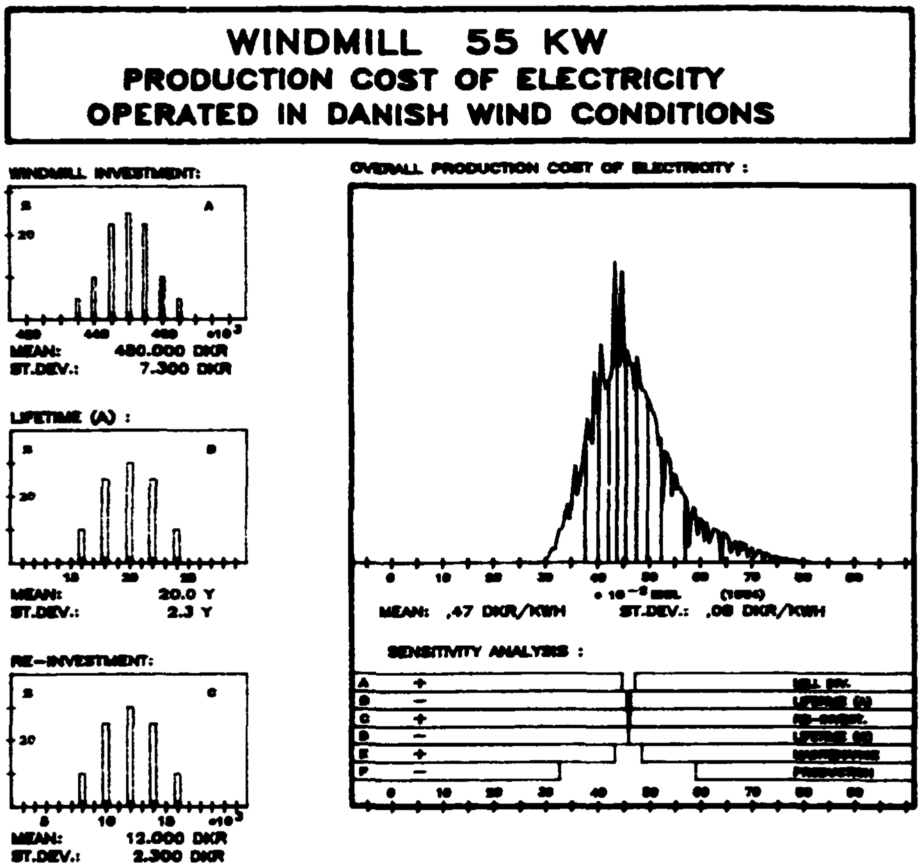
Methods are developed to permit the direct introduction of distribution functions into the analysis, allowing a broad basis of information to enter the assessments. Uncertainties in data can be converted to a resulting uncertainty in relevant technical and economic key descriptors.

The necessary software for such calculations are now operational for calculations presuming that input is uncorrelated data distributions.

The development of the methods has now reached a stage where the models have been used for several practical calculations for windmills, heat pumps, coal prices, etc.

During 1984 extensions have been added to the models. Software has been developed for general applications. An example is a computer model of a calculational structure used in coal price forecasting. This model has been utilized for overviewing the total effect and relative impact of a number of interacting uncertainties.

The models use graphical presentations of data and results extensively in order to facilitate the overview. Figure 2.4 shows an example of a main presentation sheet for an uncertainty calculation. Here the production cost of electricity from 55 kw windmills operated under Danish wind conditions is evaluated. Due to the discrete data histograms, given on the left of the figure, the calculated probability distribution shows an irregular shape.




ELECTRICITY from 55 kw windmills. Danish wind conditions has been assumed.

Overall production cost of electricity on a national economic basis. An interest rate of 7% p.a. has been used.

Figure (G) shows the probability distribution for the production cost of electricity. Vertical lines divide this distribution into intervals each covering 10% probability (fractiles).

Sensitivity analysis: The gap in the horizontal bars indicates the influence on the overall productions costs originating from the respective parameter. The narrower the gap, the less the influence.

Figures (A,B,C,D,E,F) show the basis of calculation: Windmill investment (A), covers all initial costs (1984). This includes a connection to the grid. The lifetime of this investment is shown on (B). Maintenance cost pr. year (E). The annual electricity output from the windmill is shown on figure (F).

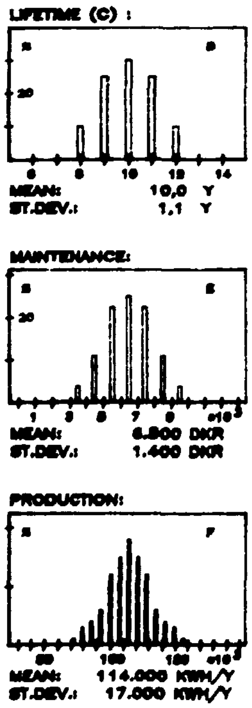



Fig. 2.4. Example of uncertainty calculation.

Research in this field is ongoing. At present work is carried out under contract with the Nordic Council of Ministers.

## 2.5. The Effects of Structural Changes on Energy Consumption.

In 1984 the Danish Ministry of Energy initiated a study on the effects of structural changes in Danish energy consumption.

The study is carried out within the framework of an Input-Output model, which is based on a matrix formulation of the transactions of goods and services among industries and between industries and different categories of final demand (private consumption, investments, exports, etc.).

Such transaction matrices are annually compiled by the Danish Statistical Office and are at present available for the period 1966-80. The combined use of these matrices and directly compatible data matrices on energy consumption makes it possible to carry out very detailed analyses of the energy consumption in industries.

The model can be used for historic analyses as well as for calculations of the consequences of a change in the main economic variables or of, e.g., changes in the relative importance of the applied 117 industries.

The basic output of the model is a split of the changes in energy consumption into four parts covering the effects caused by changes in the interaction among industries, in the energy coefficients, in the level of final demand and in the composition of final demand. The two first components can be grouped as technology factors and the two last as demand factors.

If the effect caused by changes in the energy coefficients is to be interpreted as due to energy conservation or other technological changes, it must be assumed that the production is homogeneous over time. However, this assumption is known to be wrong and the aim of the present study is therefore to analyse how the changes in output-mix have affected Danish energy consumption.

Changes in the output-mix of industries can be revealed by a detailed study of the goods and services actually produced, but when the basic data material consists of approximately 3-4000 commodities this is not a very handy method. The present study has used a different approach, assuming that each commodity has a unique application, and any change in the distribution of output can therefore be seen as a sign of changes in the output-mix.

This assumption has been tested in some preliminary regressions, where the pattern of deliveries has been included as explanatory variable along with the relative energy price. Other expressions for changes in output-mix - e.g. changes in the share of internal deliveries and changes in the import quotas - will be tested.

The second part of the project will study whether the decrease in the Danish energy consumption has been offset by an increase in the indirect energy consumption that takes place through imports of goods and services. Such a shift may affect the security of supply for Denmark and may a first sight have a positive effect on the balance of payments, but it will not change the overall Danish use of the world's energy resources.

The analysis will include calculations of annual import quotas for each of the 117 industries and by combining these with the energy coefficients for the Danish industries, the energy intensity of imports can be compared with the energy intensity of the Danish production, and it can be analysed whether the trend in the import quotas has been similar in all industries. The result of the analysis should be to include the changes in import quotas as a separate factor in the output of the model.

The project will be completed in 1985.

## 2.6. SIKKE - a simulation model for collective combined energy systems.

Utilization of local energy resources has a high priority in the Danish energy plan, the goal being that 6% of the fuel consumption in the year 2000 should be covered by renewable energy. A large part of the units which are going to be installed will be collective plants supplying villages with electricity and heat.

Both energy demands and energy resources (e.g. wind, solar) vary with time. In order to find a reasonable strategy of operation and a correct size of the different units in the combined plant it is essential to simulate the operation of the plant.

The aim of this project is to construct and test a simulation model called SIKKE (Simulation model for Collective Combined Energy systems) which can perform the above-mentioned simulation over a year with timesteps of one hour or less. The model-diagram is shown in Fig. 2.5. The first inputs are time series for electricity and heating demand, insolation, wind speed, ambient temperature, etc.

The technical parameters for the different possible energy technologies are specified in the technology catalogue file. Presently the following units are planned to be included:

Oil, gas and coal burners/furnaces
Straw and wood furnaces
Biogas plants
Solar cells and solar heaters
Wind turbines
Heat pumps
Electricity and heat storages
District heating network.

The last input is a system definition defining which units the system under consideration is composed of together with a logical expression for the operational strategy for each unit.

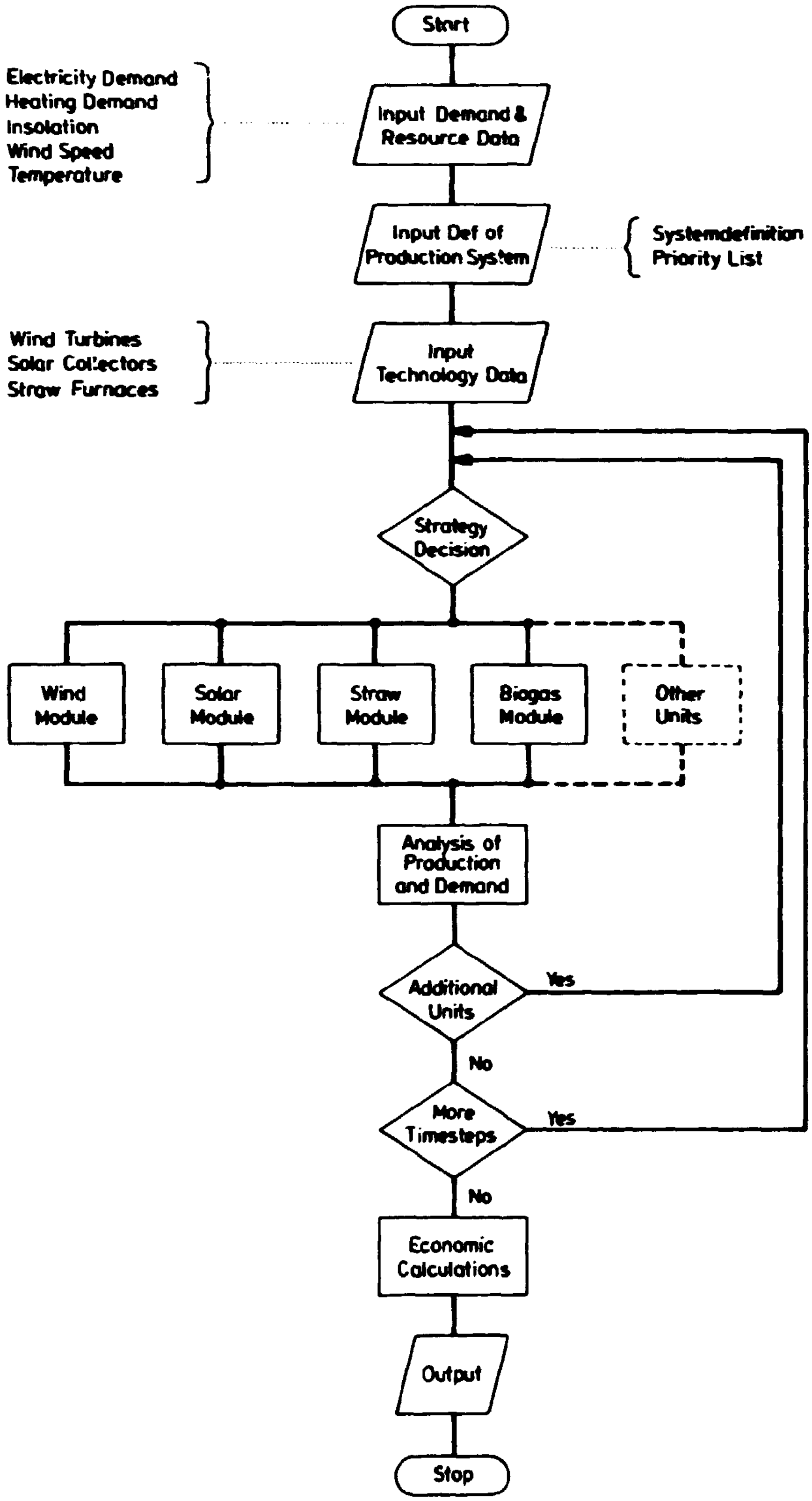



Fig. 2.5. The SIKKE-Model.

The model will then let the different units operate in every timestep in accordance with the strategy. After each timestep information of the utilized capacity for each unit, the use of energy resources and the purchase/sale of electricity are stored. After the simulation over a year the model will calculate the net present value for the system on the basis of the investment costs operational and maintenance cost for the different units and the calculated and fuel costs.

The work is carried out under contract with the Danish Energy Agency. At the moment the first model test run with a very simple system is being performed.

## 2.7. Electricity demand forecasting

ESG is member of a permanent working group set up by the Ministry of Energy and the Energy Agency to study the development of electricity demand. Primarily, the work of the group is on a sectoral basis to forecast electricity demand on a medium- to long-term time horizon.

To extend the work of this group ESG has in collaboration with the Energy Agency initiated a project centred around three main issues: 1) Investigate the development of electricity demand in the tertiary sector. 2) Calculate price-elasticities for electricity. 3) Evaluate the changing pattern of electricity demand between the two main regions of electricity supply in Denmark, ELSAM and ELKRAFT.

At present most of the work is devoted to the first issue, an analysis of the tertiary sector. This sector is described by visiting municipalities, large institutions and offices, and collecting the relevant statistical material. The key data are annual electricity consumption in physical terms and the related building size in square meters. These data are split into categories depending upon the function of the building: schools, hospitals, kindergartens, etc. Moreover, it is very important to take into account special circumstances, e.g. electrical heating.

Future work will include an evaluation of the collected data and the construction of a simple simulation model for the tertiary sector.

The second issue, calculation of price-elasticities for electricity, has only been touched on superficially; The third issue, the changing regional pattern of electricity demand, data collection has been started.

The project will be completed medio 1985.

## 2.8. Econometric analysis of demand systems

During May and June an economist from ESG visited the Energy Systems Research Group (FFE) at the University of Stockholm. Two subjects were elaborated upon during the visit: Alternative consumer demand systems to be incorporated into a model of the Swedish economy were tested, and for Denmark final estimations for three dynamic inter-fuel substitution models were made.

Concerning the consumer demand systems for Sweden the models were tested for the private household consumption split into 6 categories of consumer goods and using data for the period 1950-83. The models tested were the Rotterdam-model, the Almost Ideal Demand System, the Linear Expenditure System (LES) and combinations of the Almost Ideal Demand System and the LES-model. The conclusion from this analysis is that the theoretically superior Rotterdam and Almost Ideal Demand System models are empirically not very satisfactory and as the LES-model is theoretically very restrictive, a combination of the LES-model and the Almost Ideal Demand System is preferable.

Concerning the dynamic inter-fuel substitution models these were estimated for nine branches and three fuels using data for the period 1966-80. The partial adjustment, the error-correction mechanism and the generalized partial adjustment dynamisations of the translog model were tested against the static translog model. From this analysis the significant conclusions are that the static model gives a satisfactory representation of longterm equilibrium; however, although the model assumes the adjustment to be instantaneous, it is not. Further, to describe the dynamic path the error-correction mechanism seems empirically preferable while both the partial and the generalized partial adjustment models quite often predict either a first-year overreaction in the quantity adjustment or an alternating adjustment.

## 3. ENERGY TECHNOLOGY ASSESSMENT AND SYSTEMS ANALYSIS

During 1984 a final report on the long-term prospects of energy technologies was published and a study on the employment effects of energy conservation was completed. The work on energy technology assessment and systems analysis has been continued by the initiation of work on the development of a technical-economic model for industrial energy consumption. Finally, a new Ph.D. project on energy supply technologies for developing countries has been initiated.

### 3.1. Long-term prospects of energy technologies

A comprehensive study of the long-term prospects of energy technologies has been carried out for the Danish Ministry of Energy. The study was initiated in 1982 and completed in April 1984 with the publication of the final report. As the study covers a wide range of technologies, a number of special reports were prepared as supplements to the main report.

The study deals with the period from 2000 to 2030. The official Danish projections for the year 2000 have been used as the starting point for the study. In the study special emphasis was put on energy technologies related to the main distribution systems. In Fig. 3.1. an overview of the energy technologies which could play a role in the Danish energy system in the period 2000-2030 is presented, together with the three main distribution systems. The figure embraces both energy-demand and energy-supply technologies. In the study the prospects for the individual candidate technologies included in the figure were evaluated. The emphasis was devoted to new technologies presently at R&D level.

Although the prime subject of the study was the technological development in the energy sector, it is obvious that this development is strongly influenced by the general development in society at large. In Fig. 3.2 a number of factors influencing the technological development is illustrated, e.g. economic growth, energy prices, and population growth. These factors also influence the demand for energy and hence the possibilities for introducing of new energy technologies into the system.

The assessment of these factors for so distant a future is subject to great uncertainties. For that reason two different scenarios were analysed in the study. As the most drastic changes can be envisaged in a high-productivity society, both scenarios are based on an annual increase in productivity of 3 per cent. These two scenarios differ in that the productivity increase in the high scenariois used for consumption, whereas in the low scenario it is used for reducing working hours.

In order to evaluate the consequences, the two scenarios were simulated using the DES-model, described further in Section 2.1. The overall energy consequences are shown in Fig. 3.3. As can be seen the high scenario results in a moderate growth in energy consumption up to the year 2030, while the low one results in a decline in energy consumption from 2000 to 2030, with the demand in 2030 down to approximately the 1980 level. In Fig. 3.4 the relative gross energy consumption is shown - sector by sector - for the two scenarios together with the expectations for the year 2000. As can be seen in both scenarios, electricity will make up a higher proportion of the energy consumption in 2030.

The purpose of this study was to identify the more promising energy technologies in the period 2000-2030, with emphasis on those technologies which in an uncertain future represent robust

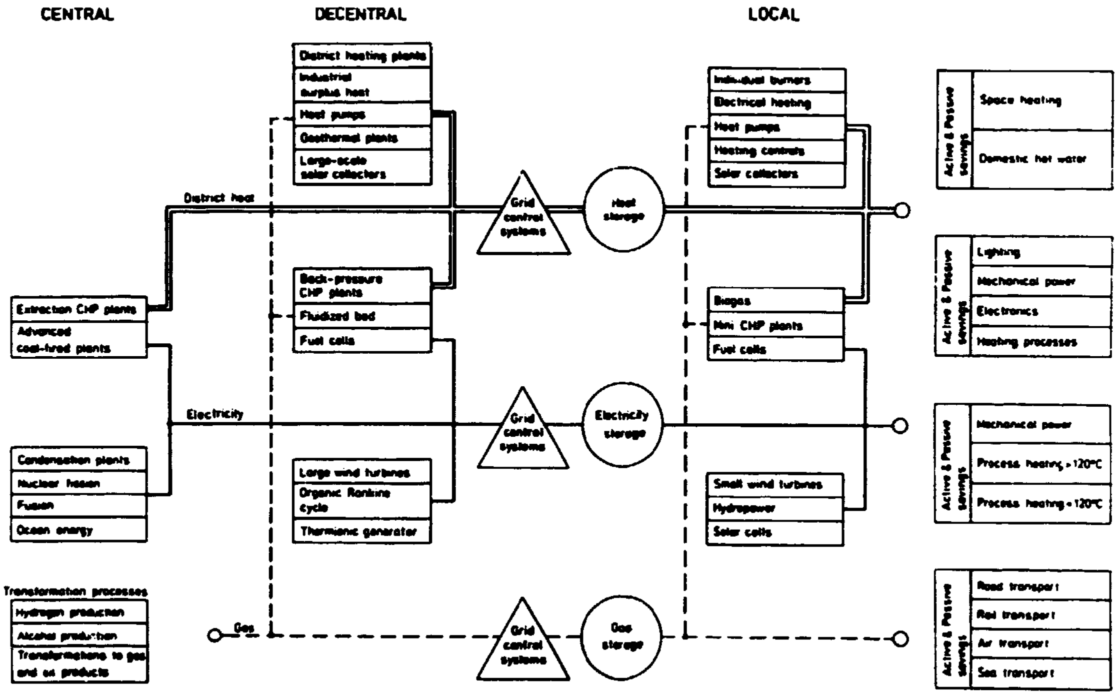



Fig. 3.1. Possible elements in the Danish energy system after the year 2000.

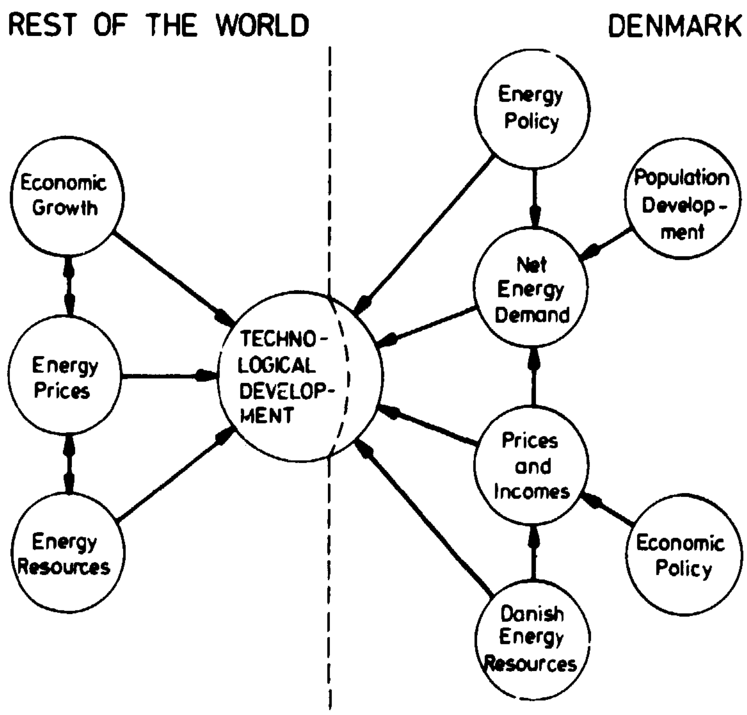



Fig. 3.2. Factors influencing the technological development.

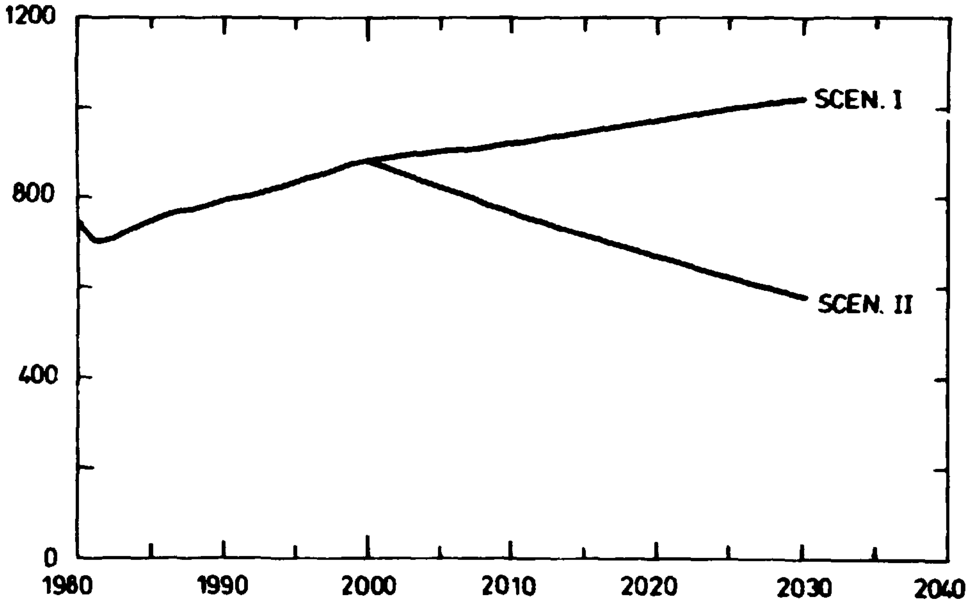



Fig. 3.3. Gross energy consumption in scenarios I and II (PJ).

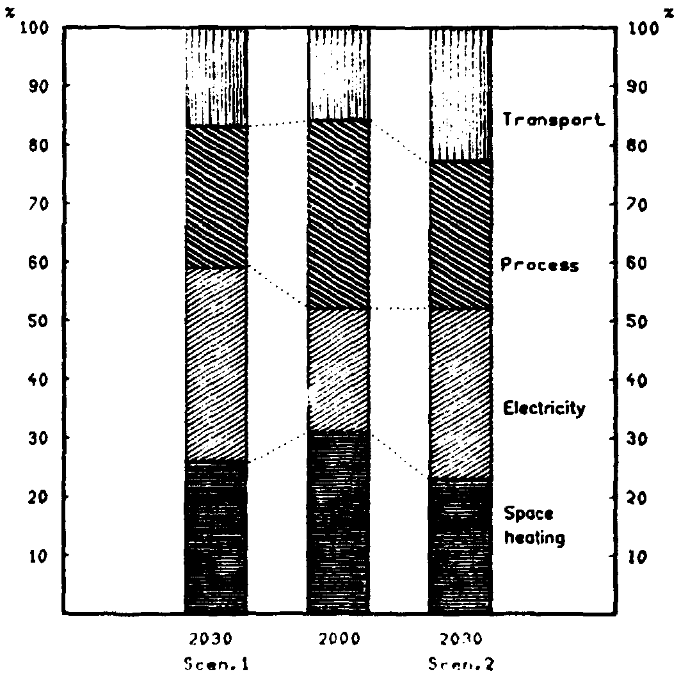



Fig. 3.4. Relative gross energy consumption by sector.

solutions, i.e. combinations of technologies, which within the span of developments suggested by the two scenarios result in a high system efficiency, and which accordingly are advisable possibilities regardless of how the future is shaped.

A general finding of the study was that a number of such robust solutions can be expected to become available. However, if the development follows the low scenario, long-term planning is necessary in order to secure the introduction of the new technologies.

Among the more specific findings of the study can be mentioned that efficiences for both demand and supply technologies are expected to be improved during the period. Similarly, increased use of indigenous resources, waste heat, etc. is expected, leading to higher complexity of the system. Furthermore, it was found that care must be taken in the space heating sector, as the market for piped energy, in that sector, could very well stagnate in the beginning of the next century.

It was also found that the development and use of sophisticated electronic equipment and energy storage facilities to regulate the shape of the demand curve must be encouraged, as these can lead to higher flexibility in the future energy system. As an example, the introduction of varying energy sources as wind energy and base load plants such as nuclear power are both facilitated hereby.

## 3.2. A technical-economic model for energy consumption by industry

Work on this model started in January 1984 and the model is planned to be operational by November 1985 so that results from the model are available and may contribute to the next energy plan from the Ministry of Energy.

The main objectives of developing the model are

- to analyse the development of industrial energy consumption over the last 15 years
- to formulate a model that converts forecasts of economic development to forecasts of industrial energy consumption.

Forecasts of economic development are obtained from the macro-economic model ADAM, which is the economic model used in most public planning. Given forecasts of economic development this energy model will produce forecasts for total energy consumption by industry split into 13 branches and four fuels.

The first task in developing the model was to define the split into the branches and fuels. In this connection preliminary analyses have shown that very large differences concerning both economic development and use of energy exist between the individual branches. This indicates a necessity to analyse branches rather than industry as an aggregate, and that a proper disaggregation into branches is essential for the model's ability to produce reliable forecasts. The criteria used for the grouping of branches are similarities in economic development and energy coefficients within branches.

The analysis of the historical development in the individual branches falls in the following two parts:

- a technical and economic description of the historical development and for which purposes energy is used
- econometric analyses to obtain relations that may be used for forecasting.

In the descriptions of the historical development it is analysed which technical and economic changes that have led to substantial changes in energy consumption, have major energy-saving technologies been introduced or have very energy-intensive productions, been introduced or shut down? Further, a status of energy use is presented and possible technical changes are indicated. Based on these technical and economic descriptions equations are formulated to determine the energy consumption as dependent on economic and technical variables. Among the typical explanatory factors are changes in the output level and the energy prices, investments in new technique and closing of energy-intensive productions within the branch. When the relevant dependencies are formulated and the equation specified it is estimated on data for the period 1966-80. Quite a number of different specifications are tested and finally the one that gives both interpretable quantitative dependencies (coefficients) and a reasonable explanation of the historical development are chosen.

At present the developments in six branches have been analysed, and it appears perhaps somewhat surprising that the reactions to the energy price increases in 1973 and 79 are very different. By far the largest part of the energy-savings observed immediately after the first rise in energy prices may be ascribed to changes in the production level and product mix. The energy savings after the second rise in energy prices appear to be a combination of changes in the product mix and the introduction of conservation technologies. The first preliminary conclusions from this analysis are therefore that changes in the product mix are critical for an explanation of changes in the industrial energy consumption, and that the introduction of energy-saving techniques were relatively unimportant before the second rise in energy prices.

## 3.3. Energy supply technologies for developing countries

In August 1984 a Ph.D. project was started in collaboration with the Laboratory for Energetics at the Technical University of Denmark. The main aims of the project are:

- to analyse the energy consumption and supply at end-use level in rural villages in a developing country,
- to evaluate different possible future energy supply technologies for individual end-uses focusing on local solutions, and

- to construct and test a model that can be used for planning and evaluating of future energy supply systems.

There are two main reasons for starting this project: One is that practically all oil-importing less-developed countries (LDC) are in a situation where problems concerring energy supply are greater than ever before. These problems manifest themselves as two different "energy crises", often connected with a "modern" energy sector and a "traditional" energy sector, although the distinction between the two may be misleading.

The "modern" energy crisis concerns the economy and security of supply of fossil fuels due to the rapid rise in oil prices, which has placed heavy burdens on the already indebted LDC's.

The crisis in the "traditional" sector is an internal crisis concerning the supply of fuel-wood and charcoal to the population in the rural areas and to the urban poor. Wood normally accounts for 50 to 90% of the total energy supply in LDC's, and this supply is being put under increasing strain by the rapidly growing populations and insufficient replanting. This leads both to shortages for the consumers and a growing deforestation which poses a severe threat to large areas of land, causing erosion and creating deserts.

These circumstances provide the background for a growing interest in energy planning and new energy supply technologies in the LDC.

Another reason for starting the project is ESG's experience in energy planning and the involvement in planning for rural areas in Denmark, where high priority is given to local available resources, mainly biomass and renewable energy.

A contact has been established with the Department of Energy in Zambia, who is expected, in 1985, to be involved directly in the project. This contact is strengthened by the recent assignment of one of ESG's staff members, to a position as energy advisor in the Department for a period of two years (on leave from ESG).

The project intends to present first an overview of the present national energy consumption and supply in Zambia, then focus on a rural district and perform detailed study and data collection in this district, examining the current energy use and supply at end use level.

Based on this knowledge about the present situation and estimates of the near future trends, possible future energy supply technologies will be examined, especially alternative electricity production possibilities are of interest to the Department. It is considered a very important part of the study to gain understanding of the social and economic relations of the local communities and what impacts new technologies may have on these relations.

The work on the project in 1984 consisted mainly of gathering information on general energy/development questions, specific existing and possible future supply sources and technologies and more country-specific data.

In addition, a great deal of effort has been devoted to establishing contact with both Danish and foreign researches working on related problems, and aid agencies as Danida and SIDA (Swedish International Development Authority).

## 3.4. Employment effects of energy conservation measures in EC countries

In 1983 and 1984 ESG took part in a European study on the employment effects of energy conservation as a subcontractor for the Fraunhofer Gesellschaft, Institut für Systemtechnik und Innovationsforschung, Karlsruhe, West Germany. The study was funded by the Commission of the European Communities (DG XVII).

The purpose of this study is to analyse the impact of additional technical measures for the rational use of energy and use of renewable energy on production, employment, income, and imports in four EC countries.

For Denmark, the following technologies were selected for the analysis: District heating supplied by CHP, insulation of residential buildings, heat exchangers for heat recovery, domestic solar hot-water systems, and biogas plants in agriculture.

The economic effects of the additional use of these technologies are analysed by means of an input-output analysis, based on modified versions of the official 1975 input-output tables published by the EC for each of the four countries. For the selected technologies the analysis includes both the positive effects of investements and operation, and the negative effects caused by the substitution of conventional energy technologies and decreased energy production and distribution.

Two scenarios have been developed to identify the additional energy saving potential for the period 1983 to 2000: A standard scenario assuming no additional government actions, and a maximum scenario with further government actions as part of an enforced energy demand policy.

The contributions by ESG have included:

- projections of the market potentials in the years 1990 and 2000 for the technologies, and the potential energy substitutions, investments and operating costs,
- interviews of firms that are producers or dealers to collect data on the input structures of the production and operation of the technologies, and
- compilation of the necessary statistical data on the development of prices, imports, exports, wages, employment, productivity, and operation surpluses since 1975 at branch level.

The work was completed mid-1984. A final report is expected to be published by the Fraunhofer Gesellschaft early in 1985.

# 4. ENERGY PLANNING

The Energy Systems Group has been involved in Danish energy planning for many years. In many of these activities the energy-economy models have been used extensively, and the use of the models for energy planning in Denmark and abroad has been the main objective for the development of existing and new models. This includes a Ph.D. project on an energy-rationing model for acute energy shortages.

A number of tasks within the field of energy planning has been carried out for the Ministry of Energy, The Danish Energy Agency, and The National Agency of Environmental Protection.

ESG took part in the work for the preparation of the Energy Plan 1981 (Ref. 1), which is the most comprehensive energy-planning activity to date. Subsequently, ESG has taken part in the efforts to update and improve the analyses and projections. The results of this work were submitted by the Ministry to Parliament as the Energy Reviews 1983 and 1984, and more detailed results were published as Status Reports on the Energy Planning (Ref. 2,3,5). This work includes the use of the DES-Model as a comprehensive database for projections and energy system data, as well as a simulation model for the total primary energy requirement and the costs of the energy system. The results of the project on evaluation of heating supply technologies in Area IV (see Section 4.1, below) is included in the Status Report 1984.

## 4.1. Evaluation of heating supply technologies in Area IV

During 1984 ESG has participated in two working groups set up by the Danish Ministry of Energy to study the space heating forms intended for the so-called Area IV, which is the part of the country scheduled to receive neither CHP-generated district heating nor natural gas, and subsequently will be supplied by single technologies or combinations of technologies. The work consisted of several tasks subdivided into two levels.

The work at the micro-level consisted of an evaluation of the single supply technologies, while the macro-level has consisted of the mapping of the heating demand and the local resources, and calculations of the overall consequences of different policies, etc.

ESG has worked intensively at the micro-level making calculations concerning profitability, foreign exchange, and employment for single supply technologies. Primarily, the supply technologies were oil and coal burners, different forms of resistant heating and renewables. These space heating forms were evaluated for new and existing dwellings and farmhouses.

Profitability was calculated at a public and a private economic level. At the public level the impacts of government subsidies, taxes, inflation, etc. were neglected, while they were taken into account in the calculations made at the private economic level.

Concerning the calculations of the related import and employment effects a special methodology was developed.

Each of the supply technologies are split into main components and the cost of installation is separated from those of materials.

Import quotas for different kinds of material are collected from relevant institutions and organisations and are used for calculating the direct import effects. The direct employment effects are calculated from the cost of installation.

The indirect effects on imports and employment are traced through the production system by applying import and employment multipliers (calculated by the Danish Statistical Office from the 1980 Input-Output table) from an industry that is relevant for the specific kind of material.

The final output of the model is a split of the investment costs into imports, employment in Denmark and gross operating surplus.

The first year employment effects of the investments in different space heating forms in new one-family dwellings (parcels) are shown in Fig. 4.1.

The work was completed by the end of 1984, and a final report is expected from the Ministry of Energy at the beginning of 1985.

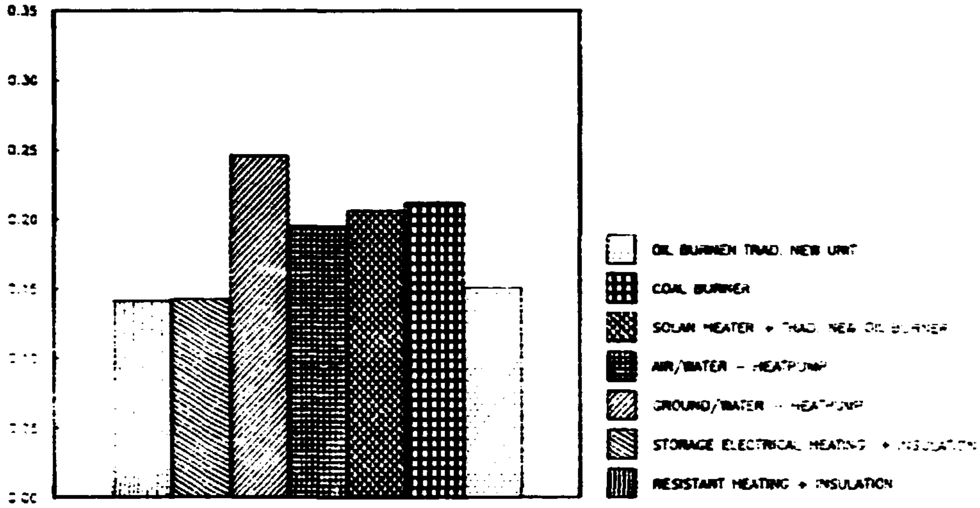



Fig. 4.1. The first-year employment effects of the investment in different space heating forms in new one-family dwellings.

## 4.2. Assessment of nuclear energy

By the end of 1984 the Ministry of Energy published a report on electricity generation based on coal or uranium (Ref. 4). At present about 95 per cent of the electricity generation in Denmark is based on imported coal, and the rest is based mostly on oil.

Like the previous assessments of nuclear power in Denmark, ESG took part in a number of working groups. In 1984 the main activities were contributions concerning the coal price forecast, the participation in the Working Group on the Economics of the Nuclear Fuel Cycle set up by the OECD/Nuclear Energy Agency, and a study of the impact of nuclear power on electricity generating costs.

The future coal price is the most important single parameter for the economic assessment of nuclear power in Denmark. The coal price forecast by the Ministry og Energy is based on the assumption that coal from the US East Coast will obtain price leadership in the long run, so the coal price in Denmark will depend on the production costs for these coal and the freight rates. The effect of uncertainties in these cost parameters for the coal price was analysed by ESG using the method described in Section 2.4.

The study of the electricity generating costs is divided into a study of the costs for a single unit and a study of the costs for the electricity generating system. The study of a single unit consists of the estimate of the cost components for a 900-MW light water reactor and a 600-MW coal-fired condensing unit, and the calculation of cash flows and discounted levelized cost per kWh from these units. The study of the electricity system consists of an analysis of the impact of the introduction of nuclear units into the Danish electricity generating system.

Like the previous studies, the DES-Model was used for the calculating cash flows for the total electricity generating system for a period of about 30 years. Alternative development plans are analysed, i.e. coal-fired plants only, and an appropriate mix of nuclear and coal-fired plants. This study, however, also included an analysis of the economic benefit of introducing a marginal nuclear unit on various assumptions for the future electricity generating system. If the costs of the nuclear unit during its lifetime are given, the benefit depends on the need for new capacity and the avoided costs of the electricity at the plant from which production is displaced by the nuclear unit.

A large and increasing part of Danish electricity production is cogenerated with heat for district heating with a marginal efficiency of around 80%, compared to 40% for condensing (electricity-only) production. Therefore two parameters are used to describe the impact of the electricity system on the avoided cost that is gained from a marginal nuclear unit, namely the load factor obtainable by the unit, and the part of the displaced electricity being cogenerated. These parameters are used for a sensitivity study of the benefit of a nuclear unit. The value of the parameters in various system situations are found using the DES-Model for a simplified simulation of a large number of situations and the SIMULACHRON-Model for a more thorough simulation of few typical situations (sections 2.1 and 2.2, respectively).

When using the discounted levelized cost method for the assessment of nuclear power it is assumed that the load factor equals the availability of the unit, and that no cogenerated heat and power is displaced. If cogeneration is displaced or the future electricity demand does not allow production from the nuclear unit at the scheduled load factor, the benefit of the nuclear unit will be smaller. This will occur if the electricity demand does not increase as expected, or if the nuclear capacity becomes too large.

The conclusion of the study is that a calculated benefit of a nuclear unit can be maintained for the first or second nuclear unit commissioned in Denmark around the year 2000, even within a large range of variation for the electricity demand. On the same assumptions, further investments in nuclear units will be unprofitable, if the electricity demand does not increase as expected.

## 4.3. Effects of Energy System Changes on the Emissions of $SO_2$ and $NO_x$

This project was initiated in 1983 by the National Agency of Environmental Protection in order to study the cost-effectiveness of reducing the emissions of $SO_2$ and $NO_x$ by measures such as energy conservation, increased efficiencies, and energy production with reduced environmental consequences.

For each type of measure a simplified economic assessment is made, in which a benefit of the reduced $SO_2$ emissions is taken into account using flue gas desulphurization (FGD) at large coal-fired power stations as a reference.

The assessments are based on the official forecasts of energy demand and prices until the year 2000 and the available studies of various measures and technologies. The measures include insulation of buildings, increased efficiencies of district heating grids, renewable energy, natural gas-fired CHP, more efficient use of electricity, etc.

Even though the avoided costs of FGD are small compared to fuel costs, and few measures not included in the official energy planning are economically attractive, the study shows, within the range of uncertainty, that there is a considerable potential for reduced emissions by measures that are economically acceptable.

The DES-Model was used to analyse the consequences of the implementation of these measures at national level.

A conservative result of these model calculations is that a 10 to 15 per cent reduction in emissions and fuel costs may be obtained through an appropriate combination of investments in this kind of measures and other modifications of the energy system (Ref. 6).

### 4.4. LINRAT - an energy rationing model for acute energy shortages

A Ph.D. project was initiated in May 1983 in collaboration with the Economic Instititute at the University of Copenhagen. The main purpose of the project is an analysis of the possibilities for an optimal allocation of scarce energy resources in the event of a short-term reduction in energy supply. The analysis involves the consideration of, for example, strategic reserves and rationing. It is planned that the result of the study will be a model which can be used to decide on the optimal allocation of energy resources according to a set of criteria defined by the user.

An energy-rationing model must operate on a highly disaggregated level, and therefore detailed information is needed about the various sectors in the economy. The model LINRAT is built as an input-output model in which a social welfare function is optimised under given constraints by the method of linear programming. As the energy shortage is assumed to last a short period, the technical coefficients in the model can be assumed constant.

In the present version of LINRAT the aggregated employment in the economy is maximised in the object function, where sector-based employment coefficients are multiplied by sector-based production values. The constraints in the model consist of an input-output account system, where the import is treated endogenously, i.e. as a function of domestic production. Further, the constraints consists of upper and lower bounds on the different final demand categories, production capacities and restrictions on imported energy products.

During 1984 LINRAT has been implemented on the Risø computer. Test runs have shown that the model is able to produce feasible as well as optimal solutions. Runs based on aggregated statistical material have been performed with the aim of generating a reference scenario, which reflects the undisturbed economy, i.e. the economy without acute energy shortage. The introduction of an acute energy shortage - implemented as a restriction on the import of an important energy product (e.g. oil) - has shown a lack in the treatment of the energy import in LINRAT. The present proportionality between domestic production and import of energy products has to be eliminated and substituted by a more flexible form.

At the present state LINRAT is based on 14 sectors/products. The official Danish 117 input-output sectors have been aggregated to

9 sectors - 4 non-energy sectors and 5 energy sectors. Two of the latter, "Oil, coal and gas" and "Refineries", have been further split into products using detailed statistical data from energy balances. This split enables an analysis of the possibilities of substituting between alternative products and to reach final demand based on energy products rather than energy sectors.

## 4.5. Security of supply

In order to study the consequences of decreasing supplies, a model that describes the use of energy in Denmark has been developed. The work was carried out for the Danish Energy Agency.

The Danish energy system is treated in the following way:

- The consumers are grouped in four energy-consuming sectors: space heating, households, industry etc., transport, and a non-energy sector (lubricating oils, asphalt, etc.). Most of these sectors are subdivided. The total number of subsectors is 24.
- The energy-conversion is assumed to take place at power stations including CHP-plants, at district heating plants including refuse incineration, at gasworks, and at refineries.
- The energy is represented by various types of oil products, coal, natural gas, wood, etc., and by the converted energies like heat, electricity, and town gas. Furthermore, in some cases a distinction is made between fuels with a storage obligation and those without. In all, 13 fuel types are modelled.
- The conversion and transmission of energy are characterised by efficiencies.
- To each fuel type an import rate is assigned together with the magnitude of the storage for those with a storage obligation.

The model is interactive, and during the execution the user is asked to specify possible changes of

- fuel imports

- energy use in various subsectors, substitution, or rationing
- fuel storages

whereafter the model will calculate the number of days elapsed from the beginning of the changes until the storages run out.

At present the model is used routinely at the Danish Energy Agency, e.g. to estimate the consequences of various supply shortages.

## 5. PUBLICATIONS AND LECTURES

### 5.1. Publications

N.E. Busch, P.S. Christensen and H. Larsen, De kommende årtiers energimæssige udvikling og fremkomsten af ny teknologi/Trends in the energy sector and the development of new technologies. Seminar om introduktion og markedsføring af nye energiteknologier, 26-27 September 1984, København, (Nordisk Ministerråd, 1984). 21-48.

P.S. Christensen, J. Fenhann, N.A. Kilde, H. Larsen and P.E. Morthorst, Den teknologiske udvikling og dennes betydning for udformningen af det fremtidige energisystem/Long-term prospects of energy technologies, Risø National Laboratory, April 1984, 312 pp. + 2 app.

P.E. Grohnheit, Reduktion af $SO_2$- og $NO_x$-emissioner ved ændringer i energisystemet/Reduction of $SO_2$ and $NO_x$ emissions through modifications of the energy system, (Miljøstyrelsen, forthcoming February 1985).

H.V. Larsen, *SIMULACHRON* - a simulation model for a combined heat and power production system, Risø-R-508, Forthcoming.

K. Møllenbach & P.E. Grohnheit, The European Natural Gas Outlook, Paper presented at the Eight Annual International Scientific Forum on Energy: Energy a Non-Issue, The Consequences of Being Wrong. 26-30 November 1984, Fort Lauderdale, Florida, USA. (to be published)

L.H. Nielsen, Nogle metoder til at anskueliggøre usikkerheder som forudsætninger for offentlige beslutninger på energiområdet/ Ways of presenting uncertainties as the basis for public decisions in the energy field, In: Energiplanlægning under usikkerhed/Energy planning under uncertainty, Seminar held March 1984 (Nordisk Ministerråd, 1984). 13-24.

E. Pløger, Input-Output Analyses of the Changes in Energy Consumption in Danish Industries 1966-79. In: Proceedings of the Fourth IIASA Task Force Meeting on Input-Output Modeling, held at Laxenburg, September 29-October 1, 1983. Ed. by A. Smyshlyaev, (IIASA 1983) 251-266.

B. Villadsen, MEDEE 3. Præsentation og anvendelse af den langsigtede energiefterspørgselsmodel/ MEDEE 3. A presentation and application of a model for long-term energy demand evaluation. Risø-M-2465.

## 5.2. Lectures

H. Larsen, Introduction to Alternative Energy Technologies, World Bank, Washington D.C. 8-11 October 1984.

E. Pløger, The Effects of Structural Changes on the Danish Energy Consumption. Fifth IIASA Task Force Meeting on Input-Output Modeling, Laxenburg, Austria 3-6 October 1984.

## 6. STAFF

Leader:
Hans Larsen M.Sc. (DtH*), Ph.D. (DtH)

Graduated in 1970 from the Technical University of Denmark as M.Sc. in Electrical Engineering. 1970 postgraduate student at Risø, Ph.D. in Reactor Physics in 1973. From 1973 to 1976 seconded to the OECD High Temperature Reactor Project, Dragon, at AEE Winfrith, Dorset U.K. 1976-80 at Risø National Laboratory working with systems reliability and reactor core performance. Head of the Energy Systems Group from July 1980. Member of a number of national and international committees:

Advisory group on long-term energy planning - the Danish Ministry of Energy, Danish National Committee of World Energy Conference, reference group on energy planning for the rural areas in Denmark - the Danish Ministry of Energy, steering group for solar energy R&D - the Danish Ministry of Energy. In 1984 involved in project on long-term prospects of energy technologies.

Deputy leader:
Poul Erik Morthorst M.Econ. (Århus)

Economist specialised in general energy planning and econometric forecasting. Research assistant at Institute of Economics, Århus University from 1976 to 1977. Joined ESG in June 1978. Main activities within ESG include general governmental energy planning, especially forecasting of electricity demand, and the implementation of the CEC medium-term model. Working on the economics of renewable energy and member of advisory group set up by the Ministry of Energy to study renewable energy in rural communi-

*The Technical University of Denmark

ties. Took part in the project on long-term prospects of energy technologies. Member of an internordic working group concerned with uncertainties in energy planning. Substitute member of the CEC working group on "Information on Energy" set up by DGXIII.

Permanent staff:

Frits Møller Andersen M.Econ. (Århus)

Economist specialised in computer modelling and econometrics. Worked as teaching assistant in the Institute of Statistics, Århus University and as economic planner in local government before joining ESG in May 1980. Main activities within ESG consists of the development, implementation, and use of econometric models for energy demand forecasting, in particular the development of the macrosectoral model. In May and June 1984 visiting research fellow at the Energy Systems Research Group at the University of Stockholm. During the visit alternative consumer demand systems were tested for Sweden and for Denmark, and final estimations for some dynamic inter-fuel substitution models were performed.

Peter Skjerk Christensen M.Sc. (DtH)

Physicist with previous experience in reactor physics, fluid mechanics, and thermodynamics in the Reactor Technology Department, Risø, before joining ESG as a founding member. Activities within ESG include modelling of electricity and heat production and transmission systems, modelling of total energy systems, and maintaining an up-to-date knowledge of the construction and operation of power reactors and the nuclear fuel cycle. During the last year primarily engaged in the study of the security of supply and the study of the long-term prospects of energy technologies.

Jørgen Fenhann M.Sc. (Copenhagen)

Physicist with mathematics and chemistry as subsidiary subjects. After 1 year of teacher training tought at high school and DtH. Since July 1977 worked on the CEC energy supply model EFOM, first with the Niels Bohr Institute, University of Copenhagen, and since November 1978 with ESG. Activities within ESG include energy studies involving wind power, long-term technological forecasts, energy for rural areas and energy statistics.

Poul Erik Grohnheit M.Econ. (Copenhagen)

Economist, before joining ESG worked with the Danish Buildings Research Institute (1969-71), as a town planning consultant (1971-72 and 1979-80) and on economic planning in local government (1973-79). Joined ESG in May 1980. Activities within ESG include the development and use of the DES-model, economic assessment of nuclear power, and economic and environmental consequences of energy system changes.

Niels A. Kilde M.Sc. (DtH)

Graduated in 1962 as chemical engineer with special emphasis on metallurgy. From 1962 to 1981 employed at the Danish Steelworks Ltd., Frederiksværk as deputy manager in the laboratory (1962-67), personal assistant to the technical director (1967-72), head of planning and implementation of new continuous casting plant and department manager for production (1972-77), and finally development and energy manager. Joined ESG in September 1981. Activities include long-term energy planning, coal technology and industrial energy use. Member of the Danish Energy Ministry's steering group for energy R&D in industrial processes.

Helge V. Larsen M.Sc. (DtH), Ph.D. (DtH)

Graduated in electronic engineering in 1974 and subsequently worked as a university demonstrator at DtH and as an electronic engineer in industry. Joined Risø National Laboratory in 1976, engaged in computer modelling of radiation heat transfer in BWR fuel elements with the Reactor Technology Department. Later worked on Nordic project on modelling of district heating systems, based at Studsvik Energiteknik, Sweden.

As Ph.D. thesis the simulation model SIMULACHRON for the operation of a CHP production system was developed. Besides further work on this model, currently involved in the development of a simulation model for integrated local energy systems.

Gordon A. Mackenzie B.Sc. (Edinburgh), Ph.D. (Edinburgh)

Physicist with a background in experimental solid state physics. First came to Denmark in 1974 to take part in neutron beam experiments, then spent 2 years at Risø, 1976-78, on postdoctoral project supported by the British Science Research Council. After one year as lecturer in physics at Edinburgh University, 1978-79, returned to Risø as guest researcher in Physics Department. Joined ESG in February 1980.

Presently on leave from Risø and working as special advisor to the Director for Department of Energy, Ministry of Power, Transport and Communications in The Republic of Zambia.

Helle Trøst Nielsen B.A. (Copenhagen), M.Sc. (DtH)

Graduated in 1984 from the Technical University of Denmark as M.Sc. in Electrical Engineering and from the University of Copenhagen with French as a subsidiary subject.

Worked as teaching assistant during period of study. Worked as engineer trainee in France and Canada during summer holidays 1982 and 1983, respectively.

Lars Henrik Nielsen M.Sc. (Copenhagen)

Physicist with mathematics as subsidary subject. Master's thesis described a model for a solar district heating system with a central heat storage. Worked as high school teacher and teaching assistant at the University of Copenhagen during period of study. Joined ESG in August 1981 as research fellow, becoming a permanent staff member in 1983. Main activities include the assessment of energy technologies, taking into account uncertainty, forecast modelling and the study of employment effects of energy conservation.

Ellen V. Pløger M.Econ. (Copenhagen)

Economist specialised in economic modelling and econometrics. Worked in the Danish Statistical Office on national accounts, energy balances and input-output models before joining ESG in November 1982. Main activities within the Group are input-output analyses of energy consumption in industries, studies of employment and import effects of energy technologies and the development and implementation of the CEC Macrosectoral Model (HERMES).

Bente Villadsen M.Math.-Econ. (Århus)

Mathematical economist specialised in modelling (econometric and operations research). During period of study worked as teaching assistant in mathematics for economists. Member of the board of the Danish Operations Research Society and editor of the Society's newsletter. Joined ESG in May 1984. Main activity within the group has been operation and maintenance of the long-term energy demand model, MEDEE3.

Postgraduate Students:

Jesper Munksgaard Pedersen M.Econ. (Copenhagen)

Graduated in 1983 from the Institute of Economics of the University of Copenhagen. Master's thesis on public investment criteria. Joined ESG as postgraduate student in May 1983 on a Ph.D. project concerned with analysing the possibilities of allocating scarce energy resources in an optimal way and constructing an energy rationing model.

John Møbjerg Christensen M.Sc. (DtH)

Graduated in 1980 as a civil engineer specialised in planning methods and practical applications. Worked from 1980-83 at the National Agency of Technology on planning and initiation of research and development activities especially within the energy area. From 1983 to 84 employed by a consulting firm as project leader and participant in projects on energy planning and renewable energy sources. Joined ESG in August 1984 as a postgraduate student on a project concerned with energy planning and new energy technologies in developing countries focused on rural villages.

Consultant:

Peter Laut, Professor, Engineering Academy of Denmark.

Programmer:

Søren Præstegaard

Secretaries:

Jette Larsen
Irma Strandvad

Temporary assistents:

Søren Theill Jensen M.pol.sc. (Copenhagen)
Karin Meyer Nielsen Librarian

Undergraduate assistant:

Jesper Schmaltz-Jørgensen

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