RM-77-42

REPORT TO THE ADVISORY COMMITTEE OF IIASA's ENERGY PROGRAM

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PREFACE

On May 3, 1977, the Advisory Committee of IIASA's Energy Systems Program (ENP) met in Salzburg, Austria, to discuss in detail the activities of the ENP. In preparation of this meeting, a report describing the progress of the ENP was submitted to the Advisory Committee. The present Research Memorandum is a revised edition of this report, published in order to provide a formal document for both IIASA and its related organizations, in particular the National Member Organizations, giving a general overview of the present status of the ENP.

ABSTRACT

In this paper the various present activities of the Energy Systems Program (ENP) and the results obtained so far are described in a summarizing report. In the first part the reader is introduced to the general time scale, the general aims and concepts, and the present status of the ENP. Furthermore, the interrelations and interactions between the individual tasks are pointed out. In the second part, several contributions describe in more detail specific activities. The following topics have been covered as examples of work done within the ENP:

- The energy demand models MUSE and MEDEE;
- The potential of coal for primary and secondary energy;
- Regional applications of solar technologies;
- Large-scale energy production and the climate;
- Health effects of energy use;
- A model for market penetration mechanisms;
- Risk assessment; and
- The computerization of the ENP's modeling effort.

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THE PROGRAM AND ITS GOALS

(W. Häfele)

The major goal of the Energy Systems Program since the last Advisory Committee Meeting in January 1976 has been, and still is, to implement the concept developed in the first phase (1973 to 1975) of the program. This concept was summarized in the "Second Status Report of the IIASA Project on Energy Systems 1975", IIASA Research Report, RR-76-1. The six tasks defined and their interrelations are as follows:

- o Evaluating the available *Energy Resources;*
- o Identifying the potential *Energy Demand;*
- o Studying technologies that are capable of providing virtually unlimited amounts of energy, the *Energy Options;*
- o Considering *Constraints in Large-scale Energy Systems* which might on a global level influence strategies for implementing and using the above technologies; and
- o Formulating *Energy Strategies* in time and in space--*Energy Deployment.*

Figure 1 summarizes this concept and points out the interactions between the above tasks.

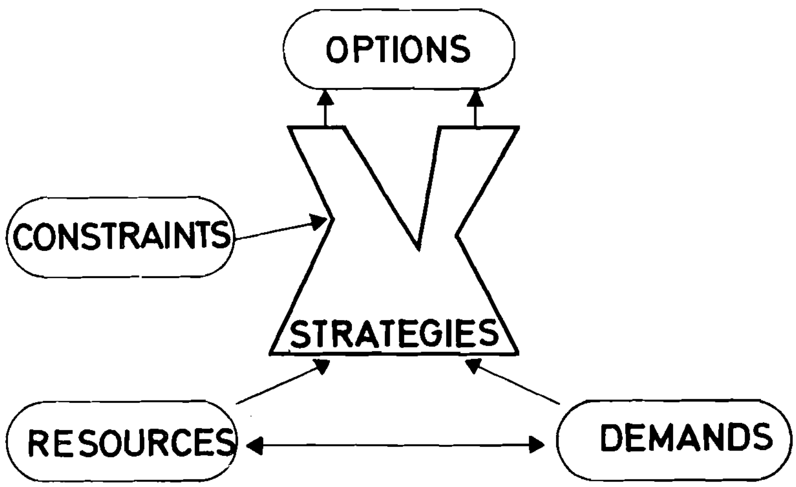

Figure 1: The Approach to Energy Systems

RESOURCES

The Task "Energy Resources", under the leadership of M. Grenon, is well under way. In July 1976--as part of a series of annual meetings on energy resources*--a highly successful conference on natural hydrocarbons was held jointly with the United Nations Institute for Training and Research, New York. This meeting brought together several top experts from East and West, as well as from consuming and producing countries. The participants presented and for the first time pooled data on conventional and nonconventional hydrocarbons. The next conference, on new technologies for the future coal supply, will be organized together with the Soviet Committee for Systems Analysis and held from November 28 to December 2, 1977 in Novosibirsk, USSR.

The second activity pursued at present is the formalization of the WELMM (Water, Energy, Land, Materials and Manpower) approach. B. Lapillonne is designing computerized data bases on WELMM characteristics and on the availability of oil, coal, gas, and uranium resources. Both data bases are used in the design of a Resources Model by I. Zimin, which is capable of assessing the long-term regional management of resources. This model is an important part of the more general modeling effort of regional energy strategies described below.

DEMAND

Since January 1976, this task has received considerable attention. As a pure econometrical approach could be misleading, in view of the time horizon of approximately 15 to 50 years, emphasis has been put on the design of energy demand models based on life-style scenario parameters, e.g. the average distance travelled, etc. Those models use GNP investment and consumption rates as further input. The aim is to have transparent and relatively simple models providing long-term disaggregated energy demand data. J.-M. Beaujean, J.-P. Charpentier, B. Lapillonne and T. Müller are at present implementing computerized versions of MEDEE (Modèle d'évolution de la demande d'énergie) and MUSE (Modeling Useful Energy Demand). MUSE has been developed as a first step which will permit the use of the modeling chain, while awaiting the adaptation of MEDEE which will then provide benchmark cases for the calibration of MUSE.

In this activity we are closely collaborating with W. Foell's group on regional environmental energy systems at IIASA and thereby with the University of Wisconsin and in particular with the "Institut Economique et Juridique de l'Energie" of the University of Grenoble, France.

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*The proceedings of the first IIASA Energy Resources Conference, May 1975, CP-76-4, were published in October 1976.

Besides the modeling effort, we are attempting to interpret energy demand in terms of the negentropy concept. This concept seems to be a fundamental feature of energy systems: the salient point is not conservation of energy but the efficient utilization of negentropy. Here, certainly, is a theme for future basic research after the termination of the current phase of the Energy Program.

OPTIONS

The study of the individual technological options capable of meeting an energy demand on the terawatt level has progressed very far under the coordination of W. Sassin. By the end of 1977 an evaluation of the potential of coal as an option for the transition period, carried out in collaboration with institutions in the UK, the USSR, Poland, the USA, and the FRG, will be completed. Similarly, the substance for judging the solar option at both the local and global levels--studies led by C. Bell and J. Weingart, respectively--is almost ready. However, a synthesizing paper summarizing the solar option as a whole is still required.

The nuclear option reached its peak in 1976 with the completion of the comparison between fission and fusion breeders, a task force in which institutions from the USSR, the USA and the FRG have participated. A comprehensive report is at present available in a draft version. Previously, two other very important aspects of the nuclear option have been studied: first, the implication of the large-scale fuel cycle described in a paper by R. Avenhaus, W. Häfele and P. McGrath, "Considerations on the Large-scale Deployment of the Nuclear Fuel Cycle", October 1975, RR-75-36, and second, the "Applications of Nuclear Power Other Than for Electricity Generation", a paper by W. Häfele and W. Sassin, November 1975, RR-75-40. At present we are looking for senior assistance in the field so that a final assessment, taking into account recent turbulent developments, can be made.

CONSTRAINTS

With the help of several institutions, in particular the Meteorological Office in Bracknell, UK, the National Center of Atmospheric Research, Boulder, Col., USA, and the Nuclear Research Center of Karlsruhe, FRG, it has been possible to run several experiments on the climatological effects of waste heat. J. Williams and G. Krömer are already far advanced in the assessment of this problem. At the same time they have progressed well in the study of the impact of CO_2 emission on the climate; the recognition that this problem is important has been growing rapidly in recent times. By 1978 at the latest, we expect that an assessment within the scope of our original intentions of certain climatological impacts of the large-scale use of energy will be possible.

V. Peterka has developed a self-consistent mathematical model explaining market penetration patterns. The model is based on fundamental economic assumptions and in particular on the hypothesis that the growth of a new industry (or the sector of an industry) is regulated by its capital flow. This model is now able to explain the market features phenomenologically observed by C. Marchetti.

The joint IAEA/IIASA risk group, led by H. Otway, has completed its first level of investigation. Risk evaluation and risk estimation are now understood to some degree. Work on the quantitative evaluation of attitudes is currently under way: in particular, the Fishbein attitude formation model will be tested by applying it to nuclear energy. Finally, we are attempting to include decision theoretical elements in our risk studies.

Part of the work on risks of large-scale technologies has involved more qualitative assessments of the risk generated by CO_2 emission. A paper by F. Niehaus has been completed on this subject. This is also very much in line with our efforts undertaken to establish procedures for standard setting. At present the work of Niehaus is being followed up by a study of the regulatory problems of oil spills as faced by the UK and Norway in the North Sea, which is undertaken in collaboration with the Management and Technology Area of IIASA.

Finally, L.A. Sagan and A.A. Afifi have almost completed a study on health effects on energy use. Here, contrary to most research in this field, not the detrimental but the beneficial effects were considered.

STRATEGIES

Very much attention has been given during the past year to an effort to model the transition phase. Indeed, this work has to be seen as an attempt to quantify our qualitative findings.

The approach chosen is to develop a set of models that can be operated both individually or in conjunction with each other. The driver of the whole chain is several macro-economic models for world regions, e.g. the US and Western Europe, which have been conceived by M. Norman and H.H. Rogner. For the less developed countries, the UNCTAD model from the United Nations, New York, will be adapted for our use by J. and K. Parikh. The purpose of these models, which are kept as simple and transparent as possible, is to produce a consistent set of estimates for the main elements of aggregated demand and supply under different assumptions about the exogenous scenario variables. The output is then further disaggregated by the energy demand models MUSE and MEDEE (see DEMAND). Once the demands for the different end uses have been determined, they are used as input for MESSAGE (Model of Energy Supply Systems And their General Environmental Impacts). This model, largely an extended version of the Häfele/Manne Linear Programming Model, optimizes energy supply for a given set of constraints. It has been developed by M. Agnew, L. Schrattenholzer and A. Voss. Its output is an optimal technological strategy determined through capacity requirements which serve as input for "Impact", an investment model. This model, which is based on a model of the Siberian Power Institute of the Siberian Branch of the Academy of Sciences of the USSR, has been designed by Y. Kononov. It computes the primary, secondary and tertiary investment requirements for the given strategy. At present, work is going on for creating an interface with the macro-economic models so that the feasibility of the investment strategy can be checked.

Strategies will thus be determined for four to six world regions. In order to check the global compatibility of these strategies in terms of exchanges of energy, resources, labor and capital transfers, the regions will have to be coupled together. For this purpose a first version of a gaming model has been set up by A. Makarov and A.S. Makarova of the Siberian Power Institute. As input, this model, which describes the competition among the regions for the above commodities, requires shadow prices for potential benefits or costs of providing oil and perhaps coal for each region. O. Helmer's arrival at IIASA will certainly be of great assistance in making this model operational. However, as a fallback position, the regions could also be coupled by a handwritten scenario.

At present, the design of all models is moving rapidly towards finalization. Already, some models are operational and first test cases are being run: the computerization is supervised and coordinated by W. Orchard-Hays. We strongly hope that the modeling effort will yield significant results by the end of 1977.

Our resilience studies have also been further pursued. At present, H.R. Grümm, M. Breitenecker and C. Riedel are applying this concept to a macro-economic model. A first version has been conceived; however, making it operational will require further extended work.

DETAILED REPORTS ON SOME ACTIVITIES

Task: Resources

Development of the WELMM Approach (M. Grenon)

The basic report describing the WELMM approach was published at the end of 1976 and has generally been well received.

WELMM is now nearing the operational phase, where it will be used to compare various energy strategies and/or options.

The content of the Resources Data Base, which was the least well defined, has been clarified and a case study has been made for the oil shale resources, showing explicitly the important

WELMM REQUIREMENTS FOR COAL TRANSPORTATION OVER 1000 KM

(23×10^6 tons per year)

			Coal Slurry	Coal Unit Train
Water	Intake	$10^6 m^3$	24.6	--
	Consumption	$10^6 m^3$	24.6	
Energy	Electricity	10^6kWh	940.7	--
	Fuel	10^9kcal	--	1697
	(Total)	10^9kcal	(2350)	(1697)
Land	Temporary Exclusive	km^2	--	--
	Temporary Non-Excl.	km^2	32.2	39
Manpower		Man-year	217	2502
CONSTRUCTION MATERIALS	Steel	(1000 tons)	243,000	795,000
	Concrete	(1000 tons)	34,000	--

Table 1: Example of Comparison of Two Energy Facilities

WELMM parameters to retain in the file. With this model, data bases will be expanded for coal and oil resources.

Some files have been filled for basic materials such as stainless steel and cement.

A number of files have been filled for various facilities for coal, oil and nuclear. An example comparing two energy facilities is shown in Table 1. A very detailed WELMM analysis has been performed for the nuclear energy chain, using various documents (Bechtel, Hittman, Stanford, Oak Ridge, EdF). This brought to light one of the difficulties involved in this work, i.e. to obtain and to select valuable data which are both coherent and referenced. This exercise shows the importance of cross-checking published data with direct information, as we are actively in process of doing in France, for instance, with various energy organizations (the coordination of this task has progressed well with EdF, CEA, IFP, CFP, Elf-Aquitaine, CNRS, IEJE, GdF, etc.).

Particular attention has been devoted to the WELMM facility files for nuclear and solar energy to allow a detailed comparison of these two very different energy options (which also appear more and more as the two main competitors during the transition period). A difficulty is created by the lack of reliable data for solar facilities. The WELMM analysis has been performed in detail on particular materials (a very crucial point) going upstream, i.e. up to the level of the mining operation (see Table 2). To begin with, we used the cutting grades given by Earl Cook; a metal by metal verification has shown the validity of this approach. The first results were very interesting and have illustrated the importance (for mining activities) of some minor metal components, such as molybdenum, a basic component of steel.

An exploration effort has been made towards computerization of the data but is still a bit premature to try to decide its final form now.

Finally, a detailed WELMM analysis has been launched for North Sea Oil. A questionnaire has been prepared and discussed with various oil experts. The next step is to send it to the various operators in the North Sea. Following this, a similar approach will be developed to "WELMM compare" the various technologies for enhanced oil recovery.

ROUGH UPSTREAM MATERIALS ANALYSIS FOR A 1000 MW(e) REACTOR

MATERIAL	TOTAL ESTIMATED QUANTITY (metric tons)	CUT-OFF GRADE (ppm)	CONVERSION TO ORE
ALUMINIUM	18	185,000	97
CHROMIUM	415	130,000	1,804
COPPER	726	3,500	207,430
IRON	34,662	200,000	173,310
LEAD	47	40,000	1,175
MANGANESE	467	250,000	1,868
MOLYBDENUM	164	1,000	164,000
NICKEL	484	9,000	53,780
SILVER	1	100	10,000
TIN	2	3,500	570
ZINC	2	35,000	57
SUBTOTAL	36,989		614,091
CEMENT	30,133		
AGGREGATE (COARSE)	90,361		
AGGREGATE (FINE)	54,855		
SUBTOTAL	166,349		

Table 2: Example of Material Analysis of an Energy Facility

Resources Model (I. Zimin)

The goals of the current resource modeling efforts of the Energy Program are as follows:

- Assessment of natural resources evolution and of the requirements for long-term resource development strategies at the regional level; and
- Analysis of the economic impacts of these strategies (capital and manpower).

The development of the resources model has four main objectives:

(1) Modeling the evolution of a given resource from its resource-base status to its actual production; this includes: the identification and estimation of investment steps necessary for the implementation of alternative development strategies;

(2) Exploring possible applications of a unified analytical methodology for the treatment of various resources;

(3) Linking together various natural resources, both statically at the "geological" level and dynamically at the exploration and production levels; and

(4) Linking the resources model to the energy supply model through functional relations between resource availability and corresponding costs (a typical example for such a cost-supply relation is shown in Figure 2).

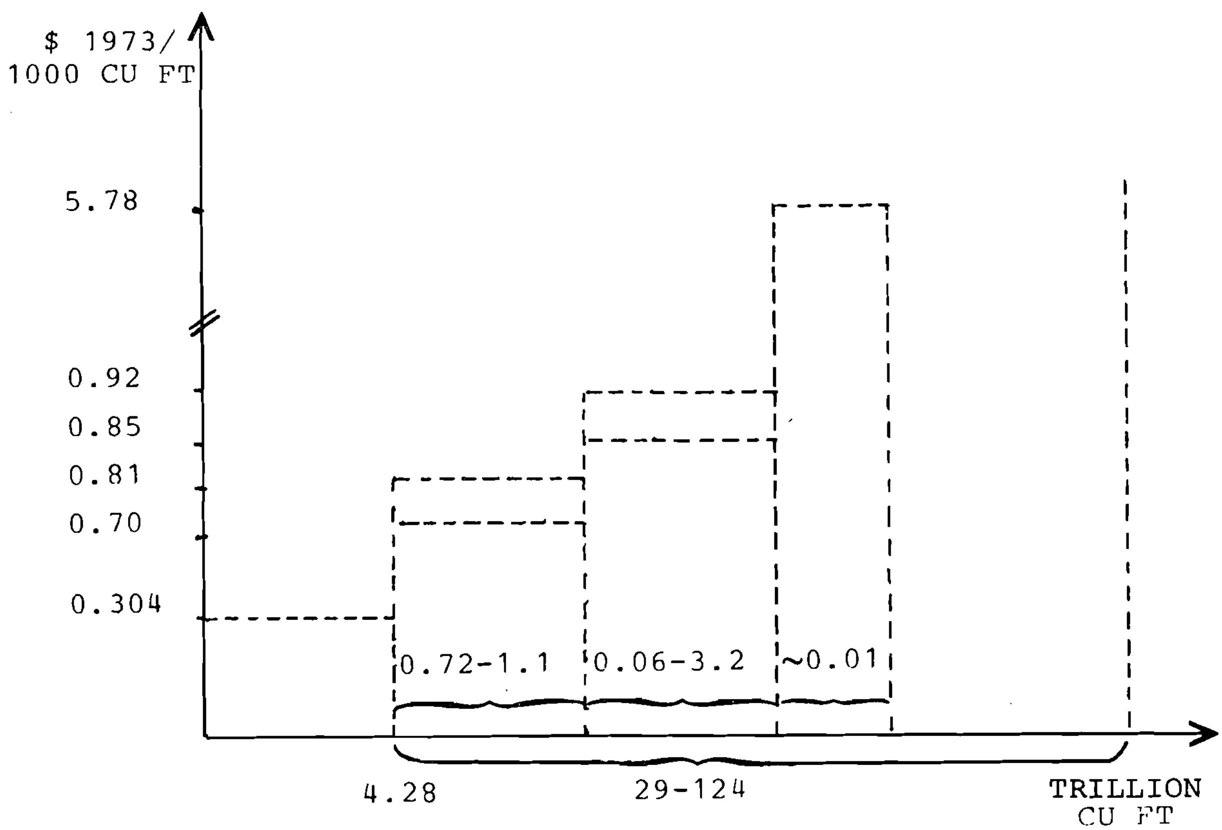

Figure 2: Resource Data Base: US Natural Gas, Subregion: PAD1 District

In the resource modeling activities we are following an explicit approach. The resources considered by the WELMM analysis are first modeled separately, and then combined for analysis at the "extraction" level. The motivation for this is derived from the WELMM approach; the decomposition of resources into various categories and their explicit (physical) consideration encourages greater accuracy in estimating limits of the physical system.

In turn, such representation of resource components provides a basis for the analysis of different economic conditions (defined externally by the energy supply and economic models of the general scheme).

At present, a first resource data base management system has been developed. For this, an interactive data management system, DATAMAT, which is part of the SESAME mathematical programming system, is being used (see TASK STRATEGIES).

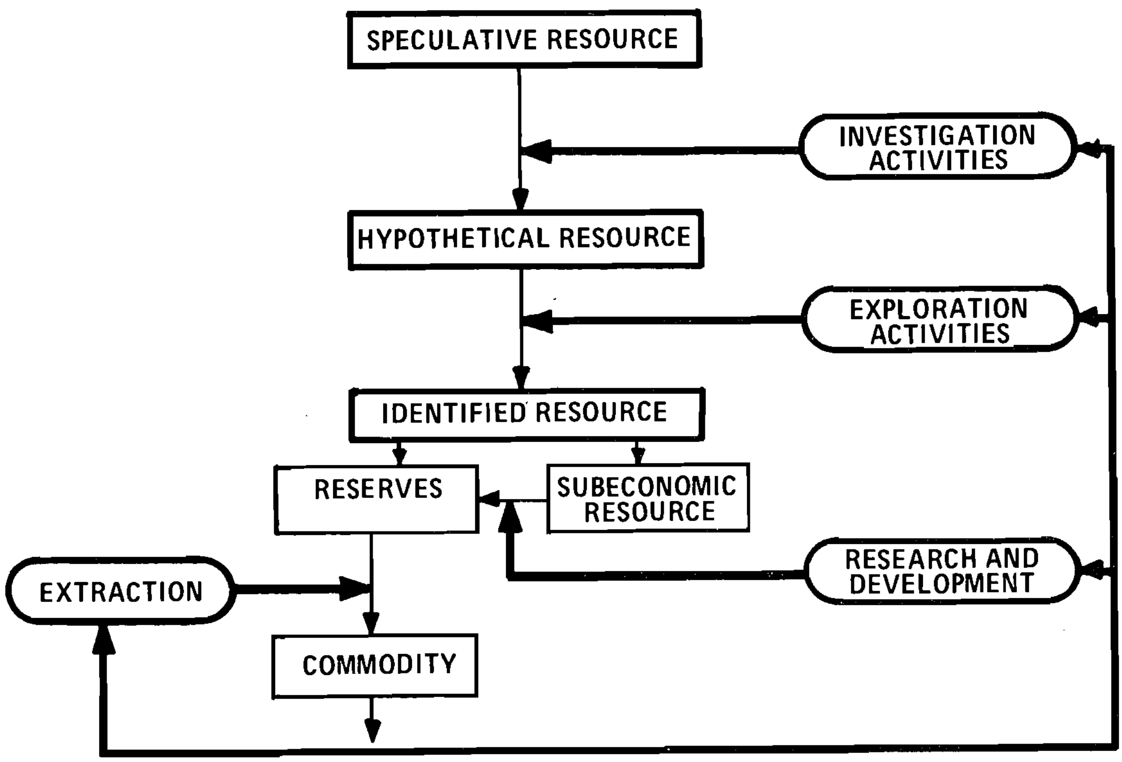

Figure 3: Resources Model: General Structure

This data base includes data for crude oil, natural gas, coal, uranium, thorium, and geothermal resources and reserves in the USA as well as for the associated extraction costs (prices). The data for oil (including gas) and coal are given for six and seven US subregions, respectively.

The second main result of the modeling activities is a conceptual general dynamic resources model describing various resource categories as well as alternative exploration and extraction technologies.

Evaluation of long-term resource development strategies via the model is accomplished by integrating submodels describing:

- Resource endowment;
- Potential technologies; and
- Economics (Figures 3 and 4).

Each of the submodels can be decomposed practically to any desired degree, depending on the particular objectives of the resources analysis:

- Short, medium, and long-term consideration;
- Decomposition of resource characteristics (various types of deposits, energy or metal content, depths of cover, thickness of seams, resource quality, etc.);
- Scale of technologies, their implementation over time and their evolution due to scientific progress;
- Economic activities: exploration, development, mining, infrastructure, etc.; and
- Environment, geological disturbance, pollution.

In conclusion it must be emphasized that this modeling is an iterative process. The model's structure and its components will have to be modified according to its data requirements and to the existence and availability of these data. The model, in its final version, will then be expanded to several world regions.

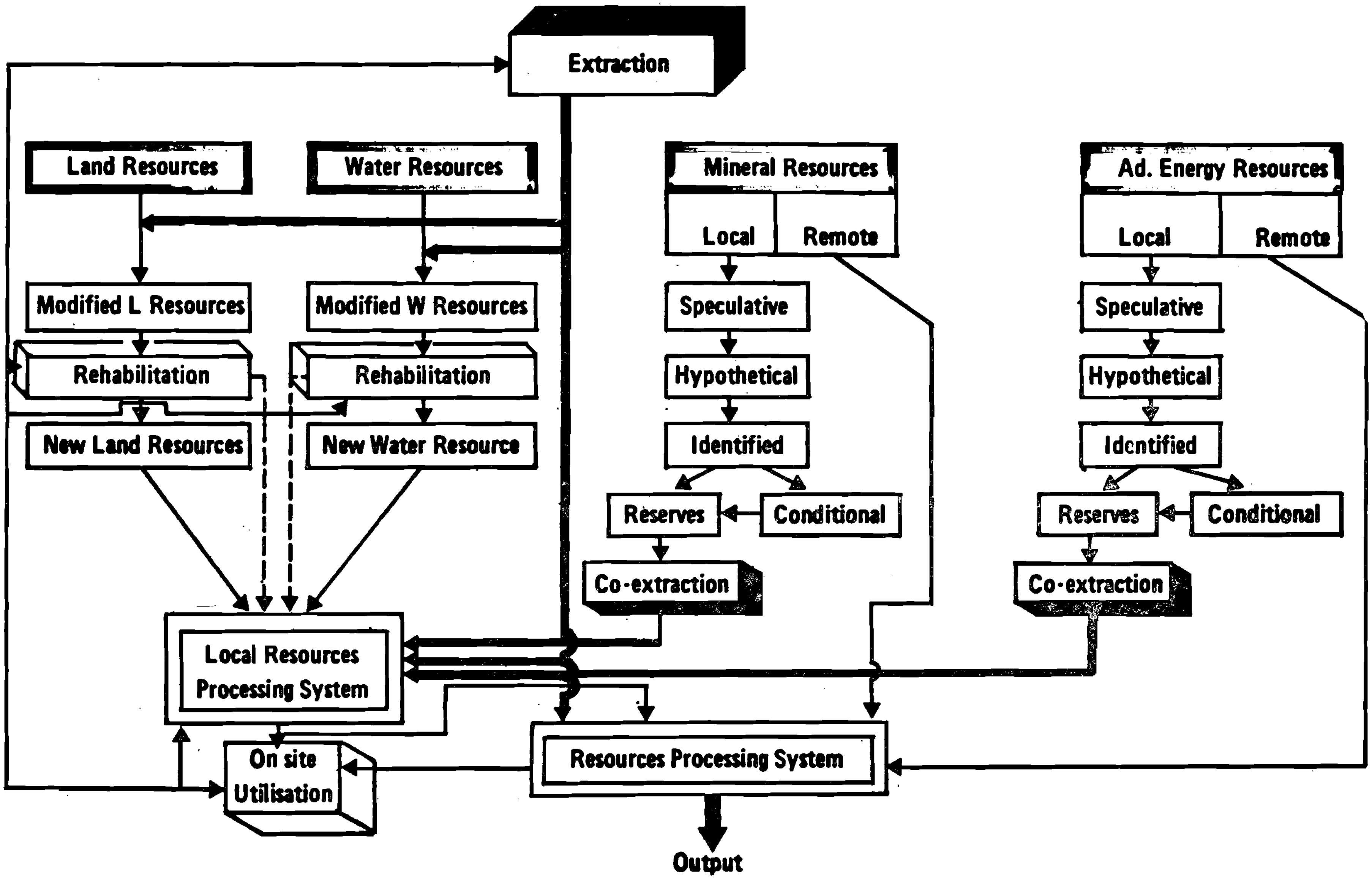

Figure 4: Resources Model: Detailed WELMM Interactions After Extraction of an Energy Resource

Task: Demand

The Energy Demand Models MUSE and MEDEE (B. Lapillonne)

The Energy Demand group is now developing two non-econometric forecasting models which simulate the long-term evolution of energy demand. These models are both driven by macro-economic variables generated by macro-economic models (GNP, value added by economic sectors, private consumption, etc.), which will give a general economic consistency to the forecastings. In addition, the evolution of some qualitative variables will be specified exogenously by means of assumptions (scenarios).

The first model, MUSE, has been developed recently by J.-M. Beaujean, J.-P. Charpentier and T. Müller to relate in a very simple and transparent way normative life-style scenarios to the energy demand development. The simplicity of the model is perfectly suited for its use in less developed countries, where the lack of data is a constraint to the use of more disaggregated models. This simplicity should also limit the work on data collection when the model is applied to world regions in a further step of the overall modeling effort of the Energy Program. MUSE considers four sectors: household and service, industry, transportation and agriculture. The household energy demand is split into three parts: room heating, hot water (including cooking), specific use of electricity (lighting and electrical appliances). This demand is derived from the following variables which can be either determined endogenously in the model or specified by life-style scenarios:

$\Delta h = \Theta_{ext} - \Theta_{int}$ difference between outdoor and indoor temperature;

Hoheat = number of heating hours;

M2CAPL = number of square meters per capita in class L of revenue;

Power = power delivery;

Hoelec = number of hours for electricity purposes;

DWCAPL = demand for water per capita day; and

SWWL = share of warm water.

The other sectors are modeled in a simpler way; the energy demand for industry is calculated for two industrial groups, heavy and light, and is derived from their respective value added. As to the transportation sector, goods and passenger transportation will be differentiated; the energy demand will be derived from the traffic carried by each mode of transportation. The energy demand for agriculture is calculated from an equation relating energy demand to the GNP, the population, and total arable land.

The model is now computerized and running for Algeria and the USA with preliminary data.

The second model, MEDEE, is much more sophisticated. It has initially been developed to forecast energy demand in France by the year 2000. It is now simplified so as to be extended easily to other countries. A first version adapted to industrialized countries is being developed and computerized by B. Lapillonne and M. Müller: the model should be running very soon for the FRG and the USA. Another version could afterwards be envisaged which would take more explicitly into account the peculiarities of the less developed countries. The MEDEE model has been designed with the following objectives:

- To take explicitly into account the saturation of certain energy needs as a country or a region is becoming highly developed (passenger transportation for instance) by detailed modeling;
- To simulate through policy scenarios alternative policies of a national government in the fields of housing, human settlement, energy conservation, urban transportation, industrial development, recycling, etc.; and
- To delimit the potential market for new energy sources, such as solar energy, district heat, electricity for heating purposes, waste heat, etc., by forecasting explicitly the energy demand for each of these markets.

In other words, MEDEE is designed so as to model in a detailed way all the components of an economy which could dramatically change on a long-term basis and whose change could significantly affect the total energy demand.

MEDEE is made up of four submodels, which are again divided into modules. For instance, the transportation submodel distinguishes the following modules: intercity passenger transportation, intracity transportation, freight transportation, other transportation (international transportation, school buses, military use, etc.). The household and service submodel considers the following modules: space heating and hot water, cooling, and miscellaneous household appliances. The space heating module distinguishes, on the one hand newly built homes and already existing homes, and on the other hand single houses and apartments, as the insulation standards of the different types of dwellings and the degree of penetration of new energy sources differ widely. The industrial submodel distinguishes five sectors for less developed countries and twelve for industrialized countries. For each sector the energy demand is split into different processes (steam, kiln use, space heat and hot water, and feedstocks) so as to better delimit the possible penetration of the industrial market by electricity, solar and district heat. For each market, a coefficient of reduction of the energy use per unit of value added is specified, so as to take into account the energy saving over time; the same coefficient is used for all industrial sectors. For industrialized countries the agricultural demand is derived very simply from the value added for this sector; for less developed countries the level of irrigation and the number of tractors are used to derive the agricultural energy demand.

For each module the energy demand is driven by the real factors which determine its level--the energy demand determinants. The choice of the determinants is not arbitrary and is the result of a comprehensive system analysis of the mechanisms of evolution of the energy demand of a country.

The inputs of the model are macro-economic variables, and scenario components that essentially characterize some aspects of the policy of the decision-makers. All these scenarios are organized in a hierarchy in order to avoid the combination of inconsistent assumptions--hierarchical scenarios.

MEDEE will be used in the near future for the FRG and the USA for two reference scenarios: an "unconstrained scenario" where no drastic government intervention will be assumed, i.e. an extrapolation of past trends, and a scenario reflecting political decisions contrasting with the past.

Parallel to this modeling effort, a group has been created to couple these energy demand models to the input-output model of I. Zimin. This group gathers all the persons involved in MEDEE and MUSE as well as Y. Kononov, C. Doblin, T. Uratani, and A. Hölzl from the Resources and Environment Area. The major methodological problem will be to express qualitative scenarios in terms of structural change in the final consumption vector of an economy--this input-output model is driven by the consumption.

Task: Options

The Potential of Coal for Primary and Secondary Energy Use (W. Sassin)

The objective of the Coal Task Force, a nonformal cooperation between the Energy Program and several national coal institutions, is to outline a global coal option, to estimate its potential and specify the requirements for its implementation. It is intended to produce a final report towards the end of 1977 that will provide a basis for comparing coal and other primary options such as nuclear or solar energy.

Despite the large resource figures which are given for coal, it is clear now that *coal* unlike nuclear and solar energy is to be considered as a *primary energy option only for a transition period.*

Two simple considerations support this statement, which is fundamental for the specific analysis carried out by the Coal Task Force. G.B. Fettweis, in a careful analysis, estimates that less than $1.1 \cdot 10^{12}$t of coal will ultimately turn out to be recoverable. This amount would support a maximum energy supply of 7 TW around 2050 (Figure 5). Present world energy consumption totals 7.6 TW and possibly will rise to some 20 TW up to more than 60 TW within the next five or six decades (Figure 6).

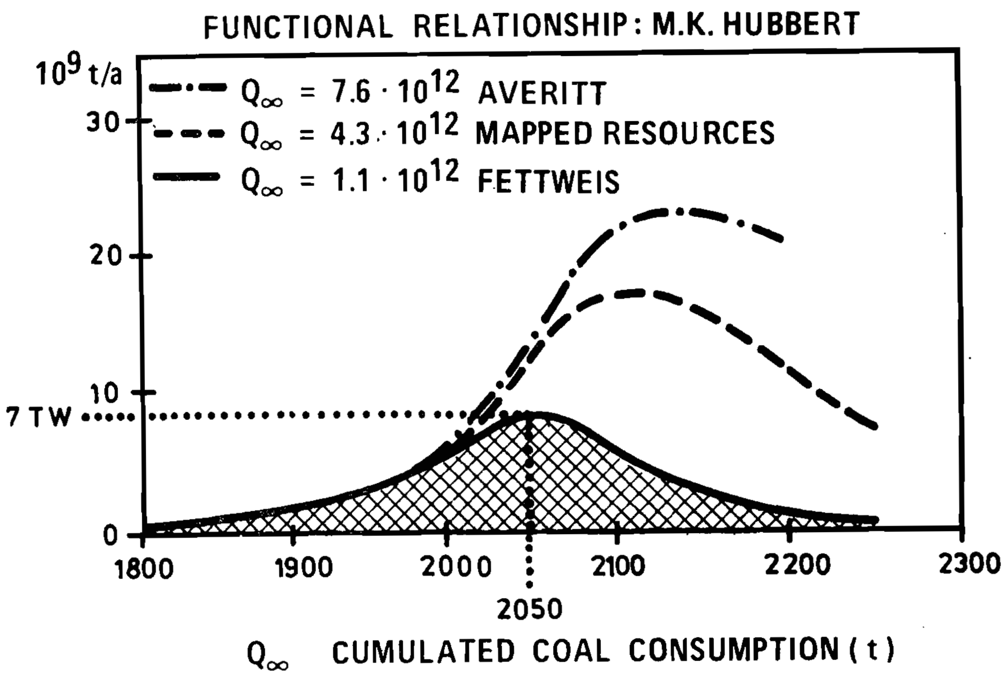

Figure 5: Coal Production and Reserves

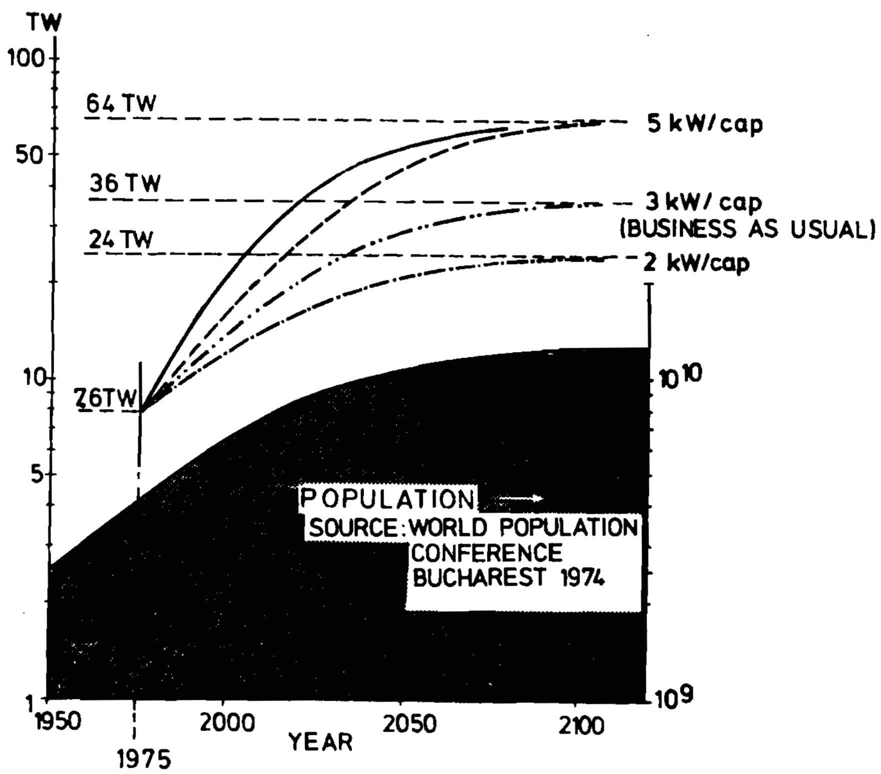

Figure 6: Global Energy Scenarios

Even if radically new mining techniques would allow the amounts of ultimately recoverable coal to double or triple, the control of the CO_2 level in the atmosphere resulting from a basically fossil global energy system poses major problems. Massive uses of coal on a global scale introduce, according to present knowledge, a serious climatic risk within the time horizon of the next 50 years.

Still there are good reasons to analyze coal at the level of a global option. In the short run, coal and nuclear energy are the only commercially viable sources which allow the transition process away from mineral oil and natural gas to start. Moreover, where accessible by open cast mining, coal is the cheapest primary energy source at present. In the long run the new "unlimited options", nuclear and solar, do not provide easily utilizable energy carriers. Their deployment requires a material that can store energy. The hydrogen-atom and the carbon-atom are the two most prominent candidates for this purpose. Coal deposits would provide for example the chemical feedstock for producing methanol, a prime candidate to replace liquid hydrocarbons, which are currently derived from crude oil.

By carrying out two case studies for the UK and the FRG, the Coal Task Force has concentrated during the last year on the problems of a coal revival. The time horizons were 2020 and 2000, respectively. Starting from the final consumer's end, possible channels for new coal products were investigated (Figure 7). It turned out that the potential to utilize coal, which has to be converted into either electricity, synthetic natural gas, or process steam for industrial purposes, will rise significantly with the commercialization of conversion technologies being developed now. These technologies could enter the market around 1990. The economic potential of the channels in Figure 7 is so large, that the real limitation for a significant

COAL SUBSTITUTES FOR	PENETRATION		NEW TECHNOLOGY
NUCLEAR	1985 850 MW	23 [a]	POWERPLANT 4000 h/a KDV, PRESS. FLUID. BED
OIL (HEAVY AND LIGHT NATURAL GAS	1990 1 GW	50 [a]	POWERPLANT 2500 h/a PRESS. FLUID. BED
HEAVY FUEL OIL	1985 200 MW	18 [a]	INDUSTR. BOILERS FLUID. BED 7000 h/a
NATURAL GAS	1990 4 GW	18 [a]	SNG PLANT LURGI 7500 h/a

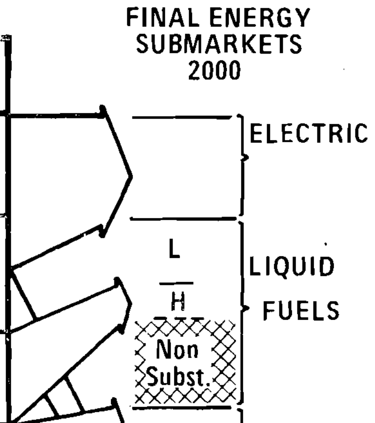

Figure 7: Channels for New Coal (FRG)

coal revival must be seen on the supply side. Figure 8 illustrates the estimated coal consumption up to 2000 for a specific scenario for the UK. The potential of future coal mining and transportation technologies will be analyzed in connection with two additional case studies, one for the USA and another for the USSR. Both studies are under preparation now and should yield the necessary information to outline the supply problems within a long-term global coal option.

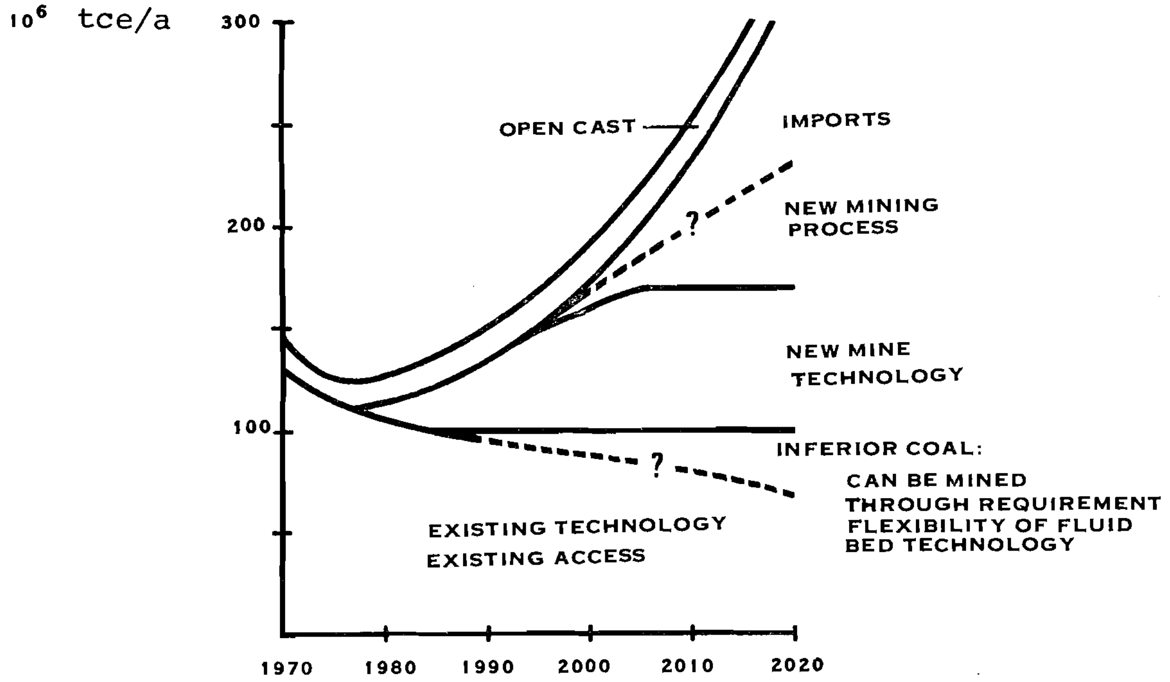

Figure 8: UK Coal Supply: Scenario 1

Regional Applications of Solar Technologies (C.R. Bell)

The study of solar energy conversion potential carried out at IIASA is an integral part of the comparison of technological options. The solar option is viewed as an element of the energy supply evaluation, which must be conducted at regional levels before a realistic synthesis of the future energy supply and demand options can be made. In the area of solar energy conversion, the large-scale implementation potential has been viewed in the solar-thermal, solar-thermal electric, and photovoltaic conversion alternatives.

The initial regional study of the solar options (1975 to 1976) centered on the "Austrian Case Study" by N. Weyss, in which the low temperature concepts for water and space heating, as well as the high temperature concepts for generating electricity, were considered. It was established that with the current prices for heating by oil and gas, the amortization time for low temperature solar systems is not economically attractive for individual home owners. Surprisingly, geographic areas were located in Austria, where the long-term potential for high temperature, solar-thermal electric conversion (STEC) appears feasible, if the system cost of future generation solar hardware can be below \$ 1100/kW(e) peak for hybrid installation. In connection with the favorable network of hydroelectric plants in Austria, such possibilities deserve future investigation. The preferred STEC concept is the receiver tower with a field of heliostats (mirrors) which concentrate direct solar irradiation and produce satisfactory temperatures for steam production. The existing hydro-storage in Austria offers the solution to the otherwise difficult problem of energy storage. Decreasing availability and increasing total cost of fossil fuels in the future are expected to provide a more favorable basis for development strategies of the solar technologies and their penetration on the Austrian market.

The current regional study of solar technologies (1976 to 1977) has been applied to the FRG by C. Bell, F. Jäger and W. Korzen, where, unlike the Austrian case, a substantial hydroelectric network does not exist, and thus the dependence on oil imports is substantial. The low temperature concepts for water and space heating are viewed as an attractive method for saving heating oil. The range of energy consumption for family houses (100 to 170 m^2 living area) of existing designs is from 15 MWh(t)/year to about 35 MWh(t)/year. Those that are not connected to district heating systems use from 3500 liters to 6000 liters of heating oil per year (of which 5-10% is for heating water). Theoretically, a significant percentage of the heating oil (i.e. 14% by the year 2000) could be saved by large-scale application of solar systems, because even for the average of 1060 kWh(t)/m^2 per year and about 1500 sunshine hours per year in the FRG, 1.0 m^2 of well-designed and manufactured flat plate collector may save 38 to 60 liters of heating oil per year. Design and economic considerations tend to limit the collector area for space and water heating to about 30 to 40 m^2 per family house, which should yield 50 to 60% reduction of heating oil demand for such houses. This is equivalent (for the estimated range of designs) to 1750 to 3600 liters of heating oil/year or (at current prices of the oil), about \$ 240 to 490/year. However, the solar systems for such designs range from \$ 5000 to \$ 9000 per unit, which means that with doubling of heating oil prices in the future and no increase of the solar system prices, such technologies may prove reasonably attractive. The diversion of capital, materials and manpower for large-scale implementation of the low temperature concepts would be nevertheless substantial. Collector area requirements for space and water heating average about 0.33 m^2/m^2 of living area in a house of 120 m^2 or smaller, and about 0.43 m^2/m^2 of living area for large houses (up to 180 m^2), if 50 to 60% of heating oil consumption should be saved. This means a collector production capacity of over $10 \cdot 10^6$ m^2 near 1985 to reach the stipulated impact on heating oil demand, or for some years nearly $8 \cdot 10^9$ m^2/year business before saturation of the theoretically available market. The manpower requirements would reach about 120 thousand before the saturation. That such large-scale implementation would require incentives beyond currently available means is obvious. Such measures are studied at IIASA in cooperation with the "Institut für Systemtechnik und Innovationsforschung (ISI)" in Karlsruhe, FRG. Modifications of restricting building construction codes, standardization of (solar) hardware quality, formulation of "solar rights", and various financial and tax incentives are among the key considerations. Still, like in the Austrian case study, the economic constraints of solar options will diminish when the prices of heating oil reach at least twice that of the current level.

The high temperature (STEC) concepts for the FRG are less favorable than for Austria, unless a suitable energy storage concept is developed. In the distant future, should the development of low-cost photovoltaic arrays prove feasible, a more competitive concept may emerge in connection with hydrogen generation. This would provide the needed energy storage medium, as well as synthetic fuel relatively compatible with the environment.

Realizing that long-term projections based on the first generation concepts of a relatively new solar technology are at best speculative, the IIASA Solar Group is conducting parametric studies aimed at delineation of near optimum solar alternatives. Such may be in the field of prefabricated houses for the low temperature concepts, and further optimization of subsystems for the high temperature STEC concepts. The recent funding commitments toward solar energy conversion in many countries are creating such a high rate of change in development aspects, that significant breakthroughs must be among the considerations for solar options. It may take a decade before the practical limits of solar technology and their economic constraints can be fully recognized.

Task: Constraints

Large-Scale Energy Production and Climate (J. Williams)

There are three main ways in which energy systems can influence climate; by the addition of waste heat, by the addition of gases and particles to the atmosphere, and by changes in the characteristics of the earth's surface.

The impact of waste heat release on climate has been studied in a series of experiments using the numerical model of the atmospheric circulation developed at the Meteorological Office (U.K.). The first two experiments considered the effect of two energy parks, each adding $1.5 \cdot 10^{14}$ W to the atmosphere, in one experiment the energy parks were located in positions A and C as indicated in Figure 9, in the second experiment the parks were located in positions B and C. A third experiment has considered one park, in location A, putting $1.5 \cdot 10^{14}$ W into the atmosphere. In a fourth experiment the parks were again in locations A and C but the energy input was only $0.75 \cdot 10^{14}$ W at each park. In each of these experiments the heat is added as sensible heat at four grid points which represent an energy park.

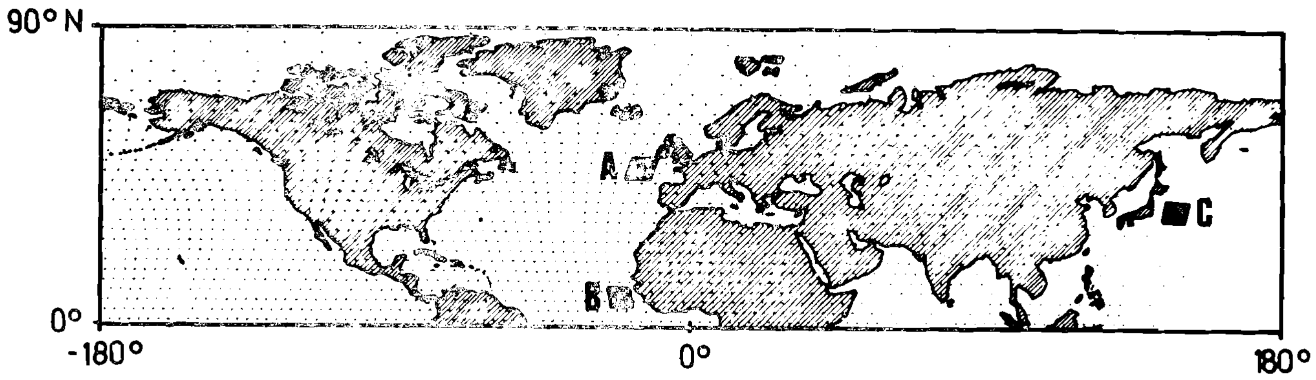

Figure 9: Locations of the Three Energy Parks

The results of cases of the model with energy parks have been compared with control cases of the model, that is, cases with no added perturbation. A particular concern has been to investigate how much of the difference between an energy park case and a control case is a result of the addition of waste heat and how much is a result of the natural model variability, i.e. to determine signal-to-noise ratios. To summarize the results of the above four energy park experiments we can say that significant changes in meteorological variables (surface pressure, temperature, precipitation, for example) are found in each case. Of major importance is the result that the addition of heat in very small areas not only influenced the local atmosphere but also had impacts elsewhere in the northern hemisphere. Secondly, we find that the changes in the simulated atmospheric circulation are different when the input of heat is changed in either amount or location; this is a good indicator of the nonlinearity of the climate system. Further experiments will study the effect of changing the method of introduction of waste heat and the influence of a megalopolis.

The problem of the addition of CO_2 to the atmosphere through the burning of fossil fuels and the influence of increasing CO_2 on climate, has primarily been examined so far in terms of a review of literature and participation in two international workshops on the topic (WMO workshop on CO_2 in December 1976, and SCOPE workshop on carbon in March 1977). We are now using all available information to improve the Niehaus model of the carbon cycle (IIASA RM-76-35) to study the implications for the atmospheric CO_2 content and climate of various energy scenarios.

In December 1976, a small workshop was held to discuss the possible impact of large-scale solar energy conversion on climate. The possible technologies of solar energy conversion were identified, their physical characteristics and the climatological implications of these were discussed, in particular the impacts of changes in albedo, surface roughness, surface hydrology and areal temperature were outlined on the basis of model experiments and analysis of analog situations. Recommendations from the workshop on data requirements and on the use of models in studying the impact on meso- and macro-scale climate will be followed up in future studies.

Health Effects of Energy Use (L.A. Sagan)

Studies have been carried out in which economic development, as measured by energy consumption, has been related to mortality. Data from 150 countries, including more than 99 percent of the world's population, were analyzed in both cross-sectional and longitudinal ways.

(1) Energy consumption per capita is highly correlated with literacy, GNP, and certain nutritional and medical variables, and can be used as a "proxy" for economic development of these variables. Literacy was the most highly related variable to both infant mortality and longevity from birth.

(2) The strong relationship among these economic variables has not changed since 1900. For example, the relationship between energy consumption and literacy has remained unchanged for the past 75 years. There are differences of 30 years in longevity between least developed and most developed countries.

(3) In addition to the effect of economic development, the data demonstrates a secular trend in which longevity has steadily increased independently of economic development. In the decades from 1940 through 1960, life expectancy increased by nine years at all levels of development. This trend appears to be decreasing, i.e. in the past decade, only 1.5 years have been added to life expectancy. There is no evidence within our data that this effect is related to improved nutrition or medical care.

(4) From the use of the relationship between energy consumption, literacy, longevity and the secular effect noted above, an equation has been developed with which longevity can be predicted with a high degree of confidence.

Figures 10 and 11 summarize some of these results.

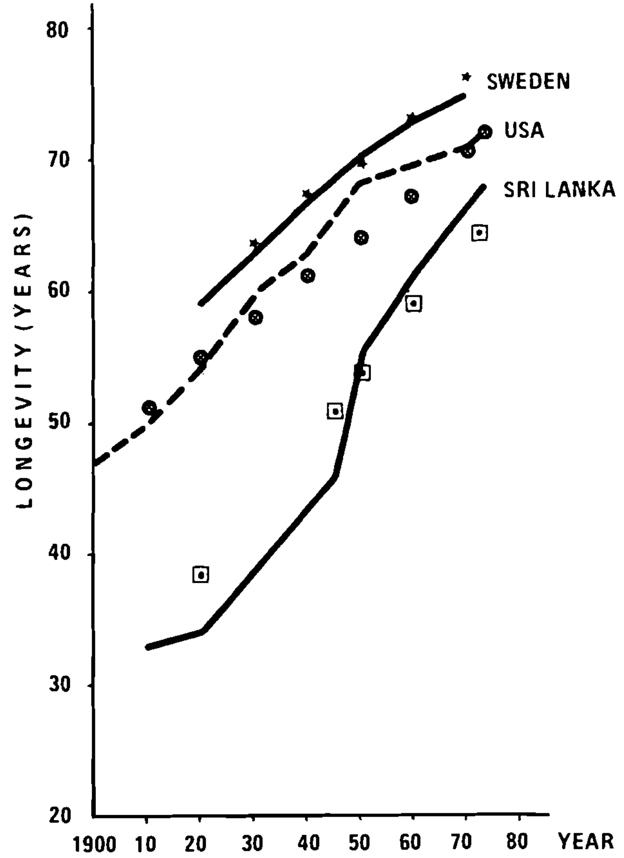

Figure 10: Longevity from Birth, Observed and Predicted Values, Selected Countries

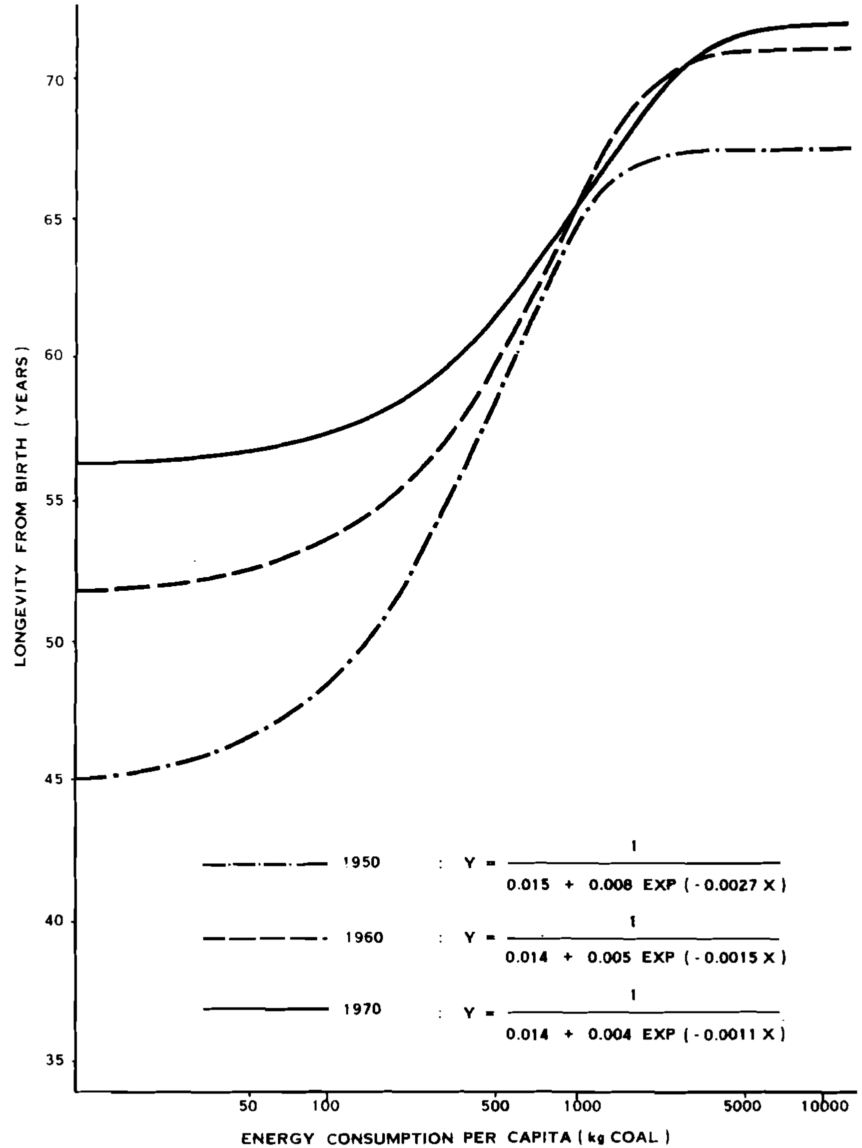

Figure 11: Relationship Between Energy Consumption and Longevity for 42 Countries (1950-1960-1970 data)

A Model for the Market Penetration Mechanisms (V. Peterka)

C. Marchetti has in the past initiated at IIASA the study of the very regular, secular trends which rule the penetration of markets by new technologies. His approach was to a great extent an empirical one.

The aim of the present work was primarily to explain the existing empirical models and rules, which appear to fit the theoretical data, and to quantitatively define the conditions under which they apply. This required the explicit formulation of the main characteristics of a new technology which determine the speed of the substitution process and of a general law describing multivariate substitution processes, i.e. with any number of competitors: present empirical models--with the exception of Marchetti's rule "first in - first out"--consider only two competing technologies.

Algorithms and computer programs both for forecasting the future course of substitution processes and for estimating model parameters from historical data for already existing technologies have been set up. For new technologies entering the market, where no historical data are available, formulas have been devised which allow computation of model parameters through an economic assessment (total production cost, investments, growth rate factor).

Finally, in order to be able to describe and evaluate the accuracy of forecasts and parameter estimates, a probabilistic model of the substitution process has been designed.

The model has been applied to the substitution process of primary energy technologies on a global level as well as for forecasting the potential market shares of new technologies (e.g. nuclear, solar) on the basis of objective and quantitatively well defined data. It also has been verified through a comparison with historical data on wood, coal, oil and natural gas.

The model, in its final form, describes the substitution process from a macro-economic point of view. It uses a system of stochastic differential equations which have been derived from long-term balances of capital flows. The main assumptions on which the model is based are:

- Competing commodities fulfill the same or similar needs and are substitutable; and
- In the long term, a particular technology has to live and grow on its own account; it is assumed that the mean value of the external capital flow is zero.

Figure 12 shows a typical output of the model. The estimation of the relative cost of electricity from nuclear energy versus the cost of electricity from oil has been taken from H. Michaelis' "Status der Wettbewerbsfähigkeit der Kernenergie", Reaktortagung 1976, Düsseldorf, FRG, 1976. According to this source, the investment costs for nuclear electricity are 1500 DM/kW and 720 DM/kW for oil. The total production costs are 0.043 DM/kWh and 0.064 DM/kWh, respectively.

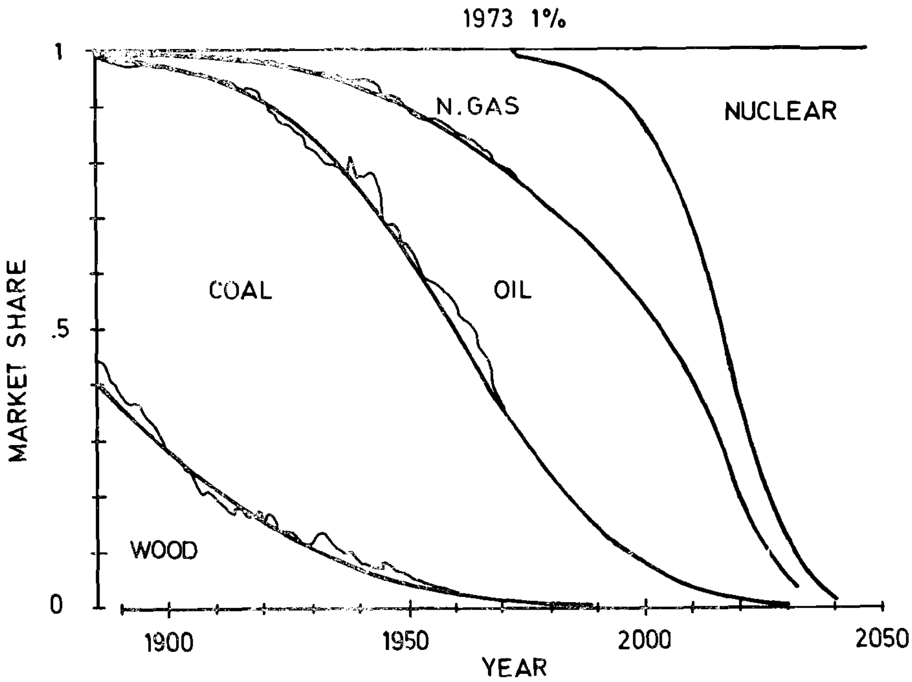

Figure 12: Global Primary Energy Substitution Process

Risk Assessment (H. Otway)

General Framework. During the past year, the work of the Joint IAEA/IIASA Research Project has become more precisely structured. The problem of technological risk assessment is conceived as one of balancing complex technical data with the corresponding social values in public planning and decision processes. Risk assessment is divided into three sub-topics: risk estimation, risk evaluation and risk management.

Risk estimation is the identification and quantification of the risks associated with technological systems. Risk evaluation is the measurement of social values and their reconciliation with risk estimates through the use of formal decision methodologies. The risk estimation and evaluation analyses can provide an ordered list of the options under consideration; therefore, risk management, in reality a function carried out at a higher political level than risk evaluation, considers the evaluated options in the light of the historical and political realities which surround the decision to be taken. The result is a choice among the alternatives offered or recommendations for modifications to systems to help facilitate their integration. Figure 13 shows, in a schematic way, how these sub-topics fit together. This figure summarizes a more detailed figure developed by the group [1,2] through a process of interdisciplinary compromise.

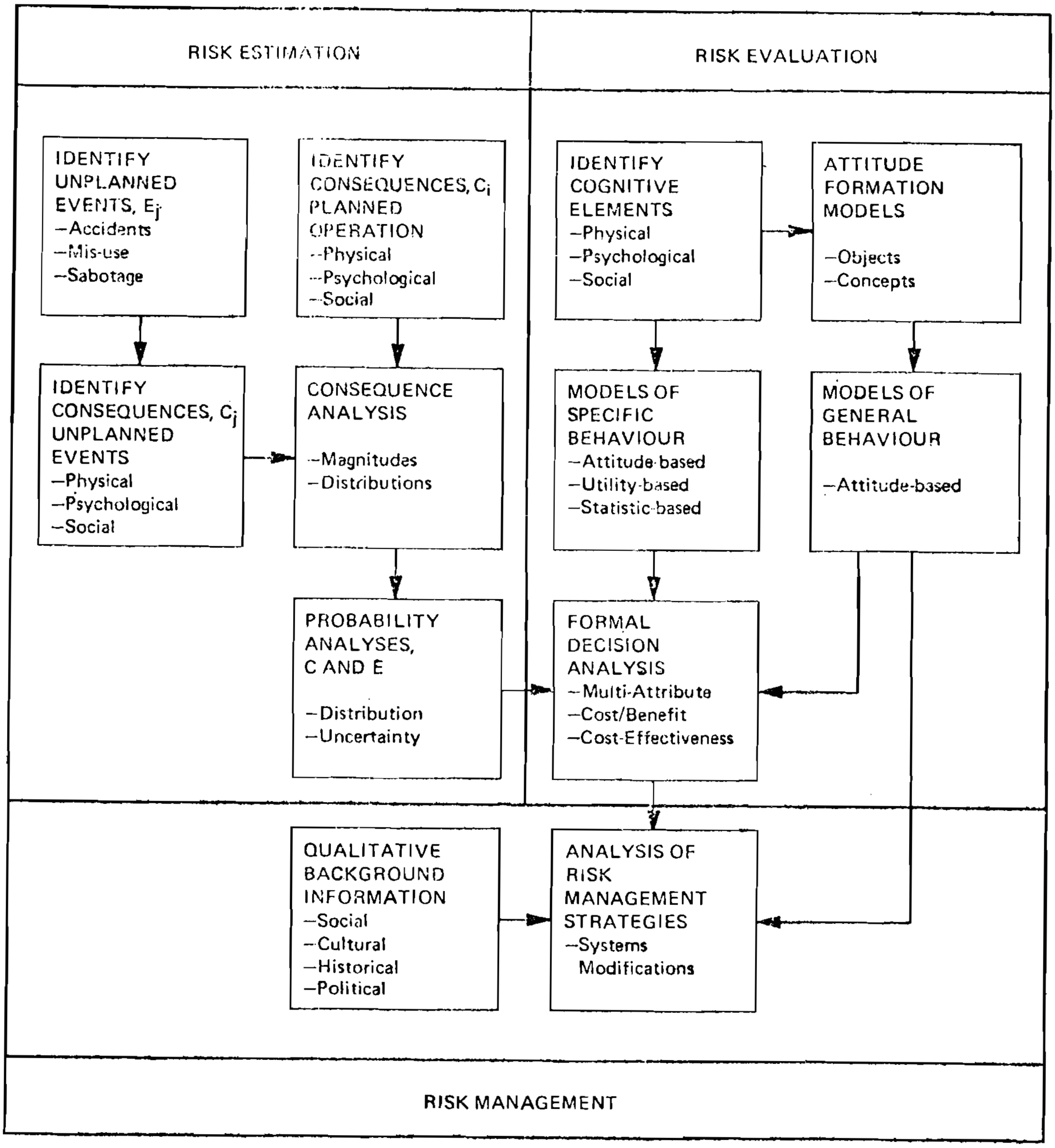

Figure 13: A Theoretical Framework for Risk Assessment Studies

The continuing interest in risk assessment research has been demonstrated since the last Advisory Committee meeting in that five additional governments have seconded scientists to work with the Joint Project on a cost-free basis.

Risk Estimation. Risk estimation is the identification and quantification of the risks posed by the technological system under consideration. As the methodologies for quantification of risks of planned operation and unplanned events are quite well understood, research in this area concentrated on application to special problems.

Data on radioactive releases for accidents in *underground site nuclear power plants* were used to determine the cost-effectiveness of additional isolation devices with regard to the preliminary $ 1000/man-rem standard value. A similar analysis was performed for the cost-effectiveness of *remote nuclear power plant siting* [3].

A computer program for *risk accountance* calculations was developed. This program uses the input/output table of an economy and statistical data on accidents to estimate the direct and indirect risk involved in the production of goods and services. A CO_2 model developed earlier is being modified and used to analyze the influence of fossil fuel consumption on the CO_2--*burden to the atmosphere* for various energy strategies [4].

A study has been started which tries to *compare* the *risks* involved in fossil and nuclear power production. Cross-sectional analysis using epidemiological data covering specific time periods in different countries will be utilized. Data collection has just begun.

Risk Evaluation. This was defined above as the measurement of social values and their reconciliation with technical data through decision-making processes. This is essentially the integration of technical and societal data; it implicitly includes the concept often called "acceptability".

Measures of Social Value: Methodologies. *Utility-based* methods have been used primarily for assessing the decision-makers' (or experts') expectation of "social utility" as a function of technical variables. Although some of these methodologies could, in principle, be extended to make utility measurements on a public survey basis, the technology for so doing does not exist at present.

Another way to approach this has been to put risks into "perspective" by comparing theoretical estimates for the "new" risk with *statistical data* on other risks existing in society. These comparisons are useful for seeing if a projected new risk might be too high from an ethical standpoint; however they are meaningless as a measure of social value, or for predicting what will be acceptable. Acceptability of risks is characterized by a number of variables besides the statistical expectation of risk. That is, each risk situation is different; comparing one risk to another is like comparing apples and oranges--in a psychological sense they are not at all comparable. We have come to the conclusion that the analysis of statistical data just cannot lead to practical rules for predicting the acceptability of risks nor can one learn much about the determinants of risk perception.

Attitudes as a Measure of Value. Attitude may be simply defined as an evaluative judgement that one likes or dislikes some object or concept, that it is good or bad, that one feels favorable or unfavorable toward it. Attitudes are a good measure of the societal values held with respect to some object or concept because attitude creates a predisposition to behave in a consistent manner toward the object in question. In other words, attitude predisposes an individual to engage in a *set* of behaviors which, taken together, are consistent with the attitude. So attitude is a measure of the general behavior that an individual will display toward the object, but is not necessarily related to any specific behavior. Beliefs, attitudes and behaviors are distinct variables, with different determinants, but with stable and systematic relations among them; the relationships among them are shown in the attitude formation model of Figure 14, which was developed by Martin Fishbein and his colleagues.

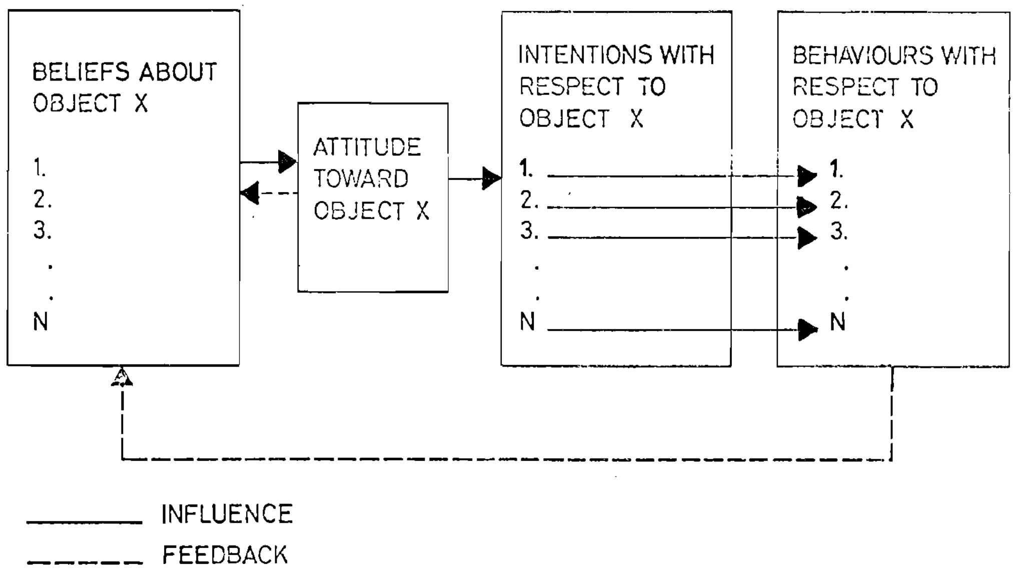

Figure 14: A Model of Attitude Formation (after Fishbein)

How Attitudes are Formed. Beliefs are the building blocks of attitudes. A belief is a person's subjective probability judgement that an object is characterized by a certain attribute. People form a number of beliefs about an object on the basis of direct personal observations, information received from outside sources or through inferential processes. Each of these beliefs simply links the object with some attribute in the person's mind. Each belief is weighted by the evaluation of the attribute in the attitude formation process. The way in which beliefs and their evaluations combine to form attitude may be written mathematically as:

$$A_o = \sum_{i}^{n} b_i e_i \quad ,$$

where

- A_o = the attitude toward object "o";
- b_i = the beliefs which link the object to specific attributes;
- e_i = the evaluations of these attributes; and
- n = the number of salient beliefs (usually only five to ten in number).

The belief component (the b_i of the equation) represents knowledge or opinions about the attitude object while the evaluative component (the e_i) is a measure of affect or feeling. (The public opinion poll usually only measures the belief component of attitude. Unlike attitude, beliefs alone may be completely unrelated to behavior.) The Fishbein Model allows not only the identification of the factors important in attitude formation, but also the respective contributions of opinion and feelings to each factor. Further, by aggregating the responses of individuals we can examine the response of any social groups and thus find out which factors differentiate between groups.

Attitudes Toward Nuclear Power. In collaboration with Fishbein [5] we did a pilot study of attitudes toward nuclear power to see if the model could be used in this area of application. The subjects were a group of people affiliated with a university energy-research institute in the USA. Many of them had degrees in science or engineering. The attitude results obtained from the model correlated highly with separate, independent measurements of the same attitude (using the semantic differential technique), which indicated the validity of the application. For the total sample, the results confirmed what we expected--that the most important attributes in determining attitudes toward nuclear power were factors concerning risks, i.e. nuclear wastes, possible destructive misuse of the technology and catastrophic accidents.

We then formed two sub-groups from the total sample. The one-third most favorable towards nuclear power were called the "pro" group and the one-third most negative the "con" group. A comparative analysis of these two groups can help understand which factors tend to differentiate between groups pro and con. These results are summarized in Figure 15. The first column of

DETERMINANT	Average Attitude Contribution $\overline{eb}$ (−9 to +9)	Average Belief Strength $\overline{b}$ (−3 to +3)	Average Evaluation $\overline{e}$ (−3 to +3)
GOOD VALUE	7.0 0.8**	2.8 0.3**	2.5 1.9
QUALITY OF LIFE	6.7 −0.5**	2.6 −0.5**	2.6 1.6**
ESSENTIAL BENEFIT	5.8 0.9*	2.2 0.3*	2.7 2.6
DESTRUCTIVE MIS-USE	−4.3 −5.7	2.0 2.2	−2.3 −2.3
DIFFICULT TO CONCEPTUALIZE	−3.4 −2.0	2.8 2.5	−1.2 −0.8
NOXIOUS WASTES	−2.7 −6.6	1.8 2.3	−1.7 −2.5*
CAN AFFECT MANY PEOPLE	−2.6 −5.3	1.9 2.6	−1.7 −2.7**
NATURAL RESOURCES	2.5 0.9	−1.0 −0.3	−2.1 −2.1
BIG GOVERNMENT/ BUSINESS	1.4 −2.2	2.9 2.6	0.4 −0.8
NEW AND DIFFERENT MODE OF DEATH	−1.2 −4.1	1.5 2.4	−1.1 −1.5
BENEFITS NOT VISIBLE	−0.7 1.0	1.6 0.9	0.0 0.3
DAILY CONTACT	0.1 −1.5	1.2 2.3	0.1 −0.5

* DIFFERENCE SIGNIFICANT AT 0.05 LEVEL
**DIFFERENCE SIGNIFICANT AT 0.01 LEVEL

PRO GROUP
CON GROUP

Figure 15: Cognitive Stucture Underlying Attitudes Toward Nuclear Power

this figure shows the contribution of each attribute to the attitude scores of the two groups. For example, it may be seen that the perceived relationship between nuclear power and "big government or business" contributes positively to the attitude of the pro group but negatively to the attitude of the con group. The reason for this difference may be understood by looking at columns 2 and 3. They show, respectively, the separate contributions of beliefs (opinion) and evaluations (feeling) to attitude. Here we see that both groups strongly believe that nuclear power is "in the hands of big government or business". However, the pro group feels that this is a good thing, but the con group valued it negatively.

There were additional items for which differences between pro and con groups were statistically significant. These items were all related to the benefits of nuclear power; they were: providing good economic value; enhancing the "quality of life"; and providing benefits which are essential to society. Again, looking at columns 2 and 3 of Figure 15, we can see what accounts for these differences. In all three cases, both groups evaluated the attributes positively, although the con group evaluated the "enhancing of the quality of life" significantly less positive, thus showing doubt about the need to further increase standards of living. However, for all these benefit items the beliefs, or opinions, were the major factor contributing to differences; the pro group strongly believed that nuclear power could provide these benefits while the con group was uncertain to somewhat negative.

There were no significant differences between the groups regarding the risks of nuclear power. Both groups believed that nuclear power was characterized by the risk attributes. The con group did feel significantly more negative about some risk attributes than did the pro group; however, these differences in feelings about risk items were not large enough to create significant differences in attitude.

The intent of this study was to test the validity of the methodology in this area of application. One should not assume that the results obtained with this small and homogeneous sample could be applied to any other group. We are now in the process of applying this model to a representative population sample by using a questionnaire with 39 attributes instead of the 12 used in this pilot study.

Decision-Making. The final, integrative step in risk evaluation is an ordering of the alternatives being considered. The limitations of the decision-maker in handling the large quantities of probabilistic data involved in many public decisions suggest the use of formal decision methodologies to aid in this process. Methods available include multi-attribute decision analysis, cost-benefit analysis, and cost-effectiveness analysis. These methodologies are, in fact, closely related: cost-benefit analysis may be derived from multi-objective analysis; cost-effectiveness is a special case of cost-benefit analysis.

Cost-benefit analysis has been a popular method for making public policy decisions; it requires that all attributes of the decisions be expressed in common units--usually monetary. A problem arises, however, if there is no observable market price for the attributes in question, such as is the case for most environmental concerns including the risks to the public's health and safety. The interest in assigning values to human life arises from the wish to evaluate changes in mortality risk for use with the cost-benefit methodology. We have reviewed the methods used [6,7] and concluded that a rigorous determination of life values is not possible because all methods are either dependent only upon income or are difficult to estimate. It was recommended that a value, such as $ 3,000,000 per life, be chosen for use in cost-benefit analysis and this value be weighted by three factors representing the personal status of those exposed; third-party interest in life-saving; and psychological factors such as those discussed earlier (degree of consent and control, ect.) [8].

An alternative procedure to placing a monetary value on each of the impacts or attributes of the decision consequence is to evaluate them in terms of "utility". In the terminology of multi-attribute decision analysis the problem of valuing each of the decision consequences in terms of utility is referred to as assessing a multi-attribute utility function over the n attributes. The basic idea of multi-attribute utility measurement is to elicit the value of each attribute in terms of the decision-maker's preference, one attribute at a time, and then to aggregate them by using a suitable aggregation rule and weighting procedure.

Probably the most widely used, and certainly the simplest aggregation rule and weighting procedure, is the SMART (Simple Multi-Attribute Scaling Technique) procedure developed by Ward Edwards, which involves taking a weighted linear average. This can be written:

$$U_i = \sum_j w_j u_{ij} \quad ,$$

where

w_i = the normalized importance weight of j_{th} value;

u_{ij} = the utility of i_{th} alternative on the j_{th} dimension; and

U_i = the aggregate utility of the i_{th} alternative.

There has been virtually no experience in using public attitudes i.e., indicators of overall social response, as a formal input in such methodologies. We have done a demonstration experiment, in collaboration with Edwards [9], in which public attitudes were used as a value measure in the SMART technique. In this experiment a group of decision-makers was given technical descriptions of six nuclear waste disposal sites as well as public attitudes toward these sites. Preliminary results indicated that the decision-making group was willing, and able, to use attitude measurement information in the decision process and that public attitudes were an important factor in the decisions taken by the group.

Risk Management. Looking again at Figure 13, the section called Risk Management refers to the actions one might take, given the information of the technical system, its risks, and the corresponding social attitudes. The possibilities to resolve conflicts lie basically in changing the technological system, the social system or the decision process.

Technology Change. One obvious advantage of risk estimation studies is that of identifying risks that might be too high and pinpointing the optimal way to change the technology in order to reduce them. Our work in attitude formation suggests, however, that attitudes would not often be very sensitive to changes in the physical characteristics of the technology. That is, changing the description of the technology (e.g., underground siting) is a change in only one information input and would not necessarily be expected to result in an equally large change in public attitudes.

Social System Change. A survey of the social psychology literature on attitude change suggests that there is no quick and easy way to change people's attitudes. Research has failed to show any evidence of consistent and controlled attitude change. The regularity with which people conduct their daily lives and the persistence of customs, myths, ideals and mores demonstrates the basic stability of attitudes and their tendency to evolve rather than to change abruptly. Accordingly, ethical questions arise, attitude change does not seem to be a productive area for risk management activities.

Decision-Making. An area in which our research might be applied is in improving the decision process and in helping to broaden participation in decisions affecting the public.

This does not mean that we think the decision process can be "mechanized". We do think it would be possible for the decision-making group to evaluate the alternatives by using a decision model, and then, by an iterative procedure, make the model results and their intuitive decision agree. This would provide a record of what variables were used in reaching a decision, what weights they were given and, most important, what values were assigned to them. This information could provide a starting point for increasing the transparency of the decision process. The wish for more participation in public decision processes is one of the important underlying issues in the opposition to technology.

Concluding Remarks. Although risk assessment is still in a research stage, we feel that the value of the potential results has been shown. At present the major contribution of such studies is a better understanding of the technical and social systems being investigated and the acquisition of insights into their interactions. Methodologies for risk estimation and evaluation have been identified, developed, and their feasibility demonstrated through application. Future work will concentrate on the operational application of these methodologies and the development of risk management strategies.

Task: Strategies

Computerization of the Energy Systems Program's Modeling Effort (W. Orchard-Hays)

The entire set of regional and global models, which the energy program's modeling group is creating, consists of diverse parts which are being formulated specifically for this effort. The set of models cannot properly be considered as forming one grand supermodel; on the contrary, they are rather loosely coupled by intent. Neither are they a collection of existing models--though based in varying degree on prior work at IIASA and many other centers--but rather a coordinated set that are subject to continuing refinement and adjustment to meet the overall goals of the project. For example, there has been a conscious--even determined--effort to avoid over-elaborate detail in areas which appear to be only incidental to the main study. On occasion, however, it is found necessary to develop more detail than anticipated in order to assure consistency and meaningful results. Consequently, a considerable degree of convenient flexibility is required in the computational schema.

Two other elements of diversity arise from the following circumstances. First, prior modeling work from which we are building, in part, has been done on a variety of computing systems and in a variety of styles. Second, the theoretical approaches differ markedly among the various component models and their forerunners. Thus a macro-economic model based on econometric concepts and fitting of time series differs in basic assumptions and techniques from a linear programming (LP) model. Hence it is necessary to be able to accomodate, operationally, both a variety of programming styles and convenient mechanisms for interfacing them and testing the sensitivity of the models to the interfacing techniques.

The central model of the set is a linear programming model and several other components are either LP models or have LP alternates. Thus a powerful LP system, with interactive capability, is one prime requisite. Of the non-LP components, only two have heavy computing requirements. The remaining components are much more characterized by data manipulation and this is likewise a strong requirement for the LP models and at least one of the others. In order to achieve the flexibility required, for instance, it is not sufficient to simply solve an

LP model with variations in a few parameters, although this is certainly one important usage. It must be possible to regenerate the model with structural changes on demand. Indeed, in many cases, generation of a model is a more complicated and costly task than obtaining a solution.

Another requirement is the ability to generate reports of various kinds which include both source data and computational results, as well as simply informational and record-keeping logs relative to the modeling work itself.

It is clear, therefore, that not only a fairly powerful computer with extensive and highly organized auxiliary storage is necessary, but also a hierarchy of software levels which can be readily coordinated and flexibly controlled. The nature of the modeling effort itself, vis-à-vis computing, is much more akin to software system development than to massive calculations such as are required in engineering work or nuclear studies.

Finally, the ability to operate the computing facility remotely is highly desirable since IIASA does not have sufficiently powerful in-house facilities. Furthermore, operation from NMOs is to be exptected and immediate transferral of such a system is a practical impossibility except under the most special circumstances.

Fortunately, a comprehensive computing system meeting essentially all these requirements is available. The required hardware and basic software is an IBM 370 with virtual central storage--namely, models 145, 155-II, 158 or 168--operating under the VM/CMS system. Such a configuration is already widely used in the US and is now available in various centers in Europe. Three of four exist in Vienna although, for the most part, these are in private commercial establishments for in-house use. The IBM Center in Vienna has a 155-II as a test facility which operates under VM/CMS during the main part of work days. IIASA has used this facility since mid-January 1977 for preliminary development. Unfortunately, neither the operational style (it is not a part of a regular service facility) nor the telecommunications setup are fully satisfactory. Although these deficiencies could probably be corrected without much difficulty, IIASA is preparing to utilize a much larger VM/CMS facility in Pisa, Italy via a leased line and under very favorable usage rates. This facility is operated by CNUCE which is a part of IIASA's Italian NMO. It is operated entirely as a service and research facility for scientific and educational institutions.

The VM/CMS system was designed and intended for interactive use via telecommunication links. Furthermore, it already includes an extensive array of basic data file facilities, a sophisticated context editor, various programming language processors, and so forth. Beyond this IBM-provided software, however, a number of powerful application systems have been developed under the VM/CMS umbrella. Of particular interest here, a comprehensive mathematical programming system (MPS) was developed at the National Bureau of Economic Research, Inc. between 1972 and 1975. This system, known as SESAME, was developed with public funds to make available to the noncommercial scientific community an MPS comparable in power and scope to the commercial systems, such as IBMs, MPSs, CDCs APEX, and privately developed systems such as MP-III (by Management Science Systems, Inc.) and UMPIRE (by SCICON, Ltd.). Additionally, however, SESAME was to operate interactively (rather than in batch mode as most other MPSs) and include simplified control mechanisms suitable to its mode of operation. The major part of SESAME, as an MPS, was completed in the winter of 1974-5 and has been operating reliably since then. It was installed at the Pisa center in Spring 1975 and also at a facility near Brussels.

The chief developer of SESAME was Wm. Orchard-Hays who has designed and often implemented a large proportion of existing MPSs beginning with early LP "codes" at the RAND Corporation. Based on experience with earlier systems, he undertook to add to SESAME a comprehensive data management subsystem specifically oriented to mathematical programming work but with considerable capability of a more general sort. This addition is known as DATAMAT (and is similar to the DATAFORM extension to MPS-III which has been used in other energy studies). DATAMAT was substantially completed by Spring 1975 when Orchard-Hays left to join IIASA, but little further work on this subsystem was done until January of this year. Since then, he has extensively enhanced and tested DATAMAT at the IBM Vienna facility and it is now being used as the main mechanism for generating LP models in the energy program as well as for various other data manipulation tasks. Elaborate report-generation features have just been checked out and are now ready for productive work.

The file handling features of VM/CMS are inherently flexible and convenient and permit coordination of data and results within the context of different modeling methodologies. No one application system or package will meet all our requirements, but under this comprehensive computing system--really system of systems--all necessary tasks should be feasible and with a large measure of convenience and flexibility.

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