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MESAP-III:
A Tool for Energy Planning
and Environmental Management

History and New Developments

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STE-Seminar, KFA Jülich, 6. September 1994

Abstract: MESAP-III: A tool for energy planning and environmental management. History and New Developments

The utilization of energy contributes substantially to environmental pollution. Increasing environmental degradation calls for quick decisions in the field of energy and environmental planning, which anyhow are subject to a high degree of uncertainty. Major investments in this field are necessary to cope with the challenging environmental targets and to provide sufficient, affordable and reliable energy for a growing population in an environmentally compatible way.

In the past so called energy master plans were developed with substantial amount of financial expenses. In most cases, the master plan focused on the expansion of one energy sector such as the electricity generation. It contained a forecast of energy or electricity demand based on certain macro-economic, technical, behavioral or engineering judgement criteria. In a second step it was analyzed, how the calculated demand could be met with a minimum of financial expenses. The master plan described a future energy scenario, which was based on a set of assumptions. These assumptions were based on uncertain parameters, which could not be influenced by the decision maker himself, such as the world energy prices or the economic development of a country or a region. Once one of these important assumptions were changed, the master plan had to be revised.

Today it is agreed that energy and environmental planning should be regarded as a continuous process and not a one-time-action. Planning is not to be seen as a prediction of the future but as a tool that gives a rational basis for taking decisions at stage today that involve high investments and which have a long impact into an uncertain future. Energy and environmental planning should not be an end in itself: it should be oriented towards specific solutions for explicit problems. Otherwise it will miss its main objective which is to assist the decision maker to find a good solution for a complex problem. Because of the complexity and the many linkages, energy and environmental planning should be integrated, which means that it should consider all economic sectors, all fuels, interregional interdependencies, the analysis of demand and supply and the feedbacks between the energy system, the economy and the environment.

The increasing complexity of energy and environmental problems require the processing of more and more information. A substantial quantity of data must be processed in order to arrive at sound conclusions and defendable policy recommendations. Energy models have been developed to process this information using validated scientific operations research methodologies. If in the dynamic planning process the energy planner wants to provide decision support on a solid basis and within short time limits, effective data management

gains a new dimension of importance.

Energy models have a long history. Initially most of the models focussed on single fuel issues or one energy subsector. An example are the electricity generation planning models in the sixties. However as the understanding of the integrated nature of energy issues increased especially concerning fuel substitution strategies, the models started to analyze the whole energy system. The next generation of models included the interactions with the economy and the environment and became widespread during the late seventies. The complexity of these energy models has been greatly influenced by the tremendous progress in the information technology. What was impossible to accomplish using yesterday's costly mainframe computers can now be handled easily with today's more powerful micro- and personal computers, which cost a fraction of the mainframe computers. Today largely because of this progress, these models have been further developed towards decision making tools.

The most widespread energy models, like WASP [1], MESSAGE [2], [3], EFOM [4], MARKAL [5], [6] etc. were developed over a long period of time and represent an important methodological know how. During the development of these energy models the energy planners tended to put much emphasis on the exactness of the mathematical algorithms. The data requirements were of secondary importance. The model was fed with the data, when the calculation process required them. The data was grouped according to the sequence of the model calculations and not according to logic entities. As a consequence data management became very difficult. In WASP for example, the technical and economic information of one power plant is scattered throughout the model set. Creating a data set was a complex, strenuous task, paved with many errors, since no check for consistency or completeness of the data was available. Scenario management and sensitivity analysis was left to the planner. As the amount of information fed into the model increased, more and more results were produced, sometimes several hundred pages for one model run. The tools to analyze these results did not keep pace with this development. Today they are still very rudimentary and basically can only produce tables.

The fact that there is no standardized format and data access protocol for information related to energy and environmental systems becomes more and more disturbing. All existing energy models use their own proprietary database format which is structured according to the procedural flow of information in the related models. We have huge models with very sophisticated scientific methodologies but transferring data or results automatically from one model to another is almost impossible even if the contents of their data sets overlap substantially. Reusing the same data within a new case study becomes extremely difficult and is rarely done although information gathering accounts for the greatest part of cost and time in a planning study. The format of the databases is complex and only the modeler himself or experienced users can interpret the stored figures. Planners who are not using the affiliated model can in general not interpret the numbers stored in the database. Because the model databases have no retrieval features and can only be used to run the affiliated computer model, they cannot be used as an information system for the case study. In general they are too specialized to store all information relevant to an energy system. Information going beyond a model run such as planning targets, historical data or general statistics cannot be stored. The planner is forced to use different tools to handle these information.

More and more options, refinements and amendments increased the size and complexity of the models to a degree that today it is nearly impossible to modify them any longer. The structure of these energy models reached a level of complexity that it becomes nearly impossible to integrate methodological improvements such as multi-objective optimization, stochastic programming or fuzzy set mathematics into the existing computer code.

Today we have reached a tremendous diversity and quality of methodological approaches but we are lacking convergence in information management. Information is the basis of any systems analysis. Methodologies are the tool to analyze and interpret the information in order to solve problems. Both depend on each other and the quality of decision support depends on the quality of the methodological algorithms as well as the information management capabilities. The methodologies have been pushed very far but the science of information management on the other side has been seriously neglected. The most sophisticated energy planning models still use ASCII files for data storage although relational, hierarchical or network database systems, whose development also started in the seventies, are widely used in other areas of computer science and business administration. It seems that the tremendous progress in software development of the past decade has very long not been noticed by the modeling society. Only in the last years we can observe first trends to integrate database technology and state of the art user interfaces with the existing planning models such as the MARKAL User Support System MUSS [7] developed at BNL, the ENPEP package [8] from Argonne National Laboratory, the LEAP model [9] from Stockholm Environment Institute and Boston Center, Tellus Institute or the SUPER/OLADE-BID package [10] developed in Ecuador.

In the early eighties IER at the University of Stuttgart started the development of the MESAP [11] system, the Microcomputer based Energy Sector Analysis and Planning system. The main objective was to improve the planning capabilities of existing models by integrating modern information management tools with the existing operations research methodologies. The first version was developed on a UNIX-based workstation system. MESAP included several FORTRAN models located around a hierarchical database system developed at the University of Stuttgart. Five years later MESAP was transferred to the PC under the DOS operating system. Today the third version of MESAP is being developed for PC's with a "Windows" based graphical user interface.

The main design principles of MESAP are flexibility concerning structure and aggregation of the analyzed system, modularity of the involved methodologies and a rigorous standardization of the model database format. MESAP combines on one computer the "classic" FORTRAN energy planning tools such as MESSAGE, WASP, MADE, MAED, INCA and EFOM and integrates them with new methodologies for different planning tasks such as operation planning, highly disaggregated energy system simulation, integrated ressource planning and general equilibrium modeling. The new central MESAP database is called NETWORK [12],[13] and is based on the relational database concept. This database fulfills two main functions: it is a case study information system which offers all retrieval features of current information management tools and it serves as a standardized database for process-engineering oriented energy and environmental planning models.

Standardization of the data structure is achieved through the representation of any energy and environmental system as a network diagramm the so called "reference energy system (RES)". The RES consists of different fuels and other material flows that being converted in a chain of processes. The only restriction in the design of NETWORK is that the energy and environmental system must be represented as a network of commodities, flows and processes. This approach allows the planner to specify the level of detail in the analysis and creates a model independent database structure that is no longer adapted to the algorithms. The concept foresees that the planning models using the RES-approach adapt to the NETWORK structure. Information management has thus moved to the center of energy planning. Since different models are using the same standardized NETWORK database format, data sharing and exchanging is improved. The planner is supported by a state of the art user interface and strong analysis tools, that now can be shared between the models.

The standardization of data structures allows the connected models to exchange input data, assumptions and results. But the easy linkage of different models will not only improve the planning capabilities. It will also lead to an integration of existing and new methodologies in the long term. Thus the beneficial effects of standardization, widely accepted in other domains of engineering, will then reach the realm of energy modeling.

MESAP has been applied in many case studies and its concept has proven powerful and flexible enough to still be up-to-date. This was mainly achieved through the strict modularity of the concept coupled with a standardized data interface that allows the uncomplicated integration of new methodologies. Thus MESAP allows the planning team to base their joint work on a commonly agreed set of data, methodologies, assumptions and objectives. It allows an easier communication and understanding among the expert team of different scientific faculties and allows them to concentrate on the essentials of the joint planning effort.

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1 Energy planning and environmental management: past and present

The role of energy planning and environmental management as an instrument for decision making is gaining more importance in a world facing increasing environmental degradation, a fast growing population and rising energy consumption. Decisions in this field are characterized by the long range of their consequences, the uncertainty of the future evolution and contradictory evaluation criteria of a multitude of aspects. The increasing complexity of energy and environmental problems has not only changed the goals and objectives of the analysis but has also created the need for new methodologies and tools. In this paper we give an overview of the tendencies in energy planning and environmental management and we propose a new conceptual design for energy and environmental planning tools.

1.1 The planning problems

The problems in energy planning and environmental management have changed in the past two decades. In the past the level of industrialization was lower, the density of population was smaller, and the traffic activities were less intensive. Energy was available in abundance and the environmental problems were locally limited and relatively easy to handle. Today the utilization of energy contributes substantially to environmental pollution. Industrialization in many countries has been very strong, the world population has increased extremely, and the traffic in our mobile society has more than tripled. As a consequence environmental damages have increased substantially, as the discussion on acid rain and greenhouse gas effects indicates. Today it is consensus that the increasing environmental degradation has become global and that some damages might be irreversible. This calls for quick decisions. Major investments are necessary to achieve the challenging environmental targets and to provide sufficient energy with a reliable supply system for a growing population in an environmentally sustainable way.

The nature of this complex problem in the field of energy and environment is characterized by many interactions between energy, economy and environment that have to be taken into consideration. The complexity makes it difficult to find simple, straightforward or even optimal solutions. In addition the evaluation of strategies depends on subjective criteria that differ from interest group to interest group. These many aspects of the problems make it necessary to involve an increasing number of disciplines into the decision making process. The multi-disciplinary character of the analysis creates communication and harmonization problems.

Furthermore the increasing complexity of energy and environmental problems require the processing of an immense amount of information in order to derive sound conclusions and defendable policy recommendations. Because the future developments of key parameters are unknown the planning assumptions underlie a high degree of uncertainty. A systematic analysis of the future energy and environmental system necessitates to apply scenario techniques and sensitivity analysis, methods that even increase the number of information.

1.2 The planning approaches

In the past so called energy master plans were established with substantial amount of financial expenses. In most cases, the master plan focused on the expansion of one energy sector such as the electricity generation. It contained a forecast of energy or electricity demand based on certain macro-economic, technical, behavioral or engineering judgement criteria. In a second step it was analyzed, how the calculated demand could be met with a minimum of financial expenses, with lowest environmental degradation, with optimal labor effects, with best intertemporal resource allocation or other decision factors. The master plan was considered to be valid over long time ranges. It described a future energy scenario, which was based on a set of assumptions for important parameters, that could not be influenced by the decision maker himself. Examples are the world energy prices or the economic development of a country or region. Once these important assumptions were changed, the whole master plan had to be revised.

Today it is agreed that energy and environmental planning should be regarded as a continuous process rather than a one-time-action. Planning is not to be seen as a prediction of the future but as a tool that gives a rational basis for taking decisions at stage today that involve high investments and that have a long impact into an uncertain future. Planning becomes a dynamic iterative process that does not only consider energy aspects but has to include economic, environmental and social concerns. It includes uncertainty aspects and tries to identify robust solutions that offer a high degree of effectiveness even for changing assumptions of the system parameters. Finally energy and environmental planning cannot be seen as an end in itself: it must be oriented toward specific decisions for explicit problems.

In the seventies and the early eighties, planning was basically done on a national level. This approach was sufficient when the problems were manifested on a regional scale. Today the environmental issues of local and global importance need harmonized strategies on all levels: globally, national, regional and local. Worldwide goals such as a limit on CO_2 emissions are targets that should be reached on a national level. Policies should be worked out to implement these targets on a regional and local level using strategies such as increasing the market share of co-generation, promoting renewable energy technologies, or focussing on the rational use of energy. International climate conventions and global environmental arrangements seem to become a necessity to give perspectives to a sustainable development of mankind.

There are other incentives to enhance the existing planning methodologies. Many governments have started to evaluate in detail the environmental effects of a project before it can be realized. This calls for new methodologies suited to these special issues, such as environmental assessments. Also many developing countries today require a dynamic planning framework that integrates energy and environmental issues in order to perform the necessary analysis to obtain international support for development projects.

1.3 The planning tools

The changing aspects of the problems and approaches necessitate modifications and enhancements of the existing planning tools. A new generation of computer models and planning instruments is being developed.

One of the reasons that computer models have been developed is that the we cannot make experiments with the reality in the area of environmental management. Therefore a representation of the real world in a model is needed. Energy models have a long history. The first energy models were based on econometric theories and correlated energy demand with macro-economic indicators like the GNP. The technology oriented "process-engineering" model generation initially focussed on single fuel issues or energy subsectors, such as the electricity generation planning models in the sixties. However as the understanding of the integrated nature of energy issues and the interactions with the economy and the environment became widespread during the seventies, energy models have grown in terms of complexities and breath. The complexity of models has been greatly influenced by the tremendous progress in the information technology. What was impossible to accomplish using yesterdays costly mainframe computers can now be handled easily with today's more powerful micro- and personal computers, which cost a fraction of the cost of the mainframe computers. Today largely because of this progress, in depth academic research has been carried out to enlarge energy modeling toward a tool that is optimized for decision support.

Planning tools in the past concentrated frequently on specific modeling issues. Their methodology often focussed only on one aspect of the problem such as costs, environmental damages, or the energy supply security (expansion planning). Usually only one economic sector such as the household sector or the industry was analyzed or only one fuel such as electricity was considered. Today planning tools are required to integrate energy, economy and environment issues in one framework. They focus on the whole system rather then on one sector or fuel and they integrate several methodologies in order to analyze all aspects of the problem.

The most widespread energy models, like WASP [1], MESSAGE [3], EFOM [4], MARKAL [6] etc. were developed over a long period of time and represent an immense pool of knowledge. The models of the past were created using procedural languages and they concentrated on the mathematical algorithms. The energy planners tended to put much emphasis on the exactness of the mathematical algorithms of the model. Data management issues were of secondary importance since the amount of data treated was easy to handle. The information was arranged according to the procedural flow of the incorporated algorithm. The model was fed with the data, when the calculation process required it. Therefore, the data input format was complex and difficult to understand. Data were grouped according to the sequence of the model calculations and not according to logic entities. In WASP for example, the technical and economic information of one power plant is scattered throughout the model set. Therefore the information in a computer file for a planning model could not be retrieved otherwise since only the associated model possessed the direct access to the file and the key to interpret the data. No general retrieval functionality was provided as it would be the case for an information system. Creating a data set was a complex, strenuous task, since no possibility was offered to check the consistency and completeness of the data. Scenario management and sensitivity analysis was left to the planner.

As the amount of information fed into the model increased, the models produced more and more results, sometimes several hundred pages for one model run. The tools to analyze these results did not keep pace with this development. Today they are still very rudimentary and basically can only produce tables.

More and more options, refinements and amendments increased the size of the models substantially. Today they have grown so large that it is hardly impossible to modify them because the structure and complexity of the models reached a level, which can not be controlled any more. Methodological improvements such as multi-objective optimization, stochastic programming or fuzzy set mathematics cannot be integrated into the existing models.

There is no standardized format and data access protocol for information related to energy and environmental systems. All existing energy models use their proprietary database format which is structured according to the procedural flow of information in the related models. We have huge models with very sophisticated scientific methodologies but transferring data or results automatically from one model to another is nearly impossible even if the contents of their data sets overlap substantially. Reusing the same data within a new case study becomes extremely difficult and is rarely done although information gathering accounts for the greatest part of cost and time in a planning study. The format of the databases is complex and only the modeler himself or experienced users can interpret the stored figures. Planners who are not using the affiliated model can in general not interpret the numbers stored in the database. Because the model databases have no retrieval features and can only be used to run the affiliated computer model, they cannot be used as an information system for the case study. In general they are too specialized to store all information relevant to an energy system.

Information going beyond a model run such as planning targets, historical data or general statistics cannot be stored. The planner has to use different tools to handle these information.

Today we have reached a tremendous diversity and quality of methodological approaches but we are lacking convergence in information management. Information is the basis of any systems analysis. Methodologies are the tool to analyze and interpret the information in order to solve problems. Both depend on each other and the quality of decision support depends on the quality of the methodological algorithms as well as the information management capabilities. The methodologies have been pushed very far but the science of information management on the other side has been seriously neglected. The most sophisticated energy planning models still use ASCII[1] files for data storage although relational, hierarchical or network database systems, whose development also started in the seventies, are widely used in other areas of computer science and business administration. It seems that the tremendous progress in software development of the past decade has very long not been noticed by the modeling society.

Only in the last years we can observe first trends to integrate database technology and state of the art user interfaces with the existing planning models. Examples are the MARKAL User Support System MUSS [7] developed at BNL, the ENPEP package [8], from Argonne National Laboratory, the LEAP model [9] from Stockholm Environment Institute and Boston Center, Tellus Institute or the SUPER/OLADE-BID package [10] developed in Ecuador or the IKARUS modeling framework [14] developed in Germany.

As a conclusion we can state that the old model generation is becoming less and less suitable for the growing challenges of the complex planning tasks that a modeler is facing today. New tools should be developed. A planning model today has to offer more than a sophisticated algorithm. It should be user-friendly and should include powerful data management features. Data management has become a crucial role in the dynamic planning process, if one has in mind the huge amount of information that has to be treated to cover all the planning aspects mentioned above. The data management systems help to organize the information, to reduce retrieval times and to create a coherent data set for the planning models. It helps the planner to quickly set up his assumptions, to analyze the modeling results and to deduce decisions from these results within short time limits. Utilizing the data management system becomes a major part of the planning task.

The future generation of planning tools are modular systems rather than one single program. In most cases they incorporate the sophisticated algorithms of the old model generation or the old models themselves and add a user interface and a data management system to them. They are created using new object oriented programming tools and languages. Their data manage-

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[1] ASCII: standardized code to represent all characters of the english alphabet including special international characters

ment systems are based on sophisticated and powerful databases. The new planning tools do not only "model" the analyzed system but they are enhanced by components that provide decision support, a support to identify those recommendations that help to reach the planning goals.

1.4 The planning goals

The planning goals in the field of energy planning and environmental management have slightly shifted over the last decades. Planning started with a single fuel or single sector approach, where the least cost expansion path or the optimal operation of a given technology park had to be determined. After the first oil crisis the issue of fuel substitution arose and the goal of the studies moved toward finding an optimal fuel mix for the energy supply system. This made it necessary to evaluate the potential of all available resources and the feasibility of new energy technologies. More and more important became the assessment of the environmental impacts of the energy system (air pollution, climate change) and the interactions between the energy system and the economy, e.g. to estimate the effects of taxation measures. On the demand side the analysis was extended toward the useful energy level or even to the level of energy services. Issues such as demand side management, least cost planning or integrated resource planning had to be handled. Actual studies try to integrate all aspects mentioned above into one analysis in order to assess all possible strategies to limit environmental damages.

Today the goals of the planning exercise are more oriented toward finding a general consensus between different involved target groups of the society that have different attitudes and very often conflicting objectives. These interest groups can range from people movements, lobbying groups, municipalities to governments as the greenhouse gas discussion is demonstrating. In general, planning tries to evaluate and quantify the long-term effects of policies and strategies or of capital intensive decisions in the field of expanding and operating the energy supply system and coping with arising environmental problems. Besides policy analysis, expansion planning or operational planning, the primary aim remains to foster rational decision making, and to arrive at sound conclusions and recommendations that are based on a broad consensus of opinions.

Achieving these goals is only possible with an integrated approach for energy planning and environmental management. Integrated in this sense means that the approach should offer methodologies suited for the study of the different components of the analyzed system. These tools should be flexible enough to be easily adapted to the needed aggregational level. They should be designed to be easily combined in order to study the principal interactions between the different elements of the analyzed system. This will help to identify the various factors of influence on the political, social, cultural, technological and ecological level. The MESAP approach (Microcomputer based Energy Sector Analysis and Planning system, [11]) presented in the following section is such an integrated approach that allows to consider all aspects and facets of the complex interactions in the energy sector and enables to expand the goals of the analysis toward the new issues of the future.

2 The MESAP concept

2.1 The requirements for an integrated planning tool

The basic requirement for an integrated planning tool is the availability of a set of validated planning models adapted to the different planning tasks and objectives. The system should include a powerful central data management system that can be used to store and manage case study related data. Access should be provided to external information systems such as central information pools that are available today for many purposes.

In general model handling and data entry should be easy. They should allow a detailed analysis within reasonable time. A user friendly interface implies form menu driven program flow, based data entry, a feature for consistency checking, on-line error trapping and a context sensitive help system. The system should be designed in such a way, that sharing data between different case studies and different models is uncomplicated. This would increase the ability to reutilize data, an important cost reducing factor.

In order to facilitate the evaluation of different strategies, the scenario analysis technique should be integrated as well as an assistance for sensitivity analysis. Finally there should be powerful and flexible analysis tools to create customized graphics and user defined reports of all kind.

The system should include decision aiding tools in order to provide convenient procedures to compare the different alternatives within a formalized framework allowing the user to be fully aware of the implicit values integrated in the comparison. Decision aiding tools are designed to help the decision making process and to enhance the capabilities to use effectively the results of the analysis.

2.2 The MESAP philosophy

The basic idea of the MESAP-System [15] is to combine the most efficient energy planning tools available for the different planning tasks on one computer, to integrate them in a modular way through a central database system and to support the analyst as much as possible by a user friendly interface. In order to provide an affordable software/hardware package, it was decided to base the concept of the MESAP-System on microcomputer and personal computer platforms and to be restrictive in terms of expensive commercial software packages.

MESAP has a long history. Its creation dates back ten years when the first version was developed on a UNIX-based workstation system. MESAP included several FORTRAN models such as MESSAGE, WASP, MADE, MAED and INCA located around the hierarchical database system RSYST [16] developed at the University of Stuttgart. Five years later MESAP was transferred to the PC under the DOS operating system. Today the third version of MESAP is being developed for PC's with a "Windows" based graphical user interface. The new central MESAP database is called NETWORK [12], [13] and is based on the relational database concept. MESAP has been applied in many case studies and its concept has proven powerful and flexible enough to still be up-to-date. This was mainly achieved through the strict modularity of the MESAP concept coupled with standardized data interfaces that allow an uncomplicated integration of new methodologies or planning models.

With MESAP, a set of energy analysis and planning tools is provided on one machine, or in an interlinked network of computers under one software environment. This configuration allows the energy planning team and the system analyst to base their joint work on one commonly agreed data base, the same methodologies, the same set of assumptions and on common objectives. This procedure allows an easier communication and understanding among the expert team of different scientific faculties. The planners will not have to discuss about basic assumptions, methodologies and data, but they are able to concentrate on the essentials of the joint work and the common interpretation of the results.

2.3 The MESAP design principles

The MESAP concept can be summarized by a set of design principles.

2.3.1 Open data interface

The core of the MESAP package forms the NETWORK Database, which is able to store all information concerning a case study. The NETWORK Database makes use of the fact, that most tools for energy analysis and planning are structured in a network format. The network approach is realized in most MESAP modules. The scope of the network can vary from one single technology assessment to a complex regionally and sectorally highly disaggregated energy system model. Different analysis and planning modules have direct access to the central network data base and can thus exchange statistical information, technology data, economic assumptions and model results. The NETWORK database can be addressed directly by the planner to store, retrieve, process or present the required information or to prepare the data for model runs or other purposes. All databases and modules can be invoked through the graphic oriented MESAP monitor. A link to central external database systems allows to retrieve data from other information systems. Finally the open data interface makes it easier for the planner to integrate additional models.

The open data interface concept provides the possibility to utilize the same information with different tools and models, e.g. to simulate around an optimization result. Additionally the standardized relational data format will facilitate the exchange of input data, assumptions and results with other case studies.

Standardization of the data structure is achieved through representing any energy and environmental system as a network diagram in a so-called "reference energy system (RES)" consisting of all kind of fuels or other material flows that are converted in a chain of processes. The representation of an energy and environmental system as a network of commodities, flows and processes is the only restriction in the design of NETWORK. This approach allows a model independent database structure that is no longer adapted to the algorithms in the models. Instead the new concept forces the planning models using the RES-approach to adapt to the NETWORK structure. Information management has thus moved to the center of energy planning, the level of detail of the analysis is left to the planner. The planner is supported by a user friendly graphical interface for entering and updating data. Strong analysis tools can be shared between different models. Data handling for different models is improved because all models are using the standardized NETWORK database format with a state of the art user interface. Finally NETWORK offers the same retrieval features as modern information systems.

2.3.2 Modularity

Modularity means, that MESAP provides a separate module with a well defined methodological approach for each planning task. Through the modular design, the MESAP-system is expandable and adjustable for new methodologies. New modules can be added, modules can be adjusted to the specific needs of the planning objective and proprietary programs from the user or commercial packages can easily be linked to the system.

2.3.3 Flexibility

Flexibility means, that MESAP can be adjusted to the problem to be analyzed and not vice versa. Flexibility is meant in both ways, methodologically and in terms of data intensity. For different issues, different methodological approaches will be necessary. The available statistical data, which are the basis of any model run, have different formats and aggregation levels in different countries and for different problem areas. MESAP as analytical tool provides several different methodological options to address specific problems and is adjustable to the available data. This implies that the regional and sectoral aggregation and the degree of detail in the analysis of the energy system can be defined by the user according to planning objectives and data availability. MESAP is designed in such a way, that with the availability of new data or additional information or new aspects to be considered, the size of the data set, the level of aggregation in terms of sectors, fuels, time steps, regions etc. can grow as well.

2.3.4 Suitability

Suitability means that the MESAP modules provided allow to analyze all questions asked by the planner. The methodologies provided are able to address the most pressing energy and environmental problems such as environmental pollution, climate change, the fuelwood problem in developing countries and energy economy interactions.

2.3.5 User friendliness

The MESAP system offers a state of the art user interface that includes menu driven flow control, form based data entry, context sensitive help and integrated consistency checking and error trapping.

2.3.6 Portability

Portability means, that the developed software programs can be implemented on different machines with a minimum of program modifications. Since the computer market is extremely dynamic, this aspect is very important. One can not be sure, whether the market leaders of today will play a significant role tomorrow. New hardware companies acquire fast substantial portions of the world market. New software products enter the market in a dynamic manner. On the other hand a harmonization process among the manufacturers of software products can be observed. A harmonization of standards will alleviate the portability issue and allows the use of commercial packages even in portable systems.. With a portable system, the hard/software configuration can be adapted to the problem size and complexity. It is also possible to use the same programs on the PC for small problems, on mainframes and even in parallel or distributed high performance computing environments for large scale problems.

2.3.7 Affordability

Since energy and environmental problems seem to increase and tend to become more complex, many people could make use of such an integrated planning tool. A high price tag for the computer system or the software reduces drastically the accessibility to such a system because a lack of sufficient funds. MESAP runs on a PC and has a flexible pricing policy with prices below US$ 5000 for the base system.

2.4 The MESAP structure

The MESAP concept places the NETWORK database at the center of the integrated planning system (see Figure 1). The analytical models are connected to this database. NETWORK is using a network representation of the energy system called "Reference Energy System (RES)"

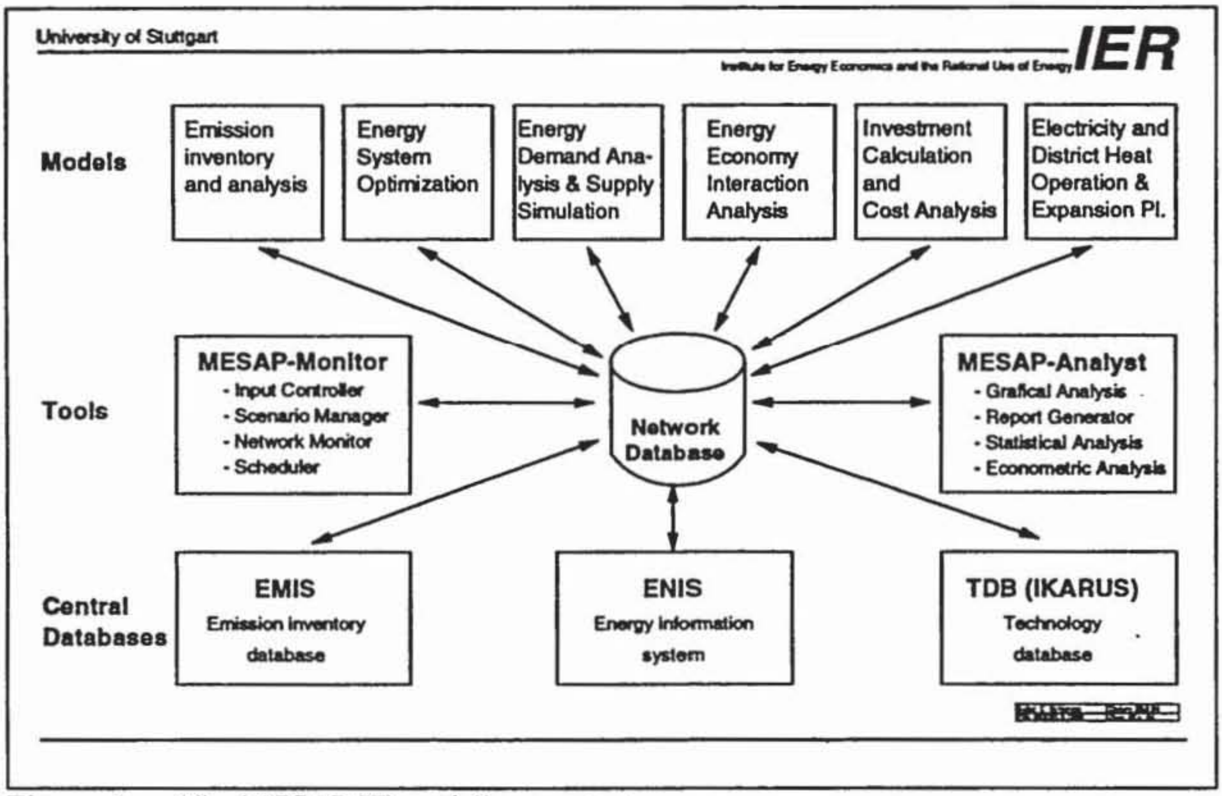

Figure 1: The MESAP-III modeling concept

to organize the data. All models are adapted to use the same standardized format of the case study oriented database. The NETWORK database thus creates a common language for energy system related data, and the same data entry, analysis and presentation tools can be shared by all models that are hooked up to this database. At the same time, the models can share case study data and exchange model results. This increases the compatibility between different modules and reduces the possibility for errors during the transfer of data and results.

Figure 2 shows the difference between the traditional way of modeling and the MESAP concept. In the past each model had its own rudimentary tools for data entry and result analysis. Often these were simple ASCII[2]-text editors and post-processors that created standardized reports to be sent to a line printer. Graphical analysis was not available. In the MESAP system there is only one database that is shared by all models. Since they all use the same standardized data format they can share one data entry tool - the MESAP Monitor - and

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[2] ASCII: standardized code to represent all characters of the english alphabet including special international characters

one analysis tool - the MESAP Analyst. The effort to make these tools user friendly and powerful can be much higher since it will be beneficial to many models, not only to one single model.

Figure 1 shows that MESAP includes modules for different aspects of energy planning and environmental management. The modules cover a broad range and allow to estimate the present and future energy demand at the service, useful or final energy level, to simulate or

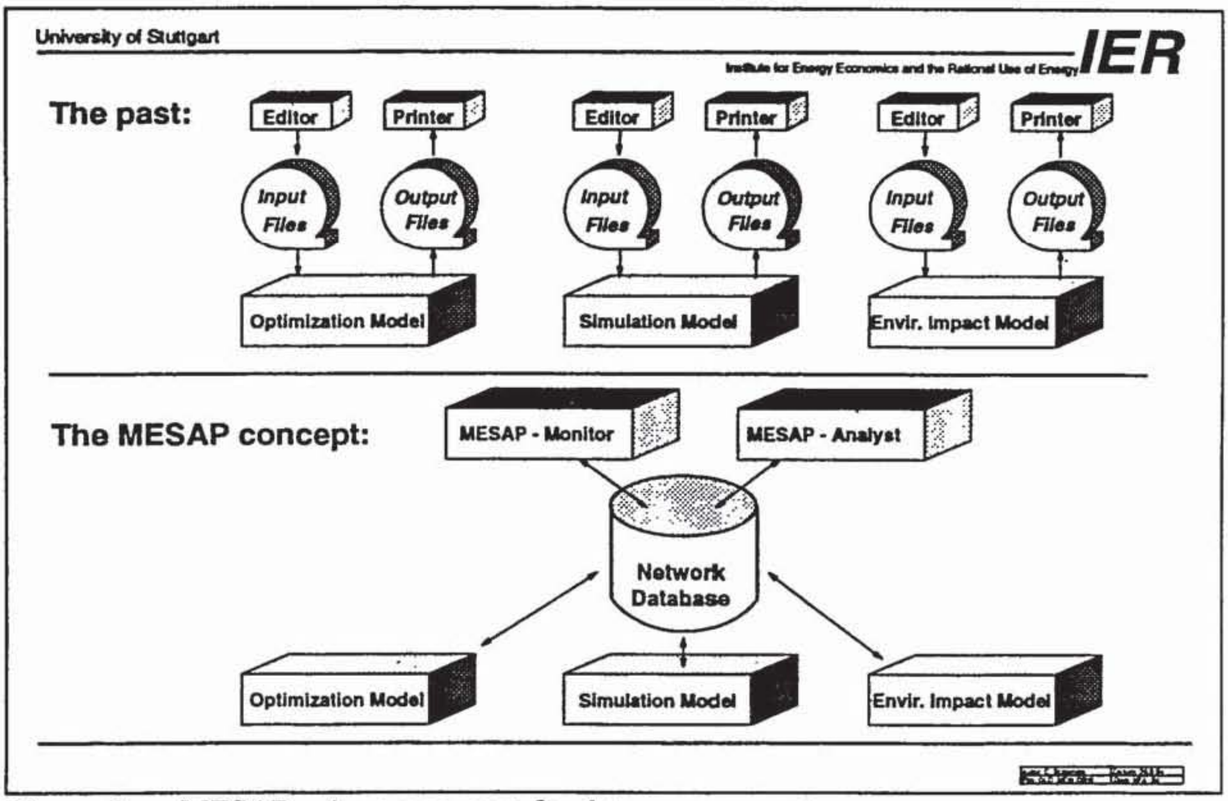

Figure 2: MESAP - A new concept for data management

to optimize the energy supply system, to perform an evaluation of the environmental impacts, to calculate the cost/benefit of different investments, to optimize the expansion or operation of district heat and electricity supply systems and to analyze interactions and feedbacks between the energy system and the economy.

Besides the case study oriented NETWORK database at the core of the MESAP system, three centralized information retrieval systems are connected to MESAP. The IKARUS technology database includes all kind of technical data for the existing energy conversion technologies. The energy information system ENIS allows to store statistics in form of time series and energy balances. The emission inventory database is the link to the models for emission analysis, usually highly disaggregated in space and time, such as dispersion models or geographical information systems. It also contains the emission coefficients for all kind of point and area sources that will allow to evaluate airborne environmental pollution.

The concept of the NETWORK database will be described in chapter 3. The different MESAP modules will be described in detail in chapter 4.

2.5 The MESAP case studies

The MESAP-System has been applied in many case studies and different fields. The predominant applications are in the field of national and regional energy and environmental analysis and planning. MESAP has also been used for energy economy and environmental analysis utilizing the cost effectiveness approach. The MESAP system has also been used to identify measures for the rational use of energy and energy conservation.

Since its ten years of existence, tailor made versions of the MESAP-System have been developed in many countries. Scientists, government agencies, energy and environmental planning consultants have been using it and MESAP has proved its suitability in several case studies. Experiences have been made in the several countries.

- in Germany in various studies of technology assessment and in the environmental field. Especially for the state of Baden-Württemberg very detailed analysis for all economic sectors and fuels have been undertaken;
- in Austria for a cost-effectiveness analysis for emission reduction measures;
- in Nigeria for a national energy planning study;
- in the Seychelles for the analysis of the future energy demand;
- in Madagascar for the setup of a detailed data base and the development of a regional energy supply concept;
- in Iran for a regionalized analysis of the perspectives of the energy supply system;
- in Zaire for the analysis of the energy system with emphasis on the rural country side;
- in Turkey for electricity expansion planning;
- in Jordan for the energy demand analysis;
- in Argentina and Morocco for specialized training courses.

The MESAP concept has proved to be appropriate for the planning tasks in the last decade and is constantly being adapted to the new requirements of energy and environmental planning in the future.

3 The MESAP core database NETWORK

The NETWORK database [12],[13] is located at the center of the MESAP system. It is a database that allows to store case study related data for all models involved in the analysis. The NETWORK database defines a standardized structure for energy system related data and represents the data interface between the models that are integrated in the MESAP system.

3.1 Objectives of the NETWORK database

The primary goal of the NETWORK project was to establish a standardized data structure for energy and environmental systems. NETWORK was developed to satisfy two functions: to be a case study information system with all features of modern information management tools and to serve as a database for process-engineering oriented energy and environmental planning models. The database design is no longer oriented along the methodological algorithms of the connected planning models but it is based upon the concept of the "Reference Energy System (RES)". This process-engineering approach to represent an energy system as a network of commodities, flows and processes is the only restriction in the design of NETWORK. Instead of adapting the database structure to the algorithms in the models the new concept forces the planning models to use the RES-approach and to adapt to the NETWORK structure. Information management is moved to the center of energy planning tools and takes the former place of the models which now have to adapt to the NETWORK structure. Data management is separated as much as possible from running a specific model. This standardization is necessary to enable different models to use the same database and the same data management facilities.

NETWORK offers great flexibility with respect to the system to be documented and the amount of information to be stored. This concerns the network structure, the sectoral and regional aggregation of the energy system, the modeling horizon covered by the time series and the type of information that can be stored. NETWORK allows to store any information related to any point in time and space for any energy and environmental systems represented by a "Reference Energy System (RES)".

NETWORK is designed as an information system. What makes NETWORK an information system? First it is easy to enter and document data, second any data encountered during a case study can be stored, and third it is easy to retrieve the information once stored in the system. In addition of being a place to store model data NETWORK can be used as a data dictionary for any information related to the analyzed system. This includes historical data, any further technology data, regional data and sectoral data. In order to fulfill these objectives, the NETWORK database system is based upon the relational data model. A transparent encoding system allows fast and flexible retrieval of any information stored in the database even for unexperienced users. NETWORK is designed in a way that it doesn't only document the data entered but that it automatically documents the structure of the energy and environmental system analyzed. The structure of the RES is used as key to locate information in the database.

NETWORK provides a state of the art graphical user interface (GUI) with form based data entry, retrieval and updating, integrated consistency checking, on line error trapping routines and a context sensitive help system. It is a standardized tool for data entry, retrieval and updating, for analysis of the results and for scenario management that can be used by any model connected. NETWORK offers transparent time series management including the treatment of historical information and projections into the future for different assumptions. Scenario management already integrated at the data entry level. Full documentation of source, quality and modifications of every information in the database should be guaranteed. Documentation of problems, objectives, strategies and assumptions within a case study is possible. The analysis tools enable to create user defined tables and graphics, user defined energy balances, graphical representations of the RES and they include statistical analysis tools.

The standardized data format of NETWORK creates an interface for planning models using a process oriented approach in analyzing energy and environmental systems. The exchange of data between case studies and planning models is facilitated through this interface and allows a better reutilization of data. Thus the coupling of different models or the direct comparison of alternative methodologies within the same case study (e.g. optimization vs. simulation) can be achieved using only one data set.

A concept for a modular architecture integrating new and existing modeling methodologies should is developed on top of NETWORK. A strict modularization of the models maximizes the facility to combine existing components with innovative methodologies to a new model. The common tools for data entry and analysis are already realized according to this modular concept. Links between NETWORK and ASCII data files bring the benefits of NETWORK to the old generation of FORTRAN models and revitalize the use of their sophisticated algorithms.

Several characteristics of the NETWORK concept, will substantially affect the costs for energy and environmental modeling. Reusing data from other models or case studies will lower the cost for data gathering during an analysis. Having powerful and user friendly tools will decrease the training periods and speed up data entry and the achievement of a consistent ("working") data set. Coupling different models within one case study will also be cheaper, since the different model runs be done on one single data set. Finally the time and cost to develop new models will be lower since the same data management, data entry and analysis tools can be used for the new models and do not have to be programmed again. Also the modular architecture will make it easier to build new methodologies on top of existing models. The costly recoding of existing know how in order to combine it with a new algorithm will stop.

3.2 The Reference Energy System Technique (RES)

The conceptual way to establish a standardized database structure and to represent the analyzed energy system is the "Reference Energy System" (RES) [17]. The RES is a graphical representation technique for energy conversion systems that has been developed in the seventies by the MARKAL-development team in Brookhaven, USA. The RES shows all possible flows within an energy and environmental network from the resource to the service and includes all technology options involved. Technically spoken the RES network diagram is a bipartite graph.

There are three types of objects used in the RES, as shown in Figure 3: commodities, processes and links. A simple set of rules apply to these objects. Commodities may represent all kind of material flows, whereas processes convert one or several commodities into other

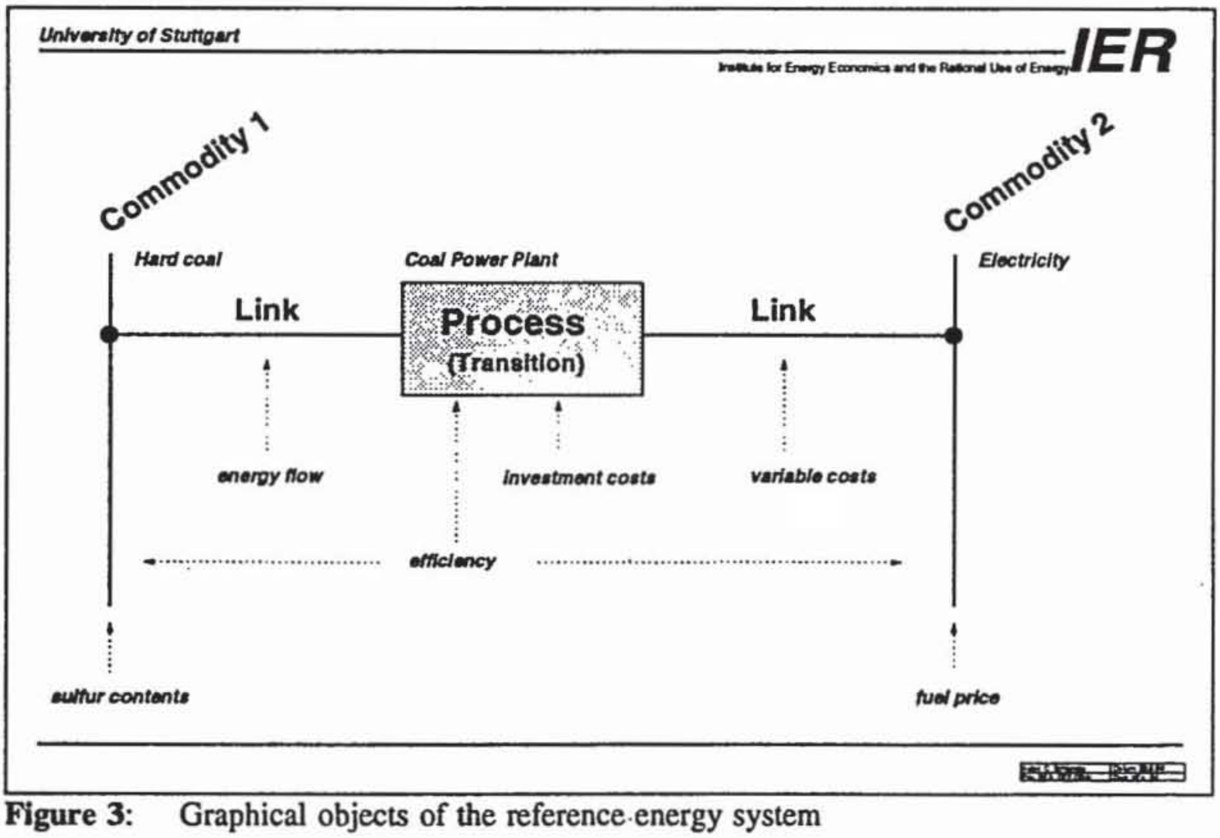

Figure 3: Graphical objects of the reference energy system

commodities. They represent a transition from one set of commodities to another set of commodities within the RES. The notion of commodities is not limited to energy carriers. All material flows that can be accounted for can be represented as a commodity, e.g. waste, steel, concrete, water, emissions, etc. In Figure 3 the commodity *hard coal* is converted by the process *coal power plant* into *electricity*. Because the network diagram is a bipartite graph, a link has always to connect a commodity with a process or the other way round. No direct links are allowed between two commodities and two processes.

The RES concept is very flexible and can be applied for many energy and environmental problems that are analyzed using a systemic approach. Any energy conversion system can be represented using a RES since the number of objects is unlimited and since the significance of the object is assigned by the user. Thus the RES can represent very complex systems, such as shown in Figure 4 for a regional energy system.

The RES does not only structure the conversion system but also offers a key that allows to unmistakably reference any information in the represented network. Information such as fuel prices, market shares, efficiencies and investment costs can be clearly assigned to an object in the RES. As shown in our example in Figure 3, information such as efficiencies, investment costs or availability factors can be assigned to a process. Others such as the fuel price, the sulfur contents or the heating value are assigned to a commodity. Finally there are information such as the market share, the variable costs or the actual energy flows that can be assigned to links into or out of a process.

The standardized RES-technique is a flexible and powerful graphical representation of an energy system. The RES technique is model independent, it offers a high degree of flexibility and the possibility to locate information within even a complex energy system by applying a few simple rules. The RES is exactly what we need to establish a model independent database structure. NETWORK is built on top of the RES concept.

3.3 Realization of the NETWORK database

The NETWORK database has been developed according to the structural framework of the "Reference Energy System" (RES) concept. It uses the relational data model as methodology to setup the database structure. The relational data model was chosen because it offers a high degree of flexibility and consistency.

Several tools are connected to NETWORK. The *MESAP-Monitor* allows to enter and update data, to manage scenarios and to control model runs. The *MESAP-Analyst* assists the user to analyze model results. Figure 5 shows the different data entry and analysis tools that are included in the NETWORK database.

The *input controller* allows to setup and to manage the RES structure and guarantees the consistency of the network structure. Data entry includes transparent time series management

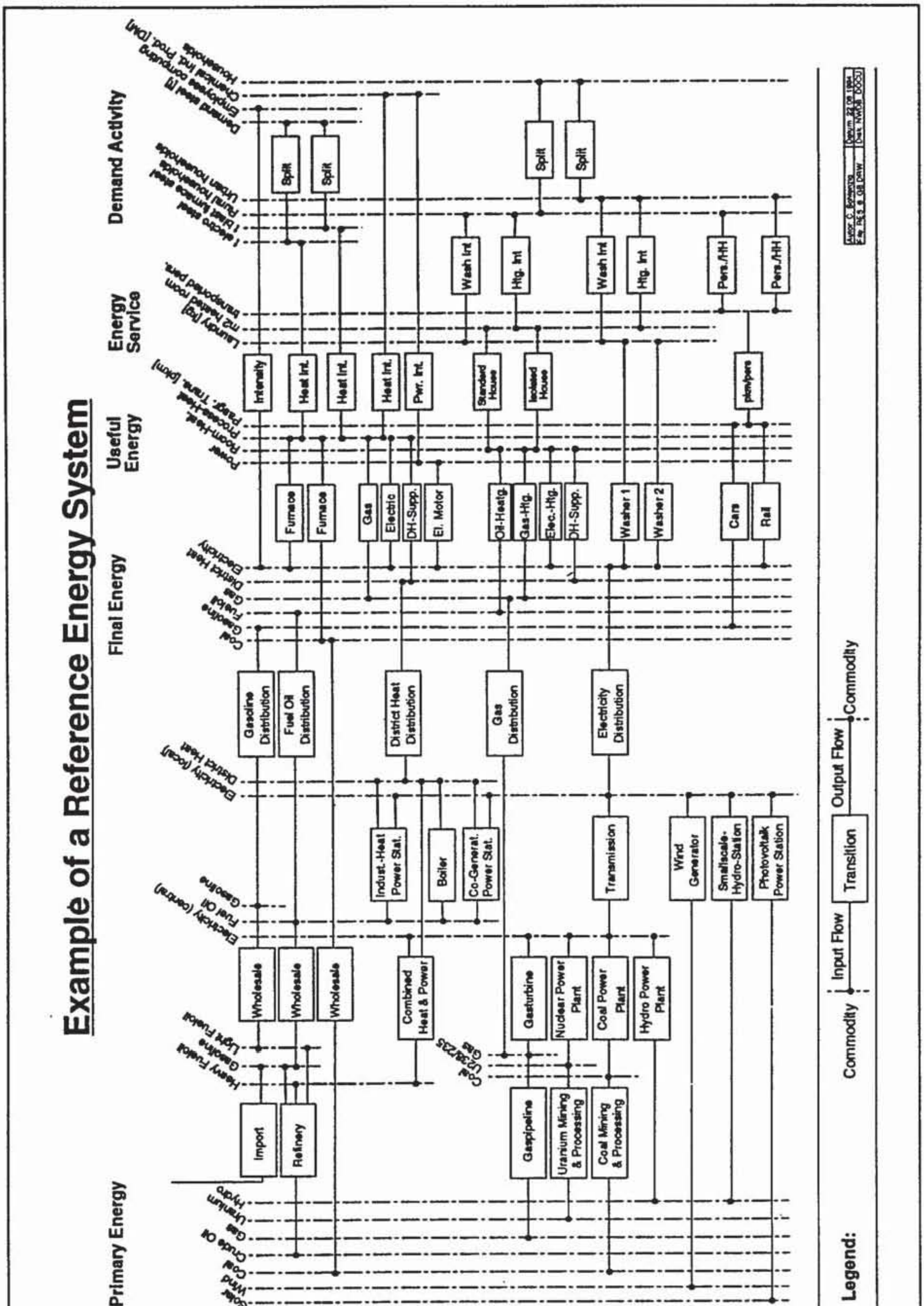

Figure 4: Example of a reference energy system

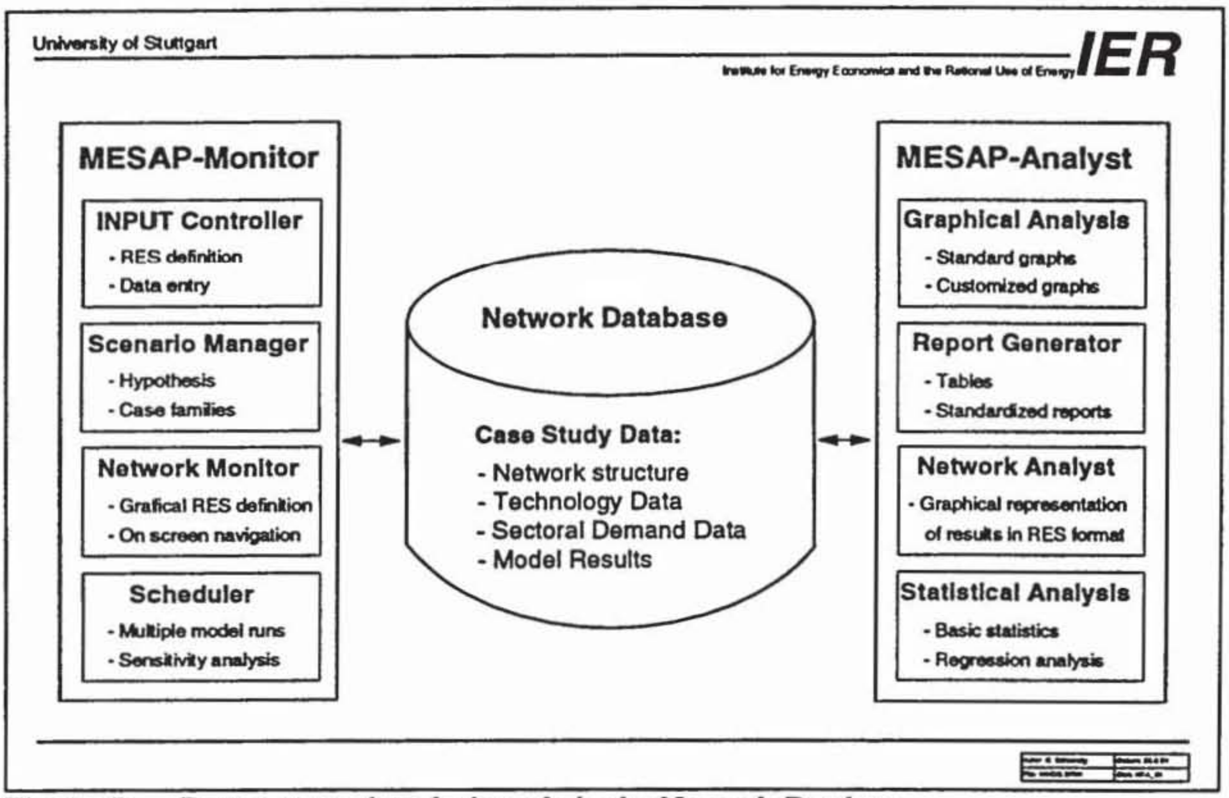

Figure 5: Data entry and analysis tools in the Network Database

and integrates scenario handling for each parameter. Several hierarchical data inheritance rules permit to easily structure the data according to the regional disaggregation and different user defined scenarios. Combined with data interpolation rules the data set in the NETWORK database becomes independent from the modeling period chosen in the case study. Using the interpolation and inheritance rules, NETWORK is abler to create the actual model data set for the selected modeling periods right before the actual model run. Of course the input controller documents source, quality and modifications of any data. Finally the expandable parameter list allows to add any information on the energy system. A SQL-link lets the user access external information systems. Import and export facilities allow the exchange of complete or partial case study data sets.

The *scenario manager* allows to create scenarios and hierarchical case families. The model parameters can be structured in different user defined groups. Different hypothesis can be assigned to the time series for any parameter in each group, representing possible future evolutions or assumptions made by the modeler. These different hypothesis can now be hierarchically combined into case families to create scenarios for a model run with a minimum of data redundancy.

The *scheduler* manages single and multiple model runs for different subregions and scenarios and offers assistance for sensitivity analysis.

The *MESAP-Analyst* allows the graphical representation of any information stored in the NETWORK database. The user is able to create an unlimited number of customized graphs to analyze model run results. Standardized as well as customized reports and tables can be generated from the contents of the NETWORK database. User defined energy balances can be calculated from the RES. Finally the MESAP-Analyst allows to perform standard statistical analysis such as the calculation of averages, regression analysis including the calculation of correlation indicators and time series analysis.

The *network monitor* is an enhancement of the input controller and allows the design any RES directly as a graphic on the computer screen. The access to the database will be achieved through on-screen navigation by selecting processes, commodities and parameter. The *network analyst* is the correspondent extension of the MESAP-Analyst and will allow the representation of model run results such as the energy flows, emissions and costs directly in the graphical RES-Format. The importance of different flows in the RES will be marked by different colors or line widths according to their importance.

The NETWORK database is programmed for PC's in Visual Basic under DOS/Windows and offers a graphical user interface that allows form based data entry, retrieval and updating. It includes an integrated consistency checking algorithm for the network structure and the completeness of the data set and a context sensitive help system.

3.4 Impacts of the standardization through NETWORK

The NETWORK database should be understood as a standardization of the data format for models analyzing energy systems. It's transparent, efficient and flexible concept is case study oriented which means that there will be one database for each case study. Information for different case studies will have the same format so that they can be easily transferred. The NETWORK database concept is especially useful for systems that can be represented and modeled in the format of a reference energy system, i.e. that can be thought of as a network of different interlinked processes.

What are the impacts of such a standardization of the data interface for the energy planner? First of all it will make life easier for him. Data entry and maintenance, scenario management and the analysis of model results will be less complicated because a powerful set of analysis tools for different models exists to support the NETWORK database. This will substantially reduce the training efforts to learn how to use the planning models. Additionally if the planner knows how to use one model, it will be very easy for him to learn to operate other models connected to the NETWORK database, since the data entry and the analysis of results follow the same procedures. Finally it will be much easier to exchange data, scenario assumptions and results between case studies and different models so that the costly work of collecting and validating data can be shared. Sharing data and analysis tools makes energy planning and model development more efficient.

The most important impact however is that the standardization of energy related data will lead to an integration of energy planning models. When different models use the same data structure they can easily work with the same data set or exchange input assumptions or results. An energy system that is analyzed using an optimization model could easily be simulated. Of course it will be necessary for the simulation to add information such as market shares to the data set. Other information such as bounds and constraints will not be used but the majority of the data necessary for a simulation is already defined in the optimization run and can directly be used for the simulation. This will finally enable the comparison and the combination of existing methodologies, a scientific approach that was theoretically possible also in the past but in practice never done because of the efforts needed. In the long term the standardization of the data interface will lead to an increasing coherence of newly developed planning models and the concept of the NETWORK database will facilitate the integration of new algorithms and methods into the existing planning framework.

4 The modules of the MESAP system

There are different fields of application for computerized energy and environmental analysis- and planning tools, which can be categorized according to the planning tasks.

Project evaluation should be seen as a detailed analysis of one investment within the expansion planning. The scope in the project evaluation encompasses one investment project (e.g. a "coal power plant" as shown in Figure 6) and its interrelations with the energy and environmental system. An example of an investment evaluation program is INCA [18], developed at the IER.

Today, the decision between different options of power-supply is not only a question of economic costs. Other aspects considered are the pollution of air, water, and soil, emission of greenhouse gases, waste disposal, health risks, supply security etc. **Life cycle analysis** is used to quantify and evaluate all economic, environmental and social impacts of the considered energy supply systems. This includes the analysis of the direct process chain from the resource extraction to the final energy to be provided, but also the investigation of indirect impacts. These are caused by the equipments needed to produce the required energy such as the construction and dismantling of power stations and the extraction and transportation equipment. Two approaches can be distinguished. **Life cycle fuel chain analysis** considers the energy conversion chain from the resource level to the final energy to be provided. Figure 7 shows the fuel chain from the coal mine to the electricity at the end user. This enables to evaluate different supply paths that produce the same amount of final energy. **Life cycle network analysis** calculates the flows and impacts involved for an energy network providing a demanded energy service, as shown in Figure 8. In this example the energy service provided is room heating and the whole network of technologies and fuels necessary to provide this energy service is analyzed. The analysis calculates all related consumptions, emissions and other mass flows for competing technology chains that provide the required energy service. Such an analysis allows the evaluation of different technology path's according to multiple criteria: cost, energy balance, environmental pollution, resource consumption, etc. Examples for fuel chain analysis models are the GEMIS [19] model and the DECADES [20] project.

Expansion and operation planning. The scope is one sector of the energy supply system, e.g. the electricity sector or the district heat sector as shown in Figure 9. **Expansion planning** examines the kind and timing of investments, which are suitable to meet a given demand with respect to certain restrictions and boundary conditions. In the expansion planning several alternative projects are analyzed, which can produce the same output. The investments as well as the generation costs of the energy products are analyzed in detail with respect to the different currencies, timing and cost categories. Local restrictions are taken into consideration. An example of a power generation expansion planning model is WASP [1] of the IAEA. The aim of **operation planning** is to get an optimal way on how to operate the existing components of a power system. The operation planning process can be differentiated into three different tasks: long term operation planning with a planning horizon between one and five years, medium term operation planning with a planning horizon from one week up to one year and short term operation planning within one day or a weekend. Beside the different planning horizons these three levels have different offsets and restrictions and also different planning aims. To get optimal results out of the hierarchical planning process the planning tasks must cooperate and work together in an optimal way. PROFAKO [21] is an example for a program system for operation planning, which supports all three planning tasks in operation planning.

Strategy development and technology assessment. These studies evaluate technologies, measures, strategies and policies according to certain goals in the context of the whole energy, environmental and social system. They consider the complete system shown in Figure 6 to Figure 9, which includes the energy demand for all carriers and every energy conversion technology in the supply network. Example: cost-effectiveness analysis of CO_2-reduction measures with an optimization model such as EFOM [4] in order to meet the Toronto agreements. Since efficient CO_2-reduction takes place in all sectors, the model has to represent the emissions of all possible sources and alternatives to provide the required energy service. Another example could be the evaluation of the consequences of integrating wind energy converters into the existing energy supply structure using e.g. the MARKAL [6] model.

In strategic energy models the conversion technologies can be modeled as entities or they can be aggregated to groups of technologies. Models that allow the evaluation of comprehensive energy systems should be flexible in the aggregated representation of different technologies and their interactions. Energy system models can be used to analyze the energy and environmental system starting from the resources, following the different conversion steps to the required energy service. All conversion technologies or combinations of technologies, which are able to produce the same energy service or which are interrelated to the service provision must be represented in the model. The system limits depend on the objectives of the analyzed system.

MESAP provides modules for each category. Figure 1 in chapter 2.4 shows the different modules that are integrated in the MESAP system and that are explained in the following sections. Multiplying the number of models available in one shell alone does not necessarily provide a better decision. But it enables the planner to select within the shell he is familiar with to choose the methodology that is best suited to his problem. Sometimes it will even be necessary to select several models to cover all methodological aspects of a complex case study analysis.

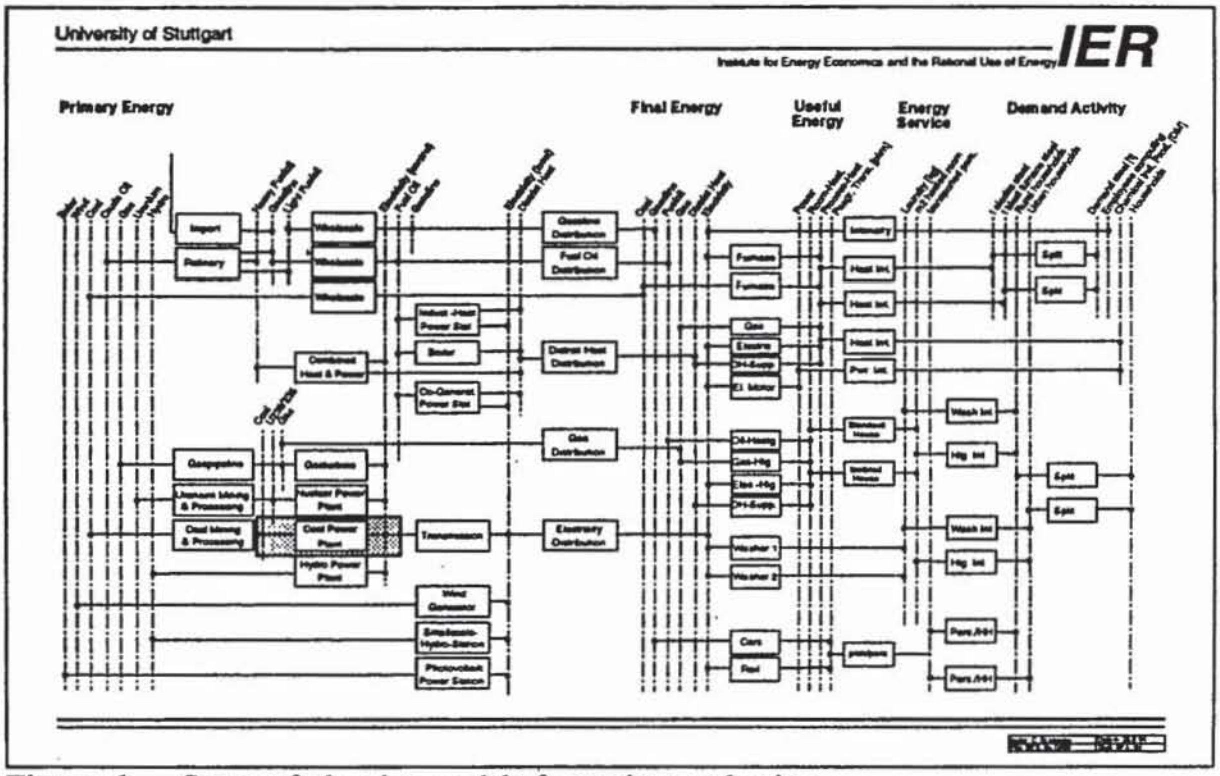

Figure 6: Scope of planning models for project evaluation

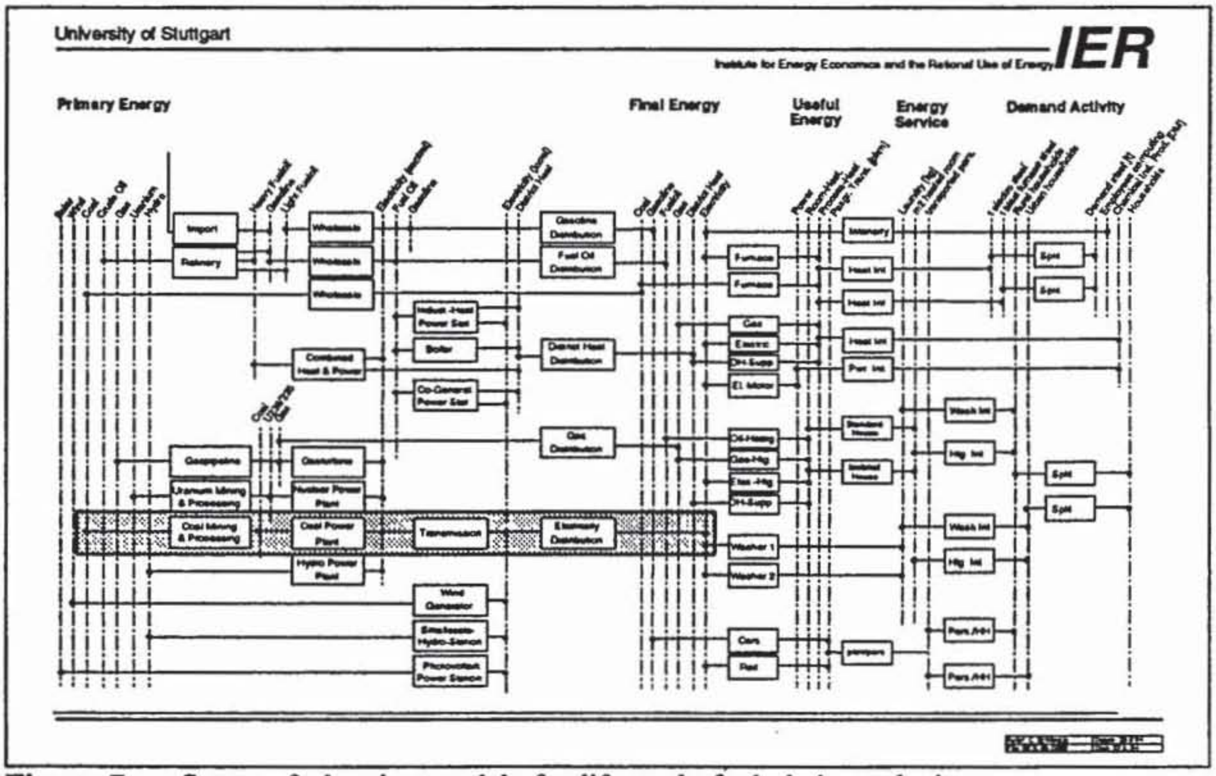

Figure 7: Scope of planning models for life cycle fuel chain analysis

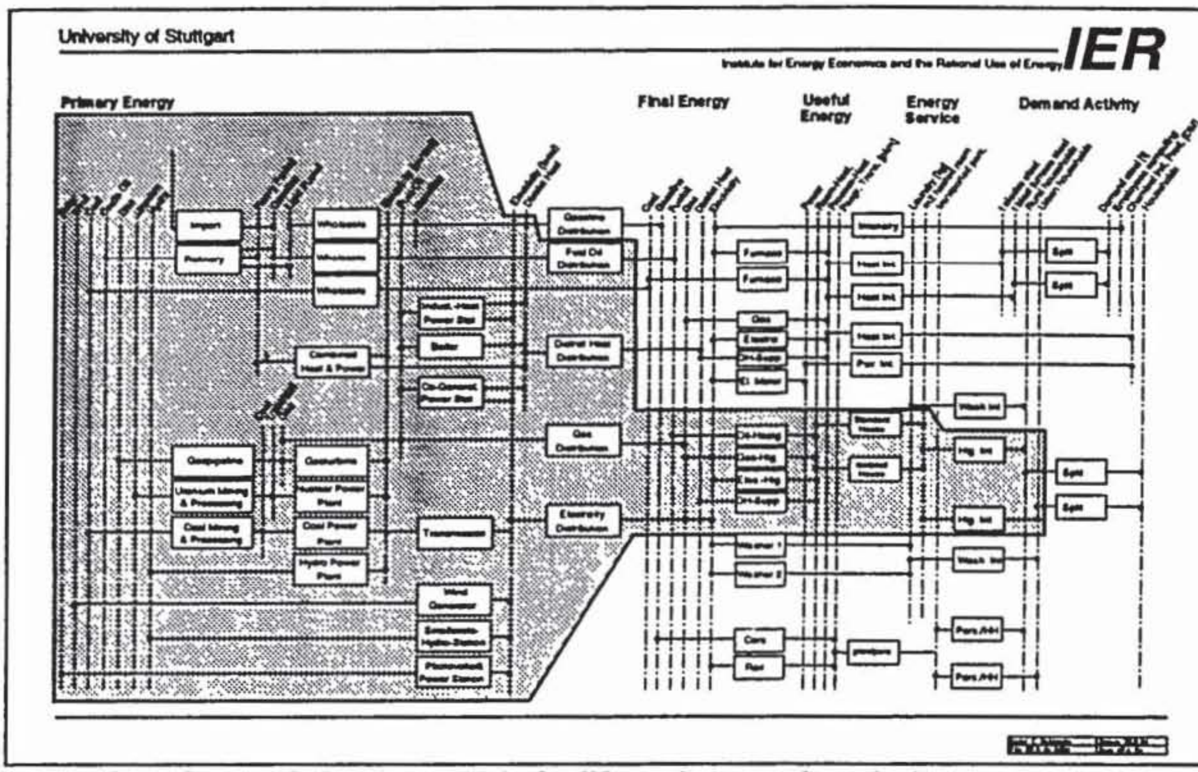

Figure 8: Scope of planning models for life cycle network analysis

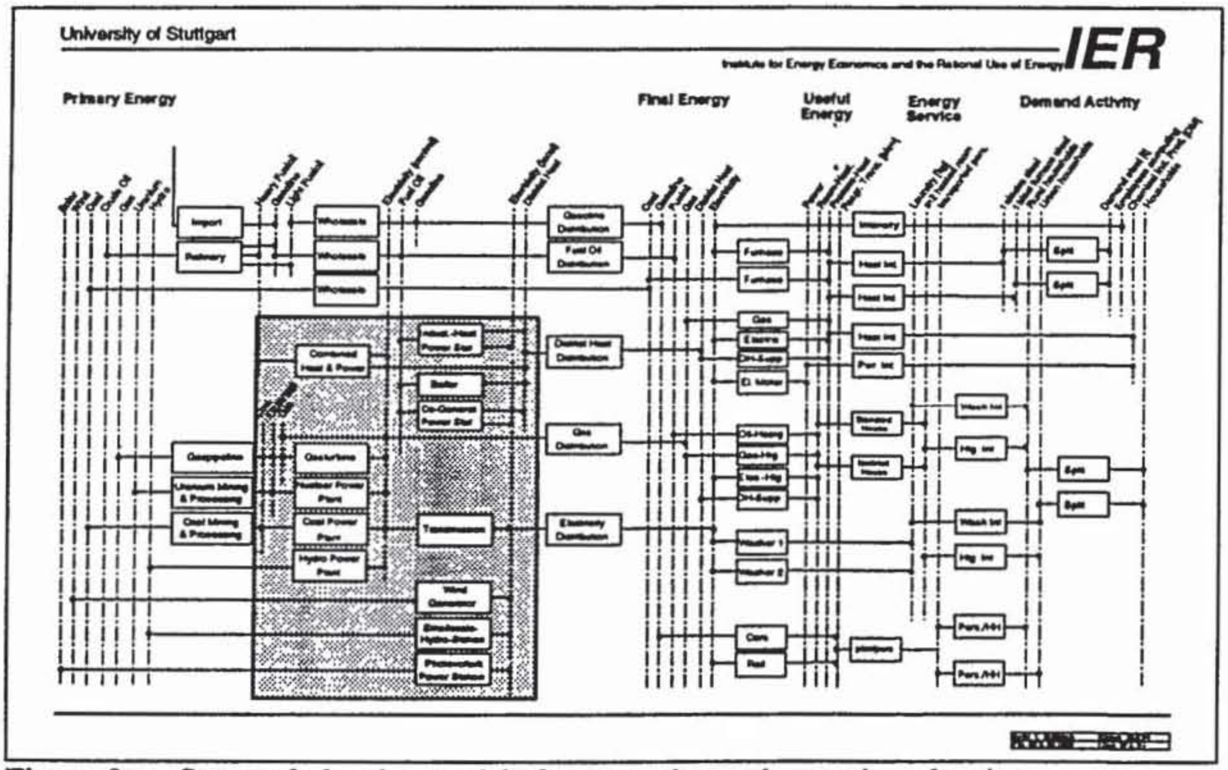

Figure 9: Scope of planning models for expansion and operation planning

4.1 Energy demand analysis and supply simulation

The energy **demand model** MADE [22] (Model for the Analysis of the Demand for Energy) provides several methodological options on how to calculate energy services, useful energy requirements or the final energy demand. These methodologies include econometric as well as process engineering technique approaches. The demand model MADE can be applied for strategy development and technology assessment.

A simulation algorithm calculates the secondary and primary energy consumption based on a process oriented network representation of the energy supply system. The analysis is not limited to energy flows but can include all material flows used or produced by the processes analyzed in the system. The level of aggregation of the network is left to the user. MADE is not linked to the NETWORK database.

A successor for this demand analysis and supply simulation model, called PlaNet [23], is currently being implemented at the IER. This model will be fully integrated into the NETWORK database concept. PlaNet consists of a demand model that allocates the economic sectors in a user defined tree structure. The supply sector can be modeled using any form of the "Reference Energy System (RES)". PlaNet has similar features as his predecessor MADE, but offers more flexibility concerning the simulation equations. It allows any number of equations for processes with multiple inputs or outputs and thus can better simulate technologies such as co-generation. PlaNet allows to define any flow of a process or any quantity of a commodity in the RES exogenously. It includes the possibility to use product shares for technology inputs in addition to market shares for technology outputs and it will check for the violation of user defined bounds and constraints. Finally it allows a higher time resolution in order to integrate load aspects in the energy demand analysis and the simulation of the supply system. Based on the calculation of all energy flows within the network, a user defined energy balance can be calculated for any time period. According to these flows the needed capacities of the energy conversion technologies are determined. A detailed cost analysis is available not only to determine total costs of the energy supply system, but also to calculate levelized production costs (per unit costs) for each commodity. A detailed evaluation of the environmental impacts will help to find major emission sources and their abatement costs.

4.2 Energy system optimization

The **energy system optimization models** currently implemented under the MESAP system are MESSAGE [3] and EFOM [4]. Both are designed to analyze in detail the energy system flow from the primary energy to the energy service demand category. The MESSAGE and EFOM models can be used for strategy development and technology assessment. They are both based on the LP (Linear Programming) approach. They are flexible in terms of the technologies and fuels considered, the sectors analyzed and with respect to the model size. They both are network oriented models. The level of detail, the time horizon and the objective function can be defined by the user. For the processing of the model results comfortable post processors are available. The models investigate, how an exogenously given energy demand vector can be met in an optimal way according to the objective function while considering the specified restrictions and bounds.

Typical applications for these kind of models are cost effectiveness analyses in the environmental field, expansion planning of the energy supply system, the analysis of possible impacts of political decisions, technology assessment studies and the identification of energy strategies and policies.

MESAP-III, the latest version of the MESAP system, will contain a new energy system optimization model called ECOLOG [24] based on the LP-GAMS [25] language. The development of this tool that has been started two years ago. It will combine the strengths of the well known representatives of LP-models such as EFOM, MESSAGE and MARKAL. The ECOLOG model has been designed to take into account a regionalized representation of energy systems and load aspects. The optimization model will be able to treat issues such as pumped storage, co-generation and the integration of renewable energies. The integration of non linear equations will allow to analyze non-linearities in the optimization framework.

In a future release ECOLOG will be enhanced by macro-economic equations toward a partial equilibrium model. This will allow to analyze price induced energy conservation in the end use sector on the useful energy level as well as on the energy service level.

4.3 Energy-economy models

Energy-economy models are developed to analyze the future development of an economy within certain assumed frame conditions in order to allow strategy development and technology assessment. To enable the simulation of the macroeconomic development, which is seen as the most important factor driving the energy demand, the econometric programming tool "InterActive Simulation System" (IAS) [26] is linked to MESAP. IAS enables to design, estimate, test and run econometric models and input-output models. Further, so called impact models can be used to analyze the effects of certain strategies on the economy as a whole. Post-processors are provided in MESAP for the simulation as well as for the optimization models in order to calculate the possible impacts of the planned strategy on the economy, the environment and other areas of interest.

The impacts of certain energy policy measures such as CO_2-taxation are not restricted to the energy system. Due to the considerable feedbacks with the rest of the economy these impacts must be analyzed within an economy-wide framework. There might be competition for scarce resources between energy policy targets and other social or economic targets such as economic growth, full employment, price stability etc.

Instruments for partial analysis like energy (supply) models are by their nature hardly suited to identify the economy-wide effects of energy policy measures[3]. In general, they capture only the direct impacts of energy policy measures on energy markets in high technological precision and take the ceteris paribus assumption in order to neglect the feedbacks from the rest of the economy. If the feedbacks are important the approach of partial analysis makes use of complementary models to take into account the indirect effects for the rest of the economy. However, the successive use of isolated partial models must be viewed critically as there are often severe problems in consistency.

On the other hand there are comprehensive economy-wide models for total analysis which keep consistency in explaining indirect price effects and feedbacks but lack important detailed technological information due to their high aggregation level. Thus the technology based options of an economy to meet energy policy constraints are not sufficiently represented.

The disadvantages of either approach call for new integrated models which allow the consistent representation of the overall economic activities as well as the detailed technological description of the energy system.

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[3] Energy models in this partial sense are energy market models with exogenous energy demands (final energies, useful energies or energy services) or at least exogenous non-energy markets (energy demand in the latter case is an endogenous variable but interdependencies resp. feedbacks between energy markets and other non-energy markets are still neglected).

Here, general equilibrium theory provides a sound microeconomic framework to meet the requirements for technological based economy-wide analysis. In practical applications the concrete formulation of general equilibrium models depend on methods which are available for solution. Models are constructed as special cases of the general form in order to simplify the computation; the simplification is often at the expense of certain economic features which "escape" the chosen modeling approach.

A simple but consistent approach of constructing energy-economy models is the combination of energy system models and neoclassical macroeconomic models within an equilibrium problem which is formulated as a nonlinear program and solved by efficient optimization software. Following similar developments like ETA-MACRO or MARKAL-MACRO (see Manne et al. [27], [28], [29]) the ECOLOG module developed at IER - University of Stuttgart is linked on the useful energy level to a one-sector Ramsey growth model (MACRO) by means of a neoclassical production function and the extended economic identity of income (production) and expenses (consumption, investment and energy system costs). Thus the energy demand is endogenous and depends on relative prices. Feedbacks between the energy system and the rest of economy which might stem from energy policy measures such as energy taxes or emission directions can be analyzed in a transparent way.

Besides the strength of computational easiness ECOLOG-MACRO uses detailed physical (energy) flow information which increases the credibility of energy-policy assessment compared to monetary-based input-output approaches. ECOLOG-MACRO turns out to be a useful tool for assessing the overall economic impacts which major energy policy changes might have. However the simple structure of the linkage is enabled through the very aggregate description of the economic activities in the non-energy system.

If several economic agents and institutional constraints (e. g. price restrictions) must be considered the single-pass optimization framework of ECOLOG-MACRO can not be maintained. One could extend ECOLOG-MACRO to a multi-sector structure including foreign trade by using sequential optimization but this approach is quite cumbersome and problem-specific (see Ginsburgh/van Heyden, Rutherford/Manne [30], [31], [32], [33]).

Another method is the iterative linkage of energy system models and multi-sectoral economy models. However, the experience of iterative linkage experiments (see ZENCAP, Messner / Strubegger [34]) is rather deterrent: Different methodological approaches for the energy system module and the economic modules lead to problems in consistency which severely influence the model results. Examples are differences in capital cost calculation or in time treatments (perfect foresight versus myopic expectations). In addition there are severe problems in getting convergence of the partial solutions towards a consistent solution for the overall system.

The restrictions of most common energy-economy modeling approaches led the IER to the use of the so-called complementarity format (see Cottle and Pang) which enables simultaneously bottom-up process-engineering modeling and top-down aggregate economic modeling. The present integrated tool GE^3M-ACT (German Energy Economy Equilibrium Model with Activity Analysis, [35]) is a multisectoral open-economy model which allows the consideration of agents with different preferences which is important in order to assess distribution and income effects of alternative energy policies. Besides the process-based representation of strategic energy sectors (such as electricity generation) the model can incorporate price and quantity constraints which often are typical features of administered energy policies. Computable general equilibrium models can be used to address the following issues:

- Consideration of feedbacks between the energy supply system and the energy demand;
- Inclusion of price responses on labor and capital market;
- Analysis of the impacts of energy and environmental policies on economic growth including feedbacks;
- Explicit treatment of taxation policies for emission mitigation strategies.

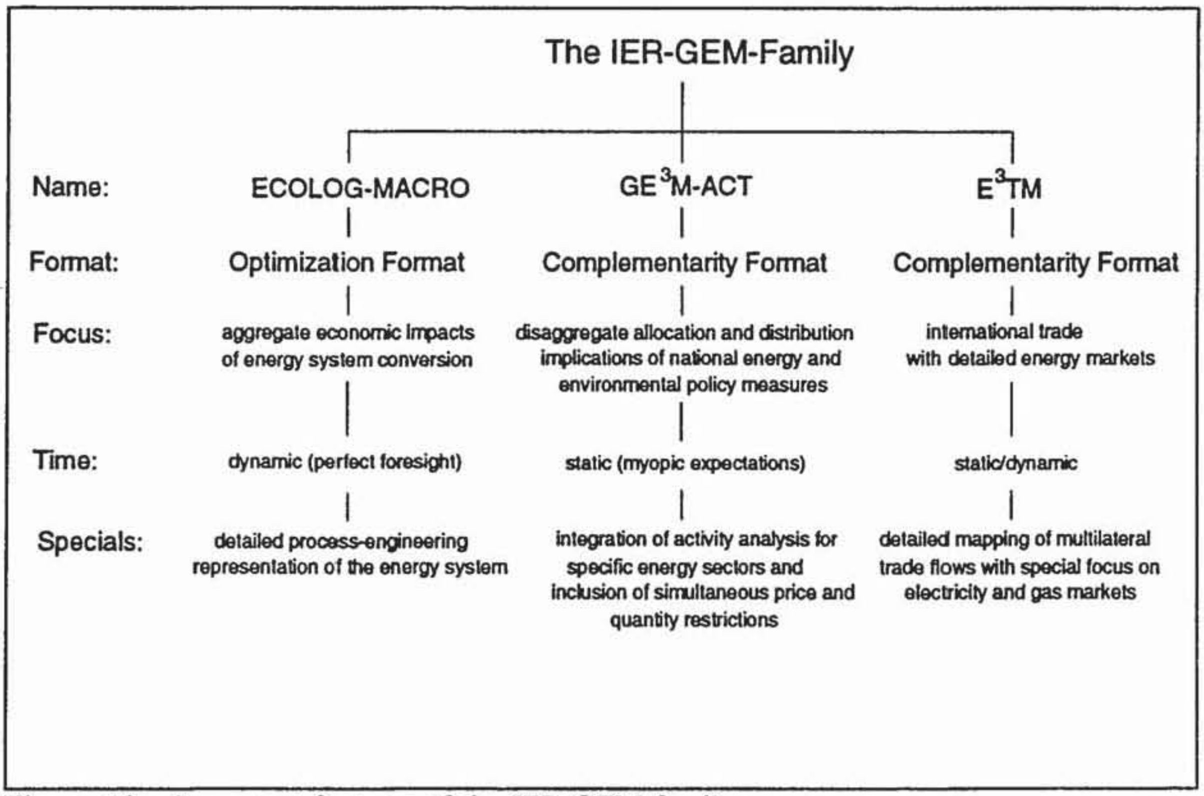

Figure 10: Important features of the IER-GEM-family

The conceptualized dynamic general equilibrium model is based on the I/O technique integrated with a process analytical representation of the energy system (LP). The model successfully has been applied to energy policy topics such as the analysis of carbon-tax exemptions for energy- and export-intensive industries or the implications of national hardcoal protection on the effectiveness of CO_2-mitigation strategies.

Future extensions of the model encompass the full integration of the existing German tax system in order to assess the impacts of tax reforms which are currently under discussion to promote economic efficiency together with environmental protection.

Though the present model version includes a sufficient representation of exports and imports in the context of national policy questions it is not suited to focus on multilateral international trade issues. In order to analyze the economic impacts of changes on international energy markets (e. g. EU-liberalization of gas and electricity markets) or combined emission mitigation strategies (international emission trading) the IER will construct a multi-regional (energy) trade model E^3TM (European Energy and Emission Trade Model).

The model set of ECOLOG-MACRO, GE^3M-ACT and E^3TM is a comprehensive and complementary analytical framework to provide valuable decision support to energy policy makers on national as well as international issues. Figure 1 summarizes the IER activities on the field of integrated energy-economy modeling.

4.4 Investment calculation and cost analysis

INCA [18] is an acronym for **In**vestment **Ca**lculation, a program which calculates the net present value of alternative investments. This model is designed for project evaluation. Based on the present value method, the model calculates the dynamic power generation costs, the yearly cash flow over the whole operating period, the amortisation time and other economic key parameters. A detailed breakdown of costs is used for these calculations. Every cost factor can have its own cost escalation assumptions.

4.5 Power plant operation planning

The power plant operation model PROFAKO [21] is a computer aided operation planning tool for cogeneration plants and systems. It supports all phases of the operation planning process from long term operation planning through medium term operation planning to the short term operation planning. The model offers flexibility in the structure of the modeled system and can therefore be applied to one power plant or a complex power system of an energy utility or a company. PROFAKO is using its own database but will cooperate with the NETWORK database system.

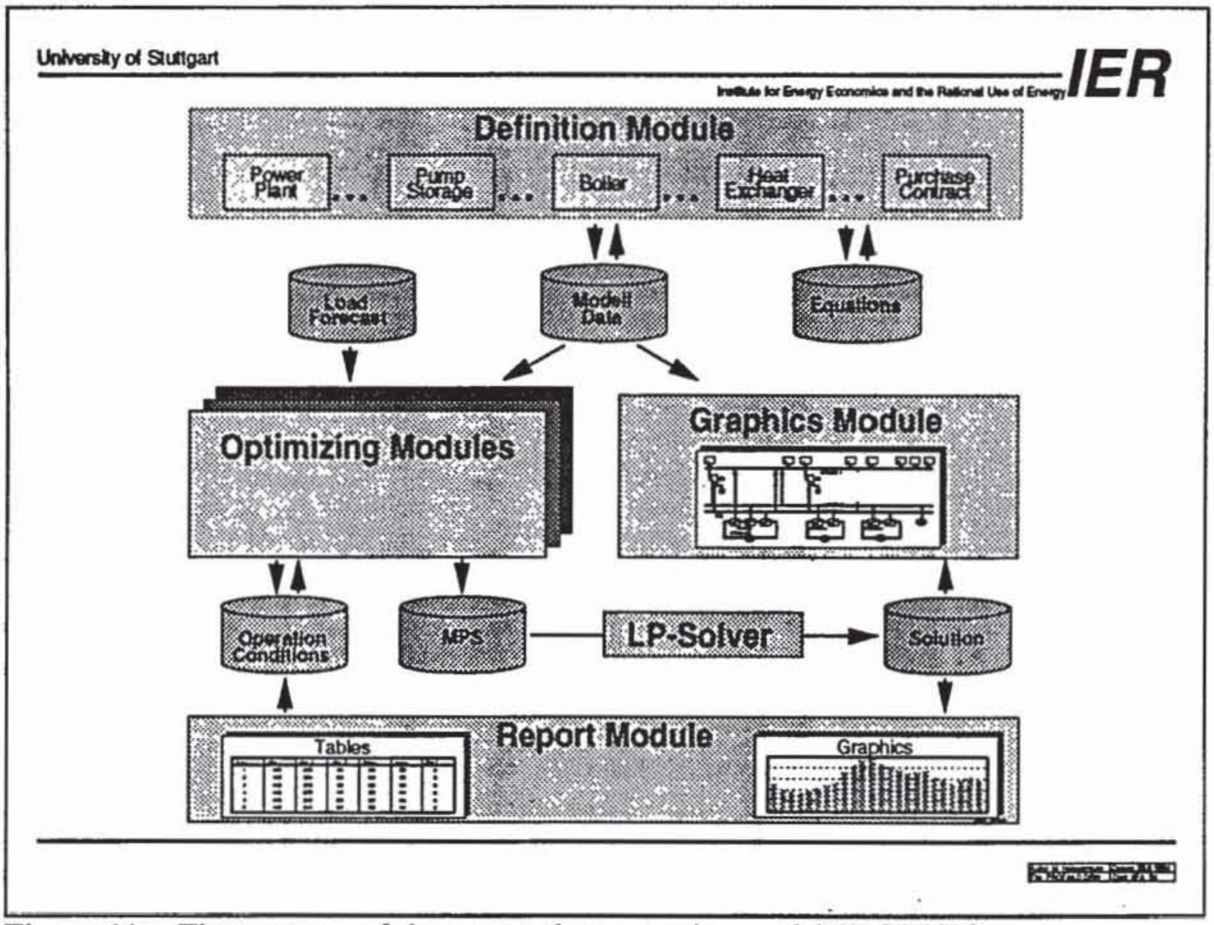

Figure 11: The structure of the power plant operation model PROFAKO

The aim of operation planning on all planning levels is to minimize the operation costs. These costs are forming the objective function and are composed of the production and start-up costs of all components and the costs for all purchases fixed in supply contracts. The objective function must be minimized concerning an amount of technical, economical and environmental restrictions.

PROFAKO is based on mixed integer linear programming (LP/MIP). Total cost of the analyzed system is taken as objective function that is to be minimized. To set up the optimization model, the production system is separated in its system components in order to get a mathematical description. There are technical components like power plants, that can be broken up into a system of boilers, turbines or heat exchanger. The economical components include contracts, duties or other financial conditions. The mathematical description of the behavior of these components and the interconnection between the components lead to a linear program with mixed integer variables.

PROFAKO has been applied to different production systems and is used by public utilities, by industrial companies for their power supply systems and in different research studies.

Until now PROFAKO uses it's own data base with a well defined interface. For the future it is planed to connect PROFAKO to the NETWORK data base system for data exchange. But also in the future PROFAKO will use it's own data base for local data access and stand alone use. (Because the PROFAKO data base has been developed for the special use within an specific context it is faster than any other data base for common use.)

4.6 Power plant expansion planning

The power plant expansion model WASP (Wien Automatic System Planning) [1] uses the dynamic programming technique for the expansion planning of electricity generation units. The model has been applied in many case studies all over the world. It belongs to the category of models for expansion and operation planning. WASP is not yet connected to the NETWORK database.

The objective of WASP is to find the economically optimal power generation system within specific constraints. It utilizes the dynamic programming method for the optimization and a probabilistic simulation for investment and production costs, unserved energy costs and for the reliability factors.

The objective function consists in the minimization of the total power generation costs B, which is the discounted sum of investments I, salvage value of investments S, fuel costs F, fuel inventory costs L, operation and maintenance costs M and costs for the energy not served O.

$$B_j = \sum_{t=t_{ini}}^{t_{end}} \left[\bar{I}(t)_j - \bar{S}(t)_j + \bar{F}(t)_j + \bar{L}(t)_j + \bar{M}(t)_j + \bar{O}(t)_j \right]$$

The optimal expansion plan is defined as the minimum of B over all expansion plans j.

4.7 Integrated Resource Planning

Integrated Resource Planning (IRP) encompasses the whole planning process of a utility or a region. It integrates supply-side and demand-side management, evaluating investment opportunities in energy supply and demand reduction on an equal economic basis. IRP includes different types of planning as it considers utility and non-utility generation, load management, conservation, pricing, alternative service levels, strategic load building and power exchanges, and as it provides explicit evaluation of the interactions among the various aspects of the planning process. In a broad sense it should consider electricity, gas and district heating. It thus encompasses the above mentioned planning tasks namely project evaluation, expansion and operation planning, strategy development and financial analysis. Nonetheless the main focus of integrated resource planning remains demand side planning and financial analysis.

In order to develop an integrated resource plan a set of tools is needed which can be used to support each planning step. It enables the user to perform an integrated analysis considering all interactions between the system components. Further requirements yield from the specific purpose of the tool. It depends whether the tool is used by a utility to support the planning process or by a research or consultancy institutions to support policy decisions. A methodology for integrated resource planning should take into account load patterns for demand of electricity, gas and heat. It should be capable to analyze the effect of additional measures (e. g. storage of electricity and/or heat) solving problems concerning the time lags between supply and demand.

Most models which are presently used in Europe represent analysis, forecasting or supply-side models. Those fields are modelled in great detail while the demand-side is usually represented in a very aggregated way. If energy saving potentials are analyzed, only the technical energy saving costs are taken into account while the consumer behavior and the costs of the measures to be taken to influence this behavior (the so called transaction costs) are neglected or just roughly considered.

Responding to the needs of the utilities to possess tools for integrated resource planning, the Electric Power Research Institute (EPRI) in the USA developed a portfolio of software models, ranging from spreadsheets to menu-driven and interactive software using the ORACLE database management system. These models are presently used by utilities in the USA. In Europe there seems to be interest in that kind of models. In addition the applicability of the american models in Europe is restricted because of the differences both in the structure of the electricity supply industry and in the end-use pattern.

IER is developing a set of tools (IRPlanner, [36]) which is meant to support integrated resource planning both on a utility and on a regional level. The above mentioned modules of

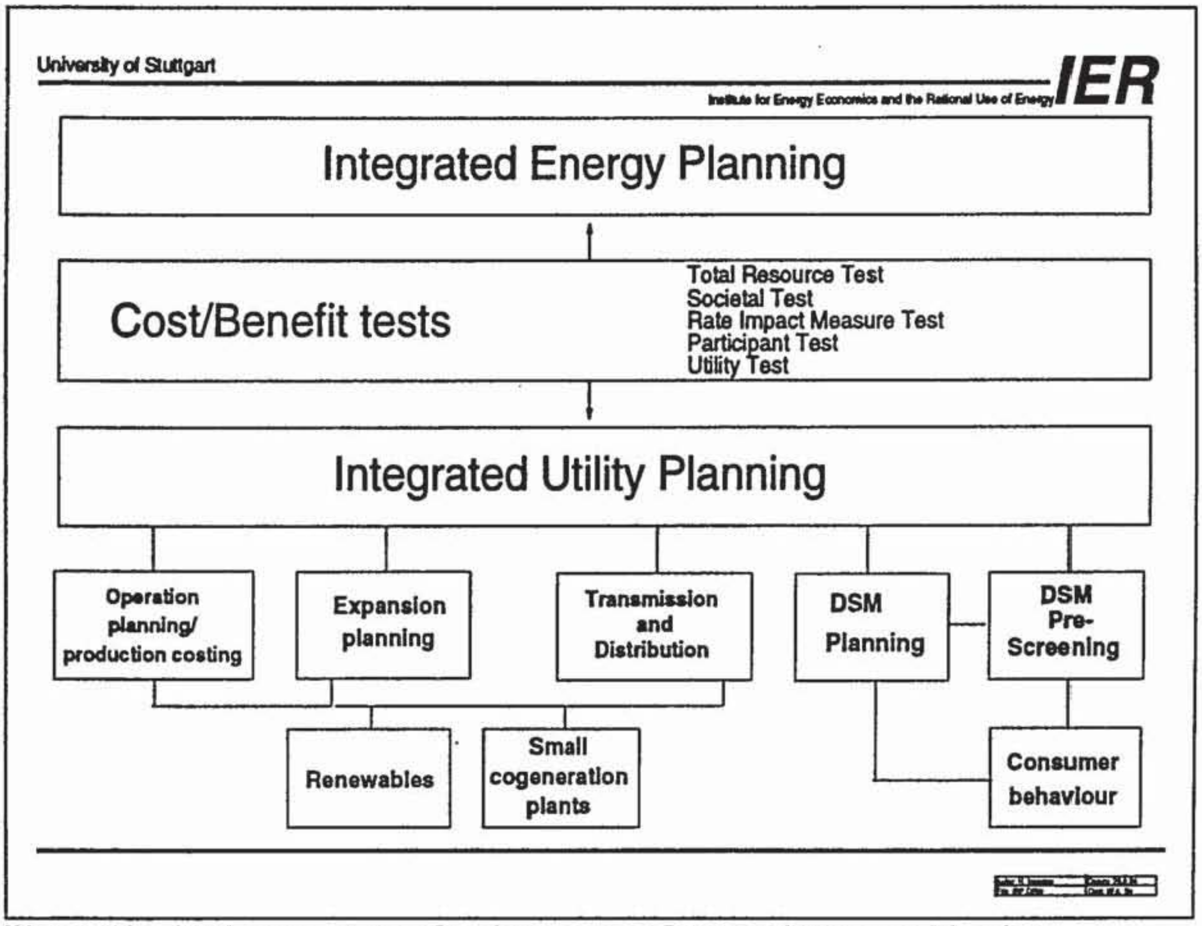

Figure 12: IRPlanner - A set of tools to support Integrated Resource Planning

MESAP are the basis for the set of tools depicted in Figure 12. Additionally a module which explains consumer behavior will be added as well as modules to analyze the effects of certain demand side management (DSM) measures. These modules will be linked to the NETWORK database. For DSM-screening the MESAP simulation model will be taken. Two options are available for integrated utility planning. Either an operation and expansion planning module will be improved by adding a detailed DSM-module or a DSM-model will be developed which can be connected to the existing operation and expansion planning models. In both cases a financial analysis module will be linked. The new optimization model ECOLOG, being developed on the basis of EFOM, will further be improved in order to support integrated energy planning.

4.8 Life cycle analysis

Life cycle analysis (LCA) is a method for the comparison of different energy supply systems that allows to quantify and evaluate the economic, environmental und social impacts. According to the German Federal Environmental Office (UBA) life cycle analysis can be subdivided into four tasks [37]:

1. System Definition
2. Life Cycle Inventory
3. Impact Analysis
4. Evaluation

The first phase of a LCA is the *Definition of the System* to be studied. It includes as main duties the consistent making of assumptions and the consistent definition of the system boundaries in order to allow a reliable comparision of different systems.

The goal of the second step, the *Life Cycle Inventory*, is the entire calculation of the systems inputs and outputs. Traditionally, a process-engineering tool is used to describe the technical system under study. But the endavour to investigate also the indirect material and energy flows finally leads to an infinite number of processes being involved. For example the providing of capital goods like the extraction equipment requires itself the providing of energy, raw materials, capital goods etc. A possible way to avoid this difficulty is the use of input-output-analysis: The input-output-tables of a national economy describe the entire production of the branches and the interdependences between them. By adding branch specific coefficients like emission factors, coefficients for waste disposal etc. to the IO-tables it becomes possible to take into account all material and energy flows caused by the production of a specific product [38]. Actually, the MESAP simulation module PlaNet [23] described in chapter 4.1 is used to perform process analysis for different energy supply systems. Extensions will be made to include the input-output-analysis into the existing RES technique.

The third step of LCA is the *impact analysis*. The impact assessment model ECOSENSE which is a tool to examine the impacts of air pollutants (see chapter 4.9) is used to quantify environmental and human health impacts of the system inputs and outputs.

The last step, called the *evaluation*, requires weight factors for each impact quantified in the impact analysis in order to allow to convert them into a single characteristic. Several different approaches are known to deduce weight factors. Here, the method of monetarisation is preferred which evaluates the impacts by taking into account costs of repair, costs of avoidence and willingness of the society to pay for the avoidence of the impact.

4.9 Impact assessment models

Although cumulated emissions are often referred to as the "environmental impact" from an energy system, emission figures might be a rather misleading indicator of potential effects on human health and the environment. The **impact assessment model** ECOSENSE currently developed at IER is an integrated tool providing data and models required to quantify impacts following a damage function approach.

Pollutants emitted from a single source or a set of various emitters are traced through the environment, starting from the emissions, following dispersion and chemical conversion processes in the atmosphere down to the physical impacts caused on the exposed receptors. Figure 13 shows the scheme of such a so called impact pathway.

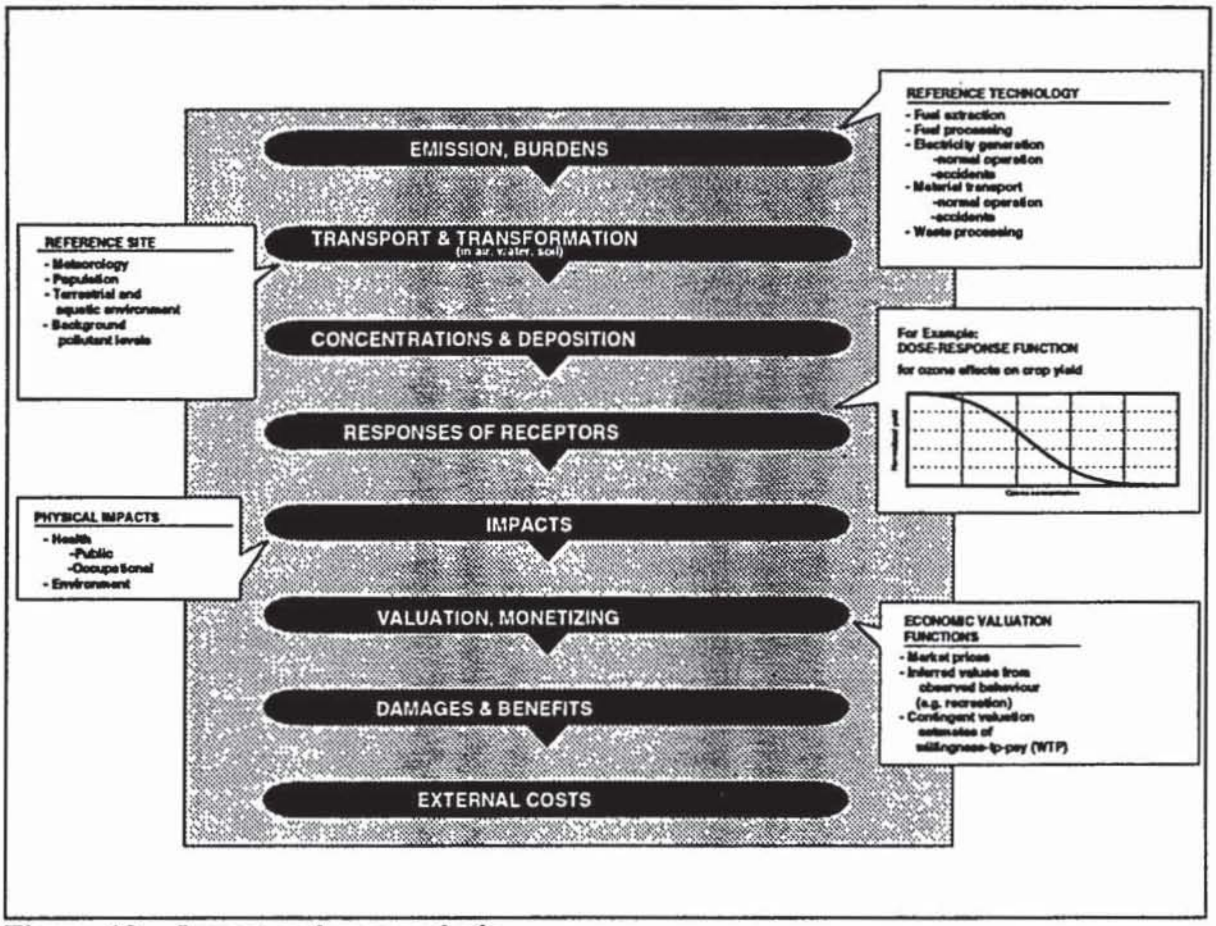

Figure 13: Impact pathway analysis

ECOSENSE in its present version provides two air transport models completely integrated into the system: a Gaussian plume model is used to model transport of pollutants from a single, high stack facility on a local range and a trajectory model for European-wide modelling of air transport and chemical conversion processes. Linking the results from air transport modelling to a set of dose-effect models (the present version includes impacts on human health, crops and building materials) leads to the quantification of environmental impacts.

Additional dose-effect relationships can be easily added to the system. Because of the considerable uncertainties in the field of cause-effect mechanisms, this flexibility is a fundamental prerequisite to present the respective state of the art.

In order to make physical impacts comparable and to bring them in line with economic parameters, an economic sub-module allows to attach a monetary value to each impact category.

Meteorological data (except for data required by the local range Gaussian plume model) as well as receptor specific data like population density or land use are provided for whole Europe on the EUROGRID-format.

ECOSENSE is used in various studies on the assessment of external costs of energy systems.

5 The MESAP databases

The MESAP system contains a series of databases as shown in Figure 1 in chapter 2.4. The NETWORK database is a case study oriented database that stores all information necessary for the different models in a case study. The other databases are designed as information systems that store general information on technology data, energy statistics and emission records. These general centralized databases can be accessed from the NETWORK database in order to search for and to retrieve information to complete the case study data set.

5.1 The NETWORK database

The NETWORK database [12], [13] contains case study related data and represents the standardized interface between the different models and central databases involved in the analysis. A copy of this database exists for each case study. It will contain the structure of the reference energy system (RES) that has been established for this case study. In addition all relevant data necessary to perform the model runs will be stored in the NETWORK database. Finally the data set can be completed by adding historical time series data for the different model parameter and the sectoral demand data. The model run results will as well be stored in the Network Database in the same format as the input assumptions and data. The concept of this database has been presented in chapter 3.

The NETWORK database has been designed as modeling database and as information system. This way once a case study involving model runs is finished, the remaining case study data set may be the foundation for the installation of an energy information system for the analyzed region. The case study data may be updated regularly and can slowly be supplemented and completed in the future.

5.2 The IKARUS technology database

The IKARUS technology database [14] is designed as information system that contains all technical and economic information for the known energy conversion technologies. The data is documented and validated. The technology database is a read only retrieval system that can be used when setting up a case study data set. The necessary technical information for conversion technologies defined in the RES can be directly looked up and retrieved from this information system into the NETWORK database.

5.3 The energy information system ENIS

The energy information system ENIS [39] contains historical time series from various statistics. This information can be retrieved and transferred to the NETWORK database in order to facilitate projections of model parameters for different scenarios. During the analysis of model run results the planner can use ENIS to relate his results to historical trends. ENIS will not only provide historical information but also allow to perform simple mathematical operations with these time series in order to calculate e.g. specific indicators such as the per capita energy consumption starting from the total energy consumption and the total population. Finally ENIS allows to calculate energy balances from the stored time series. ENIS includes the possibility to analyze the data using structured queries and to graphically represent time series in line diagrams and histograms.

5.4 The emission information system EMIS

The emission information system contains time series of emission data for point, line and area sources on various time scales, such as hourly, daily, monthly or yearly emissions. It contains also the emission factors for all pollutants for the different emission sources. Finally it offers the possibility to connect MESAP to a geographical information system.

6 Status and perspectives of the MESAP development

The MESAP system has proved to be a powerful and useful tool for energy and environmental analysis and planning in many case studies. But if we want to cope with the great challenges ahead, the MESAP tool still needs some refinement. Among those challenges is the global green house gas issue, whose analysis requires methods and tools to analyze the emissions of different energy systems in more detail and on a common basis. For this purpose the tools for life cycle analysis will be improved through the integration of dispersion models and environmental impact evaluation tools into MESAP. Also in the field of quantifying external costs more research will be done in order to refine the methodologies. Other issues, such as the evaluation of energy or emission taxation policies require new tools, which analyze the energy sector and the economy in one consistent set of equations. This can be achieved by a general equilibrium model that is being developed at the moment.

In developing countries the analysis will focus on the links and feedbacks of the energy sector with agriculture, industry and transport. The MESAP modules will be refined to integrate aspects of infrastructural development and international economic relations into the analysis.

Other modules of the MESAP package will be enhanced. The investment calculation module (INCA) will have access to the IKARUS technology database via the NETWORK database. The optimization tool will be enhanced to address co-generation issues, the temporal fluctuation of demand and supply and non-linearities. The features of the MESAP-analyst will be complemented by additional decision support capabilities. A graphic oriented network monitor will allow to design the energy network on the screen and it will offer the possibility to visualize the results in a graphical representation of the network. New decision support features will be incorporated, which assist the planner in the scenario, strategy and policy development. This will include consistency checks, sensitivity analysis and result evaluations. Additionally already existing and approved planning tools will be fully integrated to profit from the MESAP environment. Finally the complete MESAP package is going to be validated in several ongoing case studies.

Energy planning is a dynamic, continuous and iterative process. The same holds true for the development of the MESAP planning system. The refinement of this planning tool will be an on-going exercise oriented toward robust energy and environmental decision making for the future.

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