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ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROJECT


Final Report

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November 1987
Disclaimer:

This report presents results obtained in an international energy systems analysis study and does not reflect the official view of any governments or international agencies.
ABSTRACT

The objective of Annex II (July 1983 – June 1986) was to carry out a continuous exchange of information related to energy modelling, energy systems analysis and energy technology assessment in order to share experience, stimulate co-operative studies and benefit from common analysis.

The means were:
- exchange of reports, memoranda etc.
- periodic workshops or seminars
- maintenance of the MARKAL model including consultative services of the Operating Agent
- preparation and distribution of a periodical newsletter
- meetings for establishing new tasks.

ETSAP Annex II had the character of a minimum common effort to maintain the model and a common discussion forum. The main effort during 1984 was the performance and evaluation of sensitivity analyses with updated price and demand assumption for 6 representative IEA countries, which study was launched in order to provide updated Systems Analysis (SA) input to CRD discussions on the Energy Technology Policy Study.

A Summary report on this study by the Norwegian ETSAP participant was distributed including to CRD-members. (J. Nitteberg: Some Results of the ETSAP Update Runs.)

In 1985 and 1986 a proposal for a continuation of ETSAP was elaborated. The main subject: Environmental aspects of the energy system.

During Annex II of ETSAP the main results lie in the studies made by the individual countries which will be reported in the following chapter.

Briefly, the benefit of the ETSAP collaboration up to now is probably mainly to be found on the national level, in the same way as most IEA collaboration on energy technology development.
KURZFASSUNG


- Austausch von Reports, Memoranden etc.
- periodische Arbeitstreffen oder Seminare
- Wartung des MARKAL-Modells einschließlich Beratung und Unterstützung durch den Operating Agent
- Vorbereitung und Verteilung eines periodischen Newsletter
- Meetings zur Festlegung neuer Aufgaben.

ETSAP ANNEX II hatte den Charakter eines gemeinsamen Diskussionsforums und eines minimalen gemeinsamen Bemühens, das MARKAL-Modell einsatzfähig zu halten.


Kurzgefaßt liegt der Nutzen der ETSAP-Zusammenarbeit hauptsächlich auf der nationalen Ebene, in gleicher Weise wie in den meisten IEA-Kollaborationen im Bereich der Energietechnologieentwicklung.
Acknowledgement

This report was assembled by the combined efforts of many individuals from 14 countries. Based on their contributions the Operating Agent of ETSAP at Kernforschungsanlage Juelich (Günter Giesen, Gerhard Kolb, Heinz Vos) prepared a final draft of the report. Taking into account the numerous comments and contributions concerning that draft the Operating Agent edited the final version of the report.

The Operating Agent of Phase II would like to acknowledge gratefully that a careful reading of the former draft by Dr. Doug Hill, BNL, has led to removal of many typing errors and of some inconsistencies and in particular to a considerable improved English wording of the Final Report chapters.

Especially the Operating Agent would like to thank Mrs. Christel Schnitzler who conducted the typing of the report and its many corrections with engagement, with care and with never ending patience.
FOREWORD

Our understanding of the relationship between environment and energy systems has changed significantly over the past fifteen years or so. After the oil shock, during the early 70s, it was generally believed that a perhaps difficult choice had to be made between energy security and environmental quality. If the choice was energy security, the price to be paid would be in terms of lower environmental quality, and if environmental protection was the objective, the very policy aimed at reducing vulnerability in energy supply would suffer, or at least be delayed.

As the 70s and the 80s unfolded, our understanding of the complex relationship between environment and energy systems came into a sharper focus. One of the most important perceptions that has emerged during the past decade is that environmental policy and energy development are closely interrelated, and the Energy Technology Systems Analysis Project (ETSAP) is moving along this direction, although focus mainly concentrates on emissions into the atmosphere. International collaboration may help in identifying the optimum energy strategy while promoting the concept of environmentally sustainable energy development, a concept which means energy security without environmental disruption.

It is now generally accepted that energy development cannot be sustainable without explicit consideration of its impacts on the environment, and similarly a good environment and quality of life cannot be easily achieved without appropriate energy development. Furthermore, the problems set by interactions between energy and environment increasingly require a global view. Two facts concur in this perspective. On the one hand, a multiplicity of energy options seems to lie before us as a result of technological progress and advancement. These energy options can be deployed into the market and made available in the different social and economic contexts without facing major trade barriers.
On the other hand, the environmental impact associated with most energy technologies also entails long-term and large-scale effects that must be appraised and coped with through an international effort.

Several of these issues form the basis for this report which completes the work under Annex II of the Project. The report is in two parts. The first part describes the history of the project and refers to the state-of-the-art and the use of the MARKAL model in the programmes of fourteen countries and the Commission of the European Communities, participants in the Project. The second part deals with selected studies on subjects such as value flow analysis for energy technologies, links between energy and economic policies, environmental aspects of energy use, regional and urban planning.

The report is based on the material prepared by individual countries and collected by Kernforschungsanlage Juelich (KFA) which acted as Operating Agent. Specials thanks are due to Dr. Heinz Vos (KFA) for the organisation of the printed material, to Dr. Gerhard Kolb (KFA) for the final editing and to Dr. Douglas Hill of Brookhaven National Laboratory for his proof-reading.

Sergio F. Garribba
Director
Energy Research, Development and Technology Applications
International Energy Agency

20th November 1987
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1. Historical Background of ETSAP

The development of the analytical tool, the MARKAL model, as well as the preparation of input data and the analytical work for the "IEA group strategy for energy research, development and demonstration" (the Group Strategy) were carried out during 1976 to 1979 by two multinational analysis groups hosted by Brookhaven National Laboratory (BNL), USA, and Kernforschungs-anlage Jülich (KFA), Germany. During the completion of the work, a consensus emerged within the CRD, that

- the methodology and model were worth implementing in member countries

- the methodology and model needed improvement and further validation, which had to some degree been neglected during the preparation of material for the Group Strategy

- a multilateral analysis capability ought to be maintained

- a concentration of the common activities to only one host laboratory was preferable.

16 member countries and CEC participated in the following Annex I (December 1980 - June 1983). Operating Agent: KFA Jülich. Common costs: 400 000 DM/annum (1980 prices). The originally agreed duration, two years, was extended with 7 months, in order to provide time for completion of all reports.

At the end of ETSAP Annex I, the following main results were achieved:

- The MARKAL model and analysis technique were implemented and validated in 14 IEA countries.

- A users guide for MARKAL was completed. (BNL-Report 51701, July 1, 1983).
An expanded and revised technology data base was prepared and edited. (KFA/STE-Report No. 30, December 1982).

Various national analysis runs were performed, and in addition a few runs with common scenarios concerning fuel price and energy demand were carried out. Conclusions, both national and aggregated, were presented in the report "Energy after the Eighties" (Restricted edition by KFA in January 1984, published by Elsevier in 1984 as "Energy Research 6").

The total average manpower effort of Annex I in addition to the Operating Agent - was at a rough guess - 7 person-years per year.
2. Character of Annex II – Highlights of Work

The objective of Annex II (July 1983 - June 1986) was to carry out a continuous exchange of information related to energy modelling, energy systems analysis and energy technology assessment in order to share experiences, stimulate co-operative studies and benefit from common analysis.

The means were:

- exchange of reports, memoranda etc.
- periodic workshops or seminars
- maintenance of the MARKAL model including consultative services of the Operating Agent
- preparation and distribution of a periodical newsletter
- meetings for establishing new tasks.

ETSAP Annex II had the character of a minimum common effort to maintain the model and a common discussion forum. It did not include any common runs for all participants as in Annex I. It assumed that the participants have some domestic activity, but it did not contain any commitment for national contributions other than the fee to the Operating Agent (KFA Juelich), about 15 000 DM per year and participant.

Four workshops have been arranged: in March 1984 in Tokyo, in October 1984 in Paris, in November 1985 in Jülich, and in April 1986 in Vienna; the ETSAP Newsletter has appeared; discussions have taken place concerning a proposed new collaboration in the field of energy – economy interaction. However, such a task has not attracted enough interest to motivate a new Annex.

The main effort during 1984 was the performance and evaluation of sensitivity analyses with updated price and demand assumptions for 6 representative IEA countries, which study was launched in order to provide updated Systems Analysis (SA) input to CRD discussion on the Energy Technology Policy Study.
A Summary report on this study by the Norwegian ETSAP participant was distributed including to CRD-members. (J. Nitteberg: Some Results of the ETSAP Update Runs.)

In 1985 and 1986 a proposal for a continuation of ETSAP was elaborated. The main subject: Environmental aspects of the energy system.

During Annex II of ETSAP the main results lie in the studies made by the individual countries which will be reported in the following chapter.

Briefly, the benefit of the ETSAP collaboration up to now is probably mainly to be found on the national level, in the same way as most IEA collaboration on energy technology development.
3. Outlook for Proposal Annex III

Annex III and the proposal for Annex III were already available in their approved form at the time of the final report drafting. Therefore this chapter contains the proposal as approved. Annex III itself with the definitions of the activities is enclosed in the Appendix.

Proposal for Annex III:

1. Technology Characterizations

In the proposed International Forum for Energy Environment Studies (FEEST)-Project, it is a prerequisite that all technologies entering the present and future Reference Energy Systems should be characterized nationally with respect to their environmental emissions. This means specifying for each technology the emission coefficients of the pollutants of concern, which should include NOx and SO2. The emphasis on environment also means that new kinds of technology must be characterized, which fall into two classes, namely

1. Abatement technologies which clean up the potential emission. One example among many is flue gas desulphurization

2. Avoidance technologies which reduce the level of emission either by fuel switching or by novel technology, e.g., low temperature burners, high efficiency gas turbines (including abatement), renewable energy, air separation.

Characterized technologies are built into the MARKAL database by individual analysts, who also have technical or modelling difficulties to overcome, such as how to deal with the non-linear characteristics of fuel mixing technology, or how to model those abatement technologies that are retrofitted. We see a need for review of the databases for the mutual improvement of national data.
Such a review should cover:

1. The numerical data themselves, i.e., the technical and economic characteristics of the technologies themselves, with priority to abatement and avoidance technologies.

2. The Reference Energy System structures employed. This review would help to deal with the methodological difficulties referred to above.

3. Shortcomings in the levels of aggregation of technologies within sectors, which often occur because analysts have been unable to obtain suitable data.

The review and subsequent information exchange should aim to help with the individual national studies by filling the gaps in their knowledge or by improving the level of detail and realism of their models.

It would be a primary task of the Operating Agent to perform such reviews and to disseminate knowledge of the national differences and recommended improvements, promoting where necessary bilateral contacts between participants.

National data may also incorporate institutional items such as legislation on standards of emission for certain technologies, or other controls or constraints, which would form a useful part of the information exchange. To make this and other features clear it is most important that databases, (including Reference Energy Systems), submitted for review should be fully documented so that the origin of data, the reasons for structures, and thence the origins of difference can be understood with the minimum of effort on the part of the Operating Agent. In the light of the findings during the reviewing process, especially the problems encountered, the Operating Agent should be in a position to promote efficient information exchange, for example, by planning part of the agenda and timetable of Forum meetings or workshops.
2. Methodology of Environmental Analysis

All the phenomena that involve energy-environment interactions, beginning with energy service demands and ending with environmental consequences, could not possibly be comprised within a single model. The MARKAL model - the common methodology for the ETSAP group and hence this proposed ANNEX III - which is representing the entire energy system of a country can trace source of pollution and thus enables overall accounting of these pollutants related to energy technologies. Together with the results provided on total system costs, this allows for assessment of the additional costs required to meet certain environmental protection goals, the so-called trade-off.

The MARKAL model integrates the energy system across all demand sectors, from resource extraction to end-use, including energy production, conversion, transportation and conservation. It optimizes across energy sectors. The value of this is illustrated by the NOx problem where the sources include power plants, industrial plants, residential and commercial devices and automobiles. If the problem is to reduce NOx emissions at least cost, models of individual sectors won't do it.

The resulting information provides the necessary insights in the impact that environmental protection measures impose upon the energy system as a whole, including fuel switching, additional installation of abatement technologies, etc. The results can also feed other types of models that describe transport and precipitation of pollutants on a detailed regional and/or local scale. It is proposed that trade-offs between the cost involved and the associated emission reduction are made. These costs can be compared with the benefits of reducing the damage caused by environmental pollution. The performance of energy technologies under varying levels of emission control provides valuable information for the establishment and evaluation of energy R, D&D programmes.
Individual countries have studied the consequences of progressively reducing SO2 and NOx emission levels in national energy systems. Using MARKAL these reductions can be brought about by setting explicit limits on overall, sectoral or even plant-specific emissions. Another possibility is the introduction of penalties on emissions and consequently forcing their reduction on "financial" grounds.

These studies are not sufficient for an inter-country comparison of the value of various options, because of using different methodologies, models and not fully consistent databases. The international community would however benefit by understanding the options available to each country and their sensitivity to various assumptions. This information is not available from individual country studies as presently carried out.

The proposed ANNEX III would collect and compare the national options and discuss their detailed contents, making full use of the well established common methodology and analyzing capabilities associated with the MARKAL model. Although the concept is the same everywhere, the structure of MARKAL is flexible and differs between countries. Where differences appear, explanations would be given, based on detailed understanding of the structure of the energy system and assumptions involved, for example by investigating the best combinations of fuel and/or technology options under a range of environmental constraints. International review will help to further improve the model representation of the national energy systems. A further topic concerns additional pollutants produced by abatement technologies themselves. The handling of all pollutants, both by accounting and by specific reduction, can be carried out with MARKAL.

3. Transfer and Validation

Experience in previous international studies has shown very clearly that there is little or no interest in so-called "common scenarios", by which is meant the definition of common
fuel price and technology assumptions to be applied in all national studies. A useful comparability of national analyses is rather to be derived by a co-operative approach which makes the national data structures and related assumptions very explicit, and which rationalizes or justifies their inevitable differences. The emphasis here is on understanding the messages of the analysis; it is a new emphasis for this kind of work and will greatly increases its value both from a global viewpoint and to the participating nations. By nature it is an analysis of long-term developments with focus on the environment, following the trajectories of energy systems from the present day to their possible future states.

The type of results from the national analyses includes the allocation of energy technologies and abatement measures under different emission and/or cost restrictions. To win acceptance of these rather complex results, it is necessary to include experienced people from ministries and energy companies beginning with the first stage of the analysis. The work on validating the methodology and transferring the result therefore includes both the setting up of reference groups as well as the development of technical tools for the transfer.

A first step in the development of these technical tools would be the preparation of national, MARKAL style, Reference Energy Systems. Comparison of these and their associated data would enable the dissemination and widespread adoption of the best model substructures, e.g., for emission control options. The aim here is to ensure a comparable and appropriate degree of flexibility for technology switching and trade-offs within the substructure.

The ideas, the assumptions, and the results are communicated on four levels:

- on the national level between the system analyst and the national decision makers and experts;
on a formal international level (IEA annual energy-environmental forum);

- informal international co-operation about software and modelling problems and comparison between different models and methodologies;

- improvements of informal international contacts between researchers.

In order to ensure effective communication on these four levels, the following steps should be taken.

1. The set-up of a reference group within each country. This should be the responsibility of the individual system analyst.

2. The set-up of the International Forum for Energy Environment Studies by the IEA. The Forum would convene annually for three years to draw together, compare and analyze the national studies in progress.

3. The nomination of an Operating Agent (OA) to help the IEA to prepare the annual FEEST, to improve the information exchange by publishing a Newsletter, to organize modelling workshops, to coordinate the project activities in general and to take a leading role in the report preparation and in the development of technical tools.

The FEEST results would build a common understanding of the issues and trade-offs with full respect for real national differences. The aim is to bring about effective information exchange while producing material of interest.
4. **Country Activities in General**

The activities in the field of energy technology systems analysis within the participating countries vary due to the area of special interest, funding and know-how available. The following subchapters describe briefly the situation in the participating countries.
4.1 Austria

In order to provide an analytical basis for the National Energy Concepts 1984 and 1986 the Austrian Ministry for Trade, Commerce and Industry initiated an energy system analysis project in 1983. MARKAL, implemented at Energieverwertungs-agentur (E.V.A.) was readily adapted to describe the national energy system of Austria and its potential future developments.

In explaining the MARKAL to non-systems analysts, the difference between old energy forecasts versus new Energy Concepts has been stressed:
- old energy forecasts concentrated mostly on quantity, (i.e. supply shortages) and costs
- new Energy Concepts concentrate on reducing costs, environment, preferred mix of energy types and technologies and the importance of goals and choice in energy policy.

The MARKAL-approach provided a practical framework for looking at the new energy concept and allowed to organize many working groups who provided inputs to the model and expert analysis in their fields. These working parties contributed in the areas of technology characterization, scenarios for supply and price of energy in the future, demand scenarios, environment parameters, and scenario definitions.

The model results in the 1984 Energy Concept were quite plausible and were positively received politically, by the public and by the scientific community. Following this effort it was envisaged that to provide independent support to decision makers the systems analysis work would continue. Soon after presentation of the Energy Concept 1984 to Parliament support for the systems analysis work died out. The contribution for the Energy Concept 1986 was done on the basis of the updated 1984 data inputs requiring little additional effort.

The study has been shown to be an isolated effort by dedicated individuals defining the energy & environmental policy issues properly but has not lead to an ongoing support for such efforts despite the increased awareness of the problems by the public.

(J. Kaniak of ÖIR, E. Pöritz of E.V.A.)
4.2 Belgium

4.2.1 Actual Status

In Belgium the MARKAL model is implemented at CORE (Prof. Y. Smeers). Since the "Energy after the Eighties" study it has not been used. For the moment no personnel are allocated to this model so that its database has become outdated. Long term R & D Studies and investment planning are temporarily taken care by two other LP - supply models: EFOM and MPN. From 1985 on these supply-models and other energy models will also be implemented at the Ministry of Science (Energy Modelling Unit).

4.2.2 Research work which can be of interest for MARKAL-developments

4.2.2.1 Energy-Sector Models

Historically, Belgium has made use of 3 different energy supply models: MARKAL, EFOM and MPN. The EFOM model (developed in EEC framework) (1) is a RESOM-type of model in which the graphical representation of the flows in the energy sector serves as the guiding principle for the modelisation.

The MPN model (financed by the Ministry of Science) (2) is in fact a set of detailed sector models (oil, gas, electricity, coal, advanced coal...) which can be used independently or in any combination depending on the problem at hand. It is used for investment-planning in the energy sector.

The main differences between MPN and the EFOM and MARKAL models are:

a) in MPN no common representation principle is used for the different energy sector models except those necessary for the link between sectors;

b) in MPN the demand processes (except the steel industry) are replaced by external process and econometric models.
A methodological comparison of the three models can be found in a paper by SMEERS (3). It is clear that the comparison of three different supply-models is fruitful for a better representation of the energy system in the three models and for the appropriate choice of the aggregation level. To cite one example: the petroleum sector model of MPN has served as a basis for an improved representation of the petroleum sector in EFOM.

On the software side CORE (work by AMBROISE & SMEERS) has started developing a model generator in OMNI which should be capable of generating from a common database the EFOM-12-C, the MARKAL and the MPN-model (EEC-contract). Compared with existing products the main advantages will be

- complete flexibility in the decomposition of the horizon
- complete flexibility in the selection of processes with annual, seasonal and hourly operations
- corresponding flexibility with energy commodities
- flexibility in the decomposition into seasons and daily divisions
- time lag in input and output
- processes with several operating modes
- processes with variable inputs and outputs.

4.2.2.2 LP Optimisation Software (CORE)

The extension of MARKAL and other energy-sector models leads to large-scale LP problems. To increase the solution speed and the maximum size of LP's two decomposition codes have been developed: DECOMPSX for bloc-angular matrix structures and LIFT for bloc-triangular matrix structures (5). LP's with a size of 18000 constraints have already been handled by this software.
4.2.2.3 Integration of Supply and Demand Models (Partial Equilibrium Framework)

A methodological discussion of these integration issues can be found in BOUCHER & SMEERS (4). Research is going on in the following domains:

- coupling energy supply models with disaggregated LP process models for demand sectors (by decomposition methods)
- coupling energy-supply models with econometric demand models
- generating reduced demand models by using process models in simulation version
- coupling energy-supply models with simulation models (e.g., MEDEE)
- coupling of supply and demand models with departures from marginal cost pricing (revenue constraints in energy sector, non-linear pricing schedules etc.)

4.2.2.4 Integration of Energy-Sector Models and Models for the Economy (General Equilibrium Framework)

In Belgium a dynamic input-output model is used for long-term economic analysis in the energy field. This model exists in two versions: the well-known planning version and an equilibrium version. The equilibrium version incorporates a more correct representation of the savings-, balance of payments- and government budget constraints but is computationally more troublesome. This work is done at the Université Libre de Bruxelles. (Prof. GUILLAUME and GINSBURGH) (6).

The input-output coefficients can be modified using econometric demand functions for factors of production per sector. This research is carried out at the Planning Office (7).

The aim is to link the input-output model, the econometric demand models and the energy-supply models.
The methodological issues involved are discussed in (4). Work on the integration of these models is done at CORE and has up to now been concentrated on linking the input-output model with the econometric demand models. The next step will be to integrate energy-supply models. Results on the following integration exercises are available:

- Dynamic Input-Output model (Planning version) coupled with different versions (putty-putty, putty-clay) of the demand functions for factors of productions. For this a column generation technique is used (8). In another exercise a dynamic electricity supply model was added to this configuration (9).

- Integration of the Dynamic Input-Output model (Equilibrium version) with sectoral demand functions for factors of production using MANNE-CHAO-WILSON method.

Of interest of MARKAL users is also the formulation, using the MARKAL software, of a coupled MARKAL-dynamic input-output model (planning version). Numerical tests are planned.

4.2.2.5 Decision Making under Uncertainty (CORE)

Stochastic programming with recourse (which means that reaction to information becoming available in the future is endogeneous) has been applied in three different fields: energy R & D planning (10), investment problems in an economic growth model (11) and investment planning in the electricity sector (12). In the first two problems an adapted version of ETA-MACRO and in the third an LP-investment model have been used. The two last problems were solved using decomposition methods.

4.2.3 Other Research Interests in the Field of Energy Modelling in Belgium

These concern a variety of domains:
- modelling the West European gas market
- construction and linkage of regional energy-models
- modelling energy-use in the domestic sector
- use of MEDEE
- integration of energy-aspects in medium term econometric models (CEEHERMES project)

(St. Proost of D.P.W.B.)

Reference list not received.
4.3 Canada

4.3.1 State-of-the-Art

The MARKAL model has been implemented in its IBM version of KFA, W. Germany. A draft data base developed for Canada (with the help of T. Teichmann at BNL) was used for testing the model. Another data base has been developed for the province of Quebec. The electric utility sector has been reworked in close collaboration with the provincial utility which until 1983 had the rare feature of generating only hydroelectricity (except for a very short winter peak).

4.3.2 Plans for 1984/85: Developments of MARKAL for one Canadian region

- Medee-3 is a demand model which starts with a socioeconomic and energy scenario for simulating the useful energy demands and the secondary (so-called "final") energy demands. MARKAL evaluates these two energy levels also but through optimization. Two couplings of these models of supply and demand will be achieved. The coupling called Medee-MARKAL truncates MARKAL to the evaluation of secondary energy flows determined by Medee, whereas MARKAL-Medee is dominated by MARKAL which optimizes up to the stage of useful energies. The difference between the two couplings is essentially that the levels of activity of the usage technologies are simulated in the former and optimized in the latter. The comparison of the results from these couplings could indicate the full impact of demand management policies. In both couplings, one model will remain complete while the other will be truncated by removal of its secondary-to-useful-energy conversion stage. The energy flow disaggregations of the two models will be made compatible with each other; this task will be more difficult in the MARKAL-Medee than in the other coupling.
- The industrial energy demand will be detailed according to previous, sectorial work in Canada, and will include cogeneration and cascading.

- Petroleum refining is presently modeled with a pair of fixed and fully flexible refineries whose coproducts are all given the same marginal cost. The new model will be based on a sequence of typical processes, treating 3 different crudes.

- The IBM's optimization code MPSX, presently used by modelers equipped with KFA's version, can barely treat more than 6000 constraints. For achieving the dynamic optimization more quickly, MPSX will be replaced by LIFT, an optimization code developed at the CORE, Belgium for the European energy model EPOM. LIFT is a code implementing the nested decomposition algorithm "Staircase" of Ho which was derived from the decomposition principle of Dantzig and Wolfe.

4.3.3 The Potential Role of MARKAL in the Assessment of Energy R&D Opportunities

There are two main steps to go through before considering MARKAL relevant to the decision process in Canada: testing MARKAL for one Canadian region, and then regionalizing MARKAL. The fiscal year 1984/85 is concerned with the first step. Two plenary meetings of various participants involved in R&D management will be held in order to ensure that the proper data assumptions and structural hypotheses are modeled and also to identify the necessary issues for validating the results for the purpose of decision making.

(C. Berger of G.E.R.A.D.)
4.4 Denmark
4.5 Germany

In Germany, the MARKAL software is implemented and used at Nuclear Research Center Jülich (KFA-STE). The model is used for two main purposes: application to the German energy system and joint projects with developing countries.

The applications of the MARKAL model to the German energy system concentrate on the tasks within ETSAP - that means the model runs for the project report "Energy after the Eighties" and the updates for the "Energy Technology Policy Study" - and on projects performed by other groups of the Institute (e.g. a study concerning the German transport sector "Energie für den Verkehr" in collaboration with Mannheim University for Forschungsvereinigung Automobiltechnik e. V.)

A first approach to studying the environmental aspects of the energy system was initiated in 1985 ("Clean or Cheap", Status report in November 1985).

The model applications in/with developing countries have been/are:

- China
  (Planning for the Guangdong province)

- Brazil
  ("Program of research and development on the utilization of Brazilian coal and on energy systems analysis and planning for Brazil", partners SETEC, CAEBB)

- Indonesia

In addition to the MARKAL activities, STE developed a second tool for energy technology systems analysis: MARNES. This tool is used within the activities concerning "Novel Horizontally Integrated Energy System".

  (H. Vos, G. Giesen of KFA Juelich)
4.6 Ireland

The MARKAL model for Ireland is implemented at KFA Juelich. The last runs were undertaken during the preparation of "Energy after the Eighties", and the Irish national report "Energy Technologies after the Eighties".

Since then Ireland has not participated actively in ETSAP, but continued to support the work of Annex II.

During the lifetime of Annex II, much effort was put into marketing the ETSAP concept in Ireland. While MARKAL had been used by the National Board for Science and Technology for directing national R&D and for the provision of specific technology advice to government, the linkage between MARKAL and energy policy formation had never been very strong.

Consequently many workshop sessions were held with officials in the Department of Energy and other interested parties. One paper was presented at the premier Irish energy conference in 1984 (Ref. 1).

Because Ireland is a member state of the European Community, developments in the CEC's energy systems analysis programme are relevant. Ireland participated in projects using the models EFOM and MEDEE during the current period. Because of the more explicit linkage these models have with economic parameters, the CEC work was favoured by government over MARKAL.

MARKAL did, however, impress on the Department of Energy the need for an adequate energy database in Ireland. Accordingly, while the MARKAL database has not been updated since 1983, a national database is in formation within the Department of Energy.
The evolution of new tasks which occurred as part of the information exchange of Annex II has been followed with great interest in Ireland and continued participation in ETSAP is likely.


(J. Brady, B. Hanna of Nat. Board of Science and Technology)
4.7 Italy

The MARKAL model software is available in Italy by two computer centres.

The version available on the IBM 3048 computers of ENIDATA (Milano) includes: the first matrix generator implemented at KFA in Fortran, an MPSX optimizer, the MPSRG reports generator, many post optimal analysis programs. All the models of the Italian energy system used along Annex I and II of ETSAP have been implemented by means of this software. The data files have been updated until 1983. Later, by means of a new simplified model built with the same software, the energy forecasting office of ENI addressed some problems connected to the substitution of hydrocarbons with coal.

A new all-Fortran version is available on the CDC Cyber computers of NIRA (Genova); it includes: an improved version of the first matrix generator implemented at KFA, a Fortran optimizer implemented by J. K. Reid at Harwell (UK), an improved flows and cost benefit analysis report.

The all-Fortran version of the MARKAL software have been tested by comparing the numerical results given to the same model (1800 rows, 2500 columns, 13,000 non zero elements) by the two computer centres. The values of the objective function differed by one part per million, most of the activities were the same; 3 % of the primal values and 12 % of the dual one were different because the two computers distributed the same flows of value among "contiguous" knots of the same network in a different way. The CPU time of each complete run in the all-Fortran version (around 400 sec.) was double than the Fortran-MPSX version.

The all-Fortran version of the software has been used to build a model of the energy system of the Sardinia island and to analyze its long term energy options; a similar study for the island of Sicily is planned.

(G.C. Tosato, of Cesen)
4.8 Japan

The government agencies, namely, Agency of Industrial Science and Technology (AIST) and Science and Technology Agency (STA), both promoting a number of national R&D projects on energy technology, have acknowledged the significance of ETSAP Annex II and agreed with each other to act as a joint agent for this international co-operation. They have assigned two institutions, namely, Electrotechnical Laboratory and Japan Atomic Energy Research Institute, from their own affiliated organizations to the workshop staff of ETSAP and set up an ad hoc group for coordination. In order to support its data acquisition work, semi-governmental New Energy Development Organization (NEDO) has joined in the group. The status of the activities in the two institutions is as follows.

4.8.1 Electrotechnical Laboratory

Electrotechnical Laboratory (ETL), which is operated by AIST, is undertaking energy systems analysis with special attention to new energy technologies. The purpose of the analysis is to assist ETL and AIST in formulating energy technology R&D policy. As a part of its work, four systems analysts in the Systems Engineering Section of ETL have been engaged in the ETSAP.

Estimated manpower for project-related activities: about a quarter of each analyst's work has been related to ETSAP. Thus the total estimated manpower is 1 man-year/year or 3 man-years for the three years period of the Annex II.

Project using the common MARKAL framework: The framework of MARKAL is being used in the Research on Energy Technology Systems Analysis which is one of the supporting programs for the Sunshine Project (the project for developing new energy technology) of AIST.
The objective of the research is stated as the assessment of energy technologies to seek balanced attainment of the Sunshine Project.

MARKAL related software developments: In order to make MARKAL available with a general computer, the matrix generator and the report generator have been programmed using the language PL/I. The ETL version of MARKAL were extended to include those concerned with mixed integer programming (MIP); driving force for all energy carriers and non-energy materials; multiobjective optimization; and value flow analysis.

Other model related to the problem: Energy demand model has been developed and used to define the MARKAL input data of final consumer's demand. The model computes and projects the energy demand utilizing the Interindustry Table of Japan.

Future activities: Using the MARKAL framework, Systems Engineering Section of ETL will continue the assessment study of energy technologies including environmental effects as its ongoing project. A new concept of MARKAL application is being investigated as to the possibility of system synthesis to forecast and evaluate futuristic energy systems.

Judgement about future needs concerning MARKAL and other problem related tools: Updating and maintenance of energy technology data should be continued. It is necessary also to continue the software development and/or improvement in the area of energy-economy interaction model; energy demand projection model; and environmental sub-model.

(S. Ihara, S. Koyama, E. Endo of ETL)

4.8.2 Japan Atomic Energy Research Institute

Japan Atomic Energy Research Institute (JAERI) is a public corporation under the jurisdiction of STA. Recognizing the importance of nuclear energy utilization and R&D on related technologies, JAERI has been participating in the study on energy systems analysis conducted by the IEA/CRD since its beginning in 1976.
The following paragraphs describe activities since the study was reorganized as the ETSAP and the information exchange programme was initiated.

Estimated manpower for project related activities: An annual average of five members of the research staff of JAERI, each with a 20% contribution; additionally, two experts, each with 10% contribution, from outside organizations such as think-tanks have been engaged in the project related activities.

Project using the common MARKAL framework: Two studies were carried out under the ETSAP in co-operation with ETL. The first was the Phase III scenario runs, the outcome of which was summarized in "Energy after the Eighties". The second was the updated runs for the above, which was reflected in the Energy Technology Policy Study. A study on the role of high temperature nuclear heat utilization in future energy systems is now in progress under the co-operation between JAERI and MIT to seek future energy paths toward zero-emission. MARKAL will be integrated with the I/O model to analyze structurally the energy-economy system.

MARKAL-related software development: JAERI has developed the version 2.0 level of the MARKAL programme using FORTRAN. The programme to generate the ETSAP-Report has been also developed.

Other models related to the problem: JAERI has been engaged in developing the Integrated Energy-Economy-Environment Model System, which comprises four model blocks: for the dynamic scenario generation in a long-term energy-economy evolution, for the structure analysis based on the multi-sectoral energy-economy interaction model, for the strategy analysis on nuclear reactors and fuel cycle development, and for the cost-benefit-risk analysis. JAERI gave a brief review of its concept and the development status at the two ETSAP workshops held in Tokyo and at KFA.
Future activities: JAERI will continue the study on the utilization of the high-temperature nuclear heat. The role of nuclear power for future electrification will also be analyzed in the framework of the energy-economy-environment system. In addition, system analysis studies will be carried out to support the assessment of nuclear energy technologies such as small and medium power reactors with a modular concept.

Judgement about future needs concerning MARKAL and other problem related tools: The analytical tools and the data bases for the cost-benefit-risk assessment of individual energy technologies are required. The related methodologies and data bases as well as pilot studies on some typical problems are considered appropriate subjects for the information exchange programme.

(S. Yasukawa, S. Mankin, O. Sato, K. Yamaguchi, S. Ueno, of JAERI)
4.9 Netherlands

In the Netherlands the MARKAL model is implemented and used at the Energy Study Center of the National Energy Research Foundation (ESC). MARKAL's potential value as a tool to provide information for long-term energy R, D, &D planning has become acknowledged.

The activities undertaken during Annex II were primarily aimed at achieving this goal through demonstrating the potentials of MARKAL. Due to limited manpower, there was little emphasis on full-scale model applications.

4.9.1. Activities during Annex II

The implementation of MARKAL on the computer system available at ESC, the subsequent testing and further development of the model with regard to post-optimal analysis and environmental modelling have been the major efforts during the last years.

The computer facilities have also been used to test common versions of MARKAL - newly developed by the Operating Agent - on CDC/Cyber computer systems.

As a result of these activities the model is now operational, including the following features:

- an updated database, implemented on an IBM/PC for easier data handling;

- a job submission programme for easy-to-use operation of MARKAL: each step in the execution sequence is controlled by typing just one command;

- a plotting programme for graphical representation of model results;
- a post-optimal analysis programme which allows for the calculation of benefit/cost ratios of energy technologies and the associated sensitivity analysis of the results.

In 1984 a set of updated scenarios, based upon the ones used in "Energy after the Eighties", was calculated and analyzed. Due to software problems in that same period, these runs could not be finished in time to be included in the contribution to the Energy Technology Policy Study of the IEA (see also chapter 5.5).

The update included an extensive revision of energy demand projections and price assumptions, partial revision and updating of technology data and further improvement of model structures, including the treatment of initial inventory requirements for nuclear power plants.

In 1985 the inclusion of environmental effects into the model for the Netherlands was started. This consisted of extending the database with emission factors and implementation of some changes in the MARKAL model. These changes serve to impose constraints on the annual level of emission for one or more user-selected pollutants; test runs have confirmed the correct functioning of this concept.

Also in 1985 several proposals for future applications of MARKAL within national studies were prepared.

The projects under consideration are:

- a study of the potential role of renewable energy sources and technologies in the Netherlands on the long- and very long-run, the so-called DEB study;

- a study of long-term energy R,D&D options under widely varying scenario assumptions, aimed at the selection of potentially vital and/or promising options (EOS);
- a nationwide acidification study, in which results provided by MARKAL and/or other similar models will be regionalized and subsequently fed into pollution-distribution and precipitation models. Together with non-energy related sources the results are used in environmental impact models, aiming at an assessment on a highly dissaggregated, local scale.

4.9.2 Outlook

From the preceding paragraphs it will be clear that there are opportunities for using MARKAL for various projects in the Netherlands. Of the three above mentioned proposals, the EOS study is already in progress. The first model results are planned to be available by the end of 1986.

In all projects in progress or under consideration, environmental aspects are an issue of major interest besides other aspects such as cost, security, risk-exposure, etc. Hence, there is a good basis for contributions to Annex III of ETSAP and co-operative studies with other participants in this framework.

(T. Kram of Energy Study Center)
4.10 Norway

The primary interest of Norway for the IEA energy systems analysis project was generation of the technology data base. Consistent and general evaluation of a large number of technologies, both for energy supply and demand and storing the resulting parameters in an international data base, was considered very valuable.

The national need for simulation or optimization of a national energy system with MARKAL has never been of primary interest.

Being a small nation and having relatively large energy resources for export, makes it important to know the energy markets and the technologies of interest for these markets. As a logical consequence, Norway participated also by running MARKAL for Norway as input to the project. Furthermore, Norway contributed by supporting a specialist to the work of summing up results from the update runs and drawing conclusions for the CRD-committee.

Although Norway has not used MARKAL for domestic purposes, participation in ETSAP was the origin of other projects in energy systems modelling and analyses. The Norwegian electrical energy system is to approx. 95% based on hydro power, a situation not well suited for treatment by MARKAL. However, Norway is on the edge of becoming a substantial gas nation so that future expansion of the energy supply system is expected to be based on this source. Institute for energy technology which on behalf of the Government took part in ETSAP, has therefore been engaged in modelling and analysis of gasfield development. The purposes of these studies have been to determine optimum investment profile and to analyse the potential gas market when competition to other sources of energy is considered. These tasks required very special models with mixed non-linear and integer optimization procedures.

(Jan Nitteberg, Kjell O. Solberg of Institute for energy technology)
4.11 Sweden

The KFA version of MARKAL has been implemented on the IBM 3081 at the Computer Centre of Gothenburg. The Energy Systems Technology Group at the Chalmers University of Technology, Gothenburg, is responsible for the maintenance of the model. The model is used in studies related to national energy planning and policy, local energy planning and energy technology policy. There are the following users:

4.11.1 Energy Research Commission (Box 43020, S-100 72 Stockholm)

The Commission has been responsible for the Swedish participation in the IEA project and has financed the implementation of MARKAL in Gothenburg. The national model has been updated. The analysis has been focused on sensitivity analysis, time variation of shadow prices of heat and electricity, seasonal and daily regulation of hydropower, and effects of taxes. MARKAL has also been used for some consistency checks of energy projections made by the National Energy Administration. It will also be used in a study of SO$_x$ and NO$_x$ emissions by the Administration. MARKAL has been reviewed by the utilities and the results for the electricity system has been compared with those of power supply models.

4.11.2 Energy Systems Technology Group, Chalmers University of Technology, (S-412 96 Gothenburg): The main MARKAL activities of the group are:

Community energy planning. In close co-operation with the community authorities MARKAL has been applied to two communities. The studies have been used to support the development of comprehensive energy plans for the communities as well as more detailed plans for subsectors, e.g., energy conservation in existing buildings. In special studies the future market for district heating in the communities have been investigated. SO$_x$ and NO$_x$ emissions from furnaces have also been studied.
Industrial energy planning. MARKAL has been used in a study of the factory of Sandvik Coromant AB, Gimo, Sweden.

Planning methodology. In a special project MARKAL is used to study the trade-off between efficiency and robustness, following an early suggestion to the IEA Energy Systems Analysis Project 1979 ("planning under uncertainty").

Input and postoptimal models. More detailed models of specific subsystems are coupled to the MARKAL model in order to improve the input or to allow a detailed analysis of MARKAL results. These models can also be used for iterations with MARKAL. Today such models exist for the district heating subsystem and for energy conservation in existing buildings (retrofit).

4.11.3 Department of Economics, University of Gothenburg
(Viktoriagatan 30, S-411 25 Gothenburg):

The MARKAL oriented studies at the Department of Economics have mainly been concerned with long run energy planning and policy on the national level: technology competitiveness, structural change within energy supply, energy conservation vs energy supply etc. MARKAL is also used for educational purposes at the university. An on-going project is focussed on principles for decisionmaking (planning) under risk and uncertainty. In this context MARKAL is a basis for applied studies. However, in order to satisfy the demands put forward by decision theory, the standard version of MARKAL has been expanded. A supplementary set of constraints has been added. Furthermore, technologies with fuel switching capabilities have called for a specific treatment involving dummy fuels.

4.11.4 Other users: A consultant firm (Prognoskonsult, Moerbyleden 20, S-182 32 Danderyd)

Prognoskonsult has used the existing MARKAL model and data base in connection with two studies of the future energy system (the heating subsector and the power supply sector).

(G. Leman, Energy Research Commission)
4.12 Switzerland

Model Implementation

The BNL version of MARKAL has been implemented on the CDC Computer of the Federal Institute of Technology, in Zürich (ETHZ).

The model is used by the Federal Institute for Reactor Research (EIR) for the analysis of internal, national and international projects.

The manpower devoted to Energy Systems Analysis projects by EIR is in the order of 1.5 man-years per year, not including the contribution of external consultants for data acquisition problems.

The total resources thus devoted to IEA-ETSAP related activities as it is, MARKAL applications, software development and data base updating, are in the order of 5 man years.

Projects based on MARKAL

Two main projects related to MARKAL have been completed during the course of Annex II of the ETSAP Implementing Agreement:

- Implications of proposed policies to the Swiss Energy System and
- Technical measures for emission control.

The first project has been initiated by the Swiss Energy Office for investigating the consequences of the proposed "Anti Nuclear" and the "Energy" Referendum.

The University of Geneva has projected scenarios of energy demands under different assumptions of economic growth and price schedules, and it has investigated the efficiency of proposed policy measures.
MARKAL has been used to analyze supply options and the contribution of new technologies in displacing oil. The distribution of subsidies for renewables and the analysis of emission inventories were some of the problems to be studied. Results of this work have been presented in international and national conferences.

The second study has been initiated by the Institute. To date the group has failed to convince the Swiss Authorities to use MARKAL for analyzing emission control options. The study is close to completion, however, and we hope that the final report will change the situation. In any case, interest has been expressed in performing cost/benefit analysis for the different proposed measures using MARKAL.

The tendency in the Swiss Administration is to consider MARKAL as a good but complex model for studying policy questions in Switzerland. The preferences are on the side of econometrics and simple technoeconomic simulation approaches.

**MARKAL related software development**

Some ideas in coupling MARKAL to a macroeconomic framework, and an engineering simulation approach, have been made explicit. A fraction of our limited resources are devoted to this problem. The concept has been reported to a conference in Budapest and to ETSAP workshop. Internal EIR reports describe the progress obtained until now in that direction.

Minor efforts have been devoted to check the BNL version of MARKAL, and some inconsistencies have been eliminated. The plotting software for CDC users developed at EIR has been successfully implemented in the Netherlands.

Finally, the MEDEE-2 model has been modified for Switzerland and linked to MARKAL to generate demand projection.
Future Activities

The EIR group involved in energy systems analysis can only be efficient and productive if international and national co-operation with similar groups of research could be established.

We therefore are in favor of projects like ETSAP. We hope to improve, through international co-operation, the data base and the methodology applied for energy systems analysis and for the analysis of environmental issues.

Another project is also under discussion on the national level. The organization of a general and flexible framework for the analysis of global, sectoral and regional problems in energy, is foreseen. This includes Energy, Economy and Environmental Interactions.

The implementation of the software in advanced 32 bit microcomputers for industrialized and LD countries applications is also foreseen. The institutions to be involved in this project include both Federal Technical Institutes of Technology, the University of Geneva, and EIR.

Literature

- EIR-Reports 516/558, April 84 / July 85
  "Kostenoptimale Energieversorgungsszenarien für die Schweiz," S. Kypreos, P. Kesselring

- "Energieversorgungs-Szenarien für die Schweiz und die politischen Randbedingungen," S. Kypreos, Schweiz. Zeitschrift für Volkswirtschaft und Statistik, Heft 3, 84


- TM-13-86-01, Swiss Model of Energy Demand (SMEDE), S. Kypreos, March 86.

- EIR-Bulletin Nr. 57
  "Kosten von Emissionsbeschränkungen," J. Wochele, S. Kypreos, January 86

- TM-13-86-03

(S. Kypreos of Swiss Federal Inst. for Reactor Research)
4.13 United Kingdom

The MARKAL model is implemented in the UK on the IBM 3084 computer at Harwell, and makes use of the MPSX-370 and OMNI program packages.

During Annex II, several projects have been completed, as reported at the workshops and referenced below, for the Chief Scientist's Group of the Energy Technology Support Unit at Harwell, under contract to the UK Department of Energy.

A preliminary database for studying emissions of SO2, NOx and CO2 was assembled, and studies were made of the tradeoff between emissions and total system cost, examining some of the possibilities for fuel switching or emission control.

The methodology of value flows analysis was further developed and a program COSTBEN was written in the OMNI language for calculating benefit/cost ratios as part of the MARKAL package. This was supplied to KFA and the Netherlands, where it is now available in the MAGEN language.

The methodology of sensitivity analysis was developed for studying in detail the response of the energy system to gradual variation in parameters such as the oil price profile, the permitted emission levels of a pollutant, and the projected implementation level of nuclear power. The same approach was implemented for studying the response to a price shock of varying severity, whereby the energy system up to the time of the shock develops as it would have done in the absence of the shock.

The techniques mentioned above were applied to a study of the ranking of the renewable energy technologies in various scenarios, in which price rises or supply constraints departed from the assumption of a reference case or central view. This work was done in support of an evaluation by the Energy Technology Support Unit for the Advisory Council on Research and Development in Fuel and Power (ACORD).
Software developments were carried out to facilitate the above tasks and anticipated future projects involving technology assessment. Minor changes were made to the Version 2.00 matrix generator. Extensions were made to the Version 2.00 report writer, mainly to provide tables of emissions of pollutant by year and technology. Considerable effort was put into developing a comprehensive and user friendly menu system for driving MARKAL, including options for value flows analysis, benefit/cost calculations, sensitivity studies and parametric programming, and the plotting of graphs or bar charts. This software is based on the IBM system called SPF (or ISPF), which is a dialogue management system operating in the environment of the MVS Time Sharing Option (TSO).

(M. Finnis of Theoretical Physics Div.)
4.14 United States

During Annex 2, periodic runs of the MARKAL model of the U.S. energy system were made with revised assumptions as to fuel prices and energy demands. The runs were made in response to requests from the U.S. Department of Energy and in connection with the IEA Energy Technology Policy Study. The data base was substantially updated in late 1984 and is now maintained on an IBM personal computer.

In 1983-84, two sets of MARKAL runs were made to evaluate the effect of the decline in oil prices on the earlier results in which oil prices had been assumed to increase continuously from 1980. These indicated a reduction in the need for some marginal technologies that substitute for imported oil and prolonged use of some technologies that make frugal use of oil. However, the use for new energy technologies that had been found to be of greatest importance to the U.S. energy system in earlier runs was little affected by these differences in assumptions.

In 1984-85, a comparison was made by the USDOE policy office of MARKAL and another model, 3RT/ETA, with WOIL, the system dynamics model used in the biennial preparation of the U.S. National Energy Policy Plan (NEPP). For this purpose, the data base was widely reviewed in the USDOE, and changes were made in the areas of nuclear energy, renewables, industrial use, and auto and truck transportation.

In the NEPP runs, a low economic growth case and a low oil price case were compared with a base case. Demand inputs to MARKAL for these variations were obtained from the WOIL model. The principal changes in fuel use - mainly coal - resulted from changes in demand rather than response to relative fuel costs. There were few examples of fuel switching due to technology substitution.

(D. Hill of Brookhaven National Laboratory)
4.15 European Community

Within the scope of this project, the position of the European Communities and of the Services of the European Commission is different in comparison with those related to national governments.

Thus, the MARKAL model is a national model with national databases. A supranational model for the EC has not been constructed, and was not desirable due to its necessarily strong aggregation. Moreover, national energy policies are not (completely) consistent with each other.

At the other hand, the Services of the EC are dealing with similar problems, and dispose of comparable tools and corresponding databases. For these reasons, it has been considered as important to have EC participation at the technical level, maintaining standing exchange of views, discussions on input assumptions and interpretation of output results together with the participating IEA member countries of which a considerable number are also members of the EC.
5. Examples of Studies within ETSAP

As pointed out in some of the Country Reports, there was specific interest in several topics that were beyond the scope of studies of earlier phases or contributed to the elaboration of methodological issues raised previously.

The contributions in the subchapters 5.1 to 5.5 are papers written by various authors. For the sake of redactional simplicity the texts are - as far as possible - kept in the state received with their internal numbering of chapters, figures, tables, references, etc. The authors are identified under the titles of their contribution in the subchapters.

The following subjects are presented subsequently in some detail:

- Value Flow Analysis:
The technique of value flow analysis has been further developed and applied during Annex II. To summarise the progress that has been made, edited reprints of two representative reports are included. The first (Finnis et al.) describes the general theory. The second (Koyama et al.) describes actual applications of value flows analysis to determine the relative importance of the different economic factors that control the overall competitiveness of a technology. This requires a detailed value flow diagram for each technology under study. Seven examples are illustrated and discussed here.

- Energy and Economy:
On the one hand, sharp increases over the past decade in the price of oil and other primary energy carriers have pointed to the threat of an end to a period of cheap energy. The attendant inflation and the unwelcome effects on national productivity and balance of payments problems for many countries have focused attention on the vital role of energy in a nation's economy.
On the other hand, energy itself has been facing specific
difficulties for some time; e.g., its utilization requires
application of high technology and considerable capital
investment. This is true for nuclear energy as well as
fossil or renewable energy, as becomes clear when environmen-
tal, safety, and security considerations are included in
economic evaluations. Recognizing the importance of such
impacts, some related research work has been conducted in
connection with ETSAP studies.

An overview on modelling approaches (Chapter 5.2.1) has been
compiled by P. A. Bergendahl. Chapter 5.2.2 presents a de-
scription of the approach pursued at JAERI (S. Yasukawa et
al.). In chapter 5.2.3 S. Kypreos et al. report on the
energy model system at the Swiss Federal Institute for
Reactor Research (EIR) in Switzerland.

- Environmental Aspects:
Environmental effects of energy use have become more
significant in recent years and will be the principal topic
during the next ETSAP phase (Annex III).

Chapter 5.3.1 presents a study of environmental effects
performed at EIR (S. Kypreos et al.) Chapter 5.3.2 is a
contribution of H. Vos and G. Giesen on efforts at KFA to
elaborate a MARKAL version more appropriate for environ-
mental studies than the Common Version 2.10.

- Regional and Urban Planning:
Most of the MARKAL applications have been national. Probably
this is because the original intent of ETSAP was to evaluate
R+D priorities and not to give support to decisions on
concrete energy technology implementations. As soon as
MARKAL was used for applications on the latter issue,
regional and even community oriented studies came into the
focus of interest.
At least three applications of MARKAL on a subnational range are known:
A study for and in a Province of the P.R. China (Province Guangdong, see also chapter 6), a study for Sardinia, Italy, and energy planning efforts for Jönköping, Sweden. A description of the latter study is presented in this chapter (C.O. Wene et al.)

ETSAP Update Runs:
In chapter 5.5 some excerpts will be presented from the report on the ETSAP update runs, titled "Energy and Energy Technology Requirements for the Period 1980 to 2010. Some Results from the ETSAP Update Runs", August 1984, prepared by Jan Nitteberg, Institute for Energy Technology, Kjeller, Norway, with contribution of several individuals participating in the ETSAP, as listed in the Acknowledgement of the above report. These excerpts comprise parts of the chapters:

1. Introduction
2. Energy Price Projections
3. Energy Demand Projections
4. Results — Conclusions for the Group
5. Consequences for the Energy Technology Policy Study

and the references of the Nitteberg report.

Of the results only the conclusions for the group of contributors to the update runs are presented.
5.1 Value Flows Analysis

5.1.1 Value Flows in a Linear Economic Model
(M.W. Finnis, J. Gundermann, G. C. Tosato)

Abstract

We describe the concept of value flows and illustrate its use for extracting information from the cost-optimal solution of a linear program. The starting point is a system of resources and activities which comprise a linear optimization problem. The flow of value between a resource and an activity is defined, leading to formal definitions of the cost and benefit of an activity. These concepts are generalised to a set of activities with the help of a graphical representation of the system. This leads to a useful formula for the benefit/cost ratio of a project, regarded as a set of activities spread over time, in terms of the problem matrix and the shadow prices and reduced costs which are obtained from the solution of the linear program. It is shown how a study of the graphical representation of the project also helps to assess its sensitivity to variations in the input assumptions. Our emphasis is on the application of formal results, to illustrate which we discuss the simple example of an idealised coal gasification technology.

5.1.2 Introduction

Our objective is to link the linear programming concepts to the concerns of the analyst who is assessing projects. What follows is an edited version of reference (1), which gives more background information.

Dantzig has illustrated some of the practical as well as semantic difficulty in the economic interpretation of a linear program by means of a concrete example, which illuminates somewhat different aspects from those we shall describe. Some further background to the present methods is in Altdorfer, Finnis and Hill et al but no complete discussion has been published up to now, and we have taken the methods further than in previous work.
For the purpose in hand, we do not dwell on linear programming theory, nor discuss methods of solution, which are very well covered elsewhere. In the theoretical section 5.1.3 which follows, we quote only essential results, referring the reader elsewhere for proofs. In section 5.1.4 of the paper we introduce the central concept of value flows with which we derive a measure of costeffectiveness for an activity, which is its benefit/cost ratio. In section 5.1.5 we describe how to investigate the sensitivity of these value flows to the input assumptions. Section 5.1.6 introduces a graphical representation of the system, which helps in analysis in several respects. In particular it is an aid to the discussion of section 5.1.7, where we generalise the formula for benefit/cost ratio to a set of activities, or a project, which is the central result of our paper. The concepts are illustrated by a worked example in section 5.1.8, and we summarise the paper in section 5.1.9.

5.1.3 Theoretical Background

In this section we define the important quantities and relations of linear programming theory which will be used in the remainder of the paper. We quote standard results without proof. For the reader wishing to follow all the mathematical reasoning in detail there are many good textbooks on linear programming; a particularly clear account is given by Strang\textsuperscript{6}, whose notation we adopt here. An excellent formal presentation of linear programming theory and its economic interpretations is the book by Gale\textsuperscript{7}.

The problem is to minimise the total cost of a set of activities \( x = (x_1, x_2, \ldots, x_n) \). The cost is linear, and is given by \( c_1x_1 + \ldots + c_nx_n \), where the cost coefficients are supplied and the activities are to be determined. We shall assume that all activities and cost coefficients are \( \geq 0 \). The activities are subject to \( m \) constraints of the form \( \sum_j A_{ij}x_j \geq b_i \). A special type of constraint is a simple upper or lower bound on an activity; such constraints can be handled by a straightforward generalisation of the solution procedure, and are not therefore included in the matrix \( A \).
The complete problem can be stated in a convenient vector and matrix notation as follows:

\[
\begin{align*}
\text{Minimize } & \mathbf{c}^T \mathbf{x}, \text{ subject to } \mathbf{x} \succeq 0, \mathbf{A} \mathbf{x} \geq \mathbf{b}, \quad \mathbf{x}_j^L \leq x_j \leq \mathbf{x}_j^U, \\
& j = 1, \ldots, n
\end{align*}
\]  
(1)

The m inequalities are made equalities by defining a slack variable for each constraint. The matrix A is thereby extended by a further m columns, and the constraint equations can be written:

\[
\mathbf{A} \mathbf{x} = \mathbf{b}, \quad \mathbf{x} = (x_1, x_2, \ldots x_{n+m}).
\]  
(2)

It is conventional to display the structure of the problem by presenting the information on a tableau, as shown in Figure 1a. The ingredients of the problem A, b and c appear on the tableau, which has m+1 rows, including the cost row c, and n+m+1 columns, including the right-hand side column b. Nowadays computers routinely handle problems containing many thousands of variables, and the use of a tableau is purely symbolic. Henceforth when we refer to A we shall mean the original matrix of n columns and m rows.

When the problem has been solved, just m of the variables are dependent, in the sense that the remaining n are at bounds. The m dependent variables are said to be basic and denoted by the vector \(\mathbf{x}_B\). The remaining n variables are conventionally referred to as free, a somewhat confusing terminology even in 1984. They are denoted by the vector \(\mathbf{x}_F\). If we relabel the basic variables \(x_1, \ldots, x_m\), the columns corresponding to basic variables move to the left of the tableau, which can be partitioned as shown in Figure 1b. The constraint equations become:

\[
\mathbf{B}_\mathbf{x}_B + \mathbf{F}_\mathbf{x}_F = \mathbf{b},
\]  
(3)

which can be written:

\[
x_B = B^{-1}b - B^{-1}F_x_F.
\]  
(4)
The cost objective function takes the form:

\[ cx = c_B^x_B + c_F^x_F = (c_F^x - c_B^B^{-1}F) x_F + c_B^B^{-1}b \]  \hspace{1cm} (5)

in which we have substituted the solution (4) for the basic variables.

The coefficients of the free variables in (5) are known as reduced costs and denoted by \( r_i \). In vector notation:

\[ r = c_F - c_B^B^{-1}F. \]  \hspace{1cm} (6)

The coefficients of the right-hand sides \( b_i \) in (5) are known as dual activities or shadow prices and are denoted by \( y_i \). In vector notation:

\[ y = c_B^B^{-1}. \]  \hspace{1cm} (7)

With this notation we can rewrite (5) as:

\[ cx = rx_F + yb. \]  \hspace{1cm} (8)

Relation (8) enables us to understand the significance of reduced costs and shadow prices, which so far we have merely introduced as definitions. Suppose we force a free variable \( x_i \) to have a slightly higher value than it has in the optimum solution; say we move it to \( x_i + \delta \). From (8), the reduced cost \( r_i \) is the amount by which the objective function cost \( cx \) increases. Because the solution is optimal, the reduced cost must be positive if the free variable is at a lower bound; in fact that is how the solution procedures recognise that the minimum cost has been achieved. Conversely, if the free variable is at an upper bound, its reduced cost must be negative. As for shadow prices, they are always greater or equal to zero, and represent the amount by which \( cx \) increases per unit increase in corresponding right-hand side. A shadow price is zero when the corresponding constraint is non-binding (a slack row):
\[ y_i = 0 \text{ when } A_{ij}x_j = b_i. \quad (9) \]

It then makes no difference to the optimal solution or cost if the non-binding right hand side is increased up to a value at which the constraint becomes active. Condition (9), together with the equality for non-zero shadow prices \( \sum_j A_{ij} x_j = b_i \), implies that:

\[ yA x = yb. \quad (10) \]

Finally a useful equation is obtained if we extend the definition of the vector of reduced costs to include basic variables for which \( r_i \) is zero. Relation (6) can then be written as:

\[ r = c - yA. \quad (11) \]

For free variables the elements of the vector equation (11) are equivalent to those of (6). For basic variables it is simply verified that (11) becomes \( r = \mathbf{c_B} - yB \), which vanishes according to equation (7).

5.1.4 Flows of Value of Resources between Activities

In this section we introduce the idea of a flow of value which is central to the analysis of competitiveness. To introduce the general idea, let us consider the case of a factory which is producing goods. We can think of various flows of value in and out of the factory gates; raw materials go in at a certain cost, goods come out at a certain price. The quantity times the cost of raw materials is a flow of value in, while the quantity times the price of goods produced is a flow of value out. The quantities referred to are for a specific period of production, which is usually taken to be one year. Besides these two obvious flows of value, several others can be defined in such a way that there is no net flow of value into or out of the factory. These are for example the capital investment, the expenditure on wages, and the expenditures on routine maintenance and repairs; their sum is referred to as the value added at the factory.
The conservation of value at the factory or any other economic activity is reminiscent of the conservation of material quantities or energy, which is expressed by material or energy balances; in every case the sum of the inputs equals the sum of the outputs to the balance. This analogy between flows of value and physical or material flows is at the heart of the theory of linear programs. The idea that value is conserved at an activity, i.e.

\[ \text{value in} + \text{added value} = \text{value out}, \]

is closely related to the concept of duality.

With these ideas in mind, let us now formulate a precise definition of the concept of value flow for a linear program. All materials or goods, whether they are inputs or outputs to an activity, will be referred to as resources. Constraint rows which balance the outputs and inputs of a resource are referred to as resource balances. We assume that the objective function which has been minimised in the solution of the LP is expressed in units of monetary value. The unit value of a resource is its shadow price, \( y_i \). What do we mean by that? To explain the notion we recall from section 2 that \( y_i \) is the amount by which the objective function cost increases per unit increase in the right-hand side, namely \( b_i \), of the resource balance. This right-hand side can be interpreted as a final demand for the resource; in this case it is natural to interpret \( y_i \) as the marginal cost of production of the resource, and the term "unit value" is clearly appropriate. For a general resource constraint, \( b_i \) may not have such a direct physical interpretation as a final demand for some good; it may even be negative, depending on the meaning of the constraint. However, since \( b_i \) has the same mathematical or economic function whatever the interpretation of the constraint, we still refer to \( y_i \) as the unit value. It is measured in the same units as the objective function per unit of the resource, e.g. Lira per tonne, or dollars per gigajoule. We now define the total flow of value of resource \( i \) from activity \( j \) as the product \( y_i A_{ij} x_j \). 
The matrix \( A \) is the \( m \times n \) matrix of constraints defined in the original problem. Note that the flow of value is measured in monetary units, e.g., Lira. The flow of value per unit of activity as defined by \( y_{i}A_{ij} \) is sometimes a more convenient quantity than the total flow of value, because the former is not necessarily zero when the activity itself is zero.

5.1.4.1 Sources and sinks of value

With the flow of value as defined above, we introduce the idea that value is conserved at rows (resource balances) and activities. The conservation of value at rows is expressed by the relation:

\[
\sum_{j} y_{i}A_{ij}x_{j} = y_{i}b_{i}.
\]  

(12)

which holds for the optimal solution (see equation 10). The left-hand side of this balance is the total net production of resource \( i \) from all activities, multiplied by its unit value \( y_{i} \). The right-hand side is therefore interpreted as the value of the resource finally consumed. Naturally, if the right and left-hand sides are negative, the left-hand side represents a net consumption of the value of the resource and \( y_{i}b_{i} \) is a production of value. In summary, \( b_{i} \) is a sink of value if it is positive and a source of value if it is negative.

The conservation of value at activities is expressed by the relation (see equation 11):

\[
\sum_{j} y_{i}A_{ij}x_{j} = (c_{j} - r_{j})x_{j}.
\]  

(13)

The term \( \sum_{j} y_{i}A_{ij}x_{j} \) is the net flow of value out of the activity \( j \), per unit of activity. To ensure conservation of value, we interpret \( c_{j} - r_{j} \) as the value added at activity \( j \), per unit of activity.
Thus:

\[ \text{Value added at } j = (c_j - r_j) x_j = \text{net value flow out of } j = \sum_i y_i a_{ij} x_j. \]

We regard the objective function row, which contains \( c_j \), as a source of value. The reduced cost \( r_j \) is of course zero if the activity \( x_j \) is in the basis \( x_B \). If \( x_j \) is free on the other hand, its reduced cost is not zero. There are then two possibilities. In the case that the free variable \( x_j \) is at some lower bound, \( r_j \) is positive and we refer to the lower bound as a sink of value. In that case a unit value \( c_j \) enters the activity from the objective function source, and a unit value \( r_j \) leaves it as the lower bound sink. The second possibility for a free variable is that it is at an upper bound, in which case \( r_j \) is negative, and the upper bound is a source of value \( |r_j| \) per unit of activity. Notice that the unit flow of value through activity \( j \) is still meaningful even if the activity \( x_j \) is zero.

5.1.4.2 Cost-effectiveness of an activity

With the above definition of flows of value we are in a position to define a precise measure of the cost-effectiveness of an activity within a linear program. The general idea is that an activity is cost-effective if the cost of producing its output is less than the market value of that output. Let us then start by defining the cost of production, or production cost. In general an activity may have more than a single product, so it is not meaningful to associate the cost with a particular one, nor is there a meaningful way to allocate the cost between products. Instead, we take the production cost to refer to the cost of a unit of the production activity. The production activity itself may be measured in any convenient units, as long as all outputs and inputs are linearly related to it.
The production cost is then the sum of the cost coefficient and all the unit value flows into the activity, not counting value to or from bounds:

\[
\text{Cost of production of activity } j = c_j - \sum_i y_i A_{ij}^- \tag{14}
\]

We have introduced the superfix "-" to indicate that the summation only includes negative elements of \( A_{ij} \); these are the ones that correspond to flows of value into activity \( j \).

In a similar way the unit of the products of the activity that measures its benefit is given by:

\[
\text{Benefit of activity } j = \sum_i y_i A_{ij}^+ \tag{15}
\]

where the superfix "+" denotes the positive elements of \( A_{ij} \), which correspond to the flows of value out of activity \( j \).

A useful definition of cost-effectiveness is the benefit/cost ratio:

\[
\text{Benefit/cost} \quad = \frac{\sum_i y_i A_{ij}^+}{\left(c_j - \sum_i y_i A_{ij}^-ight)} \tag{16}
\]

This activity is in a "break-even" condition when the benefit/cost ratio is unity. We can rewrite the benefit/cost ratio in a more transparent way by substituting (see equation 13):

\[
c_j = r_j + \sum_i y_i A_{ij}^- + \sum_i y_i A_{ij}^+ \tag{17}
\]

which gives:

\[
\text{Benefit/cost} = \frac{\sum_i y_i A_{ij}^+}{r_j + \sum_i y_i A_{ij}^+} \tag{18}
\]

Written in this way, the ratio contains all the costs of production within the reduced costs \( r_j \). It is a convenient formula for calculation because the \( r_j \) are part of the standard output of the solution to a linear program.
Since all the \( y_i \) and \( A_{i, j} \) are positive, the benefit/cost ratio is clearly less than unity if \( r_j \) is positive. This means that the activity is uneconomic and \( x_j \) is at its lower bound, which by default is normally zero. If the benefit/cost ratio is greater than unity, it is because \( r_j \) is negative, which means that the activity is profitable and \( x_j \) stands at its upper bound. The break-even condition occurs if and only if \( r_j \) is zero, which implies that the activity \( x_j \) is in the basis.

We shall generalise this definition of cost-effectiveness to the case of a set of activities, i.e., a project. The generalisation is best understood with the help of a graphical representation of the problem, so we postpone it until section 4.

5.1.5 Sensitivity of Shadow Prices to Input Data

Besides the direct kind of measure of competitiveness which is given by an indicator such as the benefit/cost ratio, it is also of interest to know how sensitive is the optimum solution to the set of cost assumptions and other data that were used in its generation. It may be that the cost data were intrinsically uncertain and one seeks the range of optima corresponding to the range of uncertainty. Another aim may be to identify significant activities that are, by their costs, inhibiting the cost-effectiveness of a project. Cost targets can be defined for certain activities if the key activities are identified. In this section we discuss how the link between input cost and shadow price may be traced, so that the shadow prices in our benefit/cost formula can be attributed to particular assumptions.

We are concerned here with the sensitivity to variations that leave the optimal basis unchanged. Although larger variations may be of interest, their effects are not accessible from the results of the optimal solution without reoptimizing. This is the business of parametric programming, and is beyond the scope of our paper.
The information about cost-effectiveness and the sensitivity to small variations is carried by the dual solution $y$, which is related to the input costs by equation (7):

$$y = c_BB^{-1}.$$  

The reduced costs $r$, which as we saw in the preceding section are responsible for swinging the benefit/cost ratio away from unity, depend explicitly on $y$ through equation (11). In general all elements of $B^{-1}$ and $c$ are involved in $y$, so it might appear an impossible task to gain any insight into the dependencies involved. Problems of practical interest are usually sparse, however, in which case it is often possible to discover and understand in a simple way how the result depended on the input parameters, and which were most significant.

The key to this understanding lies in the fact that sparse problems can be reduced to Block Lower Triangular form by row and column interchanges. There are efficient algorithms for this purpose, for example, Duff and Reid (1978). It can easily be shown that if $B$ is of Block Lower Triangular form, so too is its inverse $B^{-1}$. The dependencies are thereby exposed and as far as possible reduced. For let us suppose that the dimension of the lower right hand block is $\ell \times \ell$, then assuming that $\ell \ll n$ the relatively few last $\ell$ elements of $y$ depend only on the last $\ell$ elements of $c_B$ through the $\ell \times \ell$ block of $B^{-1}$.

The elements of $y$ that correspond to the elements of the next block of $B^{-1}$ can then be solved in terms of the those just determined and the corresponding elements of $c$ by inversion of their block. We see that if we determine $y$ by this blockwise procedure the dependence of the elements of $y$ on the input costs is restricted to their immediate block and to the elements of $y$ already determined. We can speak of a flow of causality up the matrix. This structure is illustrated in Figure 2.
The interpretation is further simplified if it happens that the blocks are not all coupled one to the next by non-zero elements of $B^{-1}$. In this case the chain of causality is broken, and the remaining shadow prices do not depend on any of the input costs up to the break.

5.1.6 Graphical Representation

The preceding ideas can best be illustrated and applied in practice by drawing graphs. Graphs are a useful representation of an LP only if it is sparse. The type of sparse problem we have in mind is a generalisation of the transportation problem for which a graphical representation is introduced in the elementary linear programming texts. Let us represent the resources by circles. In our general case the activities can draw on more than one resource and produce more than one resource, so it is not sufficiently general to join the circles by lines as in the simple transportation problem, where the lines would represent the activities of shipment. We therefore introduce boxes to represent the activities, from which lines enter and leave to connect them to the resources, with the possibility of joining a box to several resources. Each line represents a non-zero matrix element $A_{ij}$ which joins resource $i$ to activity $j$. An arrow on the line pointing into the resource indicates that the element is positive; an arrow pointing out of the resource indicates a negative element. So in our resulting graphs circles are always connected to boxes, never directly to other circles. Similarly, boxes are connected only to circles, never to other boxes.

We could in principle draw a graph for the whole problem matrix $A$, but this would be impractical if the problem is large, and for the post-optimal analysis we are describing it is sufficient only to include circles corresponding to active constraints which have a non-zero shadow price. In practice, as we shall see, a graph is only drawn of the currently interesting part of the total problem.
The elements of a graph are illustrated in Figure 3.

The sources and sinks of value (see section 5.1.4.1) we represent by circles or boxes with a single input or output line; they arise from active bounds on activities and from the right-hand sides of constraint rows.

In general there is one circle for each active row of the matrix, but for non-binding rows, in particular for the objective function, it may be easier to associate separate circles with different activities, although they all refer to the same row.

The graphical representation of part or all of a problem certainly helps the analyst to appreciate its interconnections and sometimes in our experience leads to improvements in its formulation. As a bonus, however, we have found with the MARKAL model that the direction of causality flow can often be assigned to the links on the diagram and a solution for some of the shadow prices obtained. Even if this is partly in terms of other shadow prices, from lower blocks, it displays some of the interesting sensitivities of the problem to the input data, and perhaps all those of interest. Where possible, the causality flows are assigned simply by inspection of the graph, applying the principles outlined in section 5.1.5. The main point is that causality is only transmitted from shadow price to shadow price by basic variables; so any variables with a non-zero reduced cost are automatically "sinks" of causality, that is to say their input parameters do not directly cause any of the other shadow prices or reduced costs in the problem. Once again we stress that the analysis only refers to the optimal solution, and although the range of parameters can be determined under which the solution remains optimal, nothing can be said about the new solution if larger variations in the parameters are contemplated.

We shall illustrate the use of a graph in section 5.1.8, but first we complete our discussion of cost-benefit analysis.
5.1.7 Cost-Effectiveness of a Set of Activities

In practice one is unlikely to be interested in the cost-effectiveness of a single activity, since most projects consist of a set of activities that are interdependent. Fortunately we can readily generalise the concept of cost-effectiveness described in section 2.2 to provide an appropriate formula for the benefit/cost ratio of a set of activities. The generalisation must be done in such a way that transfers between activities within the set cancel out. If we simply calculated the net benefits separately for each activity and then added them together, the required cancellation would not occur, because the output of an activity would count as a net benefit if it was consumed by another member of the set. In the following discussion we refer to the graphical description of the problem introduced above.

The first step is to identify all the activities which form the project to be assessed. In the example of the following section, these are the elements associated with a new technology at a series of times. We then add to the graph all the resources, sources and sinks of value to which the activities are connected. Thus all the connections to the activities of the project are documented on the graph. We can draw a system boundary to enclose all the activities of the project, all their bounds, and such resources as have no linkages (including sinks or sources) outside it. By analogy with section 2.2, the production cost of the project is then the sum of the cost coefficients and all the value flows into the project:

\[
\text{Cost of production of project } = \sum_{j \in P} (c_j - \sum_{i \in N} y_i A_{ij}) x_j, \tag{19}
\]

where \( i \in N \) means that only resources which have connections outside the project, to other activities, or to sources or sinks, are to be summed over. This excludes resources which merely connect one part of the project to another. Conversely, \( j \in P \) restricts the summation over activities to those within the project.
Since several activities are involved, we can no longer consider only the flows per unit of activity as we did in equation (14), so the $x_j$ now appear explicitly.

In a similar way the net flow of value out of a project represents its benefit (cf. equation 15):

$$\text{Benefit of project} = \sum_{j \in P} \sum_{i \in N} y_i A_{ij}^+ x_j.$$  \hfill (20)

As in the case of an activity we can divide the benefit by the cost to obtain an index of competitiveness:

$$\text{Benefit/cost} = \frac{\sum_{j \in P} \sum_{i \in N} y_i A_{ij}^+ x_j}{\sum_{j \in P} c_j x_j - \sum_{j \in P} \sum_{i \in N} y_i A_{ij}^- x_j}. \hfill (21)$$

The conservation of value flows tells us that the benefit/cost ratio will be unity (break-even) if there are no sources or sinks of value within the project. To make this explicit let us substitute for $c_j$ as we did in section 5.1.4.2. We first write equation (13) in the expanded from:

$$c_j = r_j + \sum_{i \in N} y_i A_{ij}^- + \sum_{i \in N} y_i A_{ij}^+ + \sum_{i \in P} y_i A_{ij}. \hfill (22)$$

When the summation over the activities within the project is made the flows within the project cancel, leaving only source or sink terms, as described by equation (12). We substitute (22) into (21) and make use of (12) to obtain:

$$\sum_{j \in P} c_j x_j = \sum_{j \in P} r_j x_j + \sum_{i \in P} y_i b_i + \sum_{j \in P} \sum_{i \in N} y_i A_{ij}^- x_j + \sum_{j \in P} \sum_{i \in N} y_i A_{ij}^+ x_j. \hfill (23)$$

Finally, making the substitution into equation (21):

$$\text{Benefit/cost} = \frac{\sum_{j \in P} \sum_{i \in N} y_i A_{ij}^+ x_j}{\sum_{j \in P} r_j x_j + \sum_{i \in N} y_i b_i + \sum_{j \in P} \sum_{i \in N} y_i A_{ij}^- x_j}. \hfill (24)$$
Equation (24) is the central result of our paper for the benefit/cost analysis of projects within a linear program. It is well suited to calculation by a simple program because the shadow prices and reduced costs which are needed are easy to identify and read from the optimal solution. If lower bounds are active, we recall from section 2.1 that they are sinks of value, \( r_j \) is positive and they therefore tend to reduce the benefit/cost ratio. In applications, it is useful to specify small positive lower bounds for example on annual investments, so that a benefit/cost ratio of less than unity is obtained even for an unfavourable project. Otherwise it may be that all its activities are zero, and then equation (24) would not be well defined. Conversely, active upper bounds within the project are sources of value that tend to increase the benefit/cost ratio. These active upper bounds are the bottlenecks which are preventing an even more optimal solution to the problem, and if their values are subject to any uncertainty their degree of importance in (24) may recommend them for closer scrutiny. Similar remarks apply to the constraints \( b_i \). Thus equation (24) provides both an index of competitiveness and the starting point of a sensitivity analysis. A program COSTBEN has been written in the OMNI language to make benefit/cost calculations using (24) for any selected set of technologies in the MARKAL model. In order to obtain meaningful nonzero values of benefit/cost ratio for uncompetitive technologies we normally impose small lower bounds on the capacity of a technology to force a test profile of investment into the solution.

Finally it may be noted that the total net cost of the project, as defined by subtracting (20) from (19), takes a particularly simple form if we substitute (23), namely:

\[
\text{Net cost} = \sum_{j \in P} r_j x_j + \sum_{i \in P} y_i b_i. \tag{25}
\]

It represents the negative of the profit made by the project.
A comparison with (8) shows that (25) is the contribution of the project on the total system cost, which was our objective function.

5.1.8. An Example: a Technology with Time Dependent Activities

The example which we work through in this section combines the concepts of graphical representation, flows of value, flows of causality and cost-benefit analysis which were introduced in the preceding sections. The example draws upon our experience with the energy model MARKAL, but we have chosen a simple case which illustrates principles of wider generality for project assessment, in particular the way of dealing with time-dependent quantities. The case we consider is a technology which produces synthetic gas from hard coal. It is just one of many technologies which we suppose are being studied within a LP which minimises the total present value cost.

5.1.8.1 Nomenclature

The technology is represented by a number of activity variables defined at six discrete points in time; the number six is arbitrarily chosen to fix ideas. The activities are as follows:

\(X_{\text{INV}}(T), \text{ for } T = 1, 2, 3, 4, 5, 6.\)

This is the capacity of the technology added between times \(T - 1\) and \(T\).

\(X_{\text{CAP}}(T), \text{ for } T = 1, 2, 3, 4, 5, 6.\)

This is the capacity in place at time \(T\).

These activities are connected to the following constraint rows ("resources"):

\(\text{BALHCO}(T), \text{ the balance of hard coal}:\)
Sources of coal in period $T - axCAP(T) - \text{consumption} \geq 0$, \hspace{0.5cm} (26)

where $a$ is the availability factor.

$BALGAS(T)$, the balance of gas:

$$ax\epsilon xCAP(T) + \text{other sources} - \text{consumption} \geq 0, \hspace{0.5cm} (27)$$

where $\epsilon$ is the efficiency factor.

$BALKPT(T)$: the capacity/investment balance

$$\sum_{T' \leq T} XINV(T') - XCAP(T) \geq 0. \hspace{0.5cm} (28)$$

where the summation extends only as far back in time as the lifetime of the plant.

The reduced costs of the activities we denote by $RINV(T)$ and $RCAP(T)$. The shadow prices of the three kinds of rows we denote by $YHCO(T)$, $YGAS(T)$ and $YCP(T)$ respectively.

The portion of the matrix describing this technology is illustrated in Figure 4, and displayed graphically in Figure 5.

\textbf{5.1.8.2 Value flows}

We can now write down the balances of value flows at the two kinds of activity, namely, capacity and investment.

For the balance of value flow at the capacity in each time period we have:

$$CCAP(T) - RCAP(T) = ax\epsilon xYGAS(T) - AxYHCO(T) - YCP(T). \hspace{0.5cm} (29)$$

and at the investment:

$$CINV(T) - RINV(T) = YCP(T) + YCP(T+1) + \ldots YCP(T+L-1), \hspace{0.5cm} (30)$$

where $L$ is the lifetime of a plant.
The significance of equation (30) is that it distributes the investment cost, CINV, over the lifetime of the plant in portions YCPT(T) at each time period. As equation (29) shows, these portions of the investment cost are incurred by the capacity at their respective times, where they are effectively added to CCAP(T). In this way YCPT(T) represents a generalization of the concept of annualised capital cost.

5.1.8.3 Competitiveness

For a single activity it is straightforward to write down the benefit/cost ratio:

\[
\text{Benefit/cost} = \frac{Ax\€xYGAS(T)}{(CCAP(T)+axYCPT(T)+YHCO(T))} = \frac{ax\€xYGAS(T)}{(ax\€xYGAS(T)+RCAP(T))}. \tag{31}
\]

Because it refers only to the activity, this ratio indicates whether it is worthwhile to operate a plant which is already installed and not whether it should be built in the first place. There are three possibilities:

(1) RCAP(T) = 0, benefit = cost.

The variable XCAP(T) is in the basis and may therefore be a transmitter of causality. For example, if the technology is a marginal source of gas, it causes the gas price YGAS(T) by addition of value to the coal price.

(2) RCAP(T) ≥ 0, benefit ≤ cost.

The capacity is at its lower bound, which would normally be zero. It is a sink of value, and its operation is not currently economic.

(3) RCAP(T) ≤ 0, benefit ≥ cost.

The capacity is at an upper bound and would be operated profitably at a greater level if the upper bound were raised.
Finally, the benefit/cost ratio for the project as a whole is given by:

\[
\text{Benefit/cost} = \frac{a \times \varepsilon \times \sum_{T} YGAS(T) \times XCAP(T)}{\sum_{T} CCAP(T) \times XCAP(T) + \sum_{T} CINV(T) \times XINV(T) + \sum_{T} YHCO(T) \times XCAP(T)}
\]  \hspace{1cm} (33)

\[
= \frac{a \times \varepsilon \times \sum_{T} YGAS(T) \times XCAP(T)}{a \times \varepsilon \times \sum_{T} YGAS(T) \times XCAP(T) + \sum_{T} RCAP(T) \times XCAP(T) + \sum_{T} RINV(T) \times XINV(T)}
\]  \hspace{1cm} (34)

5.1.9. Summary and Conclusions

Our aim has been to introduce the concept of value flows in the interpretation of a linear program. The concept links the notions of input-output tables and cost benefit analysis with the mathematics of linear programming, and makes use of the dual solution. Based upon this concept we have derived formulae for the benefit/cost ratio of activities or projects in terms of the data and results of a cost optimization. We have also described how one can often unravel the chain of cause and effect in the optimal solution and discussed how this simplifies the analysis of sensitivity. To assist in the understanding and application of these ideas we have introduced a graphical representation of the system or sub-system under consideration.

As our final example should make clear, we regard the present results as a practical tool of analysis, and the equations as well suited to programming in conjunction with any other automatic report generation which may be at the disposal of the analyst.

Finally, although we have discussed all the present concepts in relation to a linear program, they appear to be readily adaptable to the analysis of non-linear problems.
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(3) F. Altdorfer, Implementation Scenarios for New Energy Technologies in Belgium, Prime Minister's Office, Brussels, 1980.


Legends to Figures

Figure 1: (a) The initial tableau for a linear program, and (b) the tableau for the optimal solution.

Figure 2: The flow of causality in the matrix which has been arranged in lower block diagonal form.

Figure 3: The elements of a graph representing a linear program.

Figure 4: The portion of the matrix describing the technology discussed in section 5.1.7.

Figure 5: The graph representing the technology discussed in section 5.1.7. The arrows indicate the direction of value flow and are labelled by the magnitude of the corresponding matrix element. For simplicity, only the elements of time T are drawn with all their connections, since future and past are similar.
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5.1.2 Value Flow Analysis

For Some Renewable Energy Technologies in Japan
(S. Koyama et al.)

5.1.2.1 Introduction

In order to explore and define the direction and goal of R&D on some selected renewable energy technologies including solar and ocean energy technologies, energy systems analysis has been conducted using the optimization method of MARKAL.

The optimized results have been studied further by "value flow analysis" to give information on the causality flow in the optimal solution. Such information can be used to indicate the necessary improvement in the characteristics of a technology, to assess improvement in the characteristics of a technology, and to assess the conditions of market penetration.

This paper describes the summary of the results of our value flow analysis on several energy technologies.

5.1.2.2 Scenarios for the Analysis

Two main scenarios, namely high fuel price–low energy demand and low fuel price–high energy demand have been prepared for the analysis. Each has respectively the sub-scenario of (1) cost minimum (a)base, (b)nuclear limited, (c)coal limited, (2)CO2 limited cost minimum, (3)security maximum. Thus the total number of scenarios is ten. In this paper, however, the results for (1a) and (2) are mainly discussed because the results for (1b) and (1c) are not much different from (1a) in the competitiveness of new technologies.
Scenario (2) is interesting as a preliminary step for more detailed analysis of environmental effects. The results for (3) are not discussed here in detail because of its extremity.

At first, value flow of the typical conventional electric power generating technologies of coal, oil and LWR are observed in the following section to seize the essence of the method and interpretation of the market competitiveness of the technologies, and then, some renewable energy technologies are discussed with the value flow.

5.1.2.3 Discussion on Value Flow

(1) Coal Electric Power plant

Fig. 1 shows the value flow of conventional coal electric power plants with desulfurization and denoxygening equipment. The generating capacity of these plants increases to the peak in 2005 and then decreases. In the diagram, the rectangular blocks correspond to variables with reduced costs "RC" and activities "ACT", and the ellipses correspond to constraints or functions with shadow prices. In this case, all the reduced costs of the variables are zero and all activities are positive, i.e., working.

The value outflow from the variables tends to promote their activities, and the value inflow tends to suppress them. The value inflows to all the variables from the cost objective function are just the cost coefficients of the variables. The inflow 597 to the additional capacity variable corresponds to the investment cost of the plant and its associated transmission and distribution system, 59 to the installed capacity variable corresponds to the fixed operating and maintenance cost, and 0.8 to electricity generating variables corresponds to variable operating and maintenance cost. These coefficients have been discounted to the reference time point and can be extracted from input data alone.
Values decided by the optimization are the inflows from the fuel balance relation which are suppressing forces, and the outflows to electricity peaking constraints and to electricity balance relations which are promoting forces. For example, among the promoting forces of the capacity variable 306 (=119 +0 +51 +11 +70 +8 +47 +0), 39% due to peaking purpose and 61% is due to electricity supply.

The effect of a change in characteristics of the technologies on the market competitiveness can be found by examining the value flow diagram. As the flows from the objective function are strictly related to the input data, the effects of a change in cost data on the flow values are completely determined. If the share of a specified technology is not large in the system, the effect of its data change on the fuel and electricity balance relations is not large and it will not affect their shadow prices. Therefore, the effect of the change in the cost data can be obtained from a small subset of the optimization results. That is, the inflows from the fuel balance relations are proportional to the reciprocal of the efficiency, and the outflows to the electricity balance relations through the electricity production capacity constraints are closely related to the availability factors.

Table 1 shows the variation with time of the reduced costs and activities of all variables, which may be compared to the static snapshot of the value flow in Fig. 1.

The value flows associated with inputs and outputs of the energy carriers are decided by the shadow prices of the balance relations. Fig. 2 shows an example of the shadow prices of main energy carriers for the cost minimum scenarios. In the CO2 limited scenario all the shadow prices of the secondary energy carriers become expensive. The reason is the cumulative effect of the introduction of expensive energy sources other than fossil fuels for reducing the amount of CO2 emission and the addition of penalty coefficients in the objective function for the CO2 emission.
The effect of limiting CO2 release of the fossil fuel plants depends on the combined effect of the shadow prices of fuel balance relations and electricity balance relations. The CO2 limited scenario mainly favors renewable energy technologies. However, the judgement is not straightforward for the technologies with fossil fuel backup because the effects from electricity and fuel work inversely.

Concerning the security priority scenario, we see that the promoting force for introducing the renewable energy technologies is very large and almost all renewable energy technologies are accepted, however the shadow prices of energy carriers are extremely high.

One more useful point of the value flow diagram is that it can be used for understanding or checking the modelling.

(2) Oil Electric Power Plant

The oil electric power plants in Japan provide the greatest generating capacity at present, but the scenario runs show that they decrease steadily in the future. Only existing plants are to be used and no new plants are to be built.

Fig. 3 shows the value flow of the oil electric power plant. The plant of this type is superior in the investment and O&M cost to the coal electric power plant and its value outflows to electricity relations are the same, but it is inferior in the inflow from the fuel balance relation. Thus, it seems to be less competitive in the future.

(3) Light Water Reactor Electric Power Plant

The generating capacity provided by nuclear electric power plants in Japan is presently increasing, and the scenario runs show that they increase also in the future. Fig. 4 shows the value flow of the LWR electric power plant.
As the LWR is defined as base load plant, only three electricity production variables are used instead of the six in more flexibly operable plants. The negative value of reduced cost of the capacity variables shows that the capacity is at the upper bound which means the technology is very competitive.

(4) Solar Thermal Electric Power Plant

Fig. 5 shows the value flow for the solar electric power plant. As it has been modelled simply as type "XLM" in MARKAL, electricity production variables are not explicitly used. The operating scheme was set beforehand at the input data of seasonal and diurnal capacity factors. As the additional capacity variable has a positive value in the reduced cost, this technology is not accepted in this cost minimum scenario.

Our criteria in this analysis are not sufficient, and we must be careful in the interpretation of the results. This technology should really be assessed by taking into account the general advantages of the renewable energy technologies.

(5) Industrial Solar Thermal Coupled Production Plant

Fig. 6 shows the value flow for the industrial solar thermal coupled production plant. The structure of the model of this technology is very complex with twelve electricity and heat production variables, typical of the pass-out turbine. In this case, nighttime variables and relations have no meaning, since the nighttime availability factors have been set to be zero. The scenario run shows the technology is not accepted, as seen in the positive reduced cost of the additional capacity variable. However, it is expected that this technology will be accepted if there is some improvement in the investment cost, or the availability factors, or the efficiency.

(6) Solar Photovoltaic Electric Power Generation

The solar photovoltaic electric power generation system can be used in a variety of combinations of subsystems and application
schemes; it is most advantageous in decentralized use. In the model for the analysis, this technology is used in four different ways. Its acceptability is different in each use. The results of analysis show that decentralized use is more economical than the centralized one.

Fig. 7 shows the value flow of the decentralized photovoltaic electric power generation with battery storage, in which it is seen that this technology is accepted.

(7) Ocean Thermal Gradient Electric Power Generation

Fig. 8 shows the value flow of the technology for thermal gradient electric power generation. The technology is accepted. The plant is assumed to be located in the southern part of Japan where the climate and ocean conditions are known to be suitable. The advantage of this technology is ascribed to high availability factors throughout the year. The negative value of the reduced cost of the capacity variable shows that this technology is fairly competitive.

5.1.2.4 Summary

We have presented value flow diagrams and their interpretations for several energy technologies. It has been demonstrated that the analysis of the sensitivity of key parameters for each technology can be performed efficiently. We hope this method can be applied also to the analysis in the energy-environmental study to obtain a more detailed and deeper understanding of the problems.
Figure 1: Value flow diagram for conventional coal electric power plant in 2000 in high fuel price-low demand-cost minimum scenario
Table 1: Transition of reduced cost and activity of variables for coal electric power plant in high fuel price-low demand-cost minimum scenario

<table>
<thead>
<tr>
<th>Time period</th>
<th>INV</th>
<th>CAP</th>
<th>Electricity production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RC</td>
<td>ACT</td>
<td>WD</td>
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<tr>
<td>1</td>
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<td>0.6</td>
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<tr>
<td>2</td>
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<tr>
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<tr>
<td>9</td>
<td>10.6</td>
<td>0.</td>
<td>0.8.0</td>
</tr>
</tbody>
</table>

(RC: Reduced cost, ACT: Activity)
Figure 2: Shadow price for some main energy carriers in high fuel price-
low demand-cost minimum scenario
Figure 3: Value flow diagram for oil electric power plant in 2000 in high fuel price-low demand-cost minimum scenario
Figure 4: Value flow diagram for LWR power plant in 2000 in high fuel price-low demand-cost minimum scenario.
Figure 5: Value flow diagram for solar thermal electric power plant in 2015 in high fuel price-low demand-cost minimum scenario.
E3P: SOLAR THERMAL COGENERATION
HIGH PRICE/LOW DEMAND/PRICE
5TH TIME PERIOD

Balance relations for electricity & low temperature heat
Fuel Balance
relation

Electricity & heat
production variable

Electricity & heat
production capacity
constraint

Objective
function

72.4
Installed capacity
variable

Capacity transfer relation

Additional capacity
variable

Figure 6: Value flow diagram for industrial solar thermal coupled production plant in 2000 in high fuel price-low demand-cost minimum scenario
E4C: SOLAR P.V. POWER (PRV, WITH BATTERY)
HIGH PRICE/LOW DEMAND/PRICE
8TH TIME PERIOD

Electricity balance relation

Winter  Intermediate  Summer

Installed capacity variable

Objective function

Solar cell production constraint

Capacity transfer relation

Additional capacity variable

Figure 7: Value flow diagram for decentralized solar photovoltaic electric power production in 2015 in high fuel price-low demand-cost minimum scenario
E38: OCEAN THERMAL GRADIENT ELEC. PLANT
LOW PRICE/HIGH DEMAND/PRICE
7TH TIME PERIOD

Electricity balance relation

Winter

Summer

Electricity production variable

Electricity production capacity constraint

Objective function

Installed capacity variable

Capacity transfer relation

Additional capacity variable

Figure 8: Value flow diagram for ocean thermal gradient power plant in 2010 in low fuel price-high demand-cost minimum scenario
5.2 Energy and the Economy

5.2.1 An Overview of Modelling Approaches
(P.A. Bergendahl)

The variety of modelling approaches in the energy field is to a large extent a reflection of the many aspects of the energy issues, but also of different modelling traditions. This implies that different models are used to analyze different problems.

For example, macroeconomic models are used to analyze the macroeconomic effects of changed conditions in energy supply, while more detailed energy sector models are needed to analyze and evaluate more specific energy strategies.

In this perspective it is obvious that models will differ. Primarily they differ with respect to:

- boundaries,
- level of aggregation,
- theoretical basis and
- optimization vs. simulation.

**Boundaries** refer to time and space, as well as to the principle that "everything depends upon everything else". In other words it concerns the classification in endogenous and exogenous variables.

**Level of aggregation.** The development of an economy may be described by an aggregate production function (a macro production function) or, in more detail, by a multisectoral (input-output) model.

When modelling a specific industry or sector, we may distinguish between econometric and process models. Econometric models are based on a generalized description of the factors influencing energy demand, while process models start from a detailed description of a sector in order to, e.g., analyze energy demand sensitivity.
As far as the possibilities of analyzing a specific problem are concerned, the level of aggregation in a model is of course of primary importance. As a simple example, it is not possible to analyze the balancing between district heating and individual heating in a model where energy is treated as an aggregate factor.

The theoretical basis in model specifications is of course of primary importance for each analysis. We may roughly distinguish between the following modelling approaches.

- macroeconomic models,
- system dynamics models,
- process models
- econometric models and
- "bookkeeping" models/forecasting models.

The different macroeconomic models have - to various degrees - elements from growth theory, input-output theory, production theory and consumption theory. These models are used to illustrate macroeconomic relations, e.g., the effects of energy increases on private consumption and productivity growth.

System dynamics models refer to simulation models, where a system behaviour is simulated by a set of differential equations. A system description is based on specified relationships between stocks and flows, with an emphasis on dynamic relationships (various lags, delays etc.). A system dynamics model is not necessarily different from macro-economic models, although early examples displayed distinct differences.

"Process models" is a generic name for models based on a description of the options (e.g., techniques of production) in a sector of even in a single plant. These models are very often formulated as linear programming problems.
MARKAL is an example of a process model (or activity model) for the energy sector. The Brookhaven models for the iron and steel industry and the paper and pulp industry are other examples.

In this context, the purpose of economic models is to estimate elasticities of demand, which is done on the basis of production or consumption theory and statistical/econometric methods.

Econometric analyses of the household sector aim at estimating short run and long run price and income elasticities of demand for energy carriers (gasoline, electricity etc.). Such analysis may be based on the overall pattern of consumption in households (food, housing, transportation etc.) or on more partial formulations (gasoline, demand as dependent on income, prices, number of car registrations etc.)

Studies on the industrial demand for energy are based on production function approaches. Central analytical results are own price and cross price elasticities (e.g., with respect to energy, capital, labor and material) and the directly linked elasticities of substitution. Such studies may differ, e.g., with respect to functional forms (translog, generalized Leontief, etc.) or with respect to the treatment of "non price" explanatory variables (technical progress, economies of scale, etc.)

It should be mentioned that the concept of econometric models is also used in a wider sense, i.e., not only for the estimation of parameters, but also for models using such parameters.

"Bookkeeping" models and forecasting models refer to models centered around certain structural relationships, trends or time dependencies. For example, that energy use is related to the structure of population: if the structure of population is forecasted to change, energy use will change. This category refer to models with one-way causal relationships, where there are no feedback or equilibrium features.
In summary, each model can be said to represent a certain choice of theoretical basis, boundaries and level of aggregation.

Furthermore, the distinction between optimization models and simulation models should be mentioned. Optimization models aim in principle at the derivation of normative solutions: how a system ought to be developed under specified conditions and objectives. MARKAL is an example of such a model.

Simulation models are in principle intended to "copy" (or simulate) the evolution of a system - and do not really concern themselves with the question of whether it is good or bad. The system dynamics models belong to this category.

However, the classification into optimization or simulation models is not always so clear-cut: certain models may have elements of optimization as well as of simulation. The TESOM-model (a "relative" to MARKAL at Brookhaven) might serve as such an example. The structure of the energy system is optimized in each period, which altogether - in the longer run - should simulate the evolution of the system. It should also be mentioned that a system of models may comprise optimization models as well as simulation models.
5.2.2 Integrated Energy-Economy Model and its Application in JAERI
(S. Yasukawa et al.)

(1) Integrated Energy-Economy Model

Since 1977, research and development work on "the Integrated Model for Energy-Economy Systems Analysis" has been progressing at JAERI for the purpose of quantifying the effect of introducing nuclear energy technologies into our energy-economy-environmental system. This integrated model, as shown in Fig. 1, consists of the following four model blocks.

The first model block, called the dynamic scenario generation block, can serve to construct a long-term view of socioeconomic development, on one hand, and to analyse a given scenario, on the other. The second model block, which is applicable to such analytical objectives as establishing a more structural approach to the energy-economy interaction problem, provides an analytical tool based on the combined methods of input-output and energy matrix. The third model block handles such problems as power reactor installation strategy and long-term fuel cycle analysis. The fourth model block treats cost-benefit-risk analysis.

Macro Energy Economy Model Group

The first block contains five macro energy economy models. They are the macro energy-economy multivariable auto-regressive model EEMVAR, the macro energy system dynamics model ENERGYSD, the long term macro econometric model LTMEMO, the macro energy-economy system dynamics model E²-SD, and the regional socio-energy-environment model RSEEM.

EEMVAR contains about 3500 items of energy-economy-environment time series data and the algorithm to extract dynamic characteristics of the system from these data. ENERGYSD is programmed in the DYNAMO language and forms a large data base.
It contains many energy-economy statistic data, parameters estimated from historical data, and technical and economical performance data. LT MEMO is composed of almost 70 macro functions and 40 definite equations in economics. Parameters in each function are estimated based on a national statistical data base. E\(^2\)-SD is constructed by structural-invariant bi-linear dynamic equations and is designed to provide scope for the structural transition process of energy technology in the longer term than ENERGYSD. RSEEM is a system dynamics model to evaluate quantitatively the impacts of a large scale energy facility on the regional society, economy, and environment. It consists of 14 sectors such as population, land use, transportation, industries, public facilities, financial, water resources, energy, etc.

These models have been developed for purposes of projecting, estimating, and evaluating future macro energy-economy activities in Japan, and for generating energy-economy scenarios for long-term structural analysis on energy-economy systems.

**Multi-Sectoral Energy-Economy Interactions Model**

The second block is for multi-sectoral energy-economy interaction analysis. The objective of the development is to present a degree of substitutability and complementarity among factor inputs, when various energy technologies are introduced, through quantifying the magnitude of these opposite properties taking into account the technical progress. The model can also estimate the impact upon the energy technology of the rest of the economic system.

This interaction model consists of two model blocks. The first is the economy system block in which various economic activities are quantified by the input-output model TRANS-I/O using variable technical coefficients. The second is the energy system block modeled by the energy-matrix analysis model E-MATRIX which allows combined calculations with the MARKAL model.
Major endogenous functions and/or exogenous variables in the model are the cost share functions representing inter-industrial transaction, consumption functions, investment functions, converters for operation and maintenance coefficient vectors of various energy technologies, and the response matrix representing useful energy demand-final energy demand relationship.

Long-Term Nuclear Fuel Cycle Model

The third block, for strategy analysis in the development of nuclear power reactors and related nuclear fuel cycle systems, involves the linear programming models JALTES-II and JALTES-III.

JALTES-II covers all types of nuclear power plants and the related fuel cycles. The installed capacity of each reactor type is determined by the linear programming. The objective function can be taken as a cumulative consumption of natural uranium, total system cost, or others. Constraints can be applied to an annual electricity generation, installed capacity, stocks of plutonium, and so on. The fuel cycle system in JALTES-II has various options, especially in in-core and out-core fuel management.

JALTES-III is a descendant of JALTES-II, but through fundamental modifications it has greater flexibility and higher accuracy. It can handle the storage of reactor fuels and fuel materials, and also simulate the fuel management which takes place at non-integer yearly time intervals. It can calculate the system cost in more detail than JALTES-II.

Cost-Benefit-Risk Analysis Model Group

The fourth block, for cost-benefit-risk analysis of an energy technology or a technology system, involves at present the cost assessment models and the nuclear industry financial model.
The cost assessment model can produce generating costs of a single unit power plant at a reference year by the levelized cost calculation method. The nuclear industry financial model can evaluate economy in nuclear industries and calculate process or production cost in each of the nuclear fuel cycle industries. The model can evaluate financial situations not only for various nuclear fuel cycle industries, but also for nuclear heat utilization industries.

(2) Data Base

Continued efforts have been made to update and expand the data base on energy technology characteristics. Since the environmental consequences of energy utilization are becoming a great concern, efforts are now directed to the development of a data base applicable to such studies as evaluating the energy system from the viewpoint of environmental emissions or restructuring the system toward zero emissions to the environment.

Characterized energy technologies are listed in Table 1 and Table 2. Additional technologies were added to the list to describe in detail high temperature nuclear heat and the synthetic fuel production systems. Each energy technology is characterized in terms of the data items listed in Table 3. The list was expanded to include detailed information on environmental emissions and on specific technologies to control them.

Energy Technology

Technical performance of energy technologies has been investigated to compile the data along with the items 1.1, 1.11 and 4.2 in Table 3.
The items include technical data on environmental protection technologies in addition to those set up for energy technology characterization in the ETSAP. The detailed characteristics of nuclear reactor technologies are also being compiled.

The technologies are classified into conversion technologies, process technologies, and end-use technologies. Conversion technologies such as electric power plants, cogeneration and district heating plants, and electricity storage plants are investigated. Process technologies include refinery technologies, synthetic fuel technologies, and nuclear fuel cycle technologies. End-use technologies include various heating devices and motors for industry, residential, and commercial use, and devices for transportation use. For nuclear energy technology, reactor characteristic data are compiled on such reactor types as the conventional LWR, the advanced LWR, the advanced thermal reactor (ATR), the FBR, the high conversion light water reactor (HCLWR), and the fusion reactor.

As far as cost data are concerned, items 2.1 - 2.13 in Table 3 are the same as cost data for the ETSAP Energy Technology Characterizations. However, item 2.14 is newly added for structural analysis of energy-economy systems by TRANS-I/O and E-MATRIX, and item 4.3 for cost data of environmental protection technologies.

In compiling cost data on environmental protection technologies, we take notice of the following four points: (i) detailed accounting of costs from the viewpoint of investments, operations, and maintenance of all technologies, facilities, and equipment, (ii) variation in efficiencies or net energy production when protection technologies are added, (iii) presence and amount of by-products produced by protection technologies, and (iv) estimation of credit costs of by-products for cost calculation of the main energy technologies.
As for the environmental data, the main subjects of investigation are the emission data of pollutants from energy technologies, and information on methods and equipments used by environmental protection technologies for the individual pollutants as shown in item 4.1 in Table 3.

These pollutants are classified into air pollutants, water pollutants, and wastes, as shown in items 3.1 through 3.3 in Table 3. They are measured at the exits of both energy technologies and protection technologies as shown in Fig. 2. The sources of these pollutants are raw material for nonenergy technologies and raw material and/or fuel for energy technologies.

Since we are now performing the environmental systems analysis, there may be substitutions in either technologies or kinds of energy. Therefore, in as much detail as possible, we must acquire emission data on each pollutant, distinguishing between nonenergy and energy technologies to measure how much these substitutions impact upon the environment.

End-Use Fuel Mix

Energy consumption in the industrial sector accounts at present for 58 % of the total energy consumed in Japan. This fact suggests the importance of analyzing in detail future growth of energy demand especially in the industrial sector. Here the analysis must be carried out considering possible structural changes of energy utilization within each industry.

However, each industry has a number of end-use technologies of different kinds and different sizes, and its fuel mix would depend on technology configurations. Fuel mix has historically exhibited a certain trend, so that study of the relationship between fuel mix and technology configuration is worthwhile. These relationships can be utilized to set up constraints on fuel mix for total energy system analysis. Thus the change in fuel mix can be treated properly without incorporating a prohibitive number of end-use technologies into the model.
The process model of the pulp and paper industry, one of the energy intensive industries in Japan, has been developed in JAERI by utilizing the framework of the MARKAL mode. Following is an outline of the process model.

The pulp manufacturing process is divided into ten different processes each of which has a unit process for shipping, cooking and grinding, refining, screening, bleaching, dewatering or drying. The paper and board manufacturing process is divided into blending and papermaking processes. The latter is further divided into 24 unit processes according to the fabrication methods. These unit processes are treated as "process technology" in MARKAL.

The pulp and paper industry uses purchased fuels and recovered wastes as energy sources. The former are treated as "imported carriers", the latter as "energy carriers" produced in the manufacturing process. All materials, semi-products, and finished products are also treated in the class (ENC) of the MARKAL model.

A special feature of this industry is the self-generation of a large amount of steam and electricity. The self-generation of electricity is modelled by using the "conversion technology" of MARKAL. Model results on consumption of fuels and materials and production of pulp show good agreement with actual past data.

(3) System Analysis and Technology Assessment

Nuclear Process Heat Utilization Study

Since 1984, JAERI and MIT have been carrying out a co-operative research program on systems analysis. The subject of the program is the study of the role of very high temperature reactor and nuclear process heat utilization in future energy systems. It consists of four tasks: (i) projection of energy demand and supply, (ii) energy technology characterisation,
(iii) impact analysis of energy technologies on national economy and environment, and (iv) identifying needed research and development.

As the result of preliminary studies of a technological frame for future energy systems, we have established the following five behavioral principles and performance indices of energy systems in our studies: (i) aiming at zero emission, (ii) economy, (iii) convenience, (iv) stable supply, and (v) effective utilization of energy.

We also follow these guidelines: (i) The analysis should be carried out in the $E^3$ (Energy-Economy-Environment) phase. (ii) Strategic analysis should include not only scenario generation studies but also structural analysis, and both studies should be iterated with each other. (iii) In the work of $E^2$ scenario generation, possible and conservative projections will be adopted, and sufficient sensitivity studies should be performed. (iv) All such studies as scenario generation, structural analysis, and data acquisition have to maintain "reality" and "continuity". (v) The time span of all system analysis in this study is the next 40 - 60 years.

Following the principles and guidelines, we are now carrying out systems analysis studies. The first stage of the study, i.e., establishment of the reference energy system, generation of economy and energy scenarios by LTMEMO and ENERGYSD, and data preparation for the structural analysis, is finished. Now the second stage is in progress.

**Nuclear Fuel Cycle Systems Analysis**

A study of the long-term strategy for nuclear power development in Japan was made last year by an ad-hoc group within the Science and Technology Agency. The JALTES-II model was employed to analyze nuclear fuel cycle systems in a very long time horizon (1970 - 2050).
A total of fourteen cases was analysed with two different scenarios on total nuclear capacity growth (high and low) and with four different dates of FBR commercialization (2010, 2015, 2025 and 2035. The analysis suggested that the amounts of natural uranium required would increase to prohibitive levels with the delay of FBR commercialization, and also the ATR and the HCPWR would considerably reduce the requirement for natural uranium by utilizing surplus plutonium before full commercialization of the FBR.

Another study by JALTES-II was made recently to examine preliminarily the relationships between core characteristics of the HCPWR and its performance in the long-term nuclear fuel cycle. Several types of the HCPWR with different core characteristics were prepared and analyzed within the framework of the long-term evolution of the nuclear energy system. The analysis indicated that improvement in a conversion ratio would significantly expand the contribution of the HCPWR to reducing natural uranium consumption.

**Technology Assessment of High-Temperature Gas-Cooled Reactor**

Interest is growing now in the development of the high-temperature gas-cooled reactor, especially for its modular reactor system (MRS), not only for electric power generation but for process heat production.

There are a number of technical and economic reasons for interest in the MRS: its inherently safe reactor core which makes its siting close to the high demand area practicable, its flexibility in response to size of the demand so that investment risks are reduced, high productivity of manufacturing equipment which could shorten the construction time period, cost saving through standardization and mass-production, etc.
To analyze the effect of introducing such MRS's into our future energy system, we have surveyed their economics. Major items are plant capital cost (which is disaggregated into plant components), plant operating and maintenance cost, and fuel cost. Those data are utilized as elementary data for constructing the capital coefficient vector and the operating and maintenance coefficient vector of the MRS technology in the energy-economy interaction model.
Fig. 1 Integrated Energy-Economy-Environment Model System
Measuring Points
F1,G1,H1 ; effluents from non energy
F2,G2,H2 ; effluents from energy
F3,G3 ; effluents released after control

Fig. 2 Measuring Concept of Environmental Effluent
## Table 1. List of Conversion and Process Technologies

<table>
<thead>
<tr>
<th>Technology Type</th>
<th>Technology Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Conversion Technologies</strong></td>
<td></td>
</tr>
<tr>
<td>1.1 Electricity Generation</td>
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<td>Coal Steam Electric Power Plant</td>
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<td>Coal (Low BTU Gasification) Combined Cycle Power Plant</td>
<td></td>
</tr>
<tr>
<td>Coal Atmospheric Fluidized Bed Steam Electric Power Plant</td>
<td></td>
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<tr>
<td>Coal MGD Electric Power Plant</td>
<td></td>
</tr>
<tr>
<td>Heavy Distillate Oil Steam Electric Power Plant</td>
<td></td>
</tr>
<tr>
<td>Gas Turbine Electric Power Plant</td>
<td></td>
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<tr>
<td>LNG Steam Electric Power Plant</td>
<td></td>
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<tr>
<td>LNG Cold Heat Electric Power Plant</td>
<td></td>
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<tr>
<td>LNG Combined Cycle Power Plant</td>
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<tr>
<td><strong>(Nuclear)</strong></td>
<td></td>
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<tr>
<td>BWR Nuclear Power Plant</td>
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<tr>
<td>PWR Nuclear Power Plant</td>
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<tr>
<td>ATR Nuclear Power Plant</td>
<td></td>
</tr>
<tr>
<td>HTGR Nuclear Power Plant (Steam Turbine)</td>
<td></td>
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<tr>
<td>HTGR Nuclear Power Plant (Helium Gas Turbine)</td>
<td></td>
</tr>
<tr>
<td>LMFB Nuclear Power Plant</td>
<td></td>
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<tr>
<td><strong>Nuclear Fusion Power Plant</strong></td>
<td></td>
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<tr>
<td><strong>(Renewables)</strong></td>
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<tr>
<td>Hydroelectric Power Plant</td>
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<tr>
<td>Geo-Hydrothermal Power Plant</td>
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<tr>
<td>Geo-Hydrothermal Binary Cycle Power Plant</td>
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<tr>
<td>Dry Geothermal (Hot Rock) Electric Power Plant</td>
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<tr>
<td>Central Solar Thermal Electric Power Plant</td>
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<tr>
<td>Central Solar Photovoltaic Power Plant</td>
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<tr>
<td>Decentralized Solar Photovoltaic Electric Supply</td>
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<tr>
<td>Wind Turbines, Central Electric Power Complex</td>
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<tr>
<td>Wave, Central Electric Power Plant</td>
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<tr>
<td>Oceanthermal Gradient Electric Power Plant</td>
<td></td>
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<tr>
<td>Biomass Electric Power Plant</td>
<td></td>
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<tr>
<td><strong>(Others)</strong></td>
<td></td>
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<tr>
<td>Hydrogen Fuel Cell</td>
<td></td>
</tr>
<tr>
<td>CO Gas Turbine Electric Power Plant</td>
<td></td>
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<tr>
<td><strong>1.2 Electricity Storage</strong></td>
<td></td>
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<tr>
<td>Hydroelectric Pumped Storage Power Plant</td>
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<tr>
<td>Hydrogen Production/Storage Power Plant</td>
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<td>Battery Storage (REDox)</td>
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<tr>
<td>Superconducting Magnetic Storage</td>
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<tr>
<td><strong>1.3 Cogeneration</strong></td>
<td></td>
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<tr>
<td>Cogeneration, Coal Fired</td>
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<tr>
<td>Gas Fuel Cell Coupled Production</td>
<td></td>
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<tr>
<td>LMR Coupled Production</td>
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<td><strong>1.4 District Heating</strong></td>
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<tr>
<td>District Heating Plant, Geothermal</td>
<td></td>
</tr>
<tr>
<td>District Heating Plant, Gas Fired</td>
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<td><strong>2. Process Technologies</strong></td>
<td></td>
</tr>
<tr>
<td>2.1 Fossil Energy Process</td>
<td></td>
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<tr>
<td>Coal High BTU Gasification, Lurgi Slagging</td>
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<tr>
<td>Coker Steam Gasification</td>
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<tr>
<td>Coal Hydrogasifier</td>
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<tr>
<td>Coal Gasifier</td>
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<tr>
<td>Coke Oven</td>
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<tr>
<td>Coal Pyrolysis Gasifier</td>
<td></td>
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<tr>
<td>Coal Partial Oxidation Gasifier</td>
<td></td>
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<tr>
<td>Coal Liquefaction (Hydrogenation, Abroad)</td>
<td></td>
</tr>
<tr>
<td>Coal Liquefaction (Hydrogenation)</td>
<td></td>
</tr>
<tr>
<td>Coal Liquefaction (Direct Hydrogenation, Abroad)</td>
<td></td>
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<tr>
<td>Coal Liquefaction (Fischer-Tropsch)</td>
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<tr>
<td>Coal-Oil-Mixture Production</td>
<td></td>
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<tr>
<td>Methanation</td>
<td></td>
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<tr>
<td>Gas Separation (CO2-H2)</td>
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<tr>
<td>Liquefied Coal Separation</td>
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<tr>
<td>Naphtha Gasification</td>
<td></td>
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<tr>
<td>LNG Regasification</td>
<td></td>
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<tr>
<td>Air Separation by LNG Cold Heat</td>
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<tr>
<td>Existing Oil Refinery</td>
<td></td>
</tr>
<tr>
<td>Upgrading Oil Refinery</td>
<td></td>
</tr>
<tr>
<td>Separation of Naphtha (Out of Refinery)</td>
<td></td>
</tr>
<tr>
<td>Separation of Light Distillate Oil (Out of Refinery)</td>
<td></td>
</tr>
<tr>
<td><strong>2.2 Nuclear Heat Process</strong></td>
<td></td>
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<tr>
<td>Nuclear Process Heat, VETR (EU)</td>
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<tr>
<td>Nuclear Process Heat, VETR (CH)</td>
<td></td>
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<tr>
<td>PWR for Nuclear Ship</td>
<td></td>
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<tr>
<td><strong>2.3 Nuclear Heat Utilization and Fuel Synthesis Process</strong></td>
<td></td>
</tr>
<tr>
<td>Electrolytic Hydrogen Production</td>
<td></td>
</tr>
<tr>
<td>Hydrogen Production, Thermochemical Splitting of Water</td>
<td></td>
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<tr>
<td>Production of Reducing Gas</td>
<td></td>
</tr>
<tr>
<td>Steam Reforming of CH4</td>
<td></td>
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<tr>
<td>CO2 Reforming of CH4</td>
<td></td>
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<tr>
<td>Thermochemical Pipeline</td>
<td></td>
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<tr>
<td>CO and O2 Production from CO2</td>
<td></td>
</tr>
<tr>
<td>CH4 Production from CO2 and H2</td>
<td></td>
</tr>
<tr>
<td>Steam Generator for VETR</td>
<td></td>
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<tr>
<td>Steam Turbine for VETR</td>
<td></td>
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<tr>
<td>Air Separation</td>
<td></td>
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<tr>
<td>CO Shift Process</td>
<td></td>
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<tr>
<td>Methanol Production from CO and H2</td>
<td></td>
</tr>
<tr>
<td>Methanol Production from CO2 and H2</td>
<td></td>
</tr>
<tr>
<td>Gasoline Synthesis</td>
<td></td>
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<tr>
<td>Biomass Alcohol Production</td>
<td></td>
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<tr>
<td><strong>2.4 Delivery of Energy Carrier</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2.5 Nuclear Fuel Cycle Process</strong></td>
<td></td>
</tr>
<tr>
<td>Uranium Mining and Milling</td>
<td></td>
</tr>
<tr>
<td>Uranium Conversion</td>
<td></td>
</tr>
<tr>
<td>Fabrication of Nuclear Fuel (LMFB, HTGR, LMFB, ATR, VETR)</td>
<td></td>
</tr>
<tr>
<td>Reprocessing of Nuclear Fuel (LMFB, HTGR, LMFB, ATR, VETR)</td>
<td></td>
</tr>
<tr>
<td>Waste Treatment and Disposal (LMFB, HTGR, LMFB, ATR, VETR)</td>
<td></td>
</tr>
<tr>
<td>Nuclear Fuel Storage</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. List of End-Use Technologies

1. Industrial Sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and Steel</td>
<td>Equipments common to all sectors</td>
</tr>
<tr>
<td>Non Ferrous Metals</td>
<td>1. Motor (Large Size)</td>
</tr>
<tr>
<td>Machinery</td>
<td>2. Motor (Small Size)</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td>3. Boiler (Large Size)</td>
</tr>
<tr>
<td>Chemicals</td>
<td>4. Boiler (Small Size)</td>
</tr>
<tr>
<td>Glass, Ceramics and Cement</td>
<td>Equipments specific to each sector</td>
</tr>
<tr>
<td>Textiles</td>
<td>1. Furnace of various types</td>
</tr>
<tr>
<td>Foods</td>
<td>2. Other equipments for particular processes</td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
</tr>
<tr>
<td>Fishery</td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td></td>
</tr>
</tbody>
</table>

Note:
Energy Type is available only if the technology is feasible.

2. Residential and Commercial Sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Equipment</th>
<th>Energy Type of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Lighting</td>
<td>Same as listed above</td>
</tr>
<tr>
<td>Commercial</td>
<td>Motor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Space Heating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water Heating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooking</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Conditioning</td>
<td></td>
</tr>
</tbody>
</table>

3. Transportation Sector

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy Type of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway</td>
<td>(Electricity, Light Distillate Oil)</td>
</tr>
<tr>
<td>Car</td>
<td>(Electricity, Hydrogen, LPG, Gasoline, Light Distillate Oil, Alcohol)</td>
</tr>
<tr>
<td>Bus</td>
<td>(Electricity, Hydrogen, Light Distillate Oil)</td>
</tr>
<tr>
<td>Truck</td>
<td>(Electricity, Hydrogen, Gasoline, Light Distillate Oil)</td>
</tr>
<tr>
<td>Ship Domestic</td>
<td>(Light Distillate Oil, Heavy Distillate Oil)</td>
</tr>
<tr>
<td>Ship Bunker</td>
<td>(Nuclear Propulsion Power, Light Distillate Oil, Heavy Distillate Oil)</td>
</tr>
<tr>
<td>Aviation Domestic</td>
<td>(Hydrogen, Jet Fuel)</td>
</tr>
<tr>
<td>Aviation Bunker</td>
<td>(Hydrogen, Jet Fuel)</td>
</tr>
</tbody>
</table>
Table 3. List of Data Items for Technology Characterization

1. Technical Data
   1.1 Design Capacity
   1.2 First Commercial Service Year
   1.3 Energy Inputs Per Year (Full Load)
   1.4 Energy Outputs Per Year (Full Load)
   1.5 Maximum Annual Availability
   1.6 Capacity Factor
   1.7 Overall Efficiency (Full Load)
   1.8 Overall Efficiency (Average Load)
   1.9 Design and Licensing Time
   1.10 Construction Time
   1.11 Technical Lifetime

2. Cost Data
   2.1 Construction Cost
   2.2 Owner's Cost
   2.3 Interest During Construction
   2.4 Decommissioning Cost
      Discoun ted Decommissioning Cost
   2.5 Total Capital Cost
   2.6 Economic Lifetime
   2.7 Annualized Capital Cost
   2.8 Fixed O & M Cost
   2.9 Variable O & M Cost
   2.10 Grid Connection Cost
   2.11 R & D Cost
   2.12 Input Fuel Cost
   2.13 Total Production Cost
   2.14 Disaggregated Investment and O & M Cost
      for Use in I/O (TRANS)

3. Environmental Data
   3.1 Effluents to the Atmosphere
      SOx, NOx, CO and CO$_2$, Particulates,
      Special Materials, Radioactivities,
      Heat, Others
   3.2 Effluents to the Water
      Water contaminations,
      Radioactivities, Heat, Others
   3.3 Wastes
      Industrial Wastes, Radioactive Wastes,
      Wastes at Decommissioning of Facilities,
      Others

4. Measures for Environmental Protection
   4.1 Measures for Each of Effluents or Wastes
      Protection Methods
      Protection Equipments

4.2 Technical Data of Equipments
   (in addition to items listed left)
   Effluent or Waste Inputs Per Year
   Effluent or Waste Outputs Per Year
   Operation Experience (Years)
   Loss of Energy Efficiency
   Number of Operators, Operation Mode

4.3 Cost Data of Equipments
   (in addition to items listed left)
   Credit of Outputs

5. Material Data
   5.1 Freshwater Use
   5.2 Land Use
   5.3 Material Requirements
   5.4 Employed Persons

6. Technology Implementation
   6.1 Maximum Feasible Capacity
   6.2 Factors Limiting the Implementation
5.2.3 Energy Modelling Approach at EIR, Switzerland

(S. Kypreos)

5.2.3.1 Introduction

Energy systems analysis for Switzerland concentrates on energy demand projections using the econometric model of Geneva University, and on the analysis of energy supply using the model MARKAL.

A general framework is proposed which takes the partial equilibrium problem between demand and prices into account as well as the general equilibrium problem between economic growth, demand and prices.

This objective could be obtained by a set of interlinked models:

- The macroeconomic model MACRO which describes the economic equilibrium among demand and supply and the substitution effects among capital labour and energy.
- The model SMEDE which simulates energy demand consistent with economic activity and population growth, and
- The energy allocation model MARKAL which optimizes interfuel substitution potential and technology implementation.

The objective of the proposed model is to make endogenous the effect of the energy prices on economic growth and improve the internal consistency of the analysis. The method should be simple and easily applied, and it should be able to reduce the uncertainties in generating potential demand and supply projection for Switzerland.

Since the model MARKAL is well known, a short description of the submodels SMEDE and MACRO, as well as the links of the three models is given here.

X This is a summary of the paper presented at the 12th IFIP conference in Budapest, 1985
5.2.3.2 The Energy Demand Simulation Model SMEDE\textsuperscript{x1}

5.2.3.2.1 Generalities

SMEDE is, in principle, an accounting framework of energy demand. The function of this model is to generate the disaggregated demand constraints for MARKAL. The model follows the scenario approach, and it is driven by a set of demand indicators and their specific energy consumption.

The scenario parameters of SMEDE could be grouped in two broad categories: socioeconomic data and technical data.

The socioeconomic data describe the economic growth and structural changes in industry and the service sector, the evolution of population and its structure, and the shifts in consumer preferences. The technical data describe improvements in the energy intensiveness of industry, the service sector, and the households. Conservation and substitution activities are explicitly formulated as scenario parameters by implementing new technological options.

There follows a short description of the industrial, residential, and transport sectors of the model.

5.2.3.2.2 The Industrial Sector

Four economic sectors are included in the Swiss model: manufacturing industries, construction, services and agriculture.

\textsuperscript{x1}Swiss Model of Energy Demand (Ref. 1). The model is based on MEDEE-2 (Ref. 2).
The manufacturing industry sector is subdivided into four sub-
sectors: durables or capital goods, consumer goods (non-
durables), basic materials, and other industries (including
mining and energy).

There are two options for taking the structural changes of
industry into account:

- either by an exogenous disaggregation of the GDP based on
economic studies of the problem, or

- by econometric analysis based on the macroeconomic variables
of the MACRO model.

Once the economic activities per industrial sector are known,
the next parameter required to generate projections concerns
the evolution of energy intensiveness per industrial subsector.
An assessment of the most energy intensive industries and the
trends on the evolution of intensiveness is necessary. Energy
consumption in industry is further disaggregated into space and
water heat, process heat (low temperature, steam medium tempe-
ration (up to 300°C), and high temperature) as well as mecha-
nical power. Although SMED could consider substitution effects
for fossil fuels by district heat, cogeneration solar energy
and electric heat pumps, the job is left for MARKAL. The im-
proved energy statistics for the Swiss industrial sectors are a
great help in running the model.

5.2.3.2.3 The Residential/Commercial Sector

Energy use in the residential/commercial sector is disaggre-
gated according to:

- Space heating/water heating
- Air conditioning
- Cooking and house appliances
- Process heat and air conditioning for the commercial sector
  and small industry.
Different house types are considered, such as single family houses, apartments, and commercial buildings. Each house type is described according to its energy consumption per year.

The evolution of housing stock is driven by the average family size and population growth. Conservation in buildings and inter-fuel substitution will be estimated by the optimization model.

Electricity consumption for household appliances could in principle be estimated based on a saturation curve and the specific annual energy consumption per appliance. Because it is difficult to make reliable estimations by appliance, however, econometric relationships based on the personal consumption per household have been introduced. Another problem is the shift in consumer preferences between single family houses and apartments.

5.2.3.2.4 The Transport Sector

The transport sector includes the following categories: international transport (which is correlated to GNP), freight transport (which is correlated to industrial production), and passenger transport.

Passenger transport is divided into urban and intercity transport by private or public modes of transport. Car ownership is estimated by a logistic curve, while the average distance travelled per person is assessed as an exogenous variable. Finally, load factors (passengers per car) and fuel economy are taken into consideration to generate energy demand projections.

5.2.3.3 The Macroeconomic Model MACRO

The concept of constant elasticity of substitution and a simple macroeconomic model for Switzerland has been adopted as the structure that generates the macroeconomic environment for SMEDE.
This chapter will give a short description of the equations we adopted. The model is going to be evaluated in cooperation with the St. Galler Zentrum für Zukunftsforrschung (SGZI), and it is now in a preliminary stage. The model is based on the work of H. H. Rogner of IIASA (Ref. 3).

A possibility exists of developing a disaggregated I/O structure for the industrial and service sectors once a more satisfactory I/O table for Switzerland will be available.

5.2.3.3.1 The Production Function and the Constant Elasticity of Substitution (CES)

The vehicle to analyse factors of production and substitution is the production function. The production function used in the MACRO-model is a Cobb-Douglas function for the input factors capital and labor and a CES function for the factor energy and the aggregate output of capital and labour:

\[
y = \gamma \left[ aE^{-\beta} + b(\theta k^{1-a} L^{\alpha})^{-\beta} \right]^{-\frac{1}{\beta}}
\]

(3.1)

K is the gross capital formation of the economy
L is the labour force
E is the final energy use
\(\theta\) and \(\gamma\) are time dependent functions which express the increase of the economic output over time with constant primary input factors due to the technical progress. The constants a, b, \(\theta\), and the functions \(\theta\), \(\gamma\) should be estimated by regression analysis.

The prices are correlated to the production function by assuming profit maximization conditions.

\[
E^R = \left[ p_e (1 + \epsilon L) \cdot y^\beta \cdot a^{-1} \right]^{-\sigma} \cdot y
\]

(3.2)

Equ. 3.2 specifies the energy demand \(E^R\) as a function of GDP, \(Y\) and the energy price, \(p_e\). \(\epsilon_L\) is the price elasticity of energy demand.
Similar relations could be written for the capital and the labour demand.

\begin{align}
K^D &= (1 - \alpha) \gamma^\beta \cdot v^\beta \gamma^{\beta+1} \cdot p_K^{-1} \\
M^H_D &= \alpha \cdot \gamma^\beta \cdot b \cdot v^\beta \gamma^{\beta+1} \cdot p_L^{-1}
\end{align}

The production function defines maximum potential economic output at full utilization of production factors labour and capital, and it also assumes that energy is not a constraint to economic growth.

The supply of the primary production factors must be expressed separately by another set of macroeconomic equations.

The macroeconomic model should include at least a capital formation and labour sector, the government sector, the trade sector and the price sector, together with the principal GDP identities.

This procedure defines a system of non-linear simultaneous equations on demand and supply of primary production factors and their prices.

The system is solved by the Gauss-Seidel algorithm to "clear the market" and to specify the equilibrium prices. If a new price structure is assumed, the model will specify the substitution among the production factors and it will estimate the share of primary inputs which establishes a new equilibrium.

5.2.3.3.2 Linking MACRO to SMEDE

Fig. 1 explains the overall flow of information among the three submodels and their exogenous variables in a schematic way.
Fig. 1: Overall loop of interlinked models

SMEDE drives energy demand projections based on the time evolution of some determinants. The value added in the main industrial sectors, the evolution of residential and commercial floor area, and the evolution of passenger and freight transport are the most important ones.

The time dependent values of those determinants times their corresponding energy intensiveness result in useful (or final) demand projections.

The aggregate macro-economic variables could also be correlated with the demand determinants of the other sectors. The use of judgemental parameters is in any case unavoidable, due to the degree of disaggregation in SMEDE and the specific structure of this model.
5.2.3.3.3 Linking SMEDE to MARKAL

The interface of SMEDE to MARKAL is straightforward since most of the simulation results are in terms of useful energy. Conservation options, substitution effects and technology implementation is then estimated in MARKAL for the fuel price schedules assumed in the scenario specifications.

Iterations between SMEDE and MARKAL are necessary to obtain the same energy intensiveness in both models.

5.2.3.3.4 Linking MARKAL to MACRO

Energy use and energy prices, imports, investments and labour force in the energy sector are the results of MARKAL which need to be introduced in MACRO to close the loop.

It is a necessary (but not sufficient) condition for consistency in the assumed price development that the disaggregated projections of final energy consumption, as estimated by SMEDE/MARKAL, is similar to MACRO results.

5.2.3.4 Concluding Remarks

The SMEDE/MARKAL approach makes the demand projections and the analysis of the energy supply system more transparent and understandable than econometrics.

The coupling between these energy models with the macroeconomic framework will make the projections more consistent, since the substitution effects among the production factors -- capital, labour, and energy -- would be expressed as functions of price.

Although the extension of the model to an I/O formalism seems appropriate, it is not feasible for the moment due to the absence of sufficient statistical information to estimate an I/O table.

The model in its full development could be applied for long term strategic analysis of energy demand and supply.
It could also be used for technology ranking and specification of R/D priorities. The effectiveness of different energy policies like energy taxes and subsidies could be analysed and their macroeconomic implications could be shown. Environmental control technologies have been implemented in MARKAL, and the trade-off between the cost of emission control and pollution could be studied.

Finally, the implementation of the model on advanced microcomputers makes direct feedback with high level executives and policy makers feasible, when performing analysis on the national or regional level.

However, it should never be forgotten that energy modelling is not a substitute for judgement. It is a useful instrument in the hands of experts for starting from a set of assumptions and deriving conclusions in a consistent way. Whether the input assumptions and the way the economy is modelled are reasonable or not must be decided in each case by the working team and a reference group of high level executives who can follow the study.

Energy modelling provides background information and defines boundary conditions to discuss the energy problem. It is neither a substitute for discussion nor a ready-made solution.

References

1) Swiss Model for Energy Demand, TM-13-86-01.


5.3 Environmental Aspects

5.3.1. Clean or Cheap?
(H. Vos, G. Giesen)

Introduction

This paper is a status report of the MARKAL pilot study performed at KFA/STE to find out how to handle the problems of finding reasonable pollution abatement strategies for the energy supply system of the Federal Republic of Germany in an adequate way. This is the first step which should be followed by a more detailed study in the area concerned.

The work includes gathering the necessary data in a way that is suitable for the model and changing the structure of the model if the existing MARKAL concept needs to be improved.

The following text reports on the status of this project as of November 20th 1985. The goal of this report is not to show final results or to give a detailed elaboration. Instead, some highlights of the work and a few ideas which might be of common interest for the MARKAL user audience shall be discussed. A more detailed explanation of the model and software improvements might be written when the pilot study is finished if time allows. The data set used for the calculations is available in STE and can be studied by anybody who is interested.

The results shown in the chapter "Scenario Results" compare the differences between a cost optimal scenario (ENV20) and a scenario with a penalty for SO2 emissions. Trends and options for a detailed study to be performed later can be found there. Nobody should expect refined results and a consistent model in this early stage of the work.

The last chapter of this status report gives some hints concerning future methods of energy systems analysis using the concept of the "Novel Horizontally Integrated Energy Systems" (NHIES).
Data Gathering

The tedious work of data gathering is in the relatively new area of environmental aspects even more discouraging. At the moment we are using an old MARKAL data set as it was used for the ETSAP update runs (1984). To simplify the starting phase of the pilot study on environmental questions, we concentrate on a subset of the technologies comprising the energy supply sector in former studies. For a detailed discussion we refer to the data set.

Demand Projections

The new demand projections are in preparation and will be incorporated in December. At the moment the demand projections of the ETSAP update runs are being used.

The following Figure 1 indicates the demand structure and the level of disaggregation:

<table>
<thead>
<tr>
<th>MARKAL Code</th>
<th>Demand Category Name</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>Iron and Steel</td>
<td>PJ</td>
</tr>
<tr>
<td>IX</td>
<td>Other Industry</td>
<td>PJ</td>
</tr>
<tr>
<td>NY</td>
<td>Non Energy Use</td>
<td>PJ</td>
</tr>
<tr>
<td>RT</td>
<td>Space Heat Multifamily Houses</td>
<td>PJ</td>
</tr>
<tr>
<td>R2</td>
<td>Space Heat Single Family Houses</td>
<td>PJ</td>
</tr>
<tr>
<td>R5</td>
<td>Warm Water</td>
<td>PJ</td>
</tr>
<tr>
<td>RD</td>
<td>Electrical Appliances</td>
<td>PJ</td>
</tr>
<tr>
<td>TX</td>
<td>Rail-Air-Ship Transport</td>
<td>PJ</td>
</tr>
<tr>
<td>TT</td>
<td>Truck and Bus Transport</td>
<td>PJ</td>
</tr>
<tr>
<td>TU</td>
<td>Car Transport (Small Cars)</td>
<td>Mcar</td>
</tr>
<tr>
<td>TM</td>
<td>Car Transport (Medium Cars)</td>
<td>Mcar</td>
</tr>
<tr>
<td>TO</td>
<td>Car Transport (Big Cars)</td>
<td>Mcar</td>
</tr>
</tbody>
</table>

Figure 1: Demand Categories - Codes and Units
The demands are shown in Figure 2:

<table>
<thead>
<tr>
<th>Demand Category</th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and Steel</td>
<td>782</td>
<td>587</td>
<td>587</td>
<td>587</td>
</tr>
<tr>
<td>Other Industry</td>
<td>1559</td>
<td>1562</td>
<td>1574</td>
<td>1586</td>
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<td>742</td>
<td>748</td>
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<td>Space Heat Single Family Houses</td>
<td>543</td>
<td>550</td>
<td>570</td>
<td>575</td>
</tr>
<tr>
<td>Warm Water</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Electrical Appliances</td>
<td>381</td>
<td>413</td>
<td>445</td>
<td>478</td>
</tr>
<tr>
<td>Rail-Air-Ship</td>
<td>360</td>
<td>409</td>
<td>463</td>
<td>484</td>
</tr>
<tr>
<td>Trucks and Buses</td>
<td>335</td>
<td>369</td>
<td>403</td>
<td>436</td>
</tr>
<tr>
<td>Non Energy Use</td>
<td>802</td>
<td>874</td>
<td>947</td>
<td>1019</td>
</tr>
</tbody>
</table>

Unit: PJ

Figure 2: Demand Projections

For the use of passenger cars the number of cars used has been given as demand (see Figure 3):

<table>
<thead>
<tr>
<th>Demand Category</th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Cars</td>
<td>9,200</td>
<td>9,850</td>
<td>10,500</td>
<td>11,000</td>
</tr>
<tr>
<td>Medium Cars</td>
<td>11,300</td>
<td>11,350</td>
<td>11,400</td>
<td>11,450</td>
</tr>
<tr>
<td>Large Cars</td>
<td>2,500</td>
<td>2,375</td>
<td>2,250</td>
<td>2,125</td>
</tr>
</tbody>
</table>

Unit: Mcar = Million Cars

Figure 3: Projection of the Number of Cars

Three sizes of cars are distinguished in the model: small, medium and large. They are input to the model as millions of cars (Mcar). To convert this "non energy" demand, the product of mileage and fuel consumption per km (both are time dependent) was included in the data entries of the MARKAL demand technologies.
<table>
<thead>
<tr>
<th>Demand Category</th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Cars</td>
<td>10840</td>
<td>10027</td>
<td>9279</td>
<td>9251</td>
</tr>
<tr>
<td>Medium Cars</td>
<td>12650</td>
<td>11700</td>
<td>10830</td>
<td>10790</td>
</tr>
<tr>
<td>Large Cars</td>
<td>13850</td>
<td>13200</td>
<td>13450</td>
<td>13590</td>
</tr>
</tbody>
</table>

Unit: km/year

Figure 4: Mileage of Passenger Cars

The fuel use per mile by car size is documented in the study "Energie für den Verkehr" and can be recalculated from the data in the MARKAL data set. All taxes and subsidies have been excluded from the input data within the transport sector.

Imported Energy Carriers

Prices and limits for imported energy carriers are shown in Figure 5. At the moment the model allows only for crude oil, imports and not for oil product imports. The inconsistencies caused by that crude way of modeling will be removed later by introducing product costs, limits on the amounts of imported products, and/or shadow price oriented pricing of imports. Such improvements are necessary because of the amount of product imports and exports and the existing special structure of the German refineries.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price ( $83 / GJ)</td>
<td>5,61</td>
<td>5,80</td>
<td>6,18</td>
<td>6,74</td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price ( $83 / GJ )</td>
<td>4,03</td>
<td>4,16</td>
<td>4,43</td>
<td>4,84</td>
</tr>
<tr>
<td>Upper Limit for Imports (PJ)</td>
<td>1365</td>
<td>1587</td>
<td>1745</td>
<td>1904</td>
</tr>
<tr>
<td>Lower Limit for Imports (PJ)</td>
<td>1295</td>
<td>1333</td>
<td>1199</td>
<td>749</td>
</tr>
<tr>
<td>Nuclear Fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price ( $83 / GWh )</td>
<td>3860</td>
<td>4246</td>
<td>4632</td>
<td>4632</td>
</tr>
</tbody>
</table>

Figure 5: Imported Energy - Prices and Limitations
Domestic Resources

Costs and limits for domestic production are listed in Figure 6:

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<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($83/GJ)</td>
<td>3,40</td>
<td>3,40</td>
<td>3,40</td>
<td>3,40</td>
</tr>
<tr>
<td>Lower Limit (PJ)</td>
<td>2345</td>
<td>2345</td>
<td>2204</td>
<td>1923</td>
</tr>
<tr>
<td>Brown Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($83/GJ)</td>
<td>2,00</td>
<td>2,00</td>
<td>2,20</td>
<td>2,20</td>
</tr>
<tr>
<td>Upper Limit (PJ)</td>
<td>1164</td>
<td>1179</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Lower Limit (PJ)</td>
<td>900</td>
<td>900</td>
<td>846</td>
<td>738</td>
</tr>
<tr>
<td>Crude Oil 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($80/GJ)</td>
<td>0,56</td>
<td>0,69</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fixed Amount (PJ)</td>
<td>150</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Crude Oil 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($80/GJ)</td>
<td>-</td>
<td>3,45</td>
<td>4,15</td>
<td>-</td>
</tr>
<tr>
<td>Upper Limit</td>
<td>0</td>
<td>40</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Crude Oil 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($80/GJ)</td>
<td>-</td>
<td>3,45</td>
<td>4,15</td>
<td>-</td>
</tr>
<tr>
<td>Upper Limit (PJ)</td>
<td>0</td>
<td>10</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Gas 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($80/GJ)</td>
<td>0,56</td>
<td>0,69</td>
<td>0,83</td>
<td>0,97</td>
</tr>
<tr>
<td>Upper Limit (PJ)</td>
<td>610</td>
<td>644</td>
<td>644</td>
<td>215</td>
</tr>
<tr>
<td>Lower Limit (PJ)</td>
<td>550</td>
<td>517</td>
<td>258</td>
<td>0</td>
</tr>
<tr>
<td>Gas 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($80/GJ)</td>
<td>-</td>
<td>-</td>
<td>4,15</td>
<td>4,85</td>
</tr>
<tr>
<td>Fixed Amount (PJ)</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>32</td>
</tr>
</tbody>
</table>

Figure 6: Domestic Energy Carriers - Costs and Limitations

For the time being the "cost" figures for hardcoal contain subsidies; i.e., they are much lower than in the old MARKAL runs for the Federal Republic. The results of the model runs illustrate that this political assumption needs to be taken out in the future runs.
Technology Data

All the technologies that were previously used in the update runs will be called "standard technologies" even if they are rather new and not yet economically used in Germany (e.g., coal liquefaction). We distinguish from these "standard technologies" the technologies to make the environment cleaner (e.g., desulphurization technologies), the refinery technologies (that sector of the model will be completely remodeled based on other studies of STE), and the technologies of the "novel horizontally integrated energy systems" (those technologies are already included in the MARKAL dataset and can be included in the study for special questions).

Data for the standard technologies were taken from the update runs. Some data for power plants were updated (the emission levels for SO2 and NOx were added to the technology data). And many technologies were simply excluded from the analysis.

Based on other studies of STE, some SO2 and NOx removal technologies for power plants were included:

- 0 per cent reduction of SO2 emissions
- 50 per cent reduction of SO2 emissions
- 80 per cent reduction of SO2 emissions
- 95 per cent reduction of SO2 emissions
- 100 per cent reduction of SO2 emissions

- 0 per cent reduction of NOx emissions
- 50 per cent reduction of NOx emissions
- 80 per cent reduction of NOx emissions
- 95 per cent reduction of NOx emissions
- 100 per cent reduction of NOx emissions

The amount of SO2 coming from oil use was estimated simply by connecting an SO2 emission of 2.57 Mmol to the use of one PJ crude oil. The explicit model for that sector will be included later.
The emissions caused by end users are not yet included in the model. That will be changed in the future model runs when the NOx emissions are included. At the moment, only the SO2 emissions have been included to check the feasibility of the model for questions to be answered in the future. The SO2 emissions come mainly from industry and the electricity sector (see Figure 7). Therefore, we did not pay much attention to the minor sources (transport and R&C). The data on emissions coming from industry need a lot of additional work; no such data are included at the moment.

Therefore only the electricity generating sector is modeled adequately to make statements about emissions and emission control policies.

Figure 7: Emissions of SO2 and NOx in 1984 (Source: TÜV)

Concerning the future work on NOx emissions, it should be mentioned that most of the effort will be spent on modelling the emissions of the transport sector. In that context, careful investigations concerning aldehyde emissions will be included in the work. A simple switching to "clean" motor fuels like ethanol or methanol causes new kinds of pollution as already documented in Brazil.
Modelling

To tackle the new kind of problem, some thought had to be given to balancing and limiting the emissions, the solution of multi-objective problems, stoichiometry, and modelling of a more flexible utilization of technologies. The first steps are documented in the following sections.

Balancing of Emissions

To model the emissions of pollutants properly, the inequality constraints on the balances of pollutants in the standard version of MARKAL has to be changed to equality constraints; i.e., "production equals in consumption". That special need was satisfied by the introduction of a new table (Table BALTYP) in the MARKAL dataset and some minor changes in the software. Those changes have been tested for the case handled in the study mentioned below.

The analysis, test and use of the improved MARKAL version including the special tables reporting emissions became obsolete because the changes in the dataset combined with minor modifications of the software and two additional procedures in the MARKAL environment used at KFA - there should be mentioned the new procedures PREPARE1 and PREPARE2 and the new report concept for MARKAL. The additional options and information provided by the new approach guarantee more efficient work in the new area of investigation.

Limits for Emissions

One option for limiting the amount of emitted pollutants could be the introduction of right-hand sides for the so-called "environmental functions" of the MARKAL model. The necessary change of the software in this case was avoided by using other options; i.e., all emissions were handled like exports.
The problenatical question of depositing pollutants - e.g. gypsum - could be handled similar to a stockpile technology. In that case, costs and limits of such deposits can be modeled in an appropriate way. At the moment there is no stockpiling of pollutants included in the model, but that is mainly a question of missing data and experience and not caused by missing options in the model software.

Multi Objective Functions

To find a compromise between the contrary goals "as cheap as possible" and "as clean as possible" there should be given some description of the possible developments of the energy supply system starting with the cheapest solution and ending with the cleanest one. In other words, the trade-off between the two objectives has to be calculated and discussed.

As all pollutants are included in balances of the equality type, nothing can be thrown away by the system. There are only two chances for pollutants to leave the energy system: either you make something useful out of them (that could be gypsum products) within a process technology including all cost items necessary, or they escape to the environment in the form of an "export" which can be limited or combined with a cost entry (penalty for emissions) which can be changed stepwise. That solution enables the user to calculate the trade-off functions he likes and to set the emission limits he wants to introduce.

We found out that for working purposes the existing reporting software is sufficient.

For presentations, some polishing and refining of the report software and the introduction of a powerful three-dimensional plot software package seem to be necessary.
How to find a compromise if you know the possible options is a more complicated question. In that field a literature survey is planned for the future. Concrete plans for the introduction of a formalized model showing the decision process and the way of finding compromises do not exist at the moment and may not be part of our business.

Material Flows

As you will have already realized, the MARKAL model is changed qualitatively. One of the stable features of the old MARKAL was the way of handling the balances. The balances handled energy flows measured in energy units, and nothing else was mentioned.

The pilot version of MARKAL in this study can distinguish flows of different qualities; there exist, for example, flows of SO2 which can hardly be modeled as energy carrier flows. For such substances a different quality of the flow within the model has to be assumed. For building the model it does not matter whether the flows have different qualities; they are just inputs to processes or outputs, and for matrix generation and optimization no problems will occur. The only problem is the way to report the results. In the version applied at the moment, different reports are generated for flows of different qualities. A complete export can be generated for SO2 in mol, for example, or for NOx in tons\(^1\), or for oil in mtoe, if the data are provided in the appropriate form.

The new pilot version overcomes some of the inconvenience caused by the rather rigid framework given by the old version of MARKAL.

\(^1\) In the scenarios shown later the NOx emissions are given in Gmol
Modelling of Changing Technology Utilization

The improved flexibility of the balance concept also allows for a more reasonable connection of technology capacity and different utilizations or operation modes of that technology. That kind of improvement was required for the areas of

- the refinery structure,
- coupled production,
- improvements of existing capacities.

Especially the problematic aspect of combining new pollution abatement technologies with existing capacities needs some consideration. The question of whether and how such combinations affect efficiencies and variable costs of the existing technology can only be answered after a more detailed data gathering process. Depending on those investigations and on the response of the solution to differences in efficiency and cost, the way to model that area adequately can be established.

Mixed Integer Programming

As the data for most of the technologies are dependent on the size of the plant — especially the investment cost per unit of capacity — the optimization results might be wrong if only fractions of that design capacity are implemented. In that case the model should take higher investment costs into consideration. One way to handle that economics-of-scale problem could be the use of mixed integer techniques. In the recent STE environment study that approach was not chosen. One — more formal — reason is the missing MIP software the other — more important — reason is the exponentially increasing computation time and the additional effort necessary to run and analyse such models.

---

2In the past a number of very specific features were introduced to address that kind of problem (e.g., the CPD concept, the limit-process-concept) or the user had to do some more or less tricky "dummy" process modelling.
Instead, a simple first step seems to be more useful; the results are checked and if such small fractional investments are found those technologies are crossed out completely in a second run.\(^3\)

**Scenarios**

For finding pollution abatement strategies you might build models of the energy supply system with continuously changed limits for the amount of emissions. The other way can be called the penalty approach, i.e., you introduce a cost per unit of emission. To get some kind of trade-off that cost can be changed starting from very low values which do not force the system to implement abatement technologies and ending with very high cost values causing dramatic changes of the supply system. As you might expect the amount of change does not depend linearly on the amount of change in the penalty. To find out the sensitive areas in the relationship should be one of the goals of analysis.

**The Pilot Scenarios ENV20 and ENV21**

To start the analysis and to get some feeling for the problem, we will compare a cost optimal scenario without any emission penalty with a "clean" scenario which has a very high penalty on SO2 emissions. That penalty of 1.0 \$80 per mol SO2 has to be paid starting with 1990.\(^4\)

---

\(^3\) As you might see, this approach evidently conflicts with some of the ideas concerning the way to find out the value of a technology.

\(^4\) As you might imagine the stable level of that penalty from 1990 onwards includes a diminishing interest in the environmental goals over time. The other time dependent cost items like import prices for foreign energy carriers and mining costs for domestic sources are supposed to increase within the given time horizon. For the time being we ignore that problem. In the long run the penalties have to be changed over time to keep the environmental goals at least as important as the cost optimization goal.
Investment

As shown in Figure 8 the overall investment in the energy supply system is only 5 per cent higher with the penalty scenario ENV21.

<table>
<thead>
<tr>
<th>Time</th>
<th>Value</th>
<th>Graphical Demonstration of the Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>31629</td>
<td>ooooooooooooooooooo</td>
</tr>
<tr>
<td></td>
<td>31642</td>
<td>*****************</td>
</tr>
<tr>
<td>1990</td>
<td>30984</td>
<td>ooooooooooooooooooo</td>
</tr>
<tr>
<td></td>
<td>35853</td>
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<tr>
<td>1995</td>
<td>37786</td>
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</tr>
<tr>
<td></td>
<td>38408</td>
<td>*****************</td>
</tr>
<tr>
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<td>38949</td>
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<tr>
<td></td>
<td>39004</td>
<td>*****************</td>
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<tr>
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<tr>
<td></td>
<td>41591</td>
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<td>ooooooooooooooooooooooooooo</td>
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<tr>
<td></td>
<td>45900</td>
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</thead>
<tbody>
<tr>
<td></td>
<td>ENV21</td>
<td>1161990</td>
</tr>
</tbody>
</table>

Upper Values for Scenario ENV20 (oXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX)
Lower Values for Scenario ENV21 (***************)
Unit: Mio. $80

Figure 8: Development of the Yearly Investment (Undiscounted)
Emissions

The development of emissions (SO2 in Figure 9; NOx in Figure 10) up to 2010 is shown by the scenario comparison (ENV21 against ENV20).

<table>
<thead>
<tr>
<th>Time</th>
<th>Value</th>
<th>Graphical Demonstration</th>
</tr>
</thead>
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<td>..........................</td>
</tr>
<tr>
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<tr>
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<td>ENV21</td>
<td>425660</td>
</tr>
</tbody>
</table>

**Upper Values for Scenario ENV20**

**Lower Values for Scenario ENV21**

**Unit:** Mmol

Figure 9: Yearly Emissions of SO2

The development of the yearly emissions of SO2 is shown in Figure 9. The sum of the sulphur dioxide emissions in scenario ENV21 up to 2010 is 65 per cent below the sum for scenario ENV20. Sulphur dioxide removal technologies are introduced with a removal rate of 100 per cent from 1990 onwards. Only in 2010 is a 95 per cent reduction chosen by the model as a result of the relatively decreasing importance of the environmental goal.
<table>
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**Summe**

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<td>ENV21</td>
<td>411100</td>
<td>( - 6 % )</td>
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Upper Values for Scenario ENV20 (ooooooooooooooooooooooooooo )
Lower Values for Scenario ENV21 ( ................................. )

Unit: Mmol

Figure 10: Yearly Emissions of NOx

Figure 10 gives the results for the NOx emissions; there you can see only a minor reduction (6 per cent) in the scenario with a penalty on sulphur dioxide emissions. This reduction of NOx emissions is a side effect caused by structural change within the energy supply system. The NOx removal technologies that are included in the model and could be chosen are not favored because there is no incentive for NOx reduction.
Primary Energy

The development of the primary energy supply and especially the differences between the scenarios ENV20 and ENV21 can be studied in Figure 11 and Figure 12.

Both tables demonstrate that the relation to the statistical values and common estimates (1985) should be a bit closer. In this respects something needs to be done in order to get compatible data for the beginning of the time horizon.

<table>
<thead>
<tr>
<th></th>
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<tr>
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<td>2806</td>
<td>3300</td>
<td>3604</td>
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<tr>
<td>Brown Coal</td>
<td>1164</td>
<td>1097</td>
<td>846</td>
<td>738</td>
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<tr>
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<td>150</td>
<td>75</td>
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<tr>
<td>Gas</td>
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<td>644</td>
<td>391</td>
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<td>Imports:</td>
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<td>355</td>
<td>355</td>
<td>355</td>
</tr>
<tr>
<td>Coke</td>
<td>223</td>
<td>223</td>
<td>223</td>
<td>223</td>
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</tbody>
</table>

Figure 11: Primary Energy in Scenario ENV20

5 That adjusting process is of importance if the results are to be persuasive. The decision maker wants to find as a model result at least what he already knows from energy statistics to be true. If those data do not fit the statistical data more or less exactly you can forget about the remaining part of your study. It would be very complicated to explain that the values for 1985 are the average values for a period starting 1982.5 and ending 1987.5 and that they have to differ from statistical data if we apply the normal MARKAL approach. Anyway, the influence of the first period on the model is rather limited, and we should put aside the scientific scruples to sell the more important messages that should be the result of our studies.
Sources of Energy Carriers | 1985 | 1990 | 2000 | 2010
---|---|---|---|---
**Domestic Production:**
Hard Coal | 2345 | 2730 | 3171 | 3473
Brown Coal | 1164 | 1097 | 846 | 738
Crude Oil | 180 | 150 | 75 | 0
Gas | 644 | 644 | 391 | 32
**Imports:**
Crude Oil | 4675 | 3857 | 3118 | 2821
Gas | 1295 | 1587 | 1745 | 1904
**Exports:**
Hard Coal | 355 | 355 | 355 | 355
Coke | 223 | 223 | 223 | 223

Unit: PJ

Figure 12: Primary Energy in Scenario ENV21

Remarkable in both scenarios is the significant reduction in crude oil imports. From 1985 to 2000 the amount of crude oil imports is cut by one third. This scenario result is supposed to be stable within the given framework of import price assumptions and estimated prices for domestic mining and will not be affected by changes in other areas of the model.

The development of domestic mining activities (see Figure 13) with a gigantic increase of hard coal mining and the decrease of brown coal mining looks a bit strange and might force some changes in the key input assumptions of the model.

Using subsidized prices for hard coal as model input will result in an economically disastrous enlargement of an uncompetitive industry.
The reconsideration of the costs for brown coal mining should include some thoughts about a possibly explicit way of modeling the open cast mining activities, including investment cost, lifetime, etc. In that area a mixed integer approach seems to be advisable because you have to run mines of such dimensions or not at all. The options in between should be excluded.

Figure 13: Development of the Goal Mining Activities
Energy Conversion

In the area headed "energy conversion" there has been some preliminary analysis in the electricity sector only. In the other important areas of that sector (which includes the refinery structure), additional work needs to be done, both in modelling and in the analysis of results.

Electricity Generation - Capacity and Production: The development of the electricity generating capacities for both scenarios are compared in Figure 14 and Figure 15. In both scenarios it becomes evident that adjustment is necessary for the beginning of the time horizon. Some minor discrepancies between optimization results and statistical data need to be eradicated.

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<td>4.0</td>
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<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
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<td>6.1</td>
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<td>6.5</td>
<td>22.6</td>
<td>27.7</td>
</tr>
<tr>
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<td>4.7</td>
<td>1.5</td>
<td>1.4</td>
</tr>
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<td>13.6</td>
<td>17.8</td>
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<td>2.0</td>
<td>2.0</td>
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<td>4.9</td>
<td>1.9</td>
<td>-</td>
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<tr>
<td>Nuclear Power Plant</td>
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<td>22.5</td>
<td>28.9</td>
<td>33.8</td>
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<td><strong>Sum</strong></td>
<td><strong>95.3</strong></td>
<td><strong>92.9</strong></td>
<td><strong>94.5</strong></td>
<td><strong>96.1</strong></td>
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</table>

Unit: GW

Figure 14: Electricity - Capacities in Scenario ENV20
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<td>2.4</td>
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<td>16.4</td>
<td>9.6</td>
<td>6.1</td>
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<td>6.9</td>
<td>20.3</td>
<td>25.4</td>
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<tr>
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<td>4.7</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
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<td>11.6</td>
<td>11.9</td>
<td>16.0</td>
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<td>2.0</td>
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<td>18.8</td>
<td>8.0</td>
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<td>Gas Turbine</td>
<td>5.0</td>
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<td>1.9</td>
<td>-</td>
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<td>38.7</td>
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<td><strong>93.7</strong></td>
<td><strong>94.4</strong></td>
<td><strong>96.9</strong></td>
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</table>

Unit: GW

Figure 15: Electricity - Capacities in scenario ENV21

The electricity generation of both scenarios is compared in Figure 16. As mentioned before, some effort will be necessary to get figures which are good enough to be compared with the statistical values for the beginning of the time horizon.
<table>
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<th>Graphical Demonstration</th>
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<td>1319</td>
<td>ooooooooooooooooooooooooooo</td>
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<tr>
<td></td>
<td>1329</td>
<td>******************************************</td>
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<tr>
<td>1990</td>
<td>1407</td>
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</tr>
<tr>
<td></td>
<td>1383</td>
<td>******************************************</td>
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<tr>
<td>1995</td>
<td>1465</td>
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</tr>
<tr>
<td></td>
<td>1498</td>
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<tr>
<td>2000</td>
<td>1497</td>
<td>ooooooooooooooooooooooooooooooooooo</td>
</tr>
<tr>
<td></td>
<td>1553</td>
<td>******************************************</td>
</tr>
<tr>
<td>2005</td>
<td>1538</td>
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<tr>
<td></td>
<td>1601</td>
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<tr>
<td>2010</td>
<td>1576</td>
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<td>1656</td>
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</table>

<table>
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<th>44010</th>
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<tr>
<td></td>
<td>ENV21</td>
<td>45100 (+ 2.5 %)</td>
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</tbody>
</table>

Upper Values for Scenario ENV20 ( oooooooooooooooooooooooooooooooooo )
Lower Values for Scenario ENV21 ( ****************************************** )
Unit: PJ

Figure 16: Yearly Electricity Generation

As you can see from Figure 16, the introduction of a penalty on SO2 emissions do not significantly change the amount of generated electricity. Total generation is reduced by 2.5 per cent only.

In the Figures 17 and 18 you can see the electricity generation by energy carrier.

"Hydro" includes running water, storage and pumped storage power plants. As you can see from the graphs, there was no variation due to optimization. Generation as well as the capacities are always constrained by the given upper limits.
For "Hard coal" we distinguish two categories of power plants: pure power plants (lower part of the "Hard coal" area up to the separation line) and plants that produce electricity and low temperature heat (remaining upper part of the "Hard coal" area).

Similar to the separation for hard coal, there exists a separation for "Brown coal". Here, the generation by coupled production plants (upper part of the "Brown coal" area) always reaches the given bounds.

"Gas" (area without shading) includes gas power plants (lower part) and gas turbines for peak load purposes (upper part).

The uppermost part "Nuclear" contains one technology only, i.e., the LWR. Other nuclear technologies might be included later.

Figure 17: Electricity Generation by Energy Carrier in Scenario ENV20
Figure 18: Electricity Generation by Energy Carrier in Scenario ENV21
Figure 19: Main Changes in Electricity Generation (ENV20 - ENV21)

The important differences caused by the introduction of the penalty on SO2 emissions are the reduction of hard coal pass out turbine power plants and - to compensate for that - the enlarged use of light water reactors (see Figure 19). Both effects could have been expected and were the same as results of MARKAL studies in other countries: i.e., less coal and more nuclear as options to avoid emissions of SO2.

The capacity utilization of the power plants in scenario ENV20 is shown in Figure 20 and for scenario ENV21 in Figure 21. As you can see, the utilization follows the given limits for several plants. To check and maybe to change some of those limits will be one of the next tasks in the ongoing study on environmental effects.
<table>
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<td>6789</td>
<td>4931</td>
<td>4945</td>
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<td>939</td>
<td>5430</td>
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<td>Gas Turbine</td>
<td>876</td>
<td>876</td>
<td>876</td>
<td>-</td>
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<td>6570</td>
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Unit: Load hours

Figure 20: Capacity Utilization of Power Plants (ENV20)

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<td>6570</td>
<td>6570</td>
<td>6570</td>
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Unit: Load hours

Figure 21: Capacity Utilization of Power Plants (ENV21)
**Low Temperature Heat:** For the changes in production of low temperature heat, there shall be given a general overview only. The generation of both scenarios is compared in Figure 22:

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<tr>
<td></td>
<td>604</td>
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</tr>
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</table>

Sum  
- ENV20: 14200  
- ENV21: 13375 (−6%)

**Upper Values for Scenario:** ENV20  
- (ooooooooooooooooooooooooooooo)

**Lower Values for Scenario:** ENV21  
- (***********************)

**Unit:** PJ

Figure 22: Yearly Production of Low Temperature Heat

A reduction of 6 per cent was caused by the introduction of the penalty on SO2 emissions.
Emissions by the Electricity Sector: The following graphs show the sources of SO2 emissions by technology and the effects of the introduction of the emissions penalty.

<table>
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<th>SO2 Producer</th>
<th>1985</th>
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<th>2000</th>
<th>2010</th>
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<td>16958</td>
<td>20814</td>
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<td>Hard Coal POT (Industry)</td>
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<table>
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<th>Sum of Electricity and District Heat Producers</th>
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<td>30132</td>
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<td>30804</td>
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<td>31359</td>
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<table>
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<th>Amount of SO2 in Crude Oil</th>
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<td>8480</td>
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<td>7526</td>
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Unit: Mmol SO2

Figure 23: Yearly Emission of SO2 in Scenario ENV20
<table>
<thead>
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<th>1990</th>
<th>2000</th>
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<tbody>
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<td>Hard Coal Power Plant</td>
<td>7003</td>
<td>5272</td>
<td>2932</td>
<td>1853</td>
</tr>
<tr>
<td>Hard Coal Pass-Out Turbine</td>
<td>5983</td>
<td>7066</td>
<td>15172</td>
<td>19029</td>
</tr>
<tr>
<td>Hard Coal POT (Industry)</td>
<td>247</td>
<td>280</td>
<td>511</td>
<td>656</td>
</tr>
<tr>
<td>Hard Coal Heating Plant</td>
<td>2553</td>
<td>3526</td>
<td>1222</td>
<td>1492</td>
</tr>
<tr>
<td>Brown Coal Power Plant</td>
<td>14218</td>
<td>12262</td>
<td>7472</td>
<td>6863</td>
</tr>
<tr>
<td>Brown Coal Pass-Out Turbine</td>
<td>0</td>
<td>1056</td>
<td>2112</td>
<td>2112</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>8</td>
<td>8</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Gas Power Plant</td>
<td>75</td>
<td>57</td>
<td>24</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum of Electricity and District Heat Producers</th>
<th>30087</th>
<th>29525</th>
<th>29448</th>
<th>31008</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2 before being removed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>SO2 Emissions</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>Amount of SO2 in Crude Oil</td>
<td>12476</td>
<td>10297</td>
<td>8207</td>
<td>7251</td>
</tr>
</tbody>
</table>

Unit: Mmol SO2

Figure 24: Yearly Production of SO2 in Scenario ENV21
The NOx emissions of both scenarios are shown in the following two figures:

<table>
<thead>
<tr>
<th>NOx Producer</th>
<th>1985</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal Power Plant</td>
<td>3293</td>
<td>3287</td>
<td>1369</td>
<td>865</td>
</tr>
<tr>
<td>Hard Coal Pass-Out Turbine</td>
<td>2793</td>
<td>3147</td>
<td>7916</td>
<td>9716</td>
</tr>
<tr>
<td>Hard Coal POT (Industry)</td>
<td>116</td>
<td>131</td>
<td>239</td>
<td>308</td>
</tr>
<tr>
<td>Hard Coal Heating Plant</td>
<td>1205</td>
<td>1584</td>
<td>636</td>
<td>763</td>
</tr>
<tr>
<td>Brown Coal Power Plant</td>
<td>5016</td>
<td>4326</td>
<td>2636</td>
<td>2068</td>
</tr>
<tr>
<td>Brown Coal Pass-Out Turbine</td>
<td>0</td>
<td>373</td>
<td>745</td>
<td>745</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>208</td>
<td>206</td>
<td>79</td>
<td>0</td>
</tr>
<tr>
<td>Gas Power Plant</td>
<td>1768</td>
<td>1432</td>
<td>604</td>
<td>71</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum of Electricity and District Heat Producers</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx Emissions</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Unit: Mmol NOx</td>
</tr>
</tbody>
</table>

Figure 25: Yearly Emissions of NOx in Scenario ENV20

<table>
<thead>
<tr>
<th>NOx Producer</th>
<th>1985</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal Power Plant</td>
<td>3269</td>
<td>2461</td>
<td>1369</td>
<td>865</td>
</tr>
<tr>
<td>Hard Coal Pass-Out Turbine</td>
<td>2793</td>
<td>3299</td>
<td>7083</td>
<td>8883</td>
</tr>
<tr>
<td>Hard Coal POT (Industry)</td>
<td>116</td>
<td>131</td>
<td>239</td>
<td>308</td>
</tr>
<tr>
<td>Hard Coal Heating Plant</td>
<td>1205</td>
<td>1664</td>
<td>577</td>
<td>704</td>
</tr>
<tr>
<td>Brown Coal Power Plant</td>
<td>5016</td>
<td>4326</td>
<td>2636</td>
<td>2068</td>
</tr>
<tr>
<td>Brown Coal Pass-Out Turbine</td>
<td>0</td>
<td>373</td>
<td>745</td>
<td>745</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>208</td>
<td>206</td>
<td>79</td>
<td>0</td>
</tr>
<tr>
<td>Gas Power Plant</td>
<td>1889</td>
<td>1432</td>
<td>604</td>
<td>71</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum of Electricity and District Heat Producers</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx Emissions</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Unit: Mmol NOx</td>
</tr>
</tbody>
</table>

Figure 26: Yearly Emissions of NOx in Scenario ENV21
Consumption of Final Energy

To show some information about the scenarios developed up to now, an overview about the consumption of final energy by industry and the residential and commercial sector is given on the following pages.

Industry

<table>
<thead>
<tr>
<th>Time</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal, Coke</td>
</tr>
<tr>
<td>1985</td>
<td>683</td>
</tr>
<tr>
<td>1990</td>
<td>746</td>
</tr>
<tr>
<td>2000</td>
<td>873</td>
</tr>
<tr>
<td>2010</td>
<td>923</td>
</tr>
</tbody>
</table>

Unit: PJ per year

Figure 27: Final Energy Consumption by Industry (ENV20)

<table>
<thead>
<tr>
<th>Time</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal, Coke</td>
</tr>
<tr>
<td>1985</td>
<td>683</td>
</tr>
<tr>
<td>1990</td>
<td>746</td>
</tr>
<tr>
<td>2000</td>
<td>874</td>
</tr>
<tr>
<td>2010</td>
<td>923</td>
</tr>
</tbody>
</table>

Unit: PJ per year

Figure 28: Final Energy Consumption by Industry (ENV21)
Residential and Commercial

<table>
<thead>
<tr>
<th>Time</th>
<th>Coal, Coke</th>
<th>Liquid Fuels</th>
<th>Gas</th>
<th>Electricity</th>
<th>Heat</th>
<th>Renewables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>113</td>
<td>1487</td>
<td>770</td>
<td>594</td>
<td>220</td>
<td>0</td>
</tr>
<tr>
<td>1990</td>
<td>56</td>
<td>1222</td>
<td>891</td>
<td>666</td>
<td>289</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>37</td>
<td>740</td>
<td>1019</td>
<td>730</td>
<td>476</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>31</td>
<td>504</td>
<td>924</td>
<td>782</td>
<td>560</td>
<td>0</td>
</tr>
</tbody>
</table>

Unit: PJ per year

Figure 29: Final Energy Consumption by the R&C Sector (ENV20)

<table>
<thead>
<tr>
<th>Time</th>
<th>Coal, Coke</th>
<th>Liquid Fuels</th>
<th>Gas</th>
<th>Electricity</th>
<th>Heat</th>
<th>Renewables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>113</td>
<td>1487</td>
<td>758</td>
<td>603</td>
<td>220</td>
<td>0</td>
</tr>
<tr>
<td>1990</td>
<td>56</td>
<td>1222</td>
<td>905</td>
<td>645</td>
<td>302</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>37</td>
<td>740</td>
<td>992</td>
<td>783</td>
<td>424</td>
<td>15</td>
</tr>
<tr>
<td>2010</td>
<td>31</td>
<td>504</td>
<td>851</td>
<td>859</td>
<td>517</td>
<td>46</td>
</tr>
</tbody>
</table>

Unit: PJ per Year

Figure 30: Final Energy Consumption by the R&C Sector (ENV21)
Changing the Penalty Sensitivity of the System

In order to find out the level of the penalty at which the structure of the energy system changes, nine additional runs with different penalties were performed. The levels of the penalty and the influence on the amount of SO2 emitted by the energy system are documented in Figure 31:

<table>
<thead>
<tr>
<th>Penalty ( $80 per mol)</th>
<th>Year</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1985</td>
<td>1990</td>
<td>2000</td>
<td>2010</td>
</tr>
<tr>
<td>0.00 (= ENV20)</td>
<td>42.6</td>
<td>41.5</td>
<td>39.7</td>
<td>40.4</td>
</tr>
<tr>
<td>0.01</td>
<td>42.5</td>
<td>41.5</td>
<td>39.5</td>
<td>40.2</td>
</tr>
<tr>
<td>0.02</td>
<td>42.5</td>
<td>41.5</td>
<td>39.2</td>
<td>39.9</td>
</tr>
<tr>
<td>0.03</td>
<td>42.4</td>
<td>12.3</td>
<td>9.9</td>
<td>10.2</td>
</tr>
<tr>
<td>0.05</td>
<td>42.4</td>
<td>12.3</td>
<td>9.9</td>
<td>9.1</td>
</tr>
<tr>
<td>0.20</td>
<td>42.3</td>
<td>12.1</td>
<td>9.9</td>
<td>9.1</td>
</tr>
<tr>
<td>0.40</td>
<td>42.2</td>
<td>12.0</td>
<td>9.8</td>
<td>9.0</td>
</tr>
<tr>
<td>0.60</td>
<td>42.3</td>
<td>11.9</td>
<td>9.8</td>
<td>8.9</td>
</tr>
<tr>
<td>0.80</td>
<td>42.2</td>
<td>11.8</td>
<td>9.7</td>
<td>8.9</td>
</tr>
<tr>
<td>1.00 (= ENV21)</td>
<td>42.6</td>
<td>10.3</td>
<td>8.2</td>
<td>7.3</td>
</tr>
<tr>
<td>2.00</td>
<td>43.4</td>
<td>10.2</td>
<td>8.0</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Unit: Gmol SO2 per year

Figure 31: Influence of Penalties on SO2 Emissions
To demonstrate the abruptness of the breaks a graph (Figure 32) showing the changes is added. The scale is a logarithmic one in both directions.

Figure 32: Structural Breaks of the System
Connection of the NHIES with the Existing Energy System

Data and Modelling

The data material necessary to model the "novel horizontally integrated energy system" (NHIES) were taken from the documentations available in STE. Because of the comparability of the MARKAL model with the model developed for the NHIES calculation we did not have any problems in transferring the NHIES structure to a MARKAL submodel which can be linked to the existing energy system structure if desired.

Only those technologies that are specific to the "novel horizontally integrated energy system" were taken over to be included in the MARKAL data set:

- Air Separation
- Electrolysis
- Molten Iron Process
- HTR Based Technology with Gas Input
- HTR Based Technology with Hard coal I. (a)
- HTR Based Technology with Hard coal I. (b)
- HTR Based Technology with Brown coal I. (a)
- HTR Based Technology with Brown coal I. (b)
- Separation Devices
  for the Different Kinds of Synthesis Gas
- Methanol Synthesis
- Coke Power Plant (Oxygen Combustion)
- Gas turbine (Oxygen Combustion)
- CO-Turbine
- Purge Gas Power Plant

The NHIES is modeled like an independent system. The system boundary and the connection with the existing energy system is
on the input side by the balances for gas, hard coal, brown coal and nuclear fuel, on the output side of the submodel by methanol. Electricity can be used in both directions, i.e., the NHIES can be a producer or a consumer (net values) of electricity.

NHIES Scenario ENV22

In the NHIES scenario (ENV22) the new system is allowed to start production at the beginning of the fifth period (center 2000). The penalty is the same as in scenario ENV21 (1%80/mol SO2). A limitation of the outputs of the NHIES was not considered, neither an upper nor a lower bound on the amount of methanol or electricity produced by the new subsystem.

The NHIES outputs resulting from the optimization are shown in Figure 33:

<table>
<thead>
<tr>
<th>NHIES Technologies</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Separation (Oxygen)</td>
<td>71</td>
<td>223</td>
<td>280</td>
</tr>
<tr>
<td>Electrolysis:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Molten Iron Process (Synthesis Gas)</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>HTR with Gas Input (Synthesis Gas)</td>
<td>189</td>
<td>386</td>
<td>386</td>
</tr>
<tr>
<td>HTR with HCO Input (a) (Synthesis Gas)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HTR with HCO Input (b) (Synthesis Gas)</td>
<td>464</td>
<td>1512</td>
<td>1966</td>
</tr>
<tr>
<td>HTR with BCO Input (a) (Synthesis Gas)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HTR with BCO Input (b) (Synthesis Gas)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Synthesis Gas Separation:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>410</td>
<td>1142</td>
<td>1396</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>131</td>
<td>366</td>
<td>458</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>101</td>
<td>306</td>
<td>385</td>
</tr>
<tr>
<td>Methane</td>
<td>36</td>
<td>108</td>
<td>137</td>
</tr>
<tr>
<td>Methanol Synthesis (Methanol)</td>
<td>180</td>
<td>503</td>
<td>617</td>
</tr>
</tbody>
</table>

Unit: Gmol

Figure 33: Yearly Output of the NHIES Technologies (Gmol)
<table>
<thead>
<tr>
<th>NHIES Technologies</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Separation</td>
<td>-692</td>
<td>-2008</td>
<td>-2524</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HTR with Gas Input</td>
<td>335</td>
<td>683</td>
<td>683</td>
</tr>
<tr>
<td>HTR with Hard Coal Input (a)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HTR with Hard Coal Input (b)</td>
<td>2304</td>
<td>7517</td>
<td>9769</td>
</tr>
<tr>
<td>HTR with Brown Coal Input (a)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HTR with Brown Coal Input (b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Synthesis Gas Separation</td>
<td>-288</td>
<td>-551</td>
<td>-551</td>
</tr>
<tr>
<td>Methanol Synthesis</td>
<td>595</td>
<td>1660</td>
<td>2039</td>
</tr>
<tr>
<td>Coke Power Plant</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CO-Turbine</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Purge Gas Power Plant</td>
<td>3045</td>
<td>9265</td>
<td>11704</td>
</tr>
<tr>
<td>Transfer to the Existing</td>
<td>-5298</td>
<td>-16565</td>
<td>-21120</td>
</tr>
<tr>
<td>Energy System</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Unit: GWh (negative values mean consumption)

Figure 34: Yearly Electricity Production of the NHIES Technologies

Comparison of the NHIES Scenario with Scenario ENV21

- Sum of Undiscounted Investment: + 0.5 per cent
- SO2 Emissions: - 1.3 per cent
- Amount of SO2 from Crude Oil: - 2.3 per cent
- NOx Emissions (Period 5): - 1.2 per cent
- NOx Emissions (Period 7): - 6.0 per cent
- Electricity Production: - 2.0 per cent
- District Heat Production: - 3.4 per cent
Comparison with Other Calculations

Compared with other results produced by STE, the NHIES results seem to be a bit too optimistic. A validation of the MARKAL results produced up to now will be necessary.
Appendix A: Literature


5.3.2 Technical Measures for Emission Control and their Costs
A Systems Analysis Approach
(S. Kypreos/J. Wochele)

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Appendix A: Technology Data
Appendix B: Specific Emissions by Technology

Remark: The Appendixes A and B are not included due to their size. They could be made available by request.
1 MAIN OBJECTIVE OF THE STUDY

The objective of the study will be to analyse the contribution of different policy measures and technologies in reducing $SO_2^*$ and $NO_x^*$ emissions related to the Swiss Energy supply system, using energy systems analysis techniques.

Figs. 1 and 2 give the historical evolution of emission release to the atmosphere as estimated by the Swiss Office of Environmental Protection (BUS**) and their disaggregation among the sectors industry, transport and residential/commercial.

The policy target is to reduce pollution to the levels of 1960 and if possible to the levels of 1950. One has to examine Fig. 1 and take into account the expected energy demand increase between 1984 and 2000, especially in the transport sector, to understand the difficulties associated with this problem. The criteria for selecting the most appropriate measures and/or technological options should be based on their effectiveness and their associated cost. The energy cost optimization model MARKAL is therefore adopted and used as one of the appropriate models to analyse the problem.

![DISTRIBUTION OF EMISSIONS ACCORDING TO PRODUCERS](image)

**Fig. 1:** Industry and households are mainly responsible for the $SO_2$ emissions, whereas the traffic causes the most $NO_x$ and $HC$ pollution.

Source: BUS (Swiss Federal Environmental Protection Office)

*) $SO_2$: Sulfur dioxide  
$NO_x$: Nitrogen oxide  
$HC$: Hydrocarbons  
**) BUS = Bundesamt für Umweltschutz (Swiss Federal Environmental Protection Office)
Fig. 2: Development of the Swiss SO2, NOx, HC Emission from 1950 to 1982
Source: BUS

2 MODEL AND DATA BASE DESCRIPTION

2.1 Methodology

The MARKAL model has been described in many reports (Ref. 1, 2).

Of interest is the application of MARKAL to the specification of the Austrian Energy Concept, where emission control has been studied*), using a similar approach to that described here.

A linear programming model has the following structure:

Minimize the objective function:

\[ Z = \sum_{j=1}^{n} c_j \cdot x_j \]

Subject to the constraints:

\[ \sum_{j=1}^{m} a_{ij} x_j \leq b_i, \quad i=1, \ldots, m \]

\[ x_j \geq 0, \quad j=1, \ldots, n \]

Until now we have used the total discounted system cost (investment, O+M\(^1\)) cost, fuel cost) as objective function.

*) Energiebericht und Energiekonzept 1984 der Oesterreichischen Bundesregierung
1) O+M = Operation and Maintenance
The most important system constraints are:

- energy balance (annual)
- electricity balance (seasonal)
- load management
- energy demand
- capacity build-up of technologies

Since in most of the cases emissions of SO2, NOx and CO2 are proportional to the energy flow through a given technology, the total emission inventories of these pollutants can also be estimated. This is the case in MARKAL. The treatment of HC emissions is more complex and not considered here.

Using MARKAL, few options are available to study emissions.

One possibility is to define a new objective function which asks for the minimization of pollutants.

Another possibility, which has been adopted in this study, is to extend the system constraints by including the constraints on SO2 and NOx, while using the same objective function (total discounted system cost).

In this case, the objective is

- to minimize the total energy system cost, consisting of
  - investment including emission control equipment,
  - operation and maintenance cost,
  - energy (fuel) costs without emission control,
  - cost of additional energy use caused by emission control, and

- to satisfy
  - the constraints to the energy system described previously and,
  - restrictions that keep all pollutants of interest below some prespecified level.

There may be cases where no solution exists to the problem defined in this way. This means that the energy system as specified cannot be modified by the emission control technologies envisaged in such a way that the required, reduced emission levels result.

Two levels are usually specified according to the policy targets.

<table>
<thead>
<tr>
<th>Target values of emissions as by the year 1960</th>
<th>Target values as by the year 1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2 90,000 tons/yr</td>
<td>SO2 50,000 tons/yr</td>
</tr>
<tr>
<td>NOx 52,000</td>
<td>NOx 22,000</td>
</tr>
</tbody>
</table>

Using the above described approach, the model will select the optimal choice of measures and technologies that satisfy the imposed limits on emissions.
To do this, all potential options for reduction of emissions should be modelled to give MARKAL the necessary flexibility.

A third possibility, not considered in this study, would be to introduce a new objective function which combines the old objective function (system cost) and a cost penalty proportional to emissions released:

\[ Z_{\text{new}} = \sum_{j=1}^{\infty} c_j x_j + \sum_{K} w_K E_M, \]

where: \( K \in \{SO_2, NO_x, CO_2, CO, CH, \ldots\} \)
while: \( w_K \) are the different weights in Fr/tons.

2.2 Measures which could be studied with MARKAL

The next question to be addressed refers to the measures and technologies that can be taken into account.

There follows a list of possibilities:
- Direct use of emission control technologies like catalytic converters in automobiles, together with use of desulfurization and denoxing systems in the industrial sector
- Use of unleaded gasoline
- Use of oil with less sulfur content
- Conservation in buildings
- Replacement of old heating systems
- Fuel switching (more gas or electricity instead of oil and coal)
- Introduction of new technologies like
  - Renewables (solar, geothermal)
  - District heat
  - Small capacity nuclear heating plants (Heizreaktor)
  - Heat pumps
  - Fluidized bed cogeneration systems in industry

Since the optimization model considers fossil power plants as potential future electricity generation systems, denoxing and desulfurization systems for these plants are also considered.

All these technologies will be considered simultaneously, and their best combination will be selected.

Some other measures can only indirectly be taken into account (simulated).
- The introduction of energy taxes on fossil fuels will reduce energy demand. This can best be analysed by econometrics. The demand reduction can then be taken into account as an exogenous constraint in MARKAL.
- The same is true for measures like speed reduction in autos or the increased use of public transportation systems.

There are other measures like tariff modification for electricity, which cannot be analysed explicitly, since the cost of electricity is calculated within the MARKAL model. Thus, it would be possible to propose tariff modifications that take into account future electricity consumption patterns based upon analysing of the shadow prices of the model, but not the opposite.
2.3 Reference Energy System and Technologies Included

Perhaps the best way to explain in detail the model adopted for emission accounting and control (always within the framework of the energy sources and technological options introduced in the study) is to examine the Reference Energy System which is shown in Fig. 3. To avoid complexity, not all the flows are drawn in detail but only the input and output energy carriers for a given technology.

Although the figure looks complex, it is the most exact description of the model adopted and allows the careful reader to understand what we have actually modelled.

The picture is completed, by tables characterizing the technologies considered in the study as well as fuel prices, demand disaggregation, and the technical bounds introduced. Part of this information is given in the Appendix.

It is important to notice that the oil refining sector is not explicitly introduced to this model. Oil products are regarded as directly imported. The end-use prices include fiscal charges.

The part of the Reference Energy System that describes heating oil use in the residential sector is explained here to demonstrate the approach (Fig. 4).

The processes called SR2 and SR3 "mix" heating oil, DSL, of different sulfur contents (0.3% and 0.15% respectively) to produce a fuel called DSR. This fuel is then used as input for different heating systems, R13, R23, RA3, RB3, etc.

The SO2 emissions are accounted for in the level of process SR2 or SR3. If a strong reduction to SO2 emissions is demanded (by an external constraint) then the system will build up capacity, SR3, for which there is extra cost. If no constraint on SO2 is imposed, oil of 0.3% (SR2) will be selected.

Policy simulation is also possible by forcing the proper process into the solution.

Fig. 4: Oil use of different sulfur content in the residential sector. (See text for explanations.)
### Energiequellen

<table>
<thead>
<tr>
<th>PSF</th>
<th>Kraftwerke</th>
<th>Stromerzeugung</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSF 01</td>
<td>Kohle-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 02</td>
<td>Gas-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 03</td>
<td>Petroleum-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 04</td>
<td>Gas-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 05</td>
<td>Kohle-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 06</td>
<td>Gas-Kraftwerk</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PSF</th>
<th>Industrie</th>
<th>Stromverbraucher</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSF 100</td>
<td>Kohle-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 101</td>
<td>Gas-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 102</td>
<td>Petroleum-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 103</td>
<td>Gas-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 104</td>
<td>Kohle-Kraftwerk</td>
</tr>
<tr>
<td></td>
<td>PSF 105</td>
<td>Gas-Kraftwerk</td>
</tr>
</tbody>
</table>

### Prozess

<table>
<thead>
<tr>
<th>PSF</th>
<th>Prozess (Meßorte)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSF 01</td>
</tr>
<tr>
<td></td>
<td>PSF 02</td>
</tr>
<tr>
<td></td>
<td>PSF 03</td>
</tr>
<tr>
<td></td>
<td>PSF 04</td>
</tr>
<tr>
<td></td>
<td>PSF 05</td>
</tr>
<tr>
<td></td>
<td>PSF 06</td>
</tr>
<tr>
<td></td>
<td>PSF 07</td>
</tr>
<tr>
<td></td>
<td>PSF 08</td>
</tr>
</tbody>
</table>

### Verkehr

<table>
<thead>
<tr>
<th>Verkehr</th>
<th>TNS</th>
<th>ENS</th>
<th>BNS</th>
<th>BNS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TNS</td>
<td>ENS</td>
<td>BNS</td>
<td>BNS</td>
</tr>
</tbody>
</table>

### LEGENDE

- %: % Schweröl im Brennstoff
- K/D: Heizöl / Diesel
- KW: Korkwerk
- ENW: Energieversorgung
- HDO: Heizölumpchen
- N: Kohle
- S: Gas
- S-N: Schweröl / Gas / Heizöl

### SCALES

- 1: Heizöl
- 2: Gas
- 3: Kohle

### DECIMAL EXPRESSION

- 0: Heizöl
- 1: Gas
- 2: Kohle
### 2.4 Summary of emission data and control technologies

In Table 1 the actual assumptions on specific emissions by fuel for each sector are summarized. We distinguish between boiler and engine application, different sulphur contents in the fuel, and emissions with and without emission control technologies. In Appendix B the emissions are listed in detail for each energy technology used by MARKAL.

**Table 1: Specific Emissions (Input)**

<table>
<thead>
<tr>
<th></th>
<th>boiler and heater</th>
<th>engine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SO2</td>
<td>NOx</td>
</tr>
<tr>
<td><strong>Sector: Transport in (g/km)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot; with catalytic converter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel improved</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sector: Industry in (t/PJ Input)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal 2% S 0.8% S</td>
<td>136</td>
<td>250</td>
</tr>
<tr>
<td>Oil M+S 2% S</td>
<td>546</td>
<td>250</td>
</tr>
<tr>
<td>&quot; &quot; M+S 1% S</td>
<td>955</td>
<td>200;250</td>
</tr>
<tr>
<td>&quot; &quot; EL 0.3% S</td>
<td>478</td>
<td>250</td>
</tr>
<tr>
<td>&quot; &quot; 0.15% S</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Power Stations (electricity + heat) in (t/PJ Input)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal 2% S 2% S</td>
<td>1365</td>
<td>250</td>
</tr>
<tr>
<td>&quot; &quot; 2% S</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>Fluidized Bed 2% S</td>
<td>273</td>
<td>130</td>
</tr>
<tr>
<td>Oil 2% S</td>
<td>955</td>
<td>250</td>
</tr>
<tr>
<td>&quot; &quot; 1% S</td>
<td>478</td>
<td>250</td>
</tr>
<tr>
<td>&quot; &quot; Waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**

- REA = Rauchgasentschwefelungsanlage (desulfurization systems)
- RENA = Entstickerungstechnologie (denoxing systems)
3 MAIN ASSUMPTIONS OF THE STUDY

A summary of assumptions concerning demand evolution and fuel prices adopted is given here.

3.1 Energy Demand Projections

The recent official demand projections were not made available to us, and we therefore had to generate our own projections. A modified version of MEDEE, called SMEDE (Ref. 3) has been used to evaluate energy demand. The model uses engineering simulation techniques and the scenario approach. The main reason for using this model was the unrealistic demand projections for the transport sector estimated in the past based on the econometric approach.

The demand for transport projected by Spierer/Giovaninni, looks as follows (Ref. 4, 5):

Table 2: Energy Consumption in the transportation sector (PJ/Yr).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>38.6</td>
<td>46.0</td>
<td>54.5</td>
<td>63.8</td>
</tr>
<tr>
<td>Gasoline</td>
<td>135.7</td>
<td>161.0</td>
<td>182.4</td>
<td>206.8</td>
</tr>
<tr>
<td>Kerosene</td>
<td>37.1</td>
<td>48.1</td>
<td>60.1</td>
<td>74.7</td>
</tr>
<tr>
<td>Electricity</td>
<td>7.5</td>
<td>8.0</td>
<td>8.3</td>
<td>8.6</td>
</tr>
<tr>
<td>Total</td>
<td>218.9</td>
<td>263.9</td>
<td>305.3</td>
<td>353.9</td>
</tr>
</tbody>
</table>

It is interesting to estimate the equivalent number of private cars which correspond to that projection. Although it is difficult to know the fraction of diesel consumption that corresponds to private cars, one could simplify the estimation assuming that 210 PJ of energy is consumed by private cars in the year 2000. Assuming an average distance travelled by cars per year of 14500 km, at 8.0 l/100 km we get an average annual energy consumption of 37.65 GJ/car (0.76 kg/lit / 10.2 Mcal/kg)

These assumptions result in a car population of 5.58 millions for the year 2000 or approximately 800 cars/1000 people.

If one excludes people unable to drive or legally not permitted to drive, 35 % to 38 % of total population, this figure is higher than the long term saturation value for Switzerland of 600-650 cars/1000 people. Therefore a revision of the projections in the transport sector is required.

An effort has been undertaken to introduce an assessment of energy demand in the transport sector based on the OECD report "Long term outlook for the world automobile industry," Paris 1983.
This report uses a logistic curve to estimate the passenger-cars per thousand people ($P$).

$$\ln P_T = \ln P_S - \frac{b}{T_c}$$

$P_S$ is the saturation value (600 for Switzerland) while $b$ and $c$ are constants, $T$ is the year. This study estimates 2.5 million cars in the year 1990 and 2.94 million cars for the year 2000 with $P_{2000} = 447$.

We have modified (increased) these values in SMEDE to estimate gasoline consumption ($P_{2000} = 490$), and we have also assumed a reduction of the average distance travelled by car to 14000 km. The energy consumption for freight transport and airplanes are assumed to be correlated to the GDP development.

The results of SMEDE are given in the following table.

Table 3: Energy demand projections for transport in PJ/Yr.

<table>
<thead>
<tr>
<th>System/Year</th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trucks</td>
<td>23.5</td>
<td>35.7</td>
<td>38.9</td>
</tr>
<tr>
<td>Planes</td>
<td>32.0</td>
<td>43.5</td>
<td>56.0</td>
</tr>
<tr>
<td>Passenger Cars</td>
<td>114.8</td>
<td>136.4</td>
<td>148.1</td>
</tr>
<tr>
<td>Trains</td>
<td>7.6</td>
<td>8.5</td>
<td>10.4</td>
</tr>
<tr>
<td>Other Diesel Users</td>
<td>4.8</td>
<td>5.1</td>
<td>5.3</td>
</tr>
<tr>
<td>Total</td>
<td>185.7</td>
<td>229.2</td>
<td>258.7</td>
</tr>
</tbody>
</table>

Although this projection is not of any definite nature, it has been adopted as alternative scenario for our analysis. The difference between this projection and the CUEPE* evaluation is in the order of 100 PJ for the year 2000.

SMEDE has also been used to project demand in the household, commercial and industrial sectors. The model generates demand in those sectors based on a set of assumptions. The main assumptions concerning the industrial sector refer to structural changes in industry (economic output per subsector) and the energy use per unit of value added.

The basic assumptions of the household and commercial sector refer to new dwellings and commercial floor area built, their specific energy consumption per unit of floor area, and the electricity consumption for house appliances and commercial process heat.

The socioeconomic parameters and the structural changes in the industry rely on the work of St. Gallen Center for Future Research (SGZZ). All these assumptions are summarized in Table 4.

* CUEPE: Centre Universitaire d'Etude des Problèmes de l'Energie
An effort has been made to reduce the number of exogenous parameters used in SMEDe and to take price effects into account. This is obtained to a degree by coupling the useful demand projections of SMEDe with the energy allocation model MARKAL.

Table 4: Socioeconomic and Technical Data

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (Mio)</td>
<td>6.03</td>
<td>6.61</td>
<td>6.74</td>
<td>6.88</td>
<td>7.02</td>
</tr>
<tr>
<td>Labor force (Mio)</td>
<td>3.01</td>
<td>3.13</td>
<td>3.07</td>
<td>3.012</td>
<td>2.95</td>
</tr>
<tr>
<td>Persons per Household</td>
<td>2.59</td>
<td>2.5</td>
<td>2.43</td>
<td>2.36</td>
<td>2.3</td>
</tr>
<tr>
<td>GDP (Billion SFr 1970)</td>
<td>102.6</td>
<td>124.7</td>
<td>146.0</td>
<td>171.0</td>
<td>200.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distribution of GDP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
</tr>
<tr>
<td>Agriculture</td>
</tr>
<tr>
<td>Construction</td>
</tr>
<tr>
<td>Industry</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distribution of Industrial Value Added (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Material</td>
</tr>
<tr>
<td>Machinery</td>
</tr>
<tr>
<td>Non-durables</td>
</tr>
<tr>
<td>Miscellaneous</td>
</tr>
</tbody>
</table>

| New Dwellings (K units/YR) | 35. | 35. | 20. | 20. |
| Useful Demand (MJ/M**2/YR) | 400. | 400. | 400. | 400. |
| Cars per 1000 Inhabitants | 430. | 490. | 545. | 545. |
| Fuel consumption (liters/100 km) |
| local | 10.5 | 10. | 9.5 | 9. |
| intercity | 9. | 8.5 | 8.0 | 7.5 |

3.2 Fuel Prices and Bounds

Table 5 summarizes the price assumptions adopted in the energy allocation model MARKAL. The oil price for heating purposes is reduced to 500 Fr./ton up to the year 1990 and increased afterwards to 550 Fr. The gas price is reduced to 5.5 Rp./kWh (up to 1990) and then increased to 6 Rp./kWh until the end of the century.
Table 5: Fuel Price Assumptions (Fr/GJ)

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>85</th>
<th>90</th>
<th>95/00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel heating oil</td>
<td></td>
<td>14.4</td>
<td>12.4</td>
<td>13.4</td>
</tr>
<tr>
<td>Gas residential</td>
<td></td>
<td>17.0</td>
<td>15.6</td>
<td>16.9</td>
</tr>
<tr>
<td>Coal residential</td>
<td></td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Gasoline/Diesel</td>
<td></td>
<td>31.0</td>
<td>30.5</td>
<td>31.0</td>
</tr>
<tr>
<td>Diesel heavy</td>
<td></td>
<td>9.3</td>
<td>8.8</td>
<td>9.3</td>
</tr>
<tr>
<td>Coal industry</td>
<td></td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Gas industry</td>
<td></td>
<td>12.6</td>
<td>11.3</td>
<td>12.6</td>
</tr>
<tr>
<td>Nuclear fuel cycle for LWR’s (Rp./kWh)</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td></td>
<td>20.0</td>
<td>20.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

To complete the picture of assumption made, Table 6 gives a summary of the bounds adopted in MARKAL. The reader should remember that a non-competitive technology (or fuel) is introduced up to its lower bound, while a competitive technology (or fuel) is bounded by its upper bound.

The technology characteristics and the emission control systems are described in more detail in the Appendix.

The following bounds have been assumed for the year 2000.

Table 6: Bounds Assumed

<table>
<thead>
<tr>
<th></th>
<th>Upper</th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas imports</td>
<td>130 PJ/Yr</td>
<td>55 PJ</td>
</tr>
<tr>
<td>Heat pumps (latent heat)</td>
<td>35 PJ</td>
<td></td>
</tr>
<tr>
<td>Gas and District heating</td>
<td>100 PJ</td>
<td></td>
</tr>
<tr>
<td>District heating</td>
<td>15 PJ</td>
<td></td>
</tr>
<tr>
<td>Refuna Systems *</td>
<td>20 PJ</td>
<td></td>
</tr>
<tr>
<td>Other Systems(R/C)</td>
<td>12 PJ</td>
<td></td>
</tr>
<tr>
<td>Geothermal energy</td>
<td>35 PJ</td>
<td></td>
</tr>
<tr>
<td>New electrical heating and water heating</td>
<td>35 PJ</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Comparison of SMEDE projections and other scenarios

The following figures compare the results of SMEDE/MARKAL approach with the work of other groups like the CUEPE group of the Geneva University, the ORL group of the Swiss Federal Institute of Technology in Zürich and the INFRAS study (Ref. 6, 7).

* "Refuna" is a regional district heating system based on nuclear energy.
The original figures are taken from EIR Report 527. Comparing final energy demand projections (Fig. 5) we can conclude the following.

- SMED results, which provide the basis for the optimization with MARKAL, are similar to the CUEPE projections UB (free development) and EI (Energy Initiative).

- MARKAL introduces conservation and reduces demand towards the lower end of the Energy Initiative projections and close to the ORL group results.

Similar conclusions are derived when our results are introduced in the Fig. 6 "Oil and electricity consumption".

Finally examining Fig. 7 "General overview of demand perspectives", we realize that MARKAL results are located outside the agglomeration of the econometric model projections (large circle on right hand side) and within the range of the engineering simulations projections (small circle on left hand side) e.g. in a region where the extrapolation of the last decade trends are going to drive energy demand.

**Fig. 5**: The final Energy demand development as estimated by different models.
Finally we should make it clear that the projections of SMEDE/MARKAL are more or less an "engineering guess" of the future and certainly not "the future".

The scenario approach is based on a set of assumptions concerning socioecono-
mic development, life style and technological change and therefore the projec-
tions generated can be quite different from the econometrics.

The uncertainty associated to those projections (or the uncertainty range of the basic assumptions leading to uncertainties in the projections) is not ea-
sily quantified since the statistical basis of many input parameters is not given.

The difference between the Geneva group projections and our results is an in-
dicator of uncertainty. We believe that any projection of energy demand be-
tween 750 - 950 PJ/Yr for the year 2000 lies within the probable range of de-
mand expectations. The uncertainty involved in the specification of present and future specific emission data is greater than energy uncertainty. Since the policy goal of NOx emissions is not fulfilled even at low demand projec-
tions (as we will find out later on), energy demand projections is not the most crucial source of uncertainty.
Fig. 6: Oil and Electricity consumption

Fig. 7: General overview of demand perspectives
4 MAIN RESULTS OF THE STUDY

The main results of the analysis are discussed in this chapter. This refers to the final energy consumption, the emission balance and the trade-off among emission control and system cost.

4.1 Final Energy

The reference case is compared with two cases where emission restrictions of different levels are imposed on the energy system. The CUEPE group projection on demand is also included to complete the picture.

The estimated final energy demand with the model MARKAL is given below:

Table 7: Final Energy Demand per Fuel and Sector for the Year 2000

<table>
<thead>
<tr>
<th>Fuel / Scenario</th>
<th>CUEPE</th>
<th>MARKAL</th>
<th>MARKAL</th>
<th>MARKAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Growth</td>
<td>Reference Case</td>
<td>&quot;Medium&quot; restrictions</td>
<td>&quot;Strong&quot; restrictions</td>
</tr>
<tr>
<td>Oil products</td>
<td>730.0</td>
<td>456.9</td>
<td>421.0</td>
<td>400.1</td>
</tr>
<tr>
<td>Electricity</td>
<td>186.7</td>
<td>172.4</td>
<td>173.2</td>
<td>172.9</td>
</tr>
<tr>
<td>Gas</td>
<td>55.2</td>
<td>50.5</td>
<td>88.1</td>
<td>115.3</td>
</tr>
<tr>
<td>Solid Fuels</td>
<td>12.8</td>
<td>54.7</td>
<td>44.5</td>
<td>33.3</td>
</tr>
<tr>
<td>District Heat/Process Heat</td>
<td>-</td>
<td>35.6</td>
<td>36.7</td>
<td>39.5</td>
</tr>
<tr>
<td>Renewables</td>
<td>-</td>
<td>13.8</td>
<td>15.6</td>
<td>16.8</td>
</tr>
<tr>
<td>Total</td>
<td>984.2</td>
<td>783.8</td>
<td>778.0</td>
<td>778.0</td>
</tr>
</tbody>
</table>

The final energy demand consumption, as estimated by SMEDE/MARKAL, indicates a rather moderate growth in the transport sector and a stabilization of energy use in the residential/commercial sector. Significant differences appear among the CUEPE projections and our results in the transport sector (-100 PJ) and the residential/commercial sector (-80 PJ).

The assumption about the number of cars and their average distance travelled per year is mainly responsible for the difference in the transport sector. In the residential/commercial sector rather high penetration of conservation and of new or conventional technologies with improved efficiency is the main reason for the difference.

The modal splits (fractional distribution of fuels) among the three MARKAL cases is surprisingly robust, with the exception of gas.
In the case, unrestricted emission the low oil prices assumed improve the competitiveness of oil heating systems. The fractional and absolute contribution of oil products is reduced anyhow. Gas use is forced to remain in the present levels. Gas becomes gradually competitive and reaches its upper bound in the case where strong S02 restrictions are imposed.

District heat in the residential/commercial sector, process heat in industrial sectors, and renewables (heat pumps/geothermal energy) make rather marginal contributions.

4.2 Emissions of S02 and NOx

For better understanding of the following tables and figures it should be remembered that emission levels in the Reference Case were not restricted, whereas in the other cases restrictions on total emissions were made.

In Table 8 the emissions of the calculated cases are listed and compared with the emissions of 1960. The evolution of the S02 and NOx emissions for these scenarios are drawn in Figs. 8 and 9.

Table 8: Summary of results obtained on emission control by the year 2000

<table>
<thead>
<tr>
<th>Case</th>
<th>S02 (kt/year)</th>
<th>S02, 2000 S02, 1960</th>
<th>NOx (kt/year)</th>
<th>NOx, 2000 NOx, 1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Case (RC)</td>
<td>95.5</td>
<td>1.59</td>
<td>228.0</td>
<td>4.38</td>
</tr>
<tr>
<td>RC + Moderate Restrictions</td>
<td>50.0</td>
<td>0.83</td>
<td>113.0</td>
<td>2.18</td>
</tr>
<tr>
<td>RC + Strong Restrictions</td>
<td>40.0</td>
<td>0.67</td>
<td>99.0</td>
<td>1.90</td>
</tr>
</tbody>
</table>

This table indicates that the policy goal for S02 emissions could be realized rather easily. However, NOx emissions always remain a problem. The reduction obtained is significant, but the total emissions remain on the order of 100 Ktons/yr, which is higher than the policy goal by almost a factor of two. The sectoral distribution of emissions and the contribution of different technical measures to emission control will be explained later on.

4.2.1 S02 emissions

The historical evolution of S02 emissions is shown in Fig. 8. Examining this figure we understand that significant control has already been achieved. The maximum of emission release 140 Ktons/yr has already been reduced to approximately 80 Ktons by 1985. This control has been obtained by substituting gas, electricity and district heat for oil and by using oil of less sulfur content in the residential and industrial sectors.
The moderate growth shown between the years 1985 and 2000 for the reference case, is due to increase energy use and the model structure. (The cheapest option is always selected.)

In the cases with restricted emissions we see that the historical trend of the seventies could be extrapolated into the future if the society is prepared to pay the extra cost. In the year 1982 and in the year 2000 of the reference case, the main sources of S02 emissions are industry and the residential/commercial sector. In the restricted emission case, each sector contributes by almost equal amounts to the total emissions released in the year 2000.
Fig. 8: SO2 Emissions in kt/year.

**SO2 - EMISSIONS [KT/YEAR]**

**LEGEND**
- TRANSPORT
- RES./COMMERCIAL
- INDUSTRY
- CONVERSION

REFERENCE CASE  CONstrained CASE

---

**SO2 - EMISSIONS [KT/YEAR]**

**LEGEND**
- SWISS ENVIR. OFFICE
- REFERENCE CASE
- CONSTRAINED A
- CONSTRAINED B


YEAR

0  50  100  150  200
4.2.2 NOx Emissions

Fig. 9 shows the historical evolution and the estimated results of NOx emissions. The dramatic increase (by a factor of 4 between 1960 and 1980) is mainly due to the contribution of the transport sector which is responsible for 83% of the total emissions. This unfortunate development is common for most of the European countries.

In the reference case and without the introduction of catalytic converters for cars, a rather moderate continued growth is shown due to saturation effects in the gasoline consumption. In the emission restricted case, a rather dramatic improvement can be realized, again within the next 10 years. The level of emissions is anyhow stabilized to values around 100 Ktons, which is higher than the proposed policy goal by a factor of two. The main reason for this stabilization at high levels is again due to the contribution of the transport sector.

Fifty-five Ktons/yr are emissions released by diesel trucks for freight transport, while kerosene consumption and the gasoline cars contribute by another 23.5 Ktons. The transport sector continues to contribute almost 80% of the total emissions, or by 78.5 Ktons per year, in the year 2000. This value can only be reduced if:

a) a massive shift towards train transport for freight could be realized or if
b) technological progress could further reduce the specific emissions of trucks (we have assumed a reduction of specific emissions by 10%).

All other sectors and/or measures have a second order effect.

Table 9 compares the technology dependent emissions and summarizes the main findings of the study in respect to control obtained by technology.
**Fig. 9: NOx Emissions in kt/year**

**NOX - EMISSIONS [KT/YEAR]**

**LEGEND**
- TRANSPORT
- RESID./COMM
- INDUSTRY
- CONVERSION

**REFERENCE-CASE**

**CONstrained CASE**

**NOX - EMISSIONS [KT/YEAR]**

**LEGEND**
- SWISS ENVIRONMENTAL OFFICE
- REFERENCE CASE
- CONstrained CASE A
- CONstrained CASE B
4.3 **Emission Control Technologies Implemented**

End use technologies and production systems are implemented as follows:

a) **Conversion Systems**

By conversion systems we mean technologies or systems that convert primary resources to electricity and/or district heat.

From the optimization it follows that new electricity generation systems based on fossil fuels (including denoxing and desulfurization subsystems) are not competitive with nuclear central power stations.

On the other hand, existing district heating networks using fossil fuels like coal and municipal wastes are the main sources of emissions of conversion systems. Catalytic converters have been introduced for those conventional district heating networks in the emission restricted cases, while combined power and heat plants using municipal wastes do not show any capacity increase.

The reduction obtained is 9 ktons for NOx and 3.2 Ktons for SO2.

b) **Industrial Sector**

Systems using fluidized bed combustion (Wirbelschicht) have been implemented for process heat generation. Heating oil of 1.4 % sulfur content and coal of 0.8 % sulfur content are not sufficient for meeting the imposed restrictions on SO2. Therefore denoxing and desulfurization systems are also implemented. The total reduction obtained is 29.5 Ktons SO2 and 10.6 Ktons NOx per year.

c) **Residential/Commercial Sector**

Oil has been displaced in the emission constrained case by gas, district heat and renewables. This reduces the annual SO2 emissions by 13 Ktons, while the remaining 2.5 Ktons reduction is obtained by a partial introduction of oil with 0.15 % sulfur content. Energy conservation and efficiency improvement have also contributed to SO2 reduction, although this is not explicitly shown in Table 9. Without conservation an extra oil (0.3 %) consumption of 90 PJ/Yr could have resulted in higher annual emissions by 13 Ktons SO2 and 6.3 Ktons NOx. The implementation of renewables has contributed to a 2.4 Kton reduction of SO2 and 1.2 Kton NOx.

d) **Transport Sector**

No significant difference of SO2 emission could be shown for the emission constrained cases. On the other hand the introduction of catalytic converters in the private automobiles constitutes the most important contribution to air quality improvement. The NOx reduction due to the introduction of catalytic converters is in the order of 100 Ktons/Yr. Important to notice here is also that the specific emissions (g/km) assumed in the study reflect recent measurements of the Swiss Automobile Club (TCS). The catalytic converters also result in a significant reduction of HC and CO.
Table 9: Contribution of technologies (fuels) to SO2/NOx emissions (Ktons/Yr) by the year 2000 (rounded values)

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Reference Case</th>
<th>Reference Case with Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SO2</td>
<td>NOx</td>
</tr>
<tr>
<td><strong>a) Conversion Systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal (0,8 %) for district heating</td>
<td>10.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Coal (SCR) *</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Municipal Wastes</td>
<td>3.2</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>b) Industry</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating Oil (1,4 %)</td>
<td>17.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Heating Oil (SCR)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coal (0,8 %)</td>
<td>18.7</td>
<td>8.6</td>
</tr>
<tr>
<td>Coal (SCR) *</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gas Industry</td>
<td>-</td>
<td>2.5</td>
</tr>
<tr>
<td>Fluidized Bed</td>
<td>2.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Other Fuels</td>
<td>2.0</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>c) R/C Sector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil (0,3 %)</td>
<td>25.4</td>
<td>12.5</td>
</tr>
<tr>
<td>Oil (0,15 %)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gas</td>
<td>-</td>
<td>2.1</td>
</tr>
<tr>
<td>Wood</td>
<td>4.8</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>d) Transport Sector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerosene/Other Diesel</td>
<td>1.3</td>
<td>14.0</td>
</tr>
<tr>
<td>Gasoline Car</td>
<td>1.5</td>
<td>121.2</td>
</tr>
<tr>
<td>Gasoline (Catalytic Car)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Diesel Car</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Diesel Truck</td>
<td>8.0</td>
<td>53.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>95.5</td>
<td>228</td>
</tr>
</tbody>
</table>

* SCR = Selective Catalytic Reduction.
4.4 The Cost of Emission Control

It could be of interest to quantify the cost of emission control introduced in the Swiss Energy System by the year 2000.

Two possibilities exist in expressing this cost. Firstly, it is possible to compare the global energy generation cost increase (investment, operation, maintenance and fuel cost) due to the implementation of emission constraints, as estimated by the model. This cost difference is not due only to the investment and operation cost of the emission control systems. Fuel switching and implementation of advanced technologies (like heat pumps, district heating, renewables and conservation) also contribute to cost differences, since these systems are more expensive options than conventional technologies.

The second possibility is to explicitly consider the cost of each technological option selected by the model. This possibility could also be extended by introducing cost/benefit considerations for each technology (combined reduction of emissions versus extra cost). There are, of course, many ways to express the cost and the associated benefit. The shadow prices of fuels like electricity and/or district heat should be considered for that purpose. To avoid complexity we present here only the first cost accounting method.

Table 10 summarizes the system cost components as estimated by the model for the reference case and the emission constrained case. The reduction of NOx, SO2 and their acid equivalent* (mol H+) are also mentioned.

The conclusions drawn from this table are as follows: The average annual system cost, which is 30.84 Bio. SFr. for the Reference Case is increased by 1.5 Bio. SFr. in the constrained case. The system cost includes investments and service cost for the transport sector, which are around 13.5 Bio. SFr/Yr.

The total extra cost for the next 15 years is 22.55 Bio. SFr. while the combined reduction obtained is 684 Ktons SO2 and 1717 Ktons NOx.

One could therefore estimate an average cost/benefit ratio of 0.38 SFr./mol H+ or 9.4 SFr/(kg NOx+kg SO2), not accounting for the simultaneous reduction of HC and CO.

*) The acid equivalent of 1 mol H+ equals: 32 gr SO2 or 46 gr NOx.
(1) Bio SFr. = 10 SFr. of 1980.
Table 10: Energy System Cost Components (Bio. SFr /Yr)

<table>
<thead>
<tr>
<th>Cost / Period of 5 years</th>
<th>1990</th>
<th>1995</th>
<th>2000</th>
<th>Average annual values</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Reference Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment per period</td>
<td>50.18</td>
<td>46.11</td>
<td>48.14</td>
<td></td>
</tr>
<tr>
<td>Salvage per period</td>
<td>-5.37</td>
<td>-7.77</td>
<td>-25.27</td>
<td></td>
</tr>
<tr>
<td>Fixed, variable O+M, and fuel cost, per period</td>
<td>110.66</td>
<td>119.73</td>
<td>126.21</td>
<td></td>
</tr>
<tr>
<td>Annual system cost*)</td>
<td>31.1</td>
<td>31.6</td>
<td>29.82</td>
<td>30.84</td>
</tr>
<tr>
<td>B. Reference Case + Emission Constraints</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investments per period</td>
<td>63.82</td>
<td>38.84</td>
<td>63.52</td>
<td></td>
</tr>
<tr>
<td>Salvage per period</td>
<td>-5.25</td>
<td>-7.88</td>
<td>-32.43</td>
<td></td>
</tr>
<tr>
<td>Fixed, variable O+M, and fuel cost per period</td>
<td>113.2</td>
<td>122.1</td>
<td>129.2</td>
<td></td>
</tr>
<tr>
<td>Annual system cost*)</td>
<td>34.36</td>
<td>30.62</td>
<td>32.05</td>
<td>32.34</td>
</tr>
<tr>
<td>SO2 reduction</td>
<td>35.8</td>
<td>45.5</td>
<td>55.5</td>
<td>45.6</td>
</tr>
<tr>
<td>NOx reduction</td>
<td>98.4</td>
<td>116.2</td>
<td>128.8</td>
<td>114.47</td>
</tr>
<tr>
<td>Acid equivalent reduction</td>
<td>3.26</td>
<td>3.95</td>
<td>4.53</td>
<td>3.91</td>
</tr>
</tbody>
</table>

*) The average annual investment and service costs of the transport sector are 13.45 Bio. SFr in the Reference Case, and they must be subtracted from the annual energy system cost.

4.4.1 The trade-off curve

The trade-off curve between system cost and emission control for gradually constrained cases is given in Fig. 10. One could also consider this figure as the summary of the analysis. The components of system cost have been explained before. The values plotted here do not include investments and service cost in the transport sector.

The expression of benefits is more complex since more than one pollutant is involved.

We have decided to combine SO2 and NOx reduction by using their acid equivalent. The basic assumption underlying this combination is a direct correlation between acid deposition and acid rain.
The benefits are therefore expressed as reduction in acid equivalent (mol H⁺).

This Figure again shows that in the emission constrained case a reduction of 57% of acid deposition could be obtained by a cost increase of 8.7%, in relation to the reference case. This is equivalent to 1.5 Bio. SFr/Yr or 0.7 Rp/kWh of final energy consumption.

Fig. 10: Trade-off curve

Annual system cost versus reduction of acid equivalent deposition

The average annual system cost is increased by 9% for an annual reduction of acid equivalent of 57% by the year 2000. The estimated acid equivalent deposition in the year 2000 for the reference case is 7.8 GMOL H⁺.
The extrapolation of the trade-off curve is not further analyzed, since most of the reduction potential has already been obtained.

A further reduction relying on technical options included in the model is in principle feasible, but it will result in some extreme solutions, like a full scale introduction of electric cars for urban traffic combined with nuclear power stations, or extreme penetration of nuclear district heat, conservation and renewables.

Since the model in its present formulation is not able to analyze other options, like shifts towards public transport systems, is not realistic to analyze extremely by expensive technical solutions.

4.4.2 System cost versus social or external cost

A few remarks should also be made about the social or external cost of pollution.

By social cost we mean the cost the society has to pay due to pollution. This refers to morbidity cost (health deterioration), cost of increased mortality rates, loss of agricultural production, dying forests and finally loss of cultural property like monuments, buildings, etc. The assessment of social cost is a very difficult exercise, but recent studies of the Basle University have concluded the following for Switzerland:

- The morbidity and mortality cost are assessed to be in order of 300 Mio. SFr/Yr.
- The lost value of agricultural production is in the order of magnitude of 1 Bio. SFr./Yr.
- The value of dying forest and of lost cultural property cannot be assessed, but it could be in the same order of magnitude.

From this it should be clear that a pollution control cost of 1.5 Bio. SFr/Yr, (0.6 Bio.SFr. of which refers to catalytic converters for cars) is an optimal, realistic and feasible solution from the national point of view.

5 MAIN CONCLUSIONS OF THE STUDY

- The SO2 emissions do not represent any significant problem. The policy goal of reducing SO2 emission to the level of 1950 could be rather easily obtained by technical measures.

- The opposite is true as far as the NOx emissions are concerned. Although a reduction by 50% is possible (mainly due to the introduction of catalytic converters in the private automobiles), the original policy goal cannot be satisfied.
In other words, it is unrealistic to believe that a reduction of NOx emissions to the level of 50 - 60 Kt ons/yr is feasible with the measures considered here.

The prerequisite for obtaining a reduction to this low level is either a massive shift towards public transport systems (especially in the freight transport sector), or a significant technical improvement for truck motors, or both. This conclusion is valid provided that the demand projections in the transport sector are realistic. If higher demand is expected, one could definitely say that technically speaking the policy goal is infeasible.

- The energy system cost is increased by 9 % due to emission control technologies and fuel switching.

An average cost/benefit indicator is the following:

\[
\frac{\text{cost}}{\text{benefit}} = 0.4 \frac{Fr}{\text{mol H}_2} \quad \text{or} \quad 10 \frac{Fr}{\text{kg (NOx+S02)}} \quad \text{or} \quad 0.7 \frac{Rp}{\text{kWh final energy}}
\]

According to the study of Basle University the social or external costs of emissions, are of the same or higher order of magnitude. Therefore, emission control or cost internalisation is, from the national point of view, a good policy.

- The fuel mix (modal splits) is not significantly modified to obtain this qualitative improvement in air quality.

The only significant change the model has shown is a switching towards gas instead of oil in the case of strong constraints on SO2 emissions.

The reason for this stability is related to the low oil and gas prices assumed in the study.

- Important also is the contribution of selective catalytic converters in the industry.

- Electricity and district heat production in Switzerland is based on nuclear energy (combined power and heat systems).

- Conservation in buildings and construction of new dwellings and commercial buildings with low specific energy consumption remain attractive, independent of the low fossil fuel prices assumed.

6 FUTURE ACTIVITIES

MARKAL is a very first step in the analysis of energy and environmental interactions. The model is appropriate to analyze the policy goals specified by the Swiss authorities. One is able to account for pollutants related to the energy system like NOx, SO2, CO, CO2, HC, heat release and radioactive wastes, and identify technical solutions and the cost for pollution control. This contribution is obtained with relatively low investments on software develop-
ment and for data acquisition.

There are, however, problems requiring further work:

The database on emissions is quite uncertain and it should be gradually improved. We hope that new measurements could contribute to the quality of data used and the information generated out of this database.

The industrial sector needs also a more disaggregated treatment. This disaggregation could be completed either on a subsectoral base and/or on process and capacity distribution base. One should not underestimate the amount of information required for this treatment.

The Transportation Sector should include an endogenous treatment for switching among public and private transport systems, relying on econometric analysis. This flexibility will allow improving the understanding of potential shifts towards public transportation systems and tariff restructuring.

Emission release to the atmosphere is one problem. The dispersion of pollutants, their space (urban and rural regions) and time distribution, as well as their correlation to social cost are other more complex problems. The analysis of these problems require extensive software development and the collection of new data. A coordination of activities on the national and international level is a prerequisite for the successful treatment of these complex questions related to energy and environmental interactions. Efforts in that direction have been initiated.

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5.4 Regional and Urban Planning

5.4.1 The Use of a Comprehensive Energy Model for Community Energy Planning
(C.O. Wene)

1. Introduction

The local communities play an important role in the on-going transition from oil-based energy systems to systems with a more diversified resource base. The management of this transition calls for comprehensive energy planning involving both the supply and demand side. This planning process is supported by different measures in different countries. In the USA sixteen cities held grants in 1981 from the Department of Energy for energy planning at the community level. In the Federal Republik of Germany the communities and the utilities are responsible for the development of regional and local energy plans. Since 1977, there is a law in Sweden stipulating that the communities have to consider energy supply and demand in their planning. An substitution to be decided upon by the city council.

The energy system for a longer community is a complex system. The optimal choice of technologies for supply, distribution and conservation depends on the local situation as well as outside factors, e.g., the development of the energy markets and the national energy policy.

Since 1981 the energy model MARKAL (1 - 3) has been used to study the energy systems in two Swedish communities (4 - 7). The objectives have been to investigate the long range development of the community energy systems considering the uncertainties in the energy markets and to see if MARKAL could be used as a tool for community energy planning. The studies were made in close co-operation with the community authorities. The experience gathered so far on the use of MARKAL as a tool in this type of planning is very positive.
Below we briefly present the two communities, the methodology used and some results. In the conclusion the general role of MARKAL is discussed.

2. The communities

The communities of Jönköping and Nässjö have been studied. They are neighbouring communities in inland southern Sweden. Jönköping, situated at the southern part of Lake Vättern, is with 108,000 inhabitants Sweden’s 8th largest community. 70,000 of the inhabitants live in the main city; most of the remaining inhabitants are found in the surrounding small suburbs. The total area of Jönköping is 1481 km$^2$. Nässjö is with 34,000 inhabitants an average sized Swedish community.

The climate for the communities is typical for inland middle Sweden with about 3700°C x days/year. Total net energy demand for space heat and warm water in 1980 was 4.3 PJ/year in Jönköping and 1.3 PJ/year in Nässjö. In 1980 a major part of this was supplied by oil products, but in recent years there have been a large number of conversions to electricity.

Both communities have a varied industrial structure, the mechanical industry being most prominent. The total energy demand for industry is 2.6 PJ/year in Jönköping and 0.9 PJ/year in Nässjö. A paper mill in Jönköping consumes 9 % of the total primary energy supplied to Jönköping (13.7 PJ/year). About 2/3 of the industrial energy comes from oil products. Jönköping has just started the building up of a district heating system; Nässjö is just considering building one. The communities lie in a region rich in peat and biomass.

3. Methodology

3.1 Co-operation with the community authorities

Fig. 1 shows the work flow. A strong involvement of the community authorities, politicians as well as civil servants in data gathering, structuring of the data base
and evaluation of the results is a prerequisite for acceptance of the results. A reference group appointed by the community council followed the work. It was interesting to see how MARKAL started a learning process in the community.

3.2 Technicalities

Fig. 2 shows the Potential of Possible Energy Systems (PES) for Jönköping. Due to lack of space it has been simplified as regards the demand structure used in MARKAL.

Only conversions and processes actually occurring in the community are modelled as true technology. Electricity from the national grid is important at 130 kV. The price for this electricity is put equal to the national marginal cost and varies between summer and winter. In the base case it increases from 0.15 Sw. Cr. (1984)/kWh in winter 1990 to 0.32 Sw. Cr. (1984)/kWh in winter 2010 due to the phasing out of nuclear power. The price for oil and coal are assumed to increase 50% between 1980 - 2000 in the base case. Twelve alternative scenarios have been studied in detail in the Jönköping case assuming different prices for oil, coal, electricity from the national grid and peat, delay in the conservation program, and subsidizing of domestic fuels.

The distribution of electricity and district heat have been modelled in a fairly detailed way. Separate district heating grids can be built up in the old city of Jönköping and in the city of Huskvarna and later merged together. The electric grid is separately modelled in 5 geographical regions and further split up in a high voltage and a low voltage grid in three of these regions. (DMD's and ADRATIO's are used for the modelling.)
The Residential & Commercial sector is separately modelled in 5 geographical regions. Conservation through retrofitting of existing buildings is modelled using the methods in (8). A special model has been built to supply data on retrofitting (9).

4. Some results

Fig. 3 shows the total supply of primary energy (PE) to the community and total investments in the community energy system for Jönköping in the base case. The PE demand decreases until beginning of the 90's and then starts to rise slowly. Part of the decrease is due to retrofitting, part of it is due to bookkeeping. During the 80's many single family houses convert from oil burners to electricity. This appears to increase the efficiency of the energy system because the losses by oil burning are accounted for inside the system while the losses by electricity production lies outside the system. During the 90's the community starts producing its own electricity by cogeneration of power and heat (CPH). The losses by this technology are once again accounted for inside the system and the PE demand increases.

Fig. 4 shows the investments during the 80's in new capacity in the electric grid in order to accommodate houses that convert from oil to electricity. Our description of the grid makes these detailed results possible.

Fig. 5 shows the development of the electrical system in Jönköping in some of the studied cases.

Fig. 6 displays the building up of the district heating grid in the base case.

Fig. 7 shows the technologies in the base case supplying heating and warm tap water in different parts of the community.
Fig. 8 shows the optimum amount of conservation by retrofitting existing buildings in different parts of the community. The effects of district heating are clearly seen as previously pointed out in (8).

5. Conclusions

What role can or should comprehensive energy system models like MARKAL play at the community level? So far our experience with MARKAL has been positive. However, there are many pitfalls and there are many subsystems with already well established practices which together make up the "community energy system". The organisations which run these subsystems often have very clear conceptions of how the system should be run. They are what Stafford Beer has called "esoteric boxes" (10). The system analyst has to act as a "go-between". As material for further discussion we show figs. 9 - 11. The first figure shows the situation "as it is" today, the second one "the world as MARKAL sees it" and the third a situation that must not be.

References:


Fig. 1 Work flow in using MARKAL for community energy planning
Fig 2 Potential Energy Systems (PES) for the community of Jönköping
Fig. 3  Supply of primary energy and investments in the base case for the community of Jönköping. The investments are given in $10^6$ Sw. Cr (1980)/year. Investments for electricity and district heat includes all investments in production units and grids in the community.
Fig 4 Investments in new capacity in the electrical grid of the community of Jönköping. The investments are given in $10^6$ Sw.Cr/year.

- **K4GS** - Base scenario
  - 4% discount
  - $\Sigma I = 75.6$ Mkr

- **K10GS** - Base scenario
  - 10% discount
  - $\Sigma I = 59.2$ Mkr

- **K4ES**
  - 10 year delay in conservation program
  - 4% discount
  - $\Sigma I = 109.9$ Mkr

- **K4EL** - Price of electricity from national grid increases only 1%/year after 1990
  - 4% discount
  - $\Sigma I = 120.2$ Mkr
Fig 5 Optimal development of the electric system in the community in four different cases
Fig 6  The district heating in the base case. Region 1 is the center of the city of Jönköping. Region 2 consists of multifamily and single family houses around the city center. Region 3 is the central part of the town of Huskvarna. Shaded area indicates that 0-40% of the buildings in the region are connected to the grid; in cross-hatched areas and black areas 40-80% and more than 80%, respectively, are connected. A solid line between region 3 and 2 shows that region 3 has been connected to the main grid. The length of the transmission is about 2 km.
Fig. 7 Technologies used for heating and warm tap water in different part of the community of Jönköping (base case). Heat pump(1): air/water with COP=1.3, heat pump(2): air/water with COP=2.2, heat pump(A): heat pump with COP=2.6 using aquifer. BC: block central, hot water distribution in small local grid.
Fig 8  Conservation through retrofitting of existing buildings in different parts of the community of Jönköping (base case)

Single and two family houses in the periphery of the town of Jönköping (District heating available)

Single and two family houses in smaller suburbs

Multifamily houses and commercial in the periphery of the town of Jönköping

Multifamily houses and commercial in the smaller suburbs

1980 90 2000 10

Percent reduction in useful energy demand

10 20 30
Fig 9  The organisation of the community energy system
Fig 10 The community energy system as MARKAL sees it
Fig 11 A disconnected energy system
5.5 ETSAP Update Runs

Redaction: G. Kolb

5.5.1 Introduction

After having been presented a summary of the results of the Energy Technology Systems Analysis Project (ETSAP), (1), (2), which was carried out in the period 1981 to 1982, the Committee of Research and Development (CRD) decided to ask the ETSAP group to prepare some new computer runs with MARKAL (4), using updated fuel prices and energy demand projections. The updated ETSAP runs together with the previous old runs could give useful information for the Energy Technology Policy Study (ETPS) initiated by CRD and carried out at the IEA Secretariat.

The Executive Committee of ETSAP accordingly agreed at its Tokyo meeting in March 1984 to make the runs and carry out some simple analysis of the results within three months. This chapter summarises the results of importance for ETPS.

Understandably not all countries participating in ETSAP were able to contribute on short notice within a time frame of three months. It is, however, admirable that as many as eight countries contributed to the ETSAP update. USA, Japan, Germany, United Kingdom and Italy have been able to run the two runs according to the rules agreed in Tokyo. Sweden has carried out one run and Switzerland and Netherlands contribute with some country specific new analysis. Summaries of common runs can only be carried out for USA, Japan, Germany, United Kingdom, Italy and Sweden. However, these six countries consume 79 % of the OECD primary energy and 89 % of the ETSAP countries' primary energy.

This report concentrates on comparisons between results of the old run with low fuel price/high demand (OLD LP/HD) and the new run with high fuel price and low demand (NEW HP/LD).
The reason for this is that these two fuel price predictions are common for all runs made, while corresponding demands are country specific, taking into account predictions of national economies and specific energy conservation measures.

The two runs, OLD LP/HD and NEW HP/LD, are independent scenarios where the demand predictions in each case are based on the corresponding fuel prices in the scenario. Comparing an old low price scenario with a new high price scenario therefore represents no inconsistency. It should be noted that the new high price is lower than the former low price assumption. (Figure 1.)

Highlights of changes in Final Energy use, Primary Energy Supply and Technology Application are given only for the group of participating countries. At the end a summary of consequences for ETFS is given.

5.5.2 Energy Price Projections

The common high and low crude oil price projections assumed in the new updated and the old runs are compared in Figure 1. The prices given in 1980 $/toe are understood to be imported prices without duties or taxes, but including insurances and freight (cif).

The real fuel prices that exist within MARKAL and contribute to the cost factors that determine the competitiveness of the individual technologies, are different and vary from country to country. (3) The monetary unit, average 1980 US $, is not changed to be able to compare results with previous runs.

In the old 1982 runs the oil price was assumed to increase steadily from the 1980 value of 32 Dollars/barrel ($/bbl) to the double price of 64 $/bbl by 2020 in the low price projection and to 80 $/bbl by 2020 in the high price projection. However, during the last four years the world has experienced oil prices that in fixed monetary units have decreased.
A more realistic price projection may therefore be a sustained low price for approximately a decade and then a relatively fast increase up to the low price projection used in the 1982 ETSAP runs, as the depletion of resources becomes more apparent. The new high and low price projections, differing only towards the end of the time period, make it possible to test the sensitivity to fuel prices of some of the new marginal technologies.

Fuel price projections of the new updated runs for gas and coal as well as for oil are given in Figure 2. A smooth closing of the price difference between oil and gas is assumed, starting with a gas/oil price ratio of 0.8 in 1980 reaching 1.0 in 2010. In the US case gas and oil prices are assumed equal beginning in 1985.

The price difference between coal and oil is also assumed to decrease in the period, starting with a coal/oil ratio of 0.4 in 1980 and ending at 0.5 in 2010.

The nuclear fuel prices are assumed to be the same as projected in the previous ETSAP runs. (2) The price of U3O8 is stable at 40 1980 $/lb between 1980 and 1990, then increases linearly from 1990, reaching the double price of 80 1980 $/lb in 2010. In the US runs the U3O8 price is 26.5 $/lb in 1980 and 42.6 $/lb in 1985, and thereafter follows the common assumptions of the group.

5.5.3 Energy Demand Projections

1. Economic Growth Rates

The new energy demand projections are consistent with an assumed growth in Gross Domestic Product (GDP) in per cent per annum as shown in Table 1. The values of the previous ETSAP high demand scenario are shown in parentheses.
Table 1
Gross Domestic Product Growth Rates (% p.a.)

<table>
<thead>
<tr>
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<tr>
<td>U.S.A.</td>
<td>2.7 (2.8)</td>
<td>2.3 (2.3)</td>
<td>2.3 (2.0)</td>
</tr>
<tr>
<td>Japan</td>
<td>4.0 (5.0)</td>
<td>3.2 (4.0)</td>
<td>2.2 (2.3)</td>
</tr>
<tr>
<td>Germany</td>
<td>1.8 (1.8)</td>
<td>1.8 (1.8)</td>
<td>1.8 (1.8)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>- (2.5)</td>
<td>- (2.5)</td>
<td>- (2.5)</td>
</tr>
<tr>
<td>Italy</td>
<td>1.5 (2.8)</td>
<td>2.0 (2.8)</td>
<td>1.5 (2.5)</td>
</tr>
<tr>
<td>Sweden</td>
<td>- (2.0)</td>
<td>- (2.0)</td>
<td>- (2.0)</td>
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</table>

U.S.A. has reduced the GDP growth rate slightly at the start and increased it at the end of the period. Japan and Italy have reduced GDP growth rates over the whole period and Germany keeps the same projections.

2. Energy Demand Projections

The received informations are not all in the same format and cannot easily be summed up. The following is extracted from the country reports and computer output.

3. Conclusions for the Group

The total final energy consumption for the group is reduced for the whole time period compared to previous predictions. Only Germany predicts no reductions while the U.S.A. shows reductions for all years except 1990. All other countries project considerable reductions in final energy consumptions.

All countries project energy reductions in the industrial and nonenergy sectors while other sectors change very little. In the U.S.A., however, the energy consumption is higher in the residential and commercial sector after an increase between 1985 and 1990.
The final energy consumption by end-use sectors summed for the group of six countries participating in this ETSAP update, is compared with corresponding old results in Figure 3. All sectors except the residential and commercial sector have reduced energy consumption. The reduction is particularly heavy in the industrial sector towards the end of the period when energy prices increase. The increased energy use in the residential and commercial sector in the US case dominates the group result.

The reduction in energy consumption generally seems to be just slightly influenced by the assumed lower energy prices during the first decade of the timer period. When reasons for reductions are reported, a combination of recession in the economy and effects of better energy conservation is mentioned. In some countries with weak currencies, however, the real fuel prices measured in national currencies have not decreased as much between 1980 and 1985 as apparently measured in dollars. The national demand projections for these countries reflect fuel that is still expensive by continued effort on energy saving. There are many indications that the economic potential of energy conservation is not fully utilized. Therefore, the energy demand will stabilize and energy use per produced unit will continue to decrease.

Achieved conservation will be permanent, and a less constrained economy in the future will not immediately bring the energy consumption back to the same high level as previously. To make better energy demand projections for the future, the energy conservation effect has to be accounted for in more detail.

5.5.4 Results

The presentation of results will follow the same sequence as the summary report of ETSAP (1) and important changes of conclusions will be noted.
1. Conclusions for the Group on End Use Technologies

Generally changes in technology importance, measured either by changes in shadow prices or utilization, are very small. When changes occur, the main reason is lower useful energy demands. Only in a few cases do the lower energy price at the start of the period result in significant changes of technology importance. As a result the few changes of technology ranking are principally between technologies that compete at the same level of importance.

Although the solutions show variations in minor details from country to country, a few common tendencies may be mentioned:

- Replacement of oil burners are postponed until after 1990 when oil prices rise again. In the U.S.A. the more efficient retrofitted oil burner takes a larger share of the market.

- Electrical resistance heating becomes more important, especially after 1990.

- Marginally attractive new technologies like heat pumps, solar heating and district heating are reduced or postponed, in some cases to the extent that they disappear.

- In the cases where energy conservation is treated as a technology, it remains very important.

- Of the renewable energy technologies solar water heat seems to be the generally most attractive technology.

A peculiar, but interesting result to note is that the commercial electrical vehicles in the UK case remains very attractive.
2. Conclusions for the Group on the Final Energy Consumption

The reductions in total final energy demand of the updated HP/LD run relative to the old LP/HD run are taken up by different energy carriers in different countries and the final result for the group cannot be seen without summations. In most countries the decreased energy use affected several energy carriers and in Japan it was distributed over all of them. However, both oil and electricity have a strong position in all countries while coal and gas use take up decreases in different countries. The biggest relative decrease often comes for energy carriers which depend on marginally attractive new technologies for utilization of renewable energy and production of heat.

3. Conclusions for the Group on Energy Conservation, Process, Extraction and Production Technologies

Time and available data have limited the possibility of going into the same detail of analysis for all countries. The methods of evaluating technologies are also different. In spite of this it is possible to draw some general conclusions, in particular by comparing new and old results.

The technologies can be grouped according to their robustness against changes of fuel prices and demand of different energy categories. The most robust technologies will have the highest shadow price, indicating high marginal value, and they will be expensive to replace. They are very often capital intensive, and the total production cost has relatively small contributions from input fuel cost and maintenance.
Some renewable technologies have no fuel cost at all, like hydro, wind and solar. Changes in fuel prices will affect their relative competitiveness but not their absolute cost.

The nuclear reactors are also robust against changes of fuel prices although additional cost has to be added for waste handling. The LWR and hydro power plants are the most valuable and robust technologies for all countries. They are limited by upper bounds in the MARKAL calculations. These bounds are determined by resource limitations for hydro and political or public resistance for nuclear. If not bounded these technologies would have filled the whole electricity market.

Capital and energy-intensive technologies with input fuel cost representing a significant share of total energy output cost are more sensitive to fuel prices. When variations of fuel prices are introduced, the market share between these technologies will change, but slowly. Coal and oil based power plants represent this category. This behaviour is illustrated in results from several countries and is the main reason for the small effect of changed fuel prices over the first decade in the new run. These technologies as well as the more robust technologies seem to share reductions in demand between them.

Less capital intensive technologies which have relatively large cost contributions from input fuel cost are more market sensitive and will adjust to new fuel prices faster. Generally the smaller the technology units, the faster and closer the adjustments to new prices will be. Examples are heat production or combined heat and electricity production based on burners using different input fuel.

Technologies most sensitive to variations in fuel prices are equipment for decentralized production of heat and several end use technologies not tied up with industrial processes. The most valuable of these technologies will just have a new share of the market between them and will not easily be wiped out.
Several new technologies are marginally attractive and will easily disappear from the market under new conditions either as a result of changed fuel prices or energy demand. Some new energy technologies using renewable input energy may also enter the market or take a bigger share as fuel prices increase. Examples are solar for water heating in most countries and for both water and space heating in the U.S.A. and in Italy. The Swedish case illustrates very well how marginally attractive new technologies jump in and out as the external conditions change.

Technologies that contribute to higher domestic production of the attractive fossil fuels oil and gas by enhancing extraction are very attractive in the U.S.A. case. Technologies for synthetic oil and gas production from coal and other input fuels are marginally attractive and easily drop out under pressure of low oil and gas prices.

The most valuable information from the update scenario is that in the long run the technologies change remarkably little in value or importance by introduction of the new fuel prices and lower energy demand projections. However, in the short run there will be a postponement in switching away from oil consuming technologies over to new technology less dependent on oil or other expensive fuels. The delay corresponds to the assumed delay in increased oil prices of approximately ten years.

4. Conclusions for the Group on Primary Energy Supply

Except Germany all countries report lower total primary energy (TPE) requirement as a result of the new updated runs. For Japan, Italy and Sweden lower TPE is reported over the whole time period.

The primary energy supply mix is summed for the group of six participating countries using different scales in the Figures 4, 5 and 6.
The new runs give lower total primary energy especially towards the end of the time period due to slower energy growth after 1990. Particularly coal, oil and nuclear exhibit this reduction. Comparing Figure 4 with the corresponding graph reporting the result for the previous ETSAP calculations, Figure 11 of (1), the similarity between the new result of the HP/LD run and the old result of the HP/LD run is striking. With 89% of energy consumption of the ETSAP group covered in the new update calculations, there is reason to believe that the result for the whole group would not have been very different. This implies that the reductions in energy consumption projected in the new runs will take place in spite of the considerable lower fuel prices of the new scenario.

The low fuel prices during the first decade in the update scenarios does not seem to result in a higher total primary energy use. This means that the effect of lower useful energy demand caused by recession and/or conservation is too strong to be counterweighted by lower fuel prices. In 1990, however, the oil consumption is slightly higher, reflecting a delayed switchover to other fuels as long as prices are low.

Generally the effect of the fuel price reduction during the first 15 years is small, and it is mainly picked up by delayed switching from oil to coal. The larger reduction of the TPE towards the end of the period as a result of reduced useful energy demand, also affects other energy carriers but varies more from country to country.

5.5 Consequences for the Energy Technology Policy Study

The new runs may be considered as an additional possible energy future or a new scenario which should be used together with the other scenarios of the previous ETSAP studies. The additional calculations and analysis are performed, however, because recent history makes it more plausible to project lower fuel prices for a period and then new rises of prices thereafter. Consequent to the new price projections, new useful energy demands fitted to the new situation had to be projected.
The revised primary energy supply mix resulting from the new more plausible projections may be the most valuable contribution to the ETPS. The main lesson to be learned is the postponement of oil reductions, making the IEA countries dependent on oil import longer into the future. Delays in the increased use of coal that will substitute for oil may be a blessing, e.g., if one uses the postponement to work for better technologies to reduce emissions. The corresponding slower introduction of nuclear energy may be utilized to find better waste storage methods and to make the technology safer to use.

Concerning R&D on more advanced new technology, the relaxed situation does not imply a difference by itself. However, it should be stressed that many of the new technologies are either very near to benefit/cost ratio of one, or they are so far away from the commercial stage that judgement of cost is not possible. R&D should therefore continue on a broad spectrum of the most valuable technologies since a high investment in development of alternatives is very important insurance against the effect of unstable fuel prices and delivery disruptions.
References


FIGURE 1
CRUDE OIL PRICE PROJECTIONS
FIGURE 2
NEW UPDATED FUEL PRICE PROJECTIONS
FIGURE 3
FINAL ENERGY CONSUMPTION BY END-USE SECTORS GROUP OF SIX COUNTRIES:
U.S.A., JAPAN, GERMANY, UNITED KINGDOM, ITALY, SWEDEN
FIGURE 4

PRIMARY ENERGY SUPPLY MIX FOR THE GROUP OF SIX COUNTRIES
U.S.A., JAPAN, GERMANY, UNITED KINGDOM, ITALY, SWEDEN
FIGURE 5

PRIMARY ENERGY SUPPLY MIX FOR THE GROUP OF SIX COUNTRIES
U.S.A., JAPAN, GERMANY, UNITED KINGDOM, ITALY, SWEDEN
FIGURE 6

PRIMARY ENERGY SUPPLY MIX FOR THE GROUP OF SIX COUNTRIES
U.S.A., JAPAN, GERMANY, UNITED KINGDOM, ITALY, SWEDEN
6. Studies with MARKAL outside ETSAP

Some studies with MARKAL outside ETSAP - mostly co-operative projects between ETSAP institutions and developing countries - have been brought to the attention of the Operating Agent of Phase IV (Annex II), e.g., Chalmers TU - Ecuador, KFA/STE, Province Guangdong (V. R. China), Brazil, Indonesia. Only of the latter activities has a report been made available: KFA/STE has been performing cooperative projects on energy systems analysis with some developing countries since 1982. In each case MARKAL was the instrument used to study future energy supply. In chapter 6.1 a short description is presented on the status of these projects. This description is an updated version of a document distributed at the 12th OECD-IEA-ETSAP-Meeting in Vienna, Austria, April 23 - 25, 1986 (R. Aringhoff et al.)
6.1 Status of the Co-operative Projects of KFA-STE with Less Developed Countries
(R. Aringhoff, M. Kleemann, G. Kolb)

Introduction

The Program Group on Systems Analysis and Technology Evaluation (STE) of the Nuclear Research Center Juelich, a non-commercial government-owned scientific organization, is engaged in bilateral co-operative projects with some Less Developed Countries (LDCs) on energy systems analysis and planning. These projects have special features and can be qualified as "energy planning for and with LDC":

- Co-operation with energy supply or planning agencies and research or energy ministries (agencies advising political decision-makers).
- Training of an inter-institutional expert team of the LDC on computer-assisted planning methodologies - models for energy demand projections and LP-energy supply models.
- Adaptation of these instruments to a certain extent to the specific situation and problems of the LDC.
- Transfer and implementation of these methodologies into the LDC.
- Assistance in the analysis of the LDC-energy system and in the model representation of this system.
- Joint study to demonstrate the capabilities of the models to result in recommendations for R+D and/or market introduction of energy technologies.

Co-operative projects were conducted with teams from the Province Guangdong of the PR China, and from Brazil and is presently under way with a team from Indonesia. All these projects are within the frame of bilateral scientific and technological co-operation agreements between the Federal Republic of Germany and the respective LDC-Partner country. In the cases of Guangdong and Brazil, industrial partners participated.
In each case the main activity in the initial phases of the project was the transfer of MARKAL to and its implementation at the partner institution in the respective LDC, accompanied by training of an expert team and some subsequent adaptations of MARKAL to specific problems and questions of the partner LDCs during the preparation of the model data sets (1), (2).

In the co-operation with Guangdong and Brazil, KFA-STE was engaged only with MARKAL-related activities. In the case of Indonesia, STE is also responsible for an energy demand projection methodology. After some consideration it was decided to develop a new methodology with some items specific for the Indonesian economy. The main part of this package is called DEMI (= Demand Energy Model for Indonesia), supplemented by three modules for major demand determinants (3) (see below).

In the next chapter the individual projects are briefly presented with their respective main objectives and status. For the sake of completeness the concluded Guangdong project is presented, too, because efforts are being made to restart this cooperation with new topics. After that, the general experience gained from these co-operative projects are discussed. The last section presents some conclusions.

The Co-operative Projects of STE with LDCs

1. China project "Energy Study for the Province Guangdong, People's Republic of China". (4)
   The German project manager was the consultant company Lahmeyer International (LI), Frankfurt, Germany. As contractor of LI, STE was responsible for the subtask "Energy Supply Strategies for the Province Guangdong up to the year 2000" (1). The STE- Contribution covered the period from January 1, 1982 to March 31, 1983.
The objectives of the project were:

- Systematic collection and assessment of information on the availability of extractable energy carriers that could be expanded in Guangdong
- Investigation of the existing energy technologies and development of proposals for the implementation of modern supply technologies
- Investigation of the organizational and institutional requirements for energy planning
- Implementation of a planning instrument capable of defining optimal energy supply strategies for a period of about 20 years, considering all significant technical and economic parameters
- Acquisition and application of a computer for the tasks of energy planning
- Detailing of recommendations for the future energy planning to Guangdong
- Education of Chinese experts in modern planning techniques and training in the operation of the implemented planning instruments.

On the German side, experts of various industrial companies contributed to the data collection. To cover the subtask "Energy Supply Strategies up to the Year 2000" STE transferred and implemented MARKAL in Guangdong. This part of the project consisted of a supply study including 8 supply scenarios together with training a Chinese expert team.

The Guangdong co-operation terminated after the completion of the project program in early 1983. After a break of roughly 2 years, the Chinese partner, then reorganized in a new institution, indicated an interest in detailed MARKAL applications to pollution reduction. In its original form the model accounted for any type of emissions (SO₂, NOₓ, dust, CO₂, etc.), but it did not directly provide a reasonable formulation for optimization.
Because environmental problems had also become great interest to the Federal Republic of Germany, STE had developed an extension of the MARKAL model to treat emission control as an objective (5). This provided a well-founded scientific basis for a co-operation with external partners on such matters. As in the first phase the second phase requires industrial participation on both sides.

2. Brazil Project "Program on Research and Development on the Utilization of Brazilian Coal and on Energy Systems Analysis and Planning for Brazil" (2).

Operating Partners of this co-operative project were the KFA Juelich and the Companhia Auxiliar de Empresas Eletricas Brasileiras (CAEEB) within the framework of a governmental agreement between the Brazilian Federal Ministerio das Minas e Energia (MME) and BMFT. The project consisted of 4 subprojects: 3 common German-Brazilian working groups were engaged with options of preparation and utilization (conversion) of the considerable, but low grade-high ash Brazilian coal resources in the deep south of the country. German partners in these working groups were industrial companies with specific know-how on coal technologies. STE, on the German side, was responsible for the fourth working group, on systems analysis studies, using the MARKAL model for the assessment on future supply strategies.

The objectives of the energy systems analysis were "comparison and analysis of different coal utilization strategies" within the frame of an "evaluation and analysis of different energy and economic scenarios," altogether aiming at reliable assessments of the economic potential of an extended domestic coal utilization in Brazil.

The main activities were again training of an government organized Brazilian team which integrated experts from all leading energy companies on MARKAL application, transfer, and implementation of the model in Brazil, and a common study with this instrument.
For the specific Brazilian situation the following economy and policy objectives were considered to be of prime importance for the development of the energy system:

- Minimize the total costs of the energy system
- Minimize the dependence on energy imports
- Minimize the necessary amount of expenditures in foreign currency in the energy sector and
- Maximize the use of domestic energy resources

These policy objectives were translated into a modified MARKAL model objective function where different weights for domestic and foreign cost shares were defined. The time span of the main project activities mentioned above covered the period from May 1982 to June 1984.

As the Working Group on Systems Analysis reached the project goals very soon, the project was extended in order to invest more time into methodologic oriented tasks. The history of MARKAL applications has shown that the choice of an appropriate demand vector, one of the most sensitive parameters, has been one of the basic shortcomings in energy system analysis.

Additionally, a concept of a MARKAL regionalization was envisaged, reflecting the different resource availability and infrastructural limitations which a continent-wide country like Brazil possesses in its economically and climatically differing regions.

There was unfortunately only a poor response of the Brazilian partner in 1985 and part of 1986 due to the establishment of their new government. This caused some delays and uncertainties in the energy companies on the prime objectives of the new government in regard to a reassessment of the country's energy policy.
Conclusions

It can be stated that those STE/LDC-co-operation projects that have already reached their original objectives in energy systems analysis (Province of Guangdong and Brazil) were very successful in the sense that teams have been trained in the utilization of planning instruments (in particular MARKAL), that the models have been adapted to some extent to basic questions and conditions in the partner LDCs, that the models have been transferred to and implemented in the partner countries, and that extensive scenario computations and result analysis have been performed. According to our information, the models have been or are used by political decision making institutions for energy expansion planning purposes, in the case of Brazil at least by the former government.

In order to be successful, it was essential in all cases that the LDC-partners organize a large team, particularly for the early project phase, not only for training in formal model handling, but in order to collect both sufficient and appropriate data for the assessments of future sectorial useful energy demand as well as for the future energy supply analyses. The list of experts required explains the necessary size of a team: economists, technologists, computer experts, and structural experts for the individual energy production and consumption sectors like coal, oil, gas, biomass, on the one side, and industry, residential and commercial sectors, traffic, etc., on the other side.

It should be mentioned that mutual trust between the teams is of paramount significance for a successful project. Basic contributions to such mutual trust are two facts amongst others: Firstly, KFA/STE is, as part of a non profit government-owned organization, a neutral partner without its own economic interests.
Secondly, these projects are unrestricted know-how transfers of energy planning and energy analysis methods and a contribution to "aid for self aid".

This mutual trust had also another pleasant aspect for STE. It induced the partners to express their interest in continuing the systems analysis co-operation in order to improve and/or extend the methodologies and to include new aspects in the studies of future energy supply that could not be treated with complete satisfaction before (e.g., regional disaggregation of the models, energy-economy interactions, or demand management). In the cases of the Brazilian and Indonesian projects such extensions are already funded and under preparation.

(R. Aringhoff, M. Kleemann, G. Kolb of KFA/STE Juelich)
At the time of the updating of this contribution (December 1986) the project partners had agreed to restart the industrial co-operation in the area of coal preparation and beneficiation. A decision on a Brazilian proposal to continue the co-operation in the area of energy systems analysis with special emphasis on a MARKAL study of the economical benefits of intensified energy conservation efforts and on appropriate energy planning methodologies for individual states of Brazil is still pending.

3. Indonesia Project "Energy and Energy R+D Strategies for Indonesia" (6)

This is a co-operative project between the KFA Juelich and the Agency for the Development and Application of Technology (BPPT = BADAN PENGKAJIAN DAN PENERAPAN TEKNOLOGI) of the Indonesian Research Ministry, with the participation of some Indonesian energy economy institutions in order to provide reliable and comprehensive data:

- BATAN = Nuclear Energy Agency
- BPS = Central Bureau of Statistics
- DLEB = Directorate of Electricity and New Energy
- LEMIGAS = Oil and Gas Technology Development Centre
- MIGAS = Directorate General of Oil and Gas
- PERTAMINA = State Oil Enterprise
- PLN = State Electricity Enterprise
- BATUBARA = State Coal Company

The objectives of the project are to develop energy and energy research strategies for Indonesia and to develop and/or to adapt appropriate energy planning and system analysis methods for Indonesian conditions.

The project objectives comprise in particular:

- the analysis of the Indonesian energy economy with regard to energy demand, resources and technologies
- the adaptation of the MARKAL model to Indonesian conditions
- the development of a computerized energy demand model using macroeconomic parameters and Input/Output-tables
- the training of an inter-institutional Indonesian expert team on the available planning instruments
- transfer to, implementation, and application of the planning instruments in Indonesia
- the derivation of strategies and recommendations for future energy supply and for energy R+D in Indonesia

The co-operative working programme consists of six main tasks:

- Energy Demand
  (Elaboration of the historical demand data base and development of a macroeconomic energy demand model MACRO and DEMI).
- Energy Resources
  (Compilation of data on all Indonesian resources)
- Energy Technologies
  (Selection of promising technologies for Indonesia)
- Energy System Modelling
  (Development of a regionalized MARKAL model)
- Strategy Analysis
  (Scenario runs and recommendations)
- Demand Management
  (How to realize the optimal solution on the real market)

The project started in mid 1983 and will last until mid 1987. Every year two workshops are held, one in Juelich and one in Jakarta, each with a duration of about 6 to 8 weeks.

At present about 80 % of the first three tasks are finished and the modelling procedure in progress. Preliminary results are expected at the beginning of 1987.

Altogether five models are used, four of them having been developed within the project: MARKAL, DEMI, MACRO, DEMO, ANALYS (3):
MARKAL

Typical of the Indonesian energy system is the necessity to consider individual regions, i.e., to take into account the geographical structure of Indonesia which consists of manifold islands characterized by a significantly non-uniform

- distribution of resources
- distribution of consumption, and
- status of development.

For the modelling, the energy system data basis of Indonesia is divided into four regions:

- Sumatera
- Jawa + Madura
- Kalimantan
- Other Islands

The energy sub-systems of the four regions are connected by interregional energy carrier flows, which are modelled by transportation technologies like pipelines, ships or high voltage lines.

DEMI (DEMAND ENERGY MODEL FOR INDONESIA)

To obtain the energy demand time series as the driving force for the MARKAL model, the demand model DEMI (written in FORTRAN) was developed. DEMI is a simulation model. Future demand scenarios are established dependent upon various determinants. The historical energy consumption pattern, the future population growth rate and future growth in economic activities are the most important ones. Energy demand estimates are always given at the level of the 4 regions defined above.

DEMI consists of four modules, RESID, TRAFF, AIC and GOVERN, which are related to the demand sectors of the energy economy.
RESID calculates the energy demand of households, TRAFF calculates the demand for transportation, AIC calculates the demand of agricultural, industrial and commercial consumers, and GOVERN calculates the demand of the public sector.

The output of DEMI are the MARKAL input tables. But the DEMI-MARKAL linkage is not done automatically because the demand figures have to be checked first.

The remaining three models, MACRO, DEMO and ANALYS, supplement DEMI in order to produce the required DEMI input for some major demand determinants.

The input-output model MACRO provides estimates of economic activities such as the production for each of the industrial sub-sectors, or the growth rate of GDP. The industry sector is broken down into more than 20 subsectors, according to the Indonesian input-output table. For the GDP each of its components, such as private consumption, government consumption, investments, exports and imports, is considered.

The demographic model DEMO estimates the annual population by regions and urban/rural areas.

The ANALYS model calculates the historical energy intensities of agricultural, industrial and commercial energy consumers.

Figure 1, taken from (3), gives a schematic description of the demand approach, showing which models are used, how they are interrelated, which input data are required, and the output of the models.

All models are implemented on the computer of the state oil enterprise PERTAMINA.

Originally this project was scheduled to be finished in the middle of 1986. But during the work it has become particularly clear that MARKAL, as an instrument which has been developed to give analytical assistance to decision-makers on energy technology R+D in industrialized countries, needs some refinements to be more useful for LDC's.
Fig. 1: Logical Flow Chart of the Energy Demand Model

- Historical Data
- Model Result
- Model
- Assumptions
One topic already mentioned is regionalization. This item can be covered in the specific case of Indonesia by the present model's software on the matrix (=modelling) side, because only for the main island Jawa does the electricity production need to be treated as load-dependent. The report writer of MARKAL only needs minor extensions for this requirement to present the individual results of the 4 regions chosen.

The main topics for methodology improvement and development are the following:

- Splitting the cost components in MARKAL's objective function into foreign and domestic cost contributions to allow for maximizing the domestic capital for energy sector investments.

- Demand management: A methodology should be developed to analyze proposals or approaches for administrative measures intended to introduce the optimal MARKAL results into energy demand and supply practice, i.e., how to manage the demand for energy by prices, incentives, subsidies, taxes, regulations, etc.

It is intended to establish the model package as a national energy planning tool in Indonesia. The Indonesian and German governments agree that the extensions mentioned above are necessary to make the package more appropriate and more complete for such planning requirements and even for the original project objectives. For these two reasons both governments have agreed upon an extension of the project until the middle of 1987.
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9.1 Background and Objectives

(a) Background. A co-operative energy systems analysis activity was begun in February, 1976 for the purpose of providing the analytical basis for an IEA Strategy for Energy Research, Development and Demonstration. This co-operative work resulted in the development of a computer model, known as MARKAL, and a set of national and group analytical results. Subsequent activities included refinement of the model, improvement of the data base, further national analytical studies and information exchange.

As a result of this work and other more specific national applications, a broad consensus has developed that environmental aspects of national energy systems are susceptible to analytical study. A major subject of concern is how various environmental constraints (e.g. \( \mathrm{SO}_2 \) emissions, \( \mathrm{NO}_x \) emissions) would affect the pattern of fuel and technology use and the choice and timing of implementation of abatement technologies.

There are many national studies on the relationship between energy use and the environment, but they all raise unanswered questions regarding how energy-environment options and basic scenarios and technical assumptions are interrelated.

A workable mechanism for comparing and evaluating national energy-environment analyses and rationalising differences is needed by the international community to supplement the apparatus of national studies in order to gain insights to assist in the development of energy and energy technology policy. The methods, models and skills for such comparative studies already exist and should be applied to this analysis.
(b) Objectives. The objectives of this Task are to provide for the continuation of a co-operative energy technology systems analysis activity and the establishment of such an activity within the context of energy and the environment:

(1) To improve the technology characterizations by their updating and by the addition of data relating to emission release, emission control technologies and their costs;

(2) To ensure the ability of the methodology to analyse environmental issues related to energy use; and

(3) To promote the effective communication of the results of national and intercountry comparisons of the value of various options for emission control.

9.2 Means

The objectives shall be achieved by:

(a) The development of technology characterizations, including environmental data, on a national level and the exchange of information regarding this work;

(b) The exchange of work reports, memoranda and documents containing descriptions of methods, data inputs and results of energy systems studies;

(c) The organization of workshops or seminar meetings, as necessary, to exchange information and experience in the areas of work covered by this Task;

(d) The organization of annual meetings of an International Forum for Energy Environment Studies (FEEST) for the Task Participants, invited speakers and other interested persons, in order to deal with national, regional and/or inter-regional aspects of:
(i) Technology characterizations, with particular emphasis on environmental aspects;

(ii) Methodological treatment of environmental issues; and

(iii) Validation and communication of results of activities undertaken under this Annex;

The FEEST's meetings should be immediately followed by an Executive Committee meeting;

(e) The carrying out of such other co-operative analytical activities as may be agreed in the annual Programme of Work.

9.3 Specific Responsibilities of the Operating Agent

(a) Project Staff. For the purpose of carrying out the above objectives, the Operating Agent shall establish, within sixty days after the Annex has entered into force, a Project Staff composed of a half-time project head and such additional assistance as may be required to fulfil the Task. The total Project Staff shall amount to at least 1.25 staff years per annum.

(b) Co-ordination. The Operating Agent shall be responsible for overall co-ordination of the Task. Specifically, the Operating Agent shall have primary responsibility for reviewing the technology characterizations relating to emissions, for making efforts to improve them and for making them comparable. The Operating Agent shall monitor and encourage the exchange of Reference Energy System (RES) substructures among the Participants in order to ensure that the best data sources and model structures are generally known and widely implemented. In addition, the Operating Agent shall compile and review any other information and data provided under this Task.
(c) Meetings and Seminars. Upon request of the Executive Committee, the Operating Agent shall organize workshops and seminars and assist the Executive Committee and the host country in organizing the annual FEEST.

(d) Preparation of Draft Programme of Work and Reports. The Operating Agent shall prepare and submit to the Executive Committee, prior to its first meeting, a draft programme of work for the three-year period of the Task. The Operating Agent shall report to the Executive Committee at least once a year, on the progress of the activities under this Task. Upon termination of this Annex, the Operating Agent shall prepare and submit to the Executive Committee for approval a draft final report on the activities carried out during the period of this Annex. Following approval, the Operating Agent shall transmit the report to the Agency and to the members of the IEA Committee on Energy Research and Development.

The Committee on Energy Research and Development may, during this Task, propose additions to the Programme of Work. The Executive Committee shall, acting by unanimity, decide whether these proposals will be added to the Programme, provided such additional work can be carried out within the resource levels set out in paragraphs 3(a) above and 5(a) below.

9.4 Specific Responsibilities of the Other Participants

Participants shall carry out to the extent possible the following activities and communicate the results to the Operating Agent in the form of computer print-outs and country reports:

(a) Collection of national data on emission release and emissions control technologies;

(b) Collection of information on RES structure and related data;
(c) Establishment of data on technology characterizations and related data;

(d) Performance of scenario analysis using the best available structures of the RES;

(e) Discussions of the data base, assumptions, methodology and results with the Members of the reference group installed in their respective countries.

9.5 Funding

(a) Common Financial Obligations. Based upon a Project Staff as described in paragraph 3 above, the Operating Agent estimates the annual costs of the activities of the Operating Agent under this Task at 1986 prices at $US 150,000. The actual costs of the Operating Agent's activities under this Task will be divided equally among all Participants. If the number of Participants changes, the shares of contribution to the costs will be adjusted proportionally. New Participants will pay the full share of the costs beginning with the project year in which they become Participants.

(b) Individual Financial Obligations. In addition to the contributions set out in sub-paragraph (a) above, each Participant shall bear all costs it incurs in carrying out this Task including the costs of participation in workshops, seminars and the annual FEEST.

9.6 Time Schedule

This Annex entered into force with effect from 1st October, 1986 and will remain in force for a period of three years. It may be extended by agreement of two or more Participants acting in the Executive Committee and taking into account any recommendation of the Agency's Committee on Energy Research and Development concerning the term of this Annex which shall thereafter apply only to those Participants.
9.7 Operating Agent

The United States Department of Energy, acting through the Brookhaven National Laboratory.

9.8 Information and Intellectual Property

(a) Executive Committee Powers. The publication, distribution, handling, protection and ownership of information and intellectual property arising from this Annex shall be determined by the Executive Committee, acting by unanimity, in conformity with this Agreement.

(b) Right to Publish. Subject only to copyright restrictions, the Participants in this Annex (referred to in this Annex as the "Participants") shall have the right to publish all information provided to or arising from this Annex except proprietary information, but they shall not publish it with a view to profit, except as agreed by the Executive Committee, acting by unanimity.

(c) Proprietary Information. The Operating Agent and the Participants shall take all necessary measures in accordance with this Annex, the laws of their respective countries, and international law to protect proprietary information. For the purposes of this Annex proprietary information shall mean information of a confidential nature such as trade secrets and know-how (for example, computer programmes, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes, or treatments) that is appropriately marked, provided such information:

(1) Is not generally known or publicly available from other sources;

(2) Has not previously been made available by the owner to others without obligation concerning its confidentiality; and

(3) Is not already in the possession of the recipient Participant without obligation concerning its confidentiality.
It shall be the responsibility of each Participant supplying proprietary information to identify the information as such and to ensure that it is appropriately marked.

(d) Production of Relevant Information by Governments. The Operating Agent should encourage the governments of all Agency Participating Countries to make available or to identify to the Operating Agent all published or otherwise freely available information known to them that is relevant to the Task. The Participants should notify the Operating Agent of all pre-existing information, and information developed independently of the Task known to them which is relevant to the Task and which can be made available to the Task without contractual or legal limitations.

(e) Production of Available Information by Participants. Each Participant agrees to provide to the Operating Agent all previously existing information and information developed independently of the Annex which is needed by the Operating Agent to carry out its function in this Task and which is freely at the disposal of the Participant and the transmission of which is not subject to any contractual and/or legal limitations:

(1) If no substantial cost is incurred by the Participant in making such information available, at no charge to the Task;

(2) If substantial costs must be incurred by the Participant to make such information available, at such charge to the Task as shall be agreed between the Operating Agent and the Participant with the approval of the Executive Committee.

(f) Use of Proprietary Information. If a Participant has access to proprietary information which would be useful to the Operating Agent in conducting studies, assessments, analyses, or evaluations, such information may be communicated to the Operating Agent in accordance with an agreement between the Operating Agent and the specific Participant setting forth the terms and conditions for such
acceptance, but the proprietary information shall not become part of reports, handbooks, or other documentation, nor be communicated to the other Participants except as may be agreed in writing between the Operating Agent and the Participant which supplied such information.

(g) Acquisition of Information for the Task. Each Participant shall inform the Operating Agent of the existence of information known to the Participant that can be of value to the Task, but which is not freely available, and the Participant shall endeavour to make the information available to the Task under reasonable conditions, in which event the Executive Committee may, acting unanimously, decide to acquire such information.

(h) Reports on Work Performed under the Task. The Operating Agent shall provide reports on all work performed under the Task and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information, to the Participants.

(i) Authors. Each Participant shall, without prejudice to any rights of authors under its national laws, take necessary steps to provide the co-operation with its authors required to carry out the provisions of this paragraph. Each Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the laws of its country.

9.9 Results

The results of this Task shall be:

(a) Maintenance and improvement of an international capability for the analysis of energy technologies and their future prospects and establishment of such a capability within the context of energy and the environment;
(b) Periodic reports on workshops or seminars and on analytical studies undertaken in connection with the Task; and

(c) A final report on the activities carried out under this Task.

9.10 Participants

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Die Entwicklungsmöglichkeiten der Energiewirtschaft in
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Nr. 3: Wibbe, H.-B.
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Nr. 5: Hensel, W.
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Nr. 6: v. Lojewski, D.
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Nr. 8: Kolb, G. (Redaktion)
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