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# ASSESSMENT OF PERSONAL COMPUTER MODELS FOR ENERGY PLANNING IN DEVELOPING COUNTRIES

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# FOR ENERGY PLANNING IN DEVELOPING COUNTRIES

# FOREWORD

The main objective of this study was to assess personal computer models for energy planning in developing countries, in order to (i) assist organization that produce energy planning models in evaluating model performance, and identify the direction in which the models could be developed; and (ii) help users of models identify available devices and select the methodology most appropriate to their needs.

Funding for this study was provided by the Swedish International Development Agency. The main author of this report is Mr. Leo Schrattenholzer, Consultant, from TEMPLAN, Vienna, Austria. Many other individuals also contributed to this report. The author wishes to thank Mr. Kurt Schenk of ESMAP, Task Manager to the Project, for his guidance during the work for this project and for his valuable suggestions. Discussions with Mr. Alastair McKechnie and Mr. Jayme Porto Carreiro, at the World Bank, were instrumental in helping formulate the original working plan, including the conceptual framework. Mr. Ernesto Cordova, during a summer assignment at the Bank, worked with some of the models described here. His written evaluation of COMPRAN was the basis for the description here, and some of his observations on ENERPLAN and LEAP have been included as well. Thanks are also due to Messrs. Enrique Crousillat, Witold Teplitz-Sembitsky, and J. P. Charpentier, who provided extensive comments to an earlier draft. The developers of the models made many valuable comments.

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Energy planners in developing countries have a number of PC energy models from which to choose. This report compares the strengths and weaknesses of some of those models. It is assumed that the reader has a particular interest, either to analyze a specific energy planning issue or to compare a known model with those discussed here. Such reference points are essential to understanding the models described in this report.

The basic premise behind the model assessments was that any energy planning model must be evaluated relative to a purpose, since the same model can be suitable for analyzing one problem and inappropriate for another. The general result of the assessments was that all the models were found suitable for the purpose for which they were designed. These models are only tools, however, and unless they are applied correctly, they are of little use. Shortcomings of a tool can often be overcome by imaginative application, but lack of experience on the part of the user, lack of data, or lack of a well-defined planning problem can never be overcome by even the best energy model.

Table 1 summarizes the results of the eight model assessments described in the main part of this report. No ranking is implied by the table.

## Table 1: OVERVIEW OF MODEL CHARACTERISTICS

| Model | Methods/ Model Type | Applicability Limitations | Hardware Required 1/ | Recommended Disk Space | Additional Software Required | User Friendliness 5/ | Data Intensiveness 6/ |
|---|---|---|---|---|---|---|---|
| ENPEP | Model System | Energy demand analysis, general-equilibrium supply optimization, power system expansion and generation simulation, detailed environmental analysis; no direct price dependence in the demand modules | AT[2] | 30 Mb | None | A | H |
| MESAP | Model System | Macroeconomic module, energy demand analysis, energy supply optimization, power system expansion, hierarchical data base | 386[3] | 30 Mb | None | B/C | M |
| ETB | Toolbox, demand and supply models | Energy demand modeling, energy supply optimization, (automatic generation of an LP model), econometric analysis, power system expansion, rural energy decision analysis; limits of model size | XT[4] | 10 Mb | LP solver LP83 (or later versions) | A | V |
| ENERPLAN | Econometric model builder, energy balances | Formulation of standardized energy balance tables, econometric modeling, statistical analyses; no supply model | XT[4] | 10 Mb | None | B | V |
| LEAP | Physical, economic, and environmental flows of demand, conversion, and supply | Analyze energy demand and supply as a function of the end-use structure, detailed description of biomass and land use, detailed environmental analysis; macroeconomic module only weakly connected, only five data years in the demand program | XT[4] | 4 Mb | None | A/B | V |
| TEESE | Input-Output based demand and supply model | Analyze the interplay between the energy sector and the rest of the economy, given an input-output matrix; no built-in dynamics | XT[4] | 3 Mb | LP solver LP83, Lotus 1-2-3 | B | L |
| MARKAL/ MUSS | LP supply model | Energy supply scenarios, analyze the potential benefit of technologies in terms of costs and environmental impact; only weak interaction of the supply system with energy demand and the rest of the economy | 386 | 32 Mb | OMNI matrix generator; LP solver, e.g., 386HSLP or XPRESS | A | H |
| MEDEE-S | Demand Model | Energy demand scenarios, analyze the effect of energy saving measures; no genuine dynamics, prices only implicit | XT[4] | 2 Mb | None | C | L |

Notes for Table 1:

1/ For all models, a mathematical coprocessor is either necessary or highly recommended.
2/ IBM AT or compatible.
3/ MESAP can run under a DOS operating system, but less limiting systems, such as UNIX, are recommended.
4/ IBM XT or compatible.
5/ Further characterizations of user friendliness.

A. *Very user friendly.*

B. *User friendly.* ENERPLAN's B reflects slowness and some inconveniences of its Version 2. Version 3 will probably solve these problems. Some features of LEAP in the version tested can make the user work more than necessary. The 1991 version of the model has eliminated most of the criticized points in LEAP. TEESE's B reflects the lack of a user's guide.

C. *User friendly with important exceptions.* For MESAP, this exception is its central database system. Other parts of MESAP are user friendly for the experienced user. New user interfaces are in preparation. MEDEE-S could be tested only in its French version. The English (AIT) version is said to be more user friendly. A completely new version of MEDEE is in preparation.

6/ Explanations of data intensiveness.

H. *High.* Although these models can be applied with a small data set, this is not the design case.

M. *Medium.* Again, the use of small data sets would be atypical.

L. *Low.* Even maximum versions of the respective models are not data intensive.

V. *Variable.* All sizes of data sets seem natural. However, these models are deliberately constructed with constraints that limit the model size and thereby the data intensiveness.

## 1. General Observations

Some general observations concerning the use of PC models for energy planning are that:

- In practice, an energy planning model is not chosen "off the shelf." The acquisition of a model, the training of its users, and the formulation of reference scenarios are usually (partially or completely) sponsored by donor agencies. Often these donors have such close connections to a particular modeling group that not much choice is left for the selection of a model once the donor has been identified. Since different models are good for different purposes, a wider range of choices would be appreciated by energy planners in developing countries.

- Generally, the designers of models that are available at little cost are concerned that their models not be applied by unqualified users, which might produce poor results and give their models a bad reputation. These concerns are reflected in the somewhat restrictive conditions for giving away those models. However, since it is increasingly recognized that model results are the responsibility of the model users, a more open access should be considered. This would have the advantage of increasing usage, which would result in faster improvement. Another possibility for increasing usage would be to offer parts of modeling systems as stand-alone models.

- Due to the generally high flexibility of the models considered here, the question of whether a model was specifically designed for developing countries was not a major ]assessment criterion. The models assessed in this report either explicitly include rural energy or provide for its inclusion.

## 2. Outlook

Although this report marks the end of the project, there are some ways in which the present task could be reasonably expanded in future projects. The first follow-up could be the dissemination of the study findings through seminars attended by energy planners from developing countries.

Other follow-up activities could be to relax any of the study's self-imposed limitations, e.g., by assessing the actual experience with energy planning models in developing countries when immediate help from the model builders was no longer available, by assessing the models described in Appendix A in more detail, or by assessing new models. Other steps might be to reassess the models again after one or two years, to study the progress made with the computer implementations, and to see which plans for improvements have been realized.

# I. INTRODUCTION

1.1 Energy-related problems continue to be a major obstacle to economic growth in most developing countries, where energy investments can absorb up to 25% of total public investment. 1/ The need for comprehensive energy assessments as a basis for formulating and implementing sound energy policies has been recognized, and ESMAP 2/ Country Assessments - performed in more than 60 developing countries at the request of local governments - are evidence of this recognition.

1.2 An increasing number of computer models for energy planning run on Personal Computers (PCs), which are more user friendly and more easily available than main-frame computers. In view of this development, ESMAP launched this study, *Assessment of Personal Computer Models for Energy Planning in Developing Countries*. One objective of the study is to "...assist organizations that produce energy planning models in evaluating the performance of those models and to identify the direction in which the models could be developed in the future." Another is to "...help users of models identify the devices available and to select a methodology most appropriate to their needs." 3/

1.3 This report is an account of the activities undertaken in pursuit of these objectives. It describes a conceptual framework; the screening, selection, and testing of PC energy planning models; and the conclusions that have been drawn.

1.4 The parameters of this project allowed for a maximum of about one working week to study each model, as compared with the up to nine weeks allocated to familiarize novice users with a particular model. For the results presented here, this means there was enough time to formulate a sufficiently comprehensive picture of each model to enable readers, at the least, to decide which ones they want to examine more closely. But there was not enough time to become familiar with every aspect of the models and their applications. Besides, no amount of time would have sufficed to find the "best" or even a single recommended model, for the simple reason that there is no best model; a model, like any other tool, is good or deficient only relative to a given purpose. Accordingly, this report addresses itself primarily to readers who have a specific model application in mind.

1.5 It is assumed that readers are already familiar with the basic concepts of energy planning; an overview is provided as a reference. We repeated these because we will be deriving the assessment criteria relative to these concepts. The emphasis in the report is on actual model application. Some familiarity with the use of Personal Computers is a prerequisite for appreciating this report.

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1/ Energy Sector Management Assistance Program, Assessment of Personal Computer Models for Energy Planning in Developing Countries, Task Description, UNDP/World Bank, September 1989.

2/ ESMAP (Energy Sector Management Assistance Program) is supported by the World Bank, the UNDP and other United Nations agencies. It also receives fund by multinational organizations and a number of individual countries.

3/ World Bank/UNDP/Bilateral aid, Energy Sector Management Assistance Program, Annual Report, Washington DC and New York, October 1989.

## The Structure of This Report

1.6 Section 2 presents a conceptual framework describing the use of computer models for energy planning. This framework forms the basis of the model descriptions and assessments. General questions about the application of energy models will be discussed here in the context of the criteria formulated. Since no assessment can be completely objective, some notes on a possible bias of the author are included. Section 3 describes the model selection process. Section 4 contains the assessments of those models that were selected for closer testing. Appendices give information about models that were studied less closely, as well as addresses and telephone numbers for model authors, a glossary of terms, and abbreviations and acronyms.

## Acknowledgements

1.7 The author is indebted to the modeling teams. Their patience in demonstrating and explaining their models is greatly appreciated. In particular, he wishes to thank Messrs. William Buehring, Bruce Hamilton, and Pablo Molina (ENPEP), Mr. Albrecht Reuter (MESAP), Mr. Ray Tomkins (ETB), Mr. Mohan Peck (ENERPLAN), Mr. Michael Lazarus (LEAP), Ms. Leena Srivastava and Ms. Sujata Gupta (TEESE), Messrs. Samuel Morris and Gary Goldstein (MARKAL), Mr. Bertrand Chateau (MEDEE-S), Mr. George Backus (COMPLEAT/ENERGY 2020), Mr. Malcolm Slesser (ECCO), Messrs. Rodney Rinholm and Dale Nesbitt (GEMS), and many others for their efforts.

## II. CONCEPTUAL FRAMEWORK

2.1 Overall national energy planning is a complex process which involves linking a country's energy system with the rest of its economic and social system. Examples of this kind of Integrated National Energy Planning (INEP) on the basis of computer models are rare. One example is documented in Munasinghe's report 4/ on an analytical framework and its implementation for Sri Lanka. The wide scope of that project -- it included many country-specific macroeconomic and sociopolitical aspects -- made it more of an energy study than an energy model, so that project is not analyzed in this report.

2.2 The emphasis in this report is on PC models themselves, their usefulness for energy planning, and their practical application. Most of the models included here describe the energy system (energy demand and supply) and its links to the economy as a whole. Some models also include a macroeconomic submodule. Any of these models might be used for some parts of INEP; any actual INEP effort, however, must be preceded by extensive analysis of the specific features of a country's energy system and institutional structure. Nonetheless, we will take Munasinghe's conceptualization of Integrated National Energy Planning as the point of departure for defining a set of criteria for model classification and evaluation.

### A Country's Energy System

2.3 Figure 2.1 gives a schematic description of the Integrated National Energy Planning Framework.

2.4 This figure shows the energy sector as one of five sectors at the macroeconomic level. Its links to the other sectors can be grouped into (1) prerequisites for the functioning of the energy system (e.g. natural resources, capital, labor); and (2) outputs demanded from the energy system (e.g. electricity, liquid fuels). The control of flows among sector subsystems is the primary focus of energy planning. In the conceptual hierarchy, the objective of energy planning is therefore defined as improving the functioning of a country's energy system. Since this objective must take into account behavioral responses to policies, risks, and uncertainties, the framework considers not only direct financial and physical flows within the energy sector itself, but also "soft" factors which play a role in energy planning.

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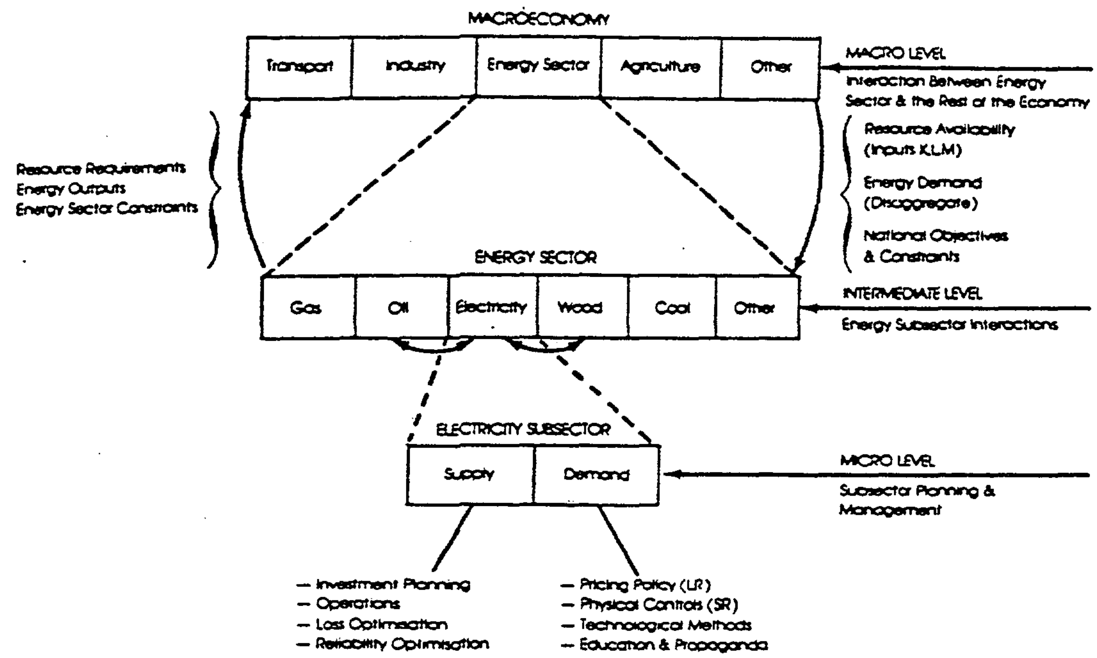
4/ Munasinghe, M., Integrated National Energy Planning and Management - Methodology and Application to Sir Lanka, World Bank Technical Paper Number 86, Industry and Energy Series, The World Bank, Washington DC, 1988.

Figure 2.1: INTEGRATED NATIONAL ENERGY PLANNING FRAMEWORK 5/




2.5 The three areas in which performance is determined in the energy sector are <u>issues, actors, and roles of the actors</u>.

2.6 The issues are (1) efficient use of energy, (2) investment programs, (3) financing, (4) pricing and taxation, (5) effective institutions, (6) educated decisionmaking, and (7) environmental protection.

2.7 The actors are (1) Government, (2) utilities and other energy suppliers such as oil companies, (3) other energy sector investors (e.g. suppliers of end-use equipment), (4) consumers, and (5) financiers.

2.8 Possible roles of Government include correcting market failures, regulating and setting standards, coordinating activities among the sectors, providing information, and influencing energy prices by levying taxes and import duties. The role of utilities is to supply good-quality, reliable, cheap energy. The role of investors is to ensure optimal allocation of financial resources.

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5/ ibid.

The role of consumers is to use energy economically (optimal resource allocation). The role of financiers is to determine the best financing strategies.

## The Role of Models

2.9 Energy planning models can assist in national planning by performing the following functions:

(a) Analytical integration of subsystems (e.g. joint consideration of the power and natural gas sectors). The government can use model evaluations of the cross impacts on individual sectors to provide information and set conditions for reaching objectives (e.g. by modifying tax policies or providing investment incentives). Utilities can better evaluate their market potential when they have a full picture of the entire energy sector.

(b) Policy analysis. The likely consequences to the socio-economic system of a proposed policy measure can be analyzed under varying assumptions about boundary conditions. Model results can be used to evaluate policy measures quantitatively, so they can be ranked by the decisionmaker.

(c) Calculation of environmental impact. On the basis of such results, the Government can take appropriate preventive measures such as standard setting, changing of the economic parameters (prices), encouraging energy efficiency improvements, and others.

(d) Describing a reference energy system for a country. Such a reference system, together with one or more scenarios for future development, is often called an "energy plan." It can improve the information flow between actors in the energy sector.

On a subnational level, energy models can assist with:

(e) Sector optimization. Utilities (power, oil, gas) can use model results to optimize their investment strategies and minimize their operating costs under various demand and price scenarios.

(f) Demand forecasting. Projections of energy demand are indispensable for efficient investments, and are therefore an important tool in decisionmaking. Energy demand can have a critical influence on the balance of payments.

(g) Project evaluation. The full value of many energy-related projects can be determined only in relation to whole energy sector. For example, the full impact of introducing a new kind of cooking device cannot be evaluated by looking at a single rural community; such an evaluation requires that the entire energy system of a region or country be considered.

(h) Financial analysis. Models can determine the feasibility of financial strategies by comparing initial investments with expected returns.

2.10 The attention paid to "soft" aspects of energy planning has increased over the past few years; this is especially true for the role played by uncertainty. Many earlier modeling efforts paid insufficient attention to uncertainty, which reflected the views that (1) models can directly calculate optimal decisions; and (2) that models could be built to map real-world energy activity as accurately as desired if only enough effort were spent on the modeling process. More recent models reflect the insight that the accuracy of results -- and the model's usefulness -- depend not only on model detail, but also on input data, and on model parameters which often include such unknown quantities as future costs or consumption levels. Accordingly, energy models have become more of a supporting tool in decisionmaking, which can be used to describe the consequences of alternative actions under various development scenarios. Professional judgment in evaluating model results still cannot be replaced by computer programs.

## Criteria for the Model Assessment

2.11 The model assessments in this report consist of three parts: description, classification, and evaluation. Although these three areas may overlap in practice, it is helpful to distinguish them conceptually.

2.12 Model description is a verbal characterization of a model's main features. Since most newer planning models are designed to be general and flexible, concrete examples of past planning applications are essential in describing the model. Other descriptors are their availability and the practical aspects of their usage. The descriptions in this report include computing requirements (hardware and software), price, and the model author's availability for support and training.

2.13 Model classification is the identification of model features from a given global set. This report uses the following four classification criteria:

(a) Classification by user. These include strategic (macro) models used by governments; micro models used by utilities and other investors; and hybrids (a combination of the two).

(b) Classification by model characteristics. These include macro-economic sector linkages, impacts, and constraints; demand-supply integration; demand models; supply models; resource development models; single-sector models; single-fuel models; and models of individual projects.

(c) Classification by approach. These include a standard method (e.g. General Equilibrium, Linear Programming); bottom-up (engineering) vs. top-down (globally comprehensive); and specific vs. "tool box" (e.g. Lotus).

(d) Model evaluation is the judgmental assessment of model performance. To make the judgment as transparent as possible, it is helpful for planners to discuss the evaluation criteria in advance. For this project, criteria were established early and communicated to the model builders. The criteria are presented here in their original form, even though minor changes were made during the course of the project. The modifications are discussed separately, in 2.4, below.

The original criteria were:

(a) User friendliness. This includes the amount of help provided by the computer program at run time, completeness and clarity of the model documentation, and resilience of the computer code against user errors.

(b) Comprehensiveness of model output. This has to do with how well and how completely a model answers questions it was designed to answer.

(c) Data intensiveness. Lack of particular data or time series can render a model inapplicable for a given purpose. It is therefore important for a model user to have an understanding of the data requirements of a model.

(d) Sophistication. The use of particular methods to formulate the model often requires specific user knowledge. This criterion describes any special skills needed to formulate model inputs and interpret results.

(e) Transparency. Model outputs should be understandable to all users, including energy planners and decisionmakers, and should be explainable to the interested public. It is therefore important that the way from the input data to the outputs is, at least in broad terms, repeatable by the human mind. A good energy planning model should therefore facilitate documentation of crucial input data, and, even more importantly, facilitate documentation of how inputs and outputs differ between two scenarios. Questions related to this criterion include (a) Is a protocol that summarizes the input data automatically generated with each model run? And (b) How well can the model results be understood in terms of its inputs?

(f) Robustness of results. Since many model parameters are uncertain, small variations in inputs should produce comparably small output changes. Any significant output changes as a consequence of minor input changes are a signal that something may be wrong with either the model or the energy system 6/. Therefore, the degree of mathematical continuity of model results should be evaluated.

6/ Cases where the underlying system lacks robustness must be carefully distinguished from model deficiencies. Discontinuities of the energy system that can best be modeled by discontinuous energy models are much more the exception than the rule.

(g) Treatment of uncertainty. How does the model take the intrinsic uncertainty of its parameters into account?

(h) Flexibility in the model's (a) adaptability to changes in the real-world environment and the decisionmaking process of the user; and in (b) its ability to adjust input needs to the actual data situation.

(i) Applicability and limitations of the model. Applicability is summarized under this item together with the model's limitations.

## The Criteria Revisited

2.14 The model testing gave rise to a number of observations with regard to the criteria described in 2.3.

(a) In reference to classification by user, the users will always be energy planners. This criterion is therefore not discussed separately for each model.

(b) Most modern user interfaces feature readily available information such as on-line help. Availability of information alone, however, is not the same as user friendliness. It must be easy to retrieve, too. Moreover, what is friendliness to the novice can be an obstacle to efficient program handling for the advanced user.

Also, novice users could benefit from tutorial programs, while advanced users would benefit from a comprehensive reference manual divided into a guide and documentation. Therefore, this report assesses user friendliness descriptively rather than qualitatively.

Another observation was that programming languages can cause problems for PCs which did not exist on mainframes. For example, PCs use function keys for program input. If this input is handled through the operating system (DOS) rather than by the program itself, any prior redefinition of the function keys takes precedence over the transmission of the correct input signal. Another problem is the buffer function for keyboard inputs. Since keystrokes are stored and processed sequentially, multiple typing of, for example, the ESCAPE key, which might be necessary to reach a desired level on the hierarchy of a program, might also cause time-consuming deviations from the program if it is typed one time too many.

(c) Since the comprehensiveness of model outputs are usually high, all the tested models let the user choose the amount of output to be produced. The practical aspects of this flexibility are discussed below.

(d) Another element of flexibility was that all the models let the user choose the degree of model detail and thereby the model's data intensiveness.

(e) A full assessment of the robustness of model results can only be made by comparing several model applications. Since it was not possible to study many different outputs for each model, information provided by actual users could have been valuable. Obtaining that information was difficult, however, since the response rate to written questions was low, and many reports on model performance were confidential. The assessment of robustness in this report is therefore more qualitative than quantitative.

(f) The uncertainty criterion was found to be largely redundant, because most models treat uncertainty in the definition of scenarios. The most notable exceptions were the models for power system expansion planning: ELECTRIC/WASP in the ENPEP and MESAP systems, and AESOP in ETB. Uncertainty has therefore been dropped as a criterion. Instead, how well a model supports the formulation and analysis of alternative scenarios has been added to the assessment.

(g) In regard to flexibility, the lower extreme of complete rigidity is obviously undesirable, while too much flexibility leaves the user with a tool box but without a model. Model builders normally resolve this tradeoff by combining the flexibility of a tool box with the formulation of a reference model that can easily be modified according to individual needs. These reference cases are particularly interesting, but they carry a lot of suggestive weight (the user's inclination to leave numbers "as they are" can obviously hamper an effort to find the most appropriate inputs, for example). On the other hand, the references define an area of experience with the model which is often reflected in an upgraded design. In any case, modern model flexibility is the reason that the art of model building is increasingly complemented by the art of model application.

(h) All models in this assessment are still evolving, and are likely to be improved. Any known plans for improvement are discussed under the heading Future Plans.

(i) The original set of model descriptors has been amended to include Easiest Access to a model. This point describes the steps that users are advised to follow to gain better knowledge of a model.

## Questions When Selecting a Model for Energy Planning

2.15 Energy planning and energy modeling are complex activities which require both scientific skills and intuitive judgments. Some questions relying on the latter are:

(a) Which aspects of the overall energy system and the economic system should be included in the model, and which should be left out?

(b) Which parts of the system should be aggregated and which should be separate?

(c) Should a normative (optimization) or a descriptive (simulation) model be used?

(d) Which variables can be expected to "behave," i.e. to move continuously within foreseeable and comparably narrow limits; which variables are under the control of national decisionmakers; and which are likely to move erratically?

2.16 For each question, the model user should have a feeling for the positive and negative aspects of the possible answers.

## A Possible Bias of This Report

2.17 The totality of intuitive judgments put into model applications can be summarized as style, which some will prefer to call bias. The author, concerned with models and their applications for many years, has, naturally, developed a style of his own. To enable readers of this report to judge the influence of this style, or bias, on the assessment results, the author here presents an account of his style.

2.18 The author's most basic thesis of model application is that an energy model should be applied to a well-defined problem or issue, such as developing a resource base or introducing a given energy conversion technology. (This thesis is shared by T. Wilbanks 7/, among others.) In practice, however, models are often used for a more general purpose, such as describing a country's energy system, establishing a framework for decisionmaking, finding an optimal development path, or similarly comprehensive purposes. These purposes are of course valid, but they do not allow for clear-cut answers to the above questions. Model size is a case in point. General scientific principles suggest that the smallest adequate model is preferable to any larger model. But how can the question of adequacy be decided without reference to a specific purpose? Moreover, since modeling is a dynamic process, and since testing leads to more reliable results with smaller models, it seems reasonable to begin any model application with a minimal model size (the smallest that gives an answer relative the problem), as long as this does not lead to oversimplification 8/.

2.19 The same questions apply to system boundaries (whether to include or omit parts of the real-world system), as well as to the aggregation and disaggregation of model variables.

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7/ Wilbanks, T.J., "Lessons from the National Energy Planning Experience in Developing Countries," in The Energy Journal, Vol. 8, 1987.

8/ It is interesting to note here that modelers rarely make direct reference to the size of their models. Models are "compact," "complex," or "comprehensive," but hardly ever "small" or "large."

2.20 Without attempting to change the meaning of established terms, it is suggested that when optimization models are applied for long-term energy planning, they are not significantly different from simulation models. It is also suggested that normative models be used for energy planning 9/ only where the normative variables are well-controlled in real life. In any case, pure examples of normative and simulation models are rare because most energy planning models contain both normative and simulation elements. Particularly when presenting results, it is therefore important to specify what part of a model is normative and what part is meant as simulation.

2.21 Given the intrinsic uncertainty of future events, one may wonder why probabilistic (stochastic) features have not been explicitly included in more energy planning models. One reason is that it is difficult to implement sophisticated mathematical methods and interpret their results. Another is that the uncertainties involved can best be quantified only by a judgmental probability distribution. Energy prices, consumer behavior, resource availabilities, and technological forecasting are typical examples. The literature on this topic (see, e.g., 10/,11/,12/,13/) suggests that the human mind performs poorly in judging such probabilities. Moreover, the issue might not be the entire probability distribution of, say, world oil prices, but rather a certain critical value which must be met for guaranteeing the payoff of investments. In such a case, what is usually needed is a quantification of the "regret," i.e., the consequences of a "wrong" decision 14/. The high degree of effort and the often low level of benefit involved in stochastic modeling must have lead modelers to the conclusion that uncertainty is best reflected by the definition and analysis of scenarios, since scenarios can be used to analyze the sensitivity of uncertain input assumptions and to describe limiting cases.

2.22 On the other hand, there are also energy planning problems in which the probability distribution of the variables is much better understood, such as in power system expansion planning, where the availabilities of electricity generating plants can be reasonably well-described in stochastic terms. Accordingly, in models of the power sector, the probabilistic approach is more suitable, and more widely used.

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9/ The situation is different, for example, when limiting cases are investigated. There, the maximum consequence of extreme efforts can be used to describe the limit of what is thought possible under given circumstances.

10/ Kahnemann, D., P. Slovic, and E. Tversky (eds.), Judgement under Uncertainty: Heuristics and Biases, Cambridge University Press, Cambridge, 1982.

11/ Wildavsky, A., and E. Tenenbaum: The Politics of Mistrust. Estimating American Oil and Gas Resources, Sage Publications, Beverly Hills, London, 1981.

12/ Schnaars, S.P., Megamistakes, Forecasting and the Myth of Rapid Technological Change, The Free Press, New York, and Collier Macmillan Publishers, London, 1989.

13/ Manne, A.S. and L. Schrattenholzer, "The International Energy Workshop - a progress report," in OPEC Review, Vol. XIII, No. 4, Vienna, 1989.

14/ However, it should be noted that there is no complete assessment if the planner does not have at least a rough idea of the "liklihood of reaching a wrong decision".

2.23 Energy prices are both highly uncertain and critical to the development of the energy system. They are therefore the cause of much difficulty in energy planning. Nevertheless, some models of energy demand do not include price variables. What may look surprising at first is, however, better understood if the role of prices in energy models is discussed in more detail.

2.24 The relation between energy prices and energy demand is usually expressed in terms of elasticities 15/, which quantify changes in demand as a function of price changes. The interrelationship between the three variables, demand, price, and elasticity, is normally represented in "closed form," i.e., any of the three variables can be mathematically calculated if the other two are known. If only one of the three is known, the relation between the other two can normally be expressed graphically as a curve. The traditional economist's approach is to use prices, elasticities, and a reference demand for the calculation of demanded quantities. In an environment where prices and elasticities are well-known, in particular in short-term projections, this is a plausible way to project demand changes, since the causal direction implied by this approach is clearly justified.

2.25 The situation is different for projecting the long-term development of energy demand, because there, the accumulation of small mistakes (resulting from slight differences between actual and assumed prices and/or elasticities) can easily lead to estimates that are far off actual future values. It is therefore reasonable to project energy demand in the long-term by some other means. However, to maintain the visibility of the relation between the three variables, it is useful to calculate a set of prices and a set of elasticities that are consistent with a given level of energy demand. The fact that these calculations can be done outside of an energy planning model means that including price variables in the model itself, while an important characterization, is not a prerequisite 16/.

2.26 These notions about modeling assign the bulk of responsibility for results to the model user, and make energy planners who regularly use models valuable sources for model assessments. This project could not tap this source as much as had been hoped, however, because written requests for comments had a low response rate, and the project did not have the resources to collect such information through visits to model users.

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15/ For this simplified discussion, we will not consider the relation between energy demand and economic activity.

16/ In many LOCs, the problem of assessing the effect of a gradual change in prices must be faced. In some of these countries it is common to find subsidized pricing policies but committed to a gradual relaxation of these policies. Therefore, it is essential to have to take into account the impact in time of pricing policy reforms.

# III. THE MODEL SELECTION PROCEDURE

## Objective and Preparatory Steps

3.1 The first goal was to find a large number of candidates from which to choose models for the final assessment. To achieve this goal, more than 100 letters were sent to model users. The letters described the purpose of the project and invited the addressee to nominate a model for consideration. For each model nominated, the addressee was asked to respond to a questionnaire characterizing its main features. (See Figure 3.1.)

Figure 3.1: QUESTIONNAIRE FOR MODEL CHARACTERIZATION

Name of the model:

Developed by:

Contact person for further information:

Model "relatives" (if the model is based on a different model):

Model documentation:

Model complexity (please mark and/or cross out accordingly):

Energy demand | energy supply included
All demand sectors | selected demand sector(s)
All primary energy supply | selected fuel(s)
Energy-economy interaction not included | included

Recent applications of the model:

Type of organization that development the model
(please mark where appropriate):

__ Commercial __ Government __ University

Hardware requirements:

Conditions of availability:

Training and support offered:

3.2 The questionnaires received in response to these letters and further suggestions resulted in the following list of candidate models.

| | | | | |
|---|---|---|---|---|
| "ATW" | D | | (E) | University of Regensburg and the World Bank |
| BEEU | D | S | | OLADE, Quito |
| BEULOCHE | (D) | | | Bariloche Foundation |
| CENECA | D | S | E | Central Planning Office, The Hague |
| DVIN etc. | D | S | E | Ministry of Fuel and Energy, Prague |
| EBIEE | D | S | | Institute of Energy Economics, Tokyo |
| ECCO | D | S | E | The Resource Use Institute, Edinburgh |
| EEDPM | D | S | E | Consulting Engineer, Pijnacker |
| EFOM-ENV | D | S | | Karlsruhe University |
| "EMIS" | D | S | | Tsinghua University, Beijing |
| ENERPLAN | D | S | E | UNDTCD, New York |
| ENPEP | D | S | E | Argonne National Laboratory |
| EPSP | D | S | E | ESCAP, Bangkok |
| ETB | D | S | E | Imperial College, London |
| GAMS | 1/ | | | World Bank |
| "GATELY" | (D) | | | New York University |
| GEMS | D | S | E | Decision Focus Inc., Los Altos |
| HEATMOD | (D) | (S) | | Technical University, Gdansk |
| HERMES | | | (E) | Commission of the European Communities, Brussels |
| INEP | D | S | E | Government of Sri Lanka, World Bank |
| "ISRAEL" | (D) | (S) | | Tahal Consulting Engineers, Tel-Aviv |
| LEAP | D | S | (E) | Stockholm Environment Institute, Boston Branch |
| MAREN | D | S | | TOTAL, Paris |
| MARKAL | (D) | S | | Brookhaven National Laboratory |
| MEDEE-EUR | D | (S) | | Commission of the European Communities, Brussels |
| MEDEE-P | D | | | Atomic Energy Commission, Islamabad |
| MEDEE-S | D | (S) | | Grenoble University |
| MELODIE | | | E | CEA, Paris |
| MESAP | D | S | E | Stuttgart University |
| OPTY | D | S | E | Polish Academy of Sciences |
| REQLOCHE | D | | | Bariloche Foundation |
| SEDM | D | | E | School of Economics, Prague |
| SIM-NRJ | D | | | Geneva University |
| TEESE | D | S | E | Tata Energy Research Institute, New Delhi |
| WINES | (D) | | | NEA, Paris |

Notes: 1/ Tool box for modeling and solving optimization problems in general.
Model names in quotes are substitutes, given by the author where no original names were available

D ... All demand sectors included
S ... All supply sectors included
E ... Energy-Economy interaction included
( ) ... All items in parentheses are only partially included

It should be noted that not all of these models were proposed to be included in the project.

## The Selection Criteria and their Application

3.3 From this list of candidates, models were selected for assessment based on the criteria below. Any unexplained part of the selection procedure that led to the final choices that did not fit the criteria can be attributed to judgment.

3.4 One problem inherent in the selection process was that models had to be selected before they were tested; another was that even if it had been possible to select the models on the basis of *a priori* knowledge, it would have been impossible to apply a single criterion to all models. It was therefore decided to evaluate models that are widely available and already in use in developing countries. Another reason for selection was whether an energy system was well-described by a model, i. e., whether it included a good treatment of both demand and supply, as well as some link to the national economy. In addition, two models, MARKAL (supply) and MEDEE-S (demand), were selected specifically because they represent the most prominent or typical models of their kind. Similar models were avoided, which meant, e.g., that if two models originated from the same basic model, only one was used.

3.5 The selection process left open the possibility that some energy planning problems in developing countries could best treated by a model not included here. Most of the problems in the field, however, can be addressed with at least one of the models presented in this report.

## Models Selected

3.6 The eight models selected for detailed assessment can be roughly categorized into three groups (see Figure 3.2).

Figure 3.2: MODELS SELECTED FOR DETAILED ASSESSMENT

| | | | | |
|---|---|---|---|---|
| ENPEP | MESAP | (ETB) | (LEAP) | 1st group |
| ENERPLAN | (ETB) | (LEAP) | TEESE | 2nd group |
| MARKAL | MEDEE-S | | | 3rd group |

3.7 The models in the first group, ENPEP, MESAP, and, to a degree, ETB and LEAP, are really model systems in which each model is well-separated from the others, with each covering a particular field of energy planning -- macroeconomic analysis, demand forecasting, supply-demand balancing, calculation of environmental impact of energy activities, and so on.

3.8 The models in the second group, ENERPLAN, ETB, LEAP, and TEESE, are much more compact, although they too can include submodules. Current development on LEAP is moving it the direction of the first level. Likewise, ETB has been included in both the first and second groups because it has characteristics of both. Conceptually, ETB and LEAP can be thought of as model systems, although their deliberate simplicity distinguishes them clearly from ENPEP and MESAP.

3.9 The models of the third group, MARKAL and MEDEE-S, are specifically designed to investigate, respectively, energy supply and demand.

3.10 The two model systems, ENPEP and MESAP, have two models in common. One is the power system expansion model, WASP (it is called ELECTRIC in ENPEP to distinguish it from the mainframe version). The other is WASP's "servant model," MAED, which is the original MEDEE-2, augmented by a part that calculates electricity demand in a way that matches the input requirements of WASP/ELECTRIC.

3.11 There is no common origin between MARKAL and MESSAGE 3 (a part of MESAP), but there is a general similarity of concept. Other models not included in the assessment are discussed in Appendix A.

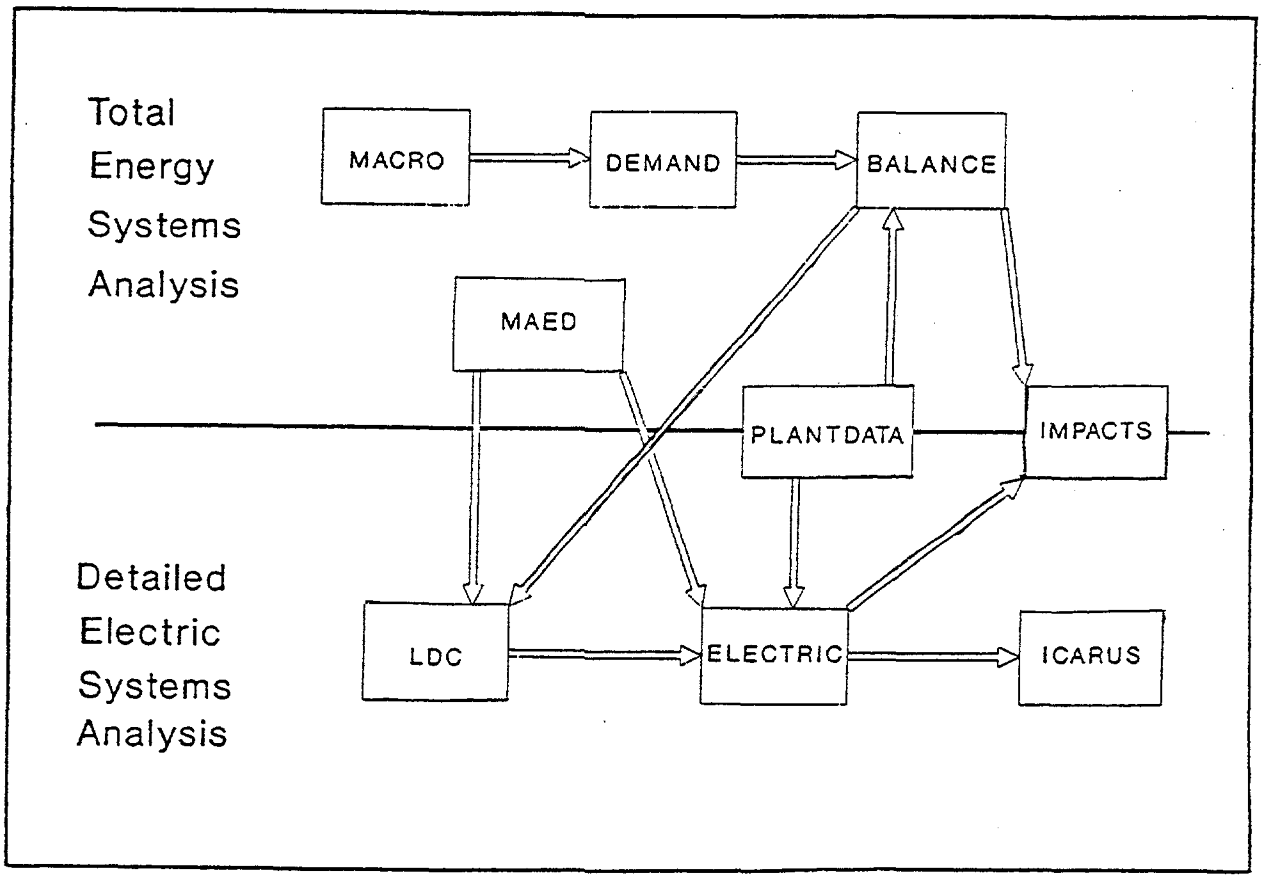
# IV. ASSESSMENT OF THE SELECTED MODELS

## The ENPEP Modeling System

### Model Description

4.1 The Energy and Power Evaluation Program (ENPEP) is a microcomputer-based program system for energy planning with a time horizon of up to 30 years. It was specifically, but not exclusively, created to provide energy analysis capabilities to developing countries 17/.

Figure 4.1: OVERVIEW OF THE ENPEP MODELING SYSTEM 18/

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17/ Jusko, M.J. et. al., Energy and Power Evaluation Program (ENPEP) - Documentation and User's Manual, Energy and Environmental Systems Division, Systems Analysis, Development, and Evaluation Group. Argonne National Laboratory, August 1987.

18/ Buehring, W.A., B.P. Hamilton, K.A. Guziel, and R.R. Cirillo, ENPEP: An Integrated Approach for Modeling National Energy Systems, Argonne National Laboratory, February 1991.

4.2 ENPEP is a system of one executive module and nine technical modules. The technical modules are as follows:

(a) MACRO is a module which transforms macroeconomic projections which are typically generated elsewhere, such as GDP growth and population, into the format required by the ENPEP modules that generate energy demand data. MACRO is not itself a planning model.

(b) DEMAND is a model to calculate either final or useful energy 19/ demand. Inputs are energy consumption figures in the base year and the sectoral economic growth rates provided by MACRO. These are combined in a straightforward way to derive energy demand projections for each economic sector. DEMAND's output directly feeds into the BALANCE module. The model does not include an explicit price dependency of energy demand.

(c) PLANTDATA is a library of basic information about thermal and hydroelectric power plants for use by the BALANCE and ELECTRIC modules.

(d) BALANCE, a successor of the mainframe model IDES, is a nonlinear general-equilibrium model which balances energy supply and demand for a period of up to 30 years. BALANCE incorporates a network representation of a country's energy system from primary sources to demands for final or useful energy. The main balancing rule is based on the relative economics of competing fuels, i. e., the cheaper a fuel the more it contributes to meeting energy demand. The inputs to BALANCE are (i) the network of nodes (such as the production or transformation of resources; decision nodes, in which a selection is made between alternate sources of supply; pricing nodes, in which government price regulations and pricing policies are modeled) and flows (energy movements between the nodes) defining a country's energy system; (ii) the energy flows in the base year, (iii) availability constraints for domestic and imported energy carriers, (iv) pricing policies, and (v) others. The model output is a complete picture of energy flows and equilibrium prices for the entire planning period.

(e) LDC (Load Duration Curve), a successor of the earlier LOAD module, is a tool for calculating a more detailed description of total electricity demand. Inputs into LOAD are (i) annual consumptions of electricity and (ii) losses during transmission and distribution. Outputs are load curves that can be directly fed into ELECTRIC. The estimated load curves can be viewed with built-in graphics. Calculation results are available in tables.

(f) MAED (Model for the Analysis of Energy Demand) is a simulation model of the MEDEE family which calculates final energy demand as a function of

19/ See the glossary in Appendix C for a definition of this and other terms.

the socioeconomic (population, sectoral GDP, etc.) and technical (end-use energy conversion characteristics) evolution pattern of a country. Energy prices are not explicitly included in the model. MAED's output includes load duration curves and can therefore be used as a direct input for ELECTRIC.

(g) ELECTRIC, 20/ a microcomputer version of the Wien Automatic System Planning Package (WASP-III), is designed to determine the generating system expansion plan that adequately meets a given demand for electric power at minimum expected cost, subject to system requirements. ELECTRIC is directed to long-term planning (more than 10 years). In a more specific mode of running, the model can evaluate a number of proposed alternatives for the expansion of the power system. The model explicitly considers two kinds of uncertainties: forced outage rates and up to five hydraulic conditions. Electricity demand is described in the form of load duration curves in up to twelve periods per year. In its optimizing mode, ELECTRIC works with both a fixed and a variable part of the power system. The fixed part includes the existing system at the start of the study period, additions that are considered definite, and scheduled retirements of old plants. The variable part describes user-defined alternatives for the expansion of the power system. The main model inputs are data on electricity demand, on the technical characteristics of power plants (unit size, fuel consumption, and others), and on plant performance (unexpected outages, scheduled maintenance, and others); costs (fuel, investment, operation and maintenance); and other economic parameters (discount rate, inflation rates) and constraints (e.g. minimum reliability). The main model output describes the performance of either a given system expansion plan or of the optimal path. Other outputs, such as on the performance of alternative possibilities and on the actual supply mix in a given demand period, are available as well.

(h) ICARUS is a simulation module that calculates production costs for up to 600 unique power plants in an electricity generating system, and calculates system-wide reliability for periods of one week to one year. ICARUS was designed to simulate short-term load scheduling. It is therefore a logical expansion of the ELECTRIC module, where model simplifications have been made to save computer run-time. The combination of ELECTRIC and ICARUS used in tandem allows the energy planner to perform long-run marginal cost (LRMC) and short-run marginal cost (SRMC) calculations for the electric power system for different years and system configurations. LRMC and SRMC provide important information for consideration in setting the structure of electricity tariffs.

(i) IMPACTS calculates the environmental burdens and resource requirements for the two parts of the energy supply system, electric and nonelectric, that

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20/ This description of ELECTRIC is essentially the same as the description of WASP in the assessment of MESAP.

are computed, respectively, by the ELECTRIC and BALANCE modules. The database used by IMPACTS is still being developed, and is expected to be completed by the fall of 1991. IMPACTS addresses air pollution, water pollution and water supply, land use, solid waste generation, human and material resource requirements, and occupational health and safety.

4.3 These technical modules are operated through the EXECUTIVE module, which handles program installation, file saving and restoring, viewing and modification of data, file editing, program execution, and tabular and graphical output of results.

Future Plans

4.4 A graphical user interface for building, reviewing, and modifying the BALANCE network is being expanded. Capabilities for analyzing price effects on final demand are being added to BALANCE as part of a U.S. application.

Applications of ENPEP in Developing Countries

4.5 Since the PC version of ENPEP was released only recently, this account includes applications for mainframe predecessors of the present models.

4.6 Argentina. In a joint Argentinean/U.S. study, WASP and AEM (Argonne Energy Model) have been applied in a "comprehensive assessment of Argentina's energy resources, needs, and uses." 21/ A base case was established and used to evaluate scenarios on fuel pricing, energy conservation, economic growth, renewable resource penetration, and imported coal.

4.7 Republic of Korea. In the same format and with analogous objectives, a joint Korean/U.S. study was undertaken to look into South Korea's energy future.

4.8 Bangladesh. WASP was used to estimate power generation capacity cost in a study of the country's power sector tariffs.

4.9 Jamaica. JINEP, a model based on IDES (the mainframe predecessor of BALANCE), was used for a study in support of Jamaica's National Energy Plan. In style and content, the study resembled the earlier assessments for Argentina and South Korea.

4.10 Pakistan. A study for Pakistan 22/ investigated the influence of different load duration curves (assuming the same total electric demand) on the country's power system planning. The conclusion, based on WASP model runs, was that optimal system expansion must take account of the expected load curves.

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21/ Government of Argentina and U.S. Department of Energy, Republic of Argentina/United States Cooperative Energy Assessment, Argonne National Laboratory, Argonne, Illinois, 1982.

22/ Mumtaz, A. et. al., A WASP-3 Based Electric System Expansion Planning Study for Pakistan with Constant and Variable Load Duration Curves, Pakistan Atomic Energy Commission, Islamabad, Pakistan, August 1990.

4.11 The PC version of ENPEP has been distributed to official agencies in a number of developing countries, 23/ i. e., Algeria, Bahrain, Cyprus, Egypt, Indonesia, Jordan, Kuwait, Malaysia, Morocco, and Tunisia. Most reports on the results of these uses are confidential, except for those by Charalambous 24/ and the International Atomic Energy Agency. 25/

Model Classification

4.12 Classification by model characteristic. ENPEP includes modules that meet the classification criteria of macroeconomic sector linkages, demand-supply integration, and demand modeling.

4.13 Classification by approach. It is difficult to classify a comprehensive modeling system because it has both top-down and bottom-up elements. BALANCE is based on a nonlinear generalized equilibrium approach. ELECTRIC is based on Probabilistic Simulation of System Operation and Dynamic Programming.

Practical Aspects of Model Availability and Usage

4.14 Minimum computing requirements. IBM AT or equivalent, 640 kb of RAM, mathematical coprocessor, hard disk (30 Mb recommended).

4.15 Additional software required. None.

4.16 Price of the model. ENPEP is available to member states of the International Atomic Energy Agency (IAEA) and to other international organizations. It is released free of charge (except for some out-of-pocket expenses), subject to standard conditions that, e.g., restrict the right to pass on the software to unauthorized users.

4.17 Support and training offered. Support and training are part of the normal transfer procedure. A typical training course for the modeling system lasts eight weeks.

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23/ Charpentier, J.P., World Bank, personal communication.

24/ Charalambous, C., et. al., Energy Planning and Assessment of the Long-Run Marginal Costs Associated with the Generation Expansion Programme (An Overview of the Cyprus Case Study), UNDP/World Bank Project on Energy Planning for European and Arab State Countries, December 1988.

25/ Experience in Energy and Electricity Supply and Demand Planning with Emphasis on MAED and WASP Among Member States of Europe, the Middle East, and North Africa, IAEA-TECDOC-607, International Atomic Energy Agency, Vienna, 1991.

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4.18 Easiest access. There is probably no easy access to a system as comprehensive as ENPEP. The best way to master the system is to study the introduction to the user's manual, which provides a good overview of ENPEP in 20 pages.

Model Evaluation

4.19 User friendliness. By all standard criteria, ENPEP is very user friendly. The user interface is excellent, with readily available on-line help. All modules have a uniform style, and there are comprehensive users guides. Even MAED (a close relative of MEDEE), which internally uses a rather restrictive internal format, can be used easily. The effort necessary to master this tool, however, must be evaluated by each user himself/herself. Although ENPEP's flexibility makes it suitable for both large and small studies, the "weight" of the full system will often be felt by the novice user.

4.20 Comprehensiveness of model output. In line with the comprehensiveness of the modeling system, the potential output of ENPEP is enormous. The user determines which parts of the output are printed.

4.21 Data intensiveness. In principle, small energy systems can be described with ENPEP and/or its submodules, although past applications have been for large systems and have thus been highly data intensive. A demonstration version of MACRO, DEMAND, and BALANCE consists of more than 280 files, 40 of which contain data. The rest contain programs and fixed program inputs such as screen definitions. The model can be set up to keep data in separate directories.

4.22 Sophistication. Although the basic methodical ingredients of ENPEP are not complicated, a full-sized application of the system can be difficult to comprehend. In addition to a good general knowledge of the energy system, the user must have specific knowledge about the power sector to understand ELECTRIC and its related modules.

4.23 Transparency. ENPEP's transparency is very much a function of the degree of detail used to model a particular problem. Simple and small systems can be easily understood in terms of inputs and outputs. The results of scenario variations in elaborate applications might be too complex to be readily understood.

4.24 Robustness of results. The BALANCE approach of matching demand and supply generates more robust results than a Linear Programming model, because the emergence of a supply mix despite cost differentials is more naturally facilitated. (Without appropriate precautions, an LP model chooses the cheapest fuel up to its limits before an alternative is used at the same time for the same demand item.) This feature is not present in ELECTRIC, where major changes in results are possible as a consequence of only minor input changes. On the other hand, it can be argued that the expansion of the electric system itself is not robust in the mathematical sense, i. e., that small differences in the performance of a technology can make a significant difference in the resulting system. In such areas, a sensitivity analysis of the critical parameters is normally undertaken. All other modules rely on more straightforward methods and are therefore likely to produce reasonably robust results.

4.25 Flexibility. Very high. The energy system to be modeled is fully determined by the user.

4.26 Applicability and limitations. The graphic representation of ENPEP (Figure 4.1) suggests two main variants for using the ENPEP system. One is the use of MACRO, DEMAND, and BALANCE to analyze the total energy system of a country. These three models are used to generate energy demand and supply scenarios as a function of (1) economic growth, (2) descriptions of the economic actors (by relating unit costs to the level of supply), (3) resource costs and availabilities, and (4) other factors. Thus, the system can be used to analyze the consequences of pricing and taxing policies, the availability of energy conversion and end-use technologies, resource constraints, and other conditions.

4.27 The other variant for using ENPEP is built around the ELECTRIC and the ICARUS models, and analyzes such details of a country's electric system as the formulation of optimal power system expansion plans or the optimal management of an existing system.

4.28 In either variant, the IMPACTS module can be used to calculate the environmental impact of energy scenarios. Of course, modules like BALANCE, MAED, or ELECTRIC can be applied in a stand-alone mode for a specific purpose. ENPEP's full power is unleashed where data about an energy system are comprehensive and fully available.

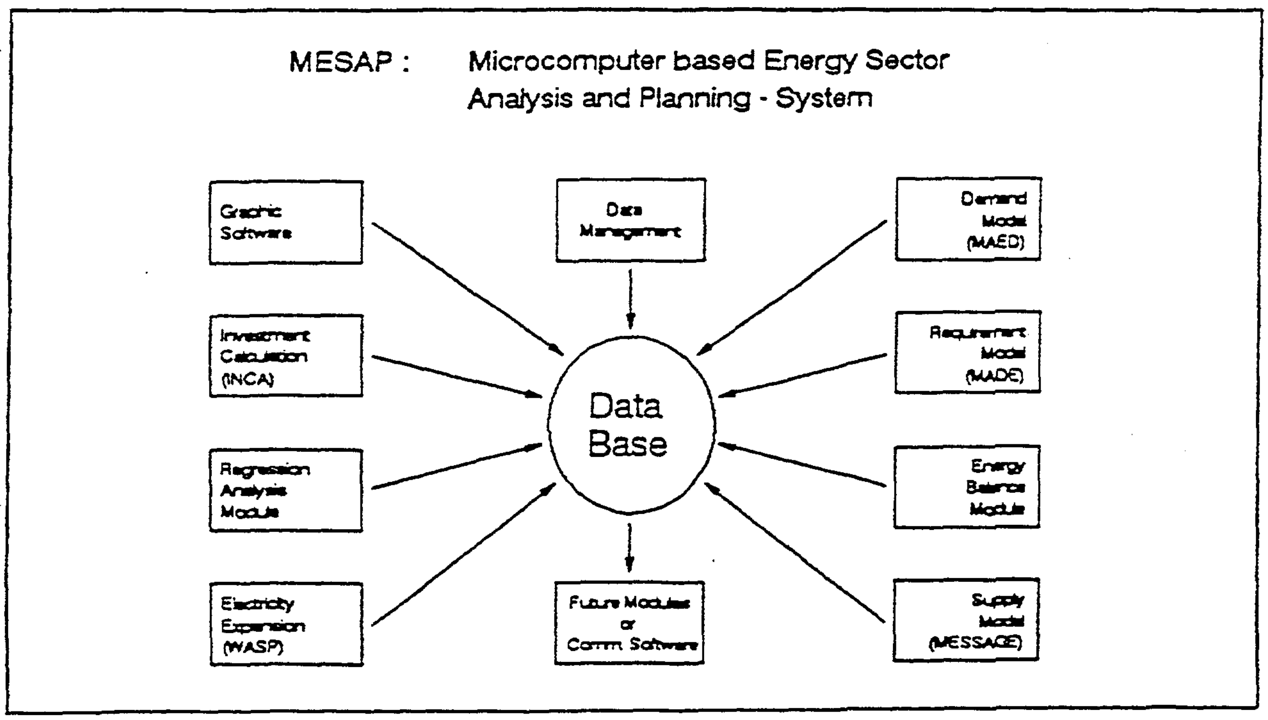
4.29 MACRO is not a macroeconomic model itself, but uses macroeconomic projections, typically generated elsewhere, to produce input data for DEMAND. Neither DEMAND nor MAED consider energy prices explicitly. The way BALANCE treats supply curves implies that capacities themselves are not optimized within this module. (If there is no central decisionmaker, this should not be much of a limitation.) This is not the case with the ELECTRIC model of the power sector (in which the existence of central decisionmaking bodies is more likely) because the calculation of capacities is part of the optimization.

## The MESAP Modeling System

### Model Description

4.30 The Microcomputer-based Energy Sector Analysis and Planning System (MESAP) is an energy modeling system developed by an energy systems analysis group at the University of Stuttgart. Since the beginning of 1990, further work on and with MESAP has been carried out by the newly-formed Institute for Energy Economics and the Rational Use of Energy (IER), also at the University of Stuttgart. One major activity of the IER is energy planning in developing countries.

Figure 4.2: OVERVIEW OF MESAP 26/




4.31 MESAP is a modular energy planning package that was designed with specific regard to the needs of developing countries. It includes data management and processing software, a set of formal energy models, and auxiliary energy planning tools.

4.32 At the core of MESAP is a software system, RSYST, for managing a hierarchical database developed at the University of Stuttgart. RSYST includes graphics software, a regression

26/ Reuter, A., et. al., Rational Use of Energy in Developing Countries - Modeling Tools: Case Study Nigeria, 25th Intersociety Energy Conversion Engineering Conference, Reno, 1990.

analysis module, an energy balance module, and interfaces to commercial software packages, including dBase, Lotus, Freelance, and others.

4.33 Built around RSYST are the following energy modules and planning tools:

(a) MAED (Model for Analysis of Energy Demand), a simulation model of the MEDEE family which calculates final energy demand as a function of the socioeconomic (population, sectoral GDP, etc.) and technical (end-use energy conversion characteristics) evolution pattern of a country. Energy prices are not explicitly included in the model. MAED's output includes load duration curves and can therefore be used as a direct input for WASP.

(b) MADE II (Model for Analysis of Demand for Energy) is a follow-up of MAED, developed at the University of Stuttgart to improve the user friendliness of the original MAED. MADE II combines projections of sectoral economic activity and demographic inputs for calculating energy demand. As an option, energy prices and price elasticities can also be included. Another option is the use of a macroeconomic module for projecting GDP, which involves relations between GDP, labor, capital stock, investments, trade, and other factors. For the calculation of household demand, MADE II uses income distributions and dwelling types, and explicitly considers urban and several types of rural households. The main output can be chosen either in useful or final energy terms; and primary and secondary energy requirements can be calculated using scenarios of energy efficiencies and penetration rates of conversion technologies. MADE II has been used in connection with the MESSAGE 3 model.

(c) MESSAGE 3 (Model for Energy Supply Systems and Their General Environmental Impact) is a dynamic Linear Programming energy supply model with the option to use Mixed Integer Programming. The main objective of the model is to minimize total energy costs, but other considerations, such as dependence on foreign exchange and imports, can be included in the objective function. The model is driven by the inputs describing energy demand. Its solution describes the optimal (in the sense of the objective function) mix of energy supply alternatives, under constraints to availability of primary resources and energy conversion technologies. Pollutant emissions can also be calculated.

(d) WASP 27/, a microcomputer version of the Wien Automatic System Planning Package (WASP-III), is designed to determine the generating system expansion plan that adequately meets a given demand for electric power at minimum expected cost, subject to system requirements. WASP is directed to long-term planning (more than 10 years). In a more specific mode of running, the model can evaluate a number of proposed alternatives for expanding the power system. The model explicitly considers two kinds of uncertainties: forced outage rates and up to five hydraulic

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27/ This description of WASP is essentially the same as the description of ELECTRIC in the assessment of ENPEP. A practical difference between the two is that the MESAP version of the model does not have the same (elaborate) user interface.

conditions. Electricity demand is described in up to twelve load duration curves per year. In its optimizing mode, WASP works with a fixed and a variable part of the power system. The fixed part includes the existing system at the start of the study period, additions that are considered definite, and scheduled retirements of old plants. The variable part describes user-defined alternatives for expanding the power system. The main model inputs are data on electricity demand, on the technical characteristics of power plants (unit size, fuel consumption), and on plant performance (unexpected outages, scheduled maintenance); costs (fuel, investment, operation and maintenance); and other economic parameters (discount rate, inflation rates) and constraints (minimum reliability). The main model output describes the performance of either a given system expansion plan or of the optimal path. Other output, such as on the performance of alternative possibilities and on the actual supply mix in a given demand period, are available as well.

(e) INCA is based on a dynamic investment calculation method. It determines microeconomic data relevant to an investment decision, including amortization period, levelized costs, annuities, cash flows, and so on.

4.34 There are two distinct ways of applying MESAP. One is to base an analysis on MAED and WASP; the other is to base it on MADE II and MESSAGE 3.

Future Plans

4.35 Work on a unified user interface is in progress. Also, the creators of MESAP routinely use applications as an opportunity for further model development.

Applications of MESAP in Developing Countries

4.36 Iran. 28/ A doctoral thesis describing regionalized scenarios of energy demand and supply for Iran in the time period 1987-2007. During the writing of this thesis, the demand module MADE II was first developed, and the energy supply module MESSAGE was expanded to reflect regional features.

4.37 Nigeria. 29/ Analysis of the country's fuelwood problem. MESAP was used to tackle the problem of Nigeria's wood consumption exceeding the regeneration rate. The results identify measures for the efficient and rational use of energy in the household sector.

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28/ Saboohi, Y.: Ein regionalisiertes Modell für die Energieplanung in Entwicklungsländern (A Regionalized Model for Energy Planning in Developing Countries), doctoral thesis describing an application for Iran, University of Stuttgart, October 1989.

29/ Reuter, A., Rational Use of Energy in Developing Countries - Modeling Tools: Case Study Nigeria, 25th Intersociety Energy Conversion Engineering Conference, Reno, 1990.

4.38 Jordan. 30/ National energy and electricity planning. Details of the results are confidential.

4.39 Cooperative contacts for using MESAP have also been established with Argentina, Burundi, India, South Korea, and Zaire.

Model Classification

4.40 Classification by model characteristic. Macroeconomic sector linkages, energy demand module(s), demand-supply integration.

4.41 Classification by approach. Energy demand simulation (combining bottom-up and top-down approaches), Linear Programming (supply module), and Probabilistic Simulation of System Operation and Dynamic Programming (electricity expansion module).

Practical Aspects of Model Availability and Usage

4.42 Minimum computing requirements. Normally, MESAP is provided along with the appropriate hardware. The minimum hardware requirement is an IBM-AT or equivalent with 1 Mb RAM and 30 Mb storage capacity on a hard disk, both under the DOS operating system. However, IER recommends using bigger machines (PCS-CADMUS or IBM PS/2) which are capable of running UNIX or an equivalent system (such as IBM's AIX).

4.43 Additional software required. None.

4.44 Price of the model. Nothing is charged for the model; the only charge is for the hardware. Normally, MESAP is provided as part of a joint project between an agency in a developing country and the IER. The project is often funded by German or international donor organizations.

4.45 Support and training offered. Support and training are part of the normal transfer procedures.

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30/ Voß, A., A. Reuter, H. Elischer, T. Muller, Y. Saboohi, and S. Schnabel, Validation of the Integrated Energy Planning System MESAP - A Country Case Study, University of Stuttgart, May 1990.

4.46 Easiest access. A brochure with an instructive overview of MESAP is available 31/. MADE II may be used as a stand-alone model which can run on an IBM XT or equivalent with 640 kb of RAM.

Model Evaluation

4.47 User friendliness. MESAP comes with a comprehensive user's guide with chapters describing the building blocks of the model system. The differing styles of these chapters reflect the rapid evolution of model documentation over the past few years, i. e., recent text is much more clearly written than the older text, such as the documentation of RSYST.

4.48 In most modules, the original batch-mode style is still transparent, and running them consists mainly of preparing a number of input files with a suitable editor. The individual modules show different degrees of user friendliness. In contrast to its counterpart in ENPEP, MESAP's version of MAED still uses the original MEDEE input format, which is more than 10 years old and hardly user friendly. By contrast, MADE II - although its inputs are prepared with the help of a text editor - is much more flexible and user friendly; it accepts free input format and thereby permits the unlimited use of comments in the input file. The input file for MESSAGE has a similar format. Both still use some non-obvious codes which are not easy for the novice user to remember.

4.49 Comprehensiveness of model output. The readable output of both MADE II and MESSAGE 3 is produced by a separate calculator program (CAP). Although it is advisable to use a standard definition of the output tables, the user has the freedom to compose new tables by combining module variables, using a number of standard functions.

4.50 Data intensiveness. Varied, depending on the user's definition of the model structure. All input data for a sample run of MADE II, excluding data from the transportation sector, consume less than 20 kb of disk space. Even this is more than is needed, since many explanations of data are included in the input file as comments. With transportation sector data included, a typical MESSAGE input file requires about 300 kb of disk space.

4.51 Sophistication. The basic version of MADE II (the example available for testing) is based on no particular methods. The additional options exhibit different levels of sophistication. The most elaborate option is the macroeconomic model, which involves relations between GDP, labor, capital stock, investments, trade, and other sectors. The most elaborate version of MESSAGE 3 involves Dynamic Linear and Mixed Integer Programming and some basic concepts of multiobjective optimization.

4.52 Transparency. MADE's transparency is high. The model equations are documented and an obvious path leads from input data to model output. The transparency of MESSAGE varies with the size of the model. For the user to understand and fully interpret the results, some technical knowledge of the LP method and its extensions is necessary.

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31/ Reuter, A., MESAP – Microcomputer-based Energy Sector Analysis and Planning System, overview brochure, University of Stuttgart, August 1990.

4.53 Robustness of results. Due to MADE II's accounting-like calculation of energy demand, this model can be expected to generate stable results. MESSAGE, like any LP model, can generate significant changes of results as a consequence of only minor input variations, which must be taken into account during all steps of model usage to avoid misleading results.

4.54 Flexibility. Both MADE II and MESSAGE are highly flexible, with many options offered in different places of the model definition. These options assist in the formulation of time series, permit the selection of alternative methods, determine the degree of model detail, and so on.

4.55 Applicability and limitations. MESAP includes a macroeconomic module in one of its energy demand models (MADE II), an energy supply module, a module to optimize the expansion of the power system, an investment calculation tool, and a databank system. MESAP can therefore be used to study energy demand scenarios and their interdependence with optimal supply strategies; the effects of policy measures affecting demand; and the consequences of the availability of energy conversion and end-use technologies. As in ENPEP, the combination of MAED and WASP can be used to optimize a country's power expansion plan.

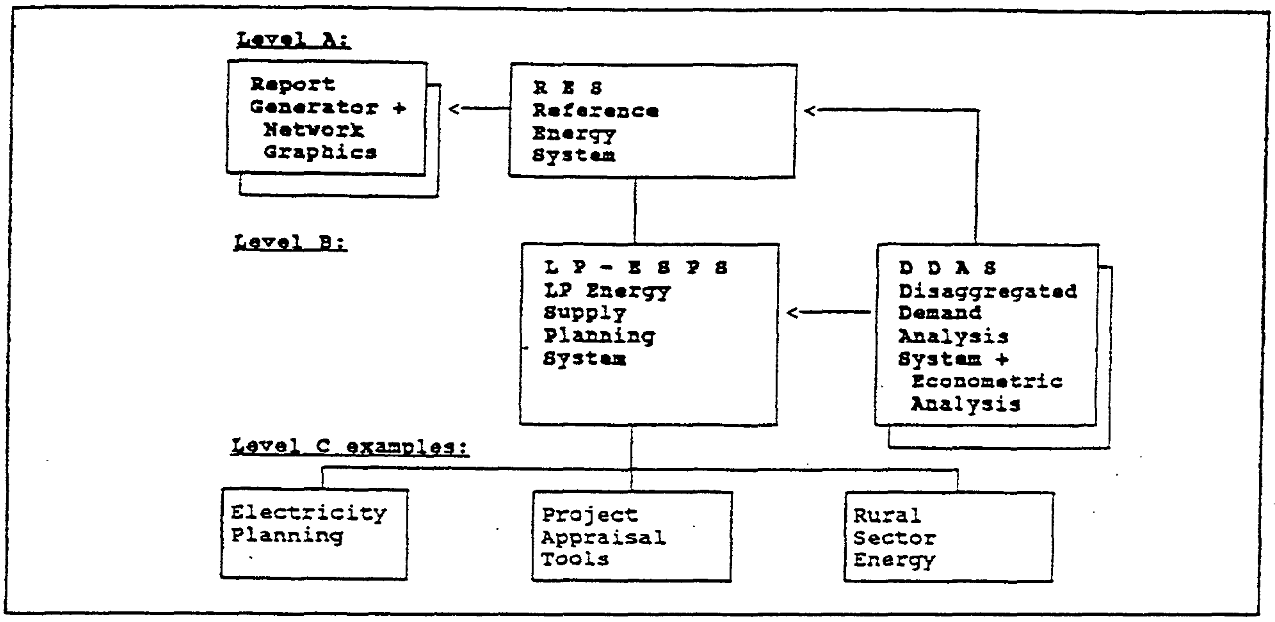
4.56 A possible limitation is that the operation of the full MESAP is likely to require the presence of an experienced user for some time. Also, conventional XT and AT computers which use DOS are not recommended for running the full MESAP system. MADE II alone, on the other hand, even fits on an XT or equivalent with 640 kb of RAM.

## The Energy Toolbox (ETB)

### Model Description

4.57 Energy Toolbox is a structured set of software tools for energy planning. It is a commercial product, developed by the Energy Policy Group at Imperial College in London, and marketed by ERL Energy Ltd., also in London. ETB comprises a number of different analysis systems arranged hierarchically on three levels.

Figure 4.3: THE STRUCTURE OF ENERGY TOOLBOX 32/




4.58 The different levels relate to varying degrees of detail and consequent degrees of difficulty. The major building blocks of ETB are:

4.59 RES, a tool to describe a reference energy system defined by the user. RES is the centerpiece of Level A. The reference energy system is a network representation of energy flows, from supply, through conversion and distribution, to final demand. Inputs defining the physical structure of the energy system include conversion efficiencies, costs, and capacity data. The input that drives this module are final energy demands, which are provided either as external inputs or by another ETB module, DDAS (see below). Other features of RES are its ability to define a basis for the LP-ESPS module (see below) and its ability to employ user-defined process models. These process models convert energy inputs into energy outputs according to rules the user programs into an external module. They are used where the normal linear definition of energy conversion activities are insufficient. The output of this module is a quantitative description of all energy flows between primary energy supply and final demand.

4.60 The Network Graphics submodule of ETB can display a graphic representation of RES on the computer screen. Hard copies can be generated by using the Print Screen function. This module can also display subwindows as well as RES data as pop-up windows.

4.61 The Report Generator can generate a number of reports automatically, including cost reports, energy balance tables, and reports that compare two different scenarios. The latter can be created in a spreadsheet style.

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32/ ERL Energy Ltd. and Halcrow Energy Associates, Energy Toolbox - A Decision Support System for Energy Planning, Users' Guide, Volumes 1 and 2, ERL Energy Ltd., London, 1990.

4.62 DDAS (Disaggregated Demand Analysis System) is a tool to derive energy demand in up to Forty time periods. It is based on a user-specified tree structure disaggregating the national economy into geographical regions and economic sectors. The user can formulate a variety of dynamic "models" (equation systems) to define energy demand as a function of activities (model variables) which are also user-defined. The resulting energy demand can thus be based on variables such as GDP, population (disaggregated into urban and rural), family size, fuel prices, end-use technologies, and so on. Econometric-type models can also be created, and the resulting demand files fed into ETB's RES and LP-ESPS modules.

4.63 The Econometric Analysis program uses regression analysis techniques to estimate single-equation econometric models and apply them to forecasting the values of variables. The tools available include Ordinary, Weighted, and Generalized Least Squares Estimation; Residuals Analysis, and Ridge Regression.

4.64 LP-ESPS is a Linear Programming Energy Supply Planning System. It extends RES by introducing capacities that can be increased by investments. It also adds dynamics to the static RES, and optimizes the fuel mix (specified by the user in RES). Inputs into LP-ESPS can be divided into organizational and substantial. The organizational inputs control, e.g., the relation among RES, the names used in LP (which must follow certain rules), and the names of the files needed for a complete run of the LP-ESPS. The substantial data include constraints on the availability of primary energy and on the expansion of energy conversion capacities (power plants, refineries); cost data; the discount rate; and -- as driving variables -- the demand data. The output of LP-ESPS describes the optimal development of energy supply over a number of time periods under the constraints specified.

4.65 Level C modules are designed to cope with more detailed sectoral planning than can be carried out in the more aggregate RES and LP-ESPS modules. The first two recently-developed Level C modules cover electricity sector planning and rural energy planning.

4.66 AESOP, Alternative Electricity Sector Opportunities Program, is designed to carry out detailed multi-period electricity system capacity expansion planning of mixed hydro-thermal systems. It interfaces with RES for initial data. An LP model is used to screen power station investment alternatives. Detailed examination is carried out using probabilistic simulation around an interactively-developed investment plan generator.

4.67 FREDA, Framework for Rural Energy Decision Analysis, is designed to carry out the balancing of supply and demand of biomass and commercial fuels in rural areas. The country or region is disaggregated into a number of local energy systems within which fuel balances are calculated by disaggregating fuel use by activities, processes, technologies, etc. Surpluses and deficits are transported between local systems to balance fuels within the region.

Future Plans

4.68 Further Level C tools were still in development at the time of testing. Among them is an environmental impact module and a first version will be ready by end of 1991. The capabilities of the Report Generator have been extended to cover the comparison of multiple results files (e.g. several years or several scenarios) and to incorporate graphics facilities for displaying results.

Applications of ETB in Developing Countries

4.69 ASEAN 2010 study. Scenarios of energy supply and demand are analyzed for each of the ASEAN member states (Brunei Darussalam, Indonesia, Malaysia, Philippines, Singapore, and Thailand). Energy balances and emissions balances are projected 33/.

4.70 Philippines. The National Power Corporation (NPC) plans to use ETB for a project evaluation (the Bago hydroelectric project) and for integrated energy planning.

4.71 Ghana. Energy demand and supply in a rural area of Upper East Ghana were analyzed using the Rural Sector Energy subsector model (Level C of the toolbox). 34/, 35/ RES and DDAS have been used to project supply and demand to the year 2000 and to examine alternative scenarios and policy options for improving the energy balance 36/.

4.72 Data from a number of countries have been analyzed by the Energy Policy group at Imperial College using ETB, including Bangladesh, Pakistan, India, Colombia, and several European countries.

Model Classification

4.73 Classification by model characteristic. ETB includes macroeconomic energy demand modeling and demand-supply integration. Recently developed modules include a single-sector model for electricity and a module describing the rural energy sector in particular detail.

4.74 Classification by approach. ETB is a toolbox which includes both bottom-up and top-down methods, as well as a Linear Programming model.

Practical Aspects of Model Availability and Usage

4.75 Minimum computing requirements. IBM XT with at least 500 kb of RAM. (The full 640 kb is recommended for larger models; also, some programs will use expanded memory if it is available.) 10 Mb disk space is reasonable. A graphics adaptor (CGA, HGC, EGA, VGA) is required to run the graphics programs. An Epson-compatible printer is required for printing network graphics.

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33/ Tomkins, R., The Use of Energy Toolbox in ASEAN 2010, available from ERL Energy Ltd., London, 1990.

34/ Nurick, R., R. Tomkins, et al., "Rural Energy Planning Studies: A Case Study of the Upper East Region of Ghana," in International Journal of Ambient Energy, Vol. 12, No. 3, July 1991.

35/ Smith, C.: Rural Energy Planning: Development of a Decision Support System and Application in Ghana, PhD thesis, Imperial College, London, 1991.

36/ Househam, I., The Energy Future of Ghana: Using the Energy Toolbox System, MSc report, Imperial College, London, September 1990.

4.76 Additional software required. The LP solver LP83 or later versions.

4.77 Price of the model. Energy Toolbox is supplied as modules, each of which costs £5,000. The price of ETB modules may be substantially reduced for projects approved by, and carried out on the recommendation of The World Bank. Module A, the entry level module, is required to run all other modules. The modules are:

| | |
|---|---|
| Module A | Level A tools; RES, Network Graphics, Report Generator. |
| Module B1 | Level B; DDAS and Econometric Analysis (demand system). |
| Module B2 | Level B; LP-ESPS (LP supply system). |
| Module C1 | Level C; AESOP (electricity system). |
| Module C2 | Level C; FREDA (rural energy system). |

4.78 Support and training are offered. Initial training and implementation is included in the package price.

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4.79 Easiest access. An informative demonstration diskette is available free of charge, and other excellent overview descriptions of ETB are available.

Model Evaluation

4.80 User friendliness. ETB is very user friendly, with a large amount of context-sensitive on-line help. ETB comes with two comprehensive manuals containing detailed descriptions of all parts of the toolbox; only the part describing LP-ESPS can serve as a tutorial. In the other parts, more illustrative examples would be more helpful for a new user than the bulk of the technical description, which might be better placed in an appendix.

4.81 Comprehensiveness of model output. ETB provides many files of printable and graphical output. A significant part of ETB is dedicated to generating reports and network graphics. The number of possible outputs is very large, and the user determines which are to be produced as a hard copy.

4.82 Data intensiveness. The size of any model constructed with the toolbox, and thus the data intensiveness, is determined by the user. The most basic groups of input data describe the Reference Energy System (RES) and the link between the national economy and energy demand.

4.83 Sophistication. An important design principle of ETB is simplicity. Nevertheless, sophisticated economic models can be formulated in the Disaggregated Demand Analysis System. Use of the Linear Programming Energy Supply Planning System presupposes familiarity with the LP approach.

4.84 Transparency. Since the structure of any ETB-generated model is determined by the user, there are no hidden assumptions. Thus transparency is high.

4.85 Robustness of results. Again, the user determines most of the model robustness by defining the relation between the Reference Energy System and the overall economy. The only place where robustness is a distinct feature is in LP. As mentioned earlier, LP models can be very sensitive to input parameter variations.

4.86 Flexibility. As one would expect from a toolbox, ETB's flexibility is high. The Reference Energy System can be freely defined; the module for analyzing energy demand accepts user-defined variables, which can be processed with user-defined formulae; and the design of output reports allows the user to choose from many possibilities.

4.87 Applicability and limitations. ETB can be used for a number of problems and studies in energy planning. Its possible applications include generating energy balances and emissions balances, calculating energy demand as the result of macroeconomic models (which can combine user-defined variables with user-defined formulae), and optimizing the energy supply system with a Linear Programming model. ETB's main limitation, at this point, relates to the sizes of the LP and demand models that can be constructed. However, these comparatively narrow limits reflect the design principle of simplicity more than genuine limitations of ETB. Most of these limits could be eliminated with minor changes in the source programs. The constraints to the size of the LP models in this study were determined by the package used (LP83), but other solvers could be used as well 37/.

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37/ It is possible to build a model with up to 400 sectors or sub-sectors, each one having up to 200 variables and 300 equation lines. Thus, the maximum size is 80,000 variables (each having 40 time periods) and 120,000 equation lines. As regards the LP model, with current LP software problems, it is possible to solve LPs with up to 1000 constraints on an AT and even more can be handled on a 386 machine.

## ENERPLAN

### Model Description

4.88 ENERPLAN is a microcomputer program specifically developed for use by energy planners in developing countries 38/. Its conceptual structure is straightforward. Instead of a flow diagram, as presented for other models, ENERPLAN's main menu is reproduced in Figure 4.4.

ENERPLAN can be used to perform such functions as:
- maintaining a database of energy and economic data (time series);
- creating standard (and other) energy balance tables; and
- producing tabular and graphical reports.

ENERPLAN's more advanced functions are:
- performing regression analyses, and
- formulating and testing simulation models.

Figure 4.4: ENERPLAN's Main Menu 39/

```
                              ENERPLAN
                              --------
                             MAIN  MENU
                             ----------
Country Name: RURITANIA

             1. ENERGY UNITS                                (Used)
             2. VARIABLE NAMES                              (Used)
             3. DATA ENTRY AND CONFIRM                      (Used)
             4. Compute ENERGY BALANCE TABLE
                          from Original Energy Data         (Used)
             5. STATISTICAL ANALYSIS                        (Used)
             6. BUILDING MODELS                             (Used)
             7. SIMULATION                                  (Used)
             8. REPORT PRODUCTION                           (Used)
             9. GRAPHICAL OUTPUT                            (Used)
             0. END
             R. RETURN TO COUNTRY SELECTION

           SELECT (1-9,0,R)?
```

38/ United Nations, Department of Technical Cooperation for Development (UNDTCD), ENERPLAN's User's Manual, Version 2.0, New York, June 1988.

39/ ibid.

4.89 The basis for the original ENERPLAN was a comprehensive description of the energy system in the form of a standard UN energy balance table with 12 energy sources, 21 intermediary transactions, and 10 final consumption activities. In addition, a few dozen macroeconomic variables were predefined. In ENERPLAN, a standard set of inputs for an application consists of time series of the historical values (of all or a selected set) of the model variables. These variables can then be used in two forecasting models, the Macro Economic Model and the Energy Model, to generate the same kind of energy balance tables for future years. Since the user has full control over these models (the set of equations can be edited), the distinction between the two is artificial; its main purpose is to allow the combination of preformulated models. An additional preformulated model simulates demand and supply potentials of traditional sources of energy.

4.90 The first extension of the old model is the version ENERPLAN-FEBT (Flexible Energy Balance Table), which allows the user to define additional formats for the model's energy balance table. Another extension is a file transfer utility that converts Lotus 1-2-3 and dBASEIII+ data into ENERPLAN format.

Future Plans

4.91 A new version of the model, ENERPLAN III, is near completion. Its release is expected in the fall of 1991. Among several other improvements, it will run faster, and it will provide context-sensitive help.

Applications of ENERPLAN in Developing Countries

4.92 The user's guide 40/ documents two cases, Costa Rica and Thailand, briefly discusses the inputs for each, and reproduces but does not discuss some model outputs.

Model Classification

4.93 Classification by model characteristic. General scheme for the systematic representation of energy conversion activities, plus a macroeconomic modeling tool.

4.94 Classification by approach. The macroeconomic part is clearly top-down. The reference energy system approach might be described as accounting.

Practical Aspects of Model Availability and Usage

4.95 Minimum computing requirements. IBM XT or compatible, 256 kb of RAM, and two floppy disk drives.

Additional software required. None.

Price of the model. The model is free if requested by governments.

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40/ ibid.

Support and training offered. Yes.

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Easiest access. The user's guide is well written and gives a good overview of the model.

Model Evaluation

4.96 User friendliness. The original ENERPLAN, released in 1985, was definitely user friendly by the standards of that time. The new Version III responds to today's standards, but its user friendliness was not assessed for this report.

4.97 Comprehensiveness of model output. The model output is completely user-defined within broad limits. Graphics and tables can be produced with any variable defined in either of the two submodels.

4.98 Data intensiveness. ENERPLAN's data intensity depends mainly on the number of macroeconomic variables considered. Normal inputs are time series of all dependent variables. The actual amount of data provided with the two case studies, which presumably describe normal-sized applications, is small (they fit on two 360 kb floppy diskettes) in comparison to other models assessed in this Report.

4.99 Sophistication. The energy balance table is straightforward and should be familiar to energy planners. The macroeconomic and energy models can be built to a high degree of sophistication.

4.100 Transparency. ENERPLAN's description of the energy system is conceptually very transparent. In practice, it takes some time to remember the names of all the variables. The transparency of the macroeconomic part depends on the model formulation.

4.101 Robustness of results. The results and thus the robustness of the user-defined simulation models clearly depend on the defined relations between the variables.

4.102 Flexibility. The part on energy balance tables has become very flexible after the introduction of FEBT. The flexibility of the Macro Economic and Energy models is, in fact, so high that a completely empty computer program (without example files describing a complete application) would be of little use for energy planners. The module for the treatment of traditional sources of energy is not very flexible, since it cannot be connected with the other models, and input and output data transfers must be made manually. Because of these problems, the module for the traditional sources of energy is no longer included in ENERPLAN III.

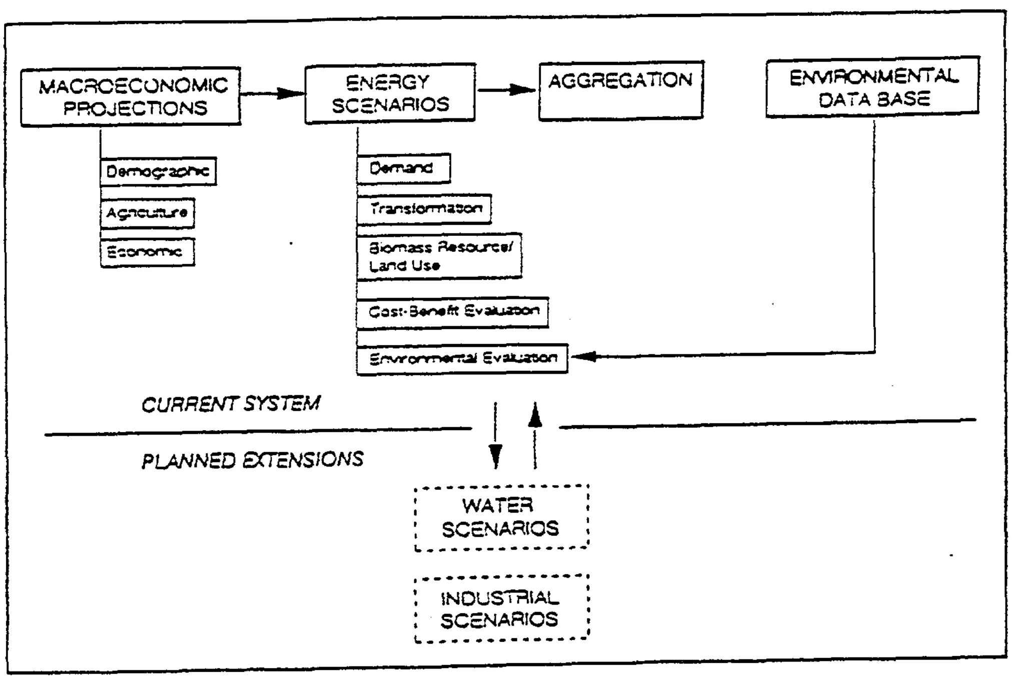
4.103 Applicability and limitations. ENERPLAN is best suited to describe a country's energy system over time (with energy balance tables), and to formulate economic models that describe the relation between the energy system and macroeconomic variables. The statistical analysis of time series is supported by a separate module. Although it is not the typical tool with which to perform engineering-type studies (energy intensities of single technical processes, etc.), its flexibility as a tool kit would allow such a usage. To trim ENERPLAN to simulate (or optimize) energy supply, however, would overstretch its flexibility.

## LEAP

### Model Description

4.104 The Long-Range Energy Alternatives Planning (LEAP) model is a computerized framework for evaluating energy policy and planning options 41/.

Figure 4.5: LEAP PROGRAM STRUCTURE 42/




41/ Mrindoko, B. J., The Application of Computerized Energy Planning in Tanzania Using the LEAP Model, Ministry of Energy Minerals and Water, Tanzania, April 1990.

42/ LEAP, A Computerized Energy Planning System, Volume 1, Overview; Volume 2, User Guide; Volume 3, Technical Description, all for LEAP version 90.01, Stockholm Environment Instutute, BostonCenter, Tellus Institute (formerly) ESRG, Boston, 1990.

4.105 The programs in LEAP's Macroeconomic Projection module can be used to develop scenarios for economics, (output by sector), demographics (population, households), and agriculture (land use, productivity). The use of these programs is optional; they are one of several possible sources of economic and demographic activity projections.

4.106 LEAP's central module describes scenarios of energy demand and conversion. Within this module, the part on energy demand is the most important. The basis for calculating energy demand is a scheme describing the demand branch structure; this scheme has (economic) sector, subsector, end-use, and device levels. Each end of the structure consists of a device that consumes a particular form of energy. All these energy consumptions are then aggregated to calculate total end-use demand.

4.107 The Transformation module simulates the energy sector conversion processes by calculating the amounts of primary resources required to deliver final fuel consumption, as calculated by the Demand module. Preferences of energy inputs in competitive situations are specified by the user directly, rather than by optimization or other built-in rules.

4.108 A Biomass Resource module is available to match biomass resource demands to the available wood stocks and yields.

4.109 Two modules evaluate the relative costs (the cost differentials between scenarios) and benefits, as well as the environmental impact of these scenarios. Ancillary modules can be used for more detailed economic, agricultural, and demographic scenarios. LEAP comes with an extensive data bank of emission factors (the Environmental Data Base) for assessing the environmental impact of energy scenarios.

4.110 A separate module facilitates the summation of subnational cases into one aggregated case.

4.111 Note: The model described here is not to be confused with another model also called LEAP, the Long-Term Energy Analysis Package of the U.S. Energy Information Administration.

Future Plans

4.112 LEAP is in rapid development. Most of what was in a planning stage when the model was tested has been completed during the finalization of this report. Most notably, most of the problems noted here are reported to have been eliminated. Modules for describing the water system and the industrial sector are still forthcoming.

Applications of LEAP in Developing Countries

4.113 Kenya 43/. LEAP was first developed as part of the Kenya Fuelwood Project of 1980-82, where it was used to evaluate different energy strategy options for ensuring a sustainable energy future. The options that were considered included increasing wood supply, fuel switching, increasing conversion efficiencies, and energy conservation.

4.114 SADCC Countries. Since 1982, LEAP has been used in SEI-Boston's collaboration with the Energy Sector's Technical and Administrative Unit (TAU) of the Southern African Development Coordination Conference 44/ (SADCC) to create an integrated picture of energy demand and supply in the region, and to identify attractive regional energy projects and policies.

4.115 Brazil 45/. Charcoal-based iron and steel making is done on a large scale in the Brazilian state of Minas Gerais, where increasing demands for charcoal created a woodfuel supply crisis. LEAP was used to analyze alternative wood supply and demand policy options for the state.

4.116 OLADE. Staff at the Latin American Energy Organization (OLADE) are using LEAP to study energy demand and supply in the 26 Latin American and Caribbean member countries. In addition, OLADE is collaborating with the Stockholm Environment Institute Boston Center and the Energy Directorate (DSE) of Costa Rica on an extensive application of LEAP in Costa Rica.

4.117 LEAP is also used by energy agencies and researchers in the SADCC member countries Tanzania 46/, Zambia, and Zimbabwe, 47/ as well as in Costa Rica, India, the Philippines, and Senegal; and has recently been transferred to Bolivia, Colombia, Ecuador, and Sri Lanka.

Model Classification

4.118 Classification by model characteristic. The model includes energy demand, energy conversion, resource use, and environmental impacts, plus an auxiliary macroeconomic module. It also includes a module describing biomass as an energy source.

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43/ The Beijer Institute and the Scandinavian Institute of African Studies of the Royal Swedish Academy of Sciences, Energy and Development in Kenya, Opportunities and Constraints, Volume 1 of the series "Energy, Environment and Development in Africa," Stockholm and Uppsala, 1984.

44/ Member countries of SADCC are Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe.

45/ Ackermann, F., and P.E. Fernandes de Almeida, "Iron and Charcoal, The Industrial Woodfuels Crisis in Minas Gerais," in Energy Policy, September 1990.

46/ Mrindoko, B. J., The Application of Computerized Energy Planning in Tanzania Using the LEAP Model, Ministry of Energy, Minerals and Water, Tanzania, April 1990.

47/ The Beijer Institute and the Scandinavian Institute of African Studies, the Royal Swedish Academy of Sciences, Zimbabwe: Energy Planning for National Development, Volume 9 of the series "Energy, Environment and Development in Africa," Stockholm and Uppsala, 1986.

4.119 Classification by approach. The main part of the model is a bottom-up calculation of energy demand and supply. Its macroeconomic part, which plays a comparatively minor role, is top-down.

Practical Aspects of Model Availability and Usage

4.120 Minimum computing requirements. XT, AT, PS/2 or compatible, 640 kb of RAM, 4 Mb space on a hard disk drive, DOS 3.0 or higher.

4.121 Additional software required. None.

4.122 Price of the model. The model is free to governmental agencies in developing countries, and is usually distributed in the context of a training course or similar activity. Others may obtain the software for a fee. In either case, the model is available only with a memorandum of understanding between the user and SEI-B/Tellus. More details of this policy are available at the address below.

4.123 Support and training offered. SEI-Boston conducts training workshops ranging from one to three weeks for the application of LEAP and energy planning methods in general. SEI-Boston also provides follow-up support services for LEAP users, including enhancements of the system to meet local needs. Typically, workshops and follow-up services are supported by donor agencies, in the context of a LEAP transfer project. Other arrangements are also possible.

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4.124 Easiest access. Articles by Raskin 48/ and Lazarus 49/ contain good overview descriptions of LEAP.

Model Evaluation

4.125 User friendliness. In general, LEAP is very user friendly, especially for its standard uses, including formulation of energy demand and supply scenarios. Scenario comparison is

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48/ Raskin, P. D., "Integrated Energy Planning in Developing Countries: The Role of Computer Systems," in AMBIO, A Journal of the Human Environment, pp. 210-213, Vol. 14, No 4-5, 1985.

49/ Lazarus, M., "Energie-Environnement: Une approche de synthèse par le système 'LEAP,'" in Liaison Énergie-Francophonie, Numéro 8, 3e Trimestre 1990, Institut de l'Energie des Pays ayant en commun l'usage du Français (IEPF), Canada, 1990.

particularly well supported; in the costing module, in fact, comparison takes precedence over the absolute calculation of costs for one case, which is not possible in this version. In the future, absolute cost calculations also will be possible.

4.126 The results calculated by the macroeconomic modules must be retyped if they are transfered to the demand part. Although this may be regarded as a shortcoming, an automatic (or even optional) data transfer was omitted deliberately to make the user aware that the macroeconomic module is but one possible way to derive demand parameters, and force the user to make an explicit choice. (The option for automated macroeconomic drivers will be included in LEAP's 1991 release.)

4.127 In the version tested, the change to new energy units is an explicit option, but many numbers must be converted manually if this option is used. The 1991 version of LEAP includes automatic conversions not only between different energy units but also conversions between energy, mass, and volume units for each fuel.

4.128 The model documentation is functionally well-structured into an Overview, a User Guide, and a Technical Description. (On-line, context-sensitive help screens are included in the 1991 version.)

4.129 Comprehensiveness of model output. The model output is comprehensive. LEAP generates files for printed output and graphics. A useful feature is the generation of "data echo" files summarizing the model input data.

4.130 Data intensiveness. LEAP's data intensity depends to a large extent on the model detail chosen by the user and on the modules used for a particular study. The inputs for one country occupy between 50 kb and 150 kb of disk space.

4.131 Sophistication. LEAP is a simple model in principle. Although the model can become quite comprehensive when all its capabilities are utilized, the underlying methods remain simple.

4.132 Transparency. As a consequence of its comparatively simple structure, LEAP is very transparent.

4.133 Robustness of results. Due to the user's ability to closely control the model structure and inputs, LEAP's results are robust. Discontinuities (as described for Linear Programming models) in the transformation module are possible, but are the direct outcome of the user's choices.

4.134 Flexibility. Very high. A good compromise was found between guiding the user and providing options. Some users may want to have the option of specifying growth rates in more places in the input data. In the version reviewed, time changes of many input data must be defined in absolute terms.

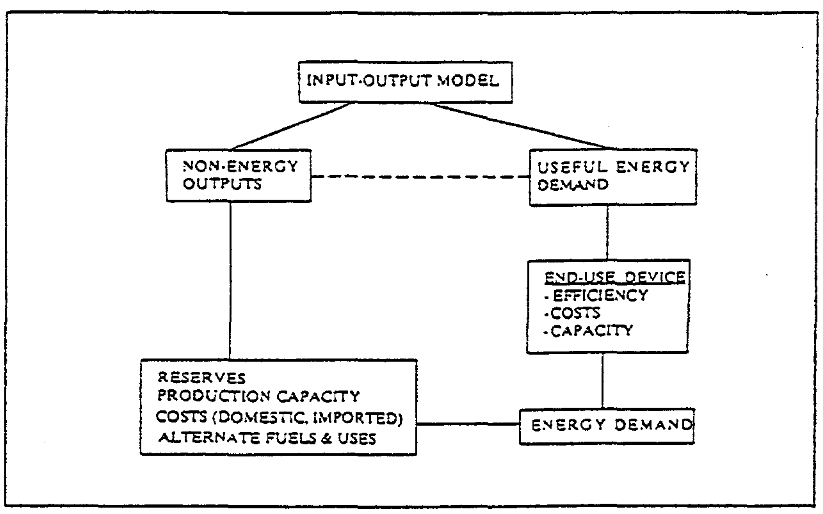
4.135 Applicability and limitations. LEAP is best used for the analysis of energy demand, supply, and pollutant emission scenarios as a function of energy end-use structure, available conversion technologies, and resource constraints. Some features, such as the Biomass Resource/Land Use module, render it particularly suitable for developing countries. Other parts, such as the macroeconomic and the demographic modules, can be used but are not fully integrated, i. e., the data flow between these modules and the scenario part is not automated. In the version tested, a similar limitation applied to the number of time periods that can be defined. For some data, there was a limit of three time periods for which inputs can be defined 50/. The results of additional (in-between) time periods can be reported, but they are merely interpolated. The influence of energy prices on demand could not be modeled within LEAP. Most of these limitations have been eliminated during the finalization of this report.

## TEESE

### Model Description

4.136 The Tata Energy Research Institute (TERI) in New Delhi has developed the TERI Energy Economy Simulation and Evaluation model, a static Linear Programming (LP) model based on an Input-Output matrix in which the original energy sectors are replaced by a detailed Reference Energy System. Total energy demand is derived from a given set of final demands in all sectors of the economy. The main linkages in TEESE are shown in Figure 4.6.

Figure 4.6: MAIN LINKAGES IN TEESE 51/




50/ The 1991 release will allow up to five time periods for these data, and other options (growth rates, etc.) for time-varying demand data. Other time-varying data, such as the start-up date of power plants, can be related to any date within the model's time horizon.

51/ Pachauri, R. K. and L. Srivastava, "Integrated Energy Planning in India: A Modelling Approach," The Energy Journal, Vol. 9, No. 4, October, 1988.

4.137 Investments in the energy sector are included in the model, creating additional demands for the rest of the economy. Electricity demand is given as a load duration curve. Household energy demand is based on a disaggregation of urban and rural population into five income groups each. The model solution is an optimal mix of energy supply flows, which minimizes total energy costs. Some environmental impacts are calculated.

Future Plans

4.138 The model is being continuously revised and updated to incorporate environmental considerations.

Applications of TEESE in Developing Countries

4.139 The TEESE Model has been applied mostly to India as a whole. Typical past applications of the model include:

(a) Estimating future energy demand scenarios associated with alternative rates of growth of the economic and various other sectors.

(b) Assessing the impact of constraints on energy imports, foreign exchange requirements, fuel substitution, and capital outlays. Also assessing the impact on economic growth of sustaining a fixed level of energy availability.

(c) On the demand side, the TEESE Model has been used for extensive scenario analyses for the domestic transportation and industrial sectors. Scenarios included the implementation of energy conservation measures, efficiency improvement, fuel switching, and so on.

(d) TEESE has also been used to assess the potential of renewable energy, based on the economics of conversion technologies and on end-use energy demand.

(e) The TEESE Model has recently been used to assess the cost effectiveness of pollution abatement measures in India. As a result, the emission levels associated with several of the scenarios described above have been calculated.

(f) Finally, TEESE has been applied to one Indian state, Gujarat, as a first step in disaggregating the country into state models. In the absence of a state level input-output model, TEESE was adapted to run on output projections levels of specific sectors.

Model Classification

4.140 Classification by model characteristic. Macroeconomic sector linkages, demand-supply integration.

4.141 Classification by approach. Input-output matrix, Linear Programming.

Practical Aspects of Model Availability and Usage

4.142 Minimum computing requirements. XT or equivalent, 256 kb of RAM; a mathematical coprocessor is optional.

4.143 Additional software required. TEESE uses the LP83 package for solving the LP problem formulated as a LOTUS 123 spreadsheet.

4.144 Price of the model. TERI makes TEESE available at no charge. However, since TERI staff will have to spend 2-3 weeks training new users (not including time for data collection), users must cover the cost of training. LOTUS 123 and LP83 or an equivalent package must be available for running TEESE.

4.145 Support and training offered. See previous item.

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4.146 Easiest access. The brochure 52/ gives a good introduction to TEESE.

Model Evaluation

4.147 User friendliness. TEESE requires entering numbers into a LOTUS 123 spreadsheet in a format that can be read by the LP83 solver. As there is no user's guide available 53/, the assistance of an experienced user is advisable. Once the user has experience with the model-specific part of the spreadsheet, the user friendliness of preparing model inputs is equivalent to LOTUS 123. TEESE is normally applied by one person. Typical running time is 5 minutes on an AT compatible with a mathematical co-processor.

4.148 Comprehensiveness of model output. TEESE's output comprises the usual LP results, i.e., total costs, optimized energy flows, capacity utilizations, marginal costs, and so on. A part of the solution is written into pre-specified areas of the spreadsheet. Graphics output is generated by a package such as Harvard Graphics which can import outputs produced by TEESE.

4.149 Data intensiveness. The most important data prerequisite is an input-output matrix or equivalent descriptor of the link between the entire economy and the energy sector. Other data

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52/ Tata Energy Research Institute, TERI Energy Economy Simulation And Evaluation Model, overview brochure.

53/ The Institute plans to complete a user's guide by the end of 1991.

include demographic information, a description of a Reference Energy System, and data on costs and environmental impacts (optional).

4.150 Sophistication. Familiarity with Linear Programming is necessary for a comprehensive interpretation of the model results. Knowledge of the input-output technique is also helpful.

4.151 Transparency. The input spreadsheet serves as documentation of the model inputs. Tracing the way from input data and data changes to model results may require studying the LP output in a specific format.

4.152 Robustness of results. LP models are known for their ability to generate significant changes of results as a consequence of only minor input variations. This characteristic must be taken into account during all steps of model usage in order to avoid misleading results.

4.153 Flexibility. The theoretical flexibility of TEESE is unlimited in the sense that any size input- output matrix (the current size is 50 by 50), and any size Reference Energy System, can be used subject to data availability. A practical upper limit is imposed by the current LP solver, which constrains the number of variables (to 253) and matrix elements (depending on the number of rows and variables).

4.154 Applicability and limitations. TEESE is best used to analyze the interplay between the economy and the energy system. It is typically applied to calculate energy demand scenarios as a function of economic growth and/or available energy conversion and consumption technologies; to analyze the economic effects of constraints in the energy supply system; and to study the costs and benefits of pollution abatement measures. TEESE is applied in connection with an established input-output matrix for any given country. The model is not dynamic. Time series must be generated with a sequence of model runs.

## MARKAL

### Model Description

4.155 MARKAL (Market Allocation) is a dynamic Linear Programming model for the technical part of the energy system. It encompasses all flows and conversions of energy from oil or gas fields or coal or uranium mines until its end use. 54/ A PC version of MARKAL is being used at the Biomedical and Environment Assessment Group at Brookhaven National Laboratory (BNL), USA. The model is run through the MARKAL Users Support System (MUSS), a user interface newly implemented for PCs which handles all aspects of the model application. This user interface greatly enhances flexibility in determining the model structure for each application case. See Figure 4.7 for a schematic description of the activities supported by MUSS. The mainframe version of MARKAL will no longer be maintained at BNL.

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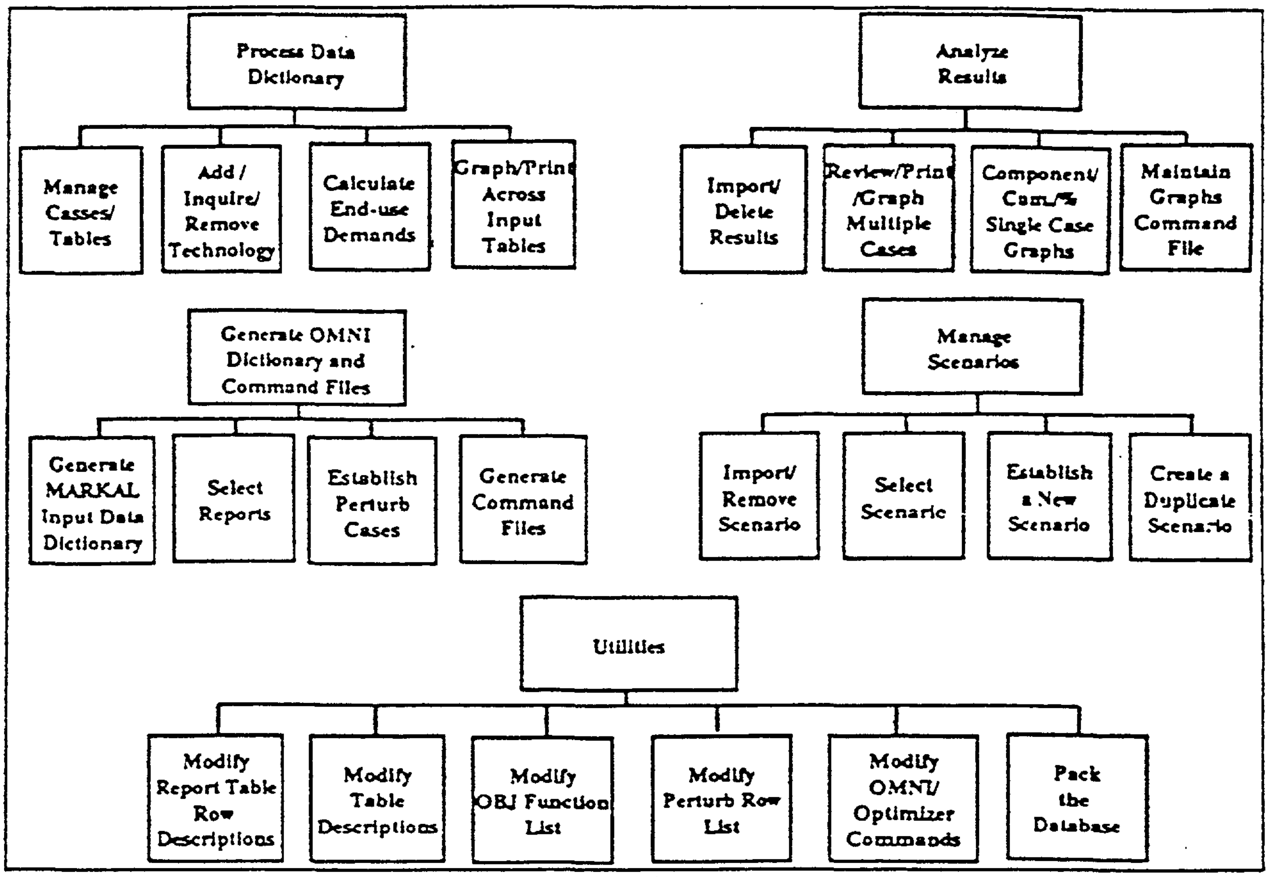
54/ Wene, C.O., Exploring and Mapping: A Comparison of the IEA-MARKAL and CEC-EFOM Technical Energy System Models and the ANL Electric Utility Model, Brookhaven National Laboratory, Associated Universities, Inc., November 1989.

Figure 4.7: MUSS SYSTEM OVERVIEW 55/




4.156 MARKAL is driven by user-specified time series describing useful energy demand. It uses a set of technologies (processes, conversion activities, etc.) to find a cost-optimal supply under constraints on availability of resources, on permitted total emissions, and on growth of technologies (market penetration constraints). MARKAL can also handle special cases of multiobjective optimization (such as supply security and low-cost supply). The model output describes primarily the optimal (as defined by the objective function) mix of energy supply activities under the given constraints. Another important output is the environmental impact of the energy system as described by the optimal solution. Thus MARKAL can analyze the interplay between emission constraints, abatement costs, total systems costs, and environmental standards.

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55/ Goldstein, G. A. and L. D. Hamilton, PC-MARKAL and the MARKAL Users Support System (MUSS), User's Guide, BNL-46319, Brookhaven National Laboratory, Associated Universities, Inc., October 1990.

Future Plans

4.157 The MUSS part of MARKAL has just been completed, and the entire existing version will likely be refined. Some extensions to the model formulation, i.e., regional electric/heat grids and seasonal demand devices, are planned.

Applications of MARKAL in Developing Countries

4.158 MUSS/MARKAL is too new to have been used for energy planning in developing countries; so far, only the mainframe version of the model has been applied.

4.159 Ecuador. 56/ MARKAL was used as a tool to create optimization scenarios of the energy demand and supply and the oil production systems. In the oil sector, MARKAL was used to investigate whether production should remain high or be reduced for the benefit of future domestic consumption.

4.160 Brazil. 57/ In the early 1980s, imported oil contributed some 40% to Brazil's primary energy supply, eating up about half the country's export revenues. MARKAL was used to analyze scenarios in which imported oil is replaced by indigenous primary energy resources such as coal and biomass.

4.161 China. 58/ In an energy study for the Guangdong province in Southeast China, the model was used to calculate cost-minimal energy supply strategies for the time period 1981-2000. Significant parts of the final project report are confidential, but Romahn 59/ gives a description of organizational aspects and of problem areas relevant to the study.

4.162 Indonesia. 60/ A joint Indonesian-German research project used a set of computer models, including a mainframe version of MARKAL, to develop proposals for national energy strategies. MARKAL was used to investigate and compare a Minimum-Cost and a Reduced-Oil Use case. The comparison yielded the economic costs of reduced domestic oil use.

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56/ Ryden, B., G. Maldonado, C.-O. Wene, R. Paz, J. Flores, and G. Franco, Metodologia de Planificacion Energetica. Applicacion del Modelo MARKAL. Presentacion del Primero Caso Base para Ecuador (Energy Planning Methodology. Application of the MARKAL Model. Presentation of a First Base Case for Ecuador), Chalmers University of Technology, Gothenburg, Sweden and Escuela Superior Politecnica del Litoral, Guayaquil, Ecuador, July 1986.

57/ Aringhoff, R., S. Bezerra, H.A. Hymmen, G. Kolb, and R. Pimentel, Program of Research and Development on the Utilization of Brazilian Coal and on Energy Systems Analysis and Planning for Brazil, joint final report, Nuclear Research Center, Juelich, F.R.G., 1984.

58/ Romahn, B., Energieversorgungsstrategien fur die Provinz Guangdong bis zum Jahr 2000, Nuclear Research Center, Juelich, F.R.G., 1984.

59/ ibid.

60/ Agency for the Assessment and Application of Technology (BPPT) and Nuclear Research Centre Juelich Ltd., Germany, Energy Strategies, Energy R+D Strategies, and Technology Assessment for Indonesia, joint Indonesian-German research project, Summary of Final Report, Jakarta and Juelich, March 1988.

Model Classification

4.163 Classification by model characteristic. Energy supply model.

4.164 Classification by model approach. Dynamic Linear Programming model.

Practical Aspects of Model Availability and Usage

4.165 Minimum computing requirements. A 386-based machine with a 80387 coprocessor, minimum 4 Mb of RAM (8 Mb recommended), a VGA or EGA graphics card, DOS 3.3 or higher. Hard disk space of 32 Mb is recommended; this will hold about 50 model cases.

4.166 Additional software required. FORTRAN-386OMNI matrix generator plus the 386HSLP optimizer together cost US$ 7500. Other programs may be used for the optimization, (e.g. XPRESS, which MUSS's developer claims is five times as fast as the standard MARKAL software). LIST, the Norton Utilities, and PKZIP/PKUNZIP (compress/archive utilities) are optional but recommended. Arrangements can be made with MUSS/MARKAL for the programs to be delivered if the buyer signs the necessary license agreements.

. Price. US$ 5000.

4.167 Support and training offered. Yes. Annual training courses are being planned. Other bilateral arrangements can be made.

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4.168 Easiest access. A demonstration version of the MUSS part of the MUSS/MARKAL system, which contains most of the parts requiring user input, is available.

Model Evaluation

4.169 User friendliness. MUSS has brought MARKAL up to a high standard of user friendliness. The PC model has two kinds of on-line context-sensitive help systems. A drawback is that the naming of variables is constrained by conventions used by the LP solver. MUSS supports menus that cross-reference tables of names and their descriptions, however; and eliminating the references to internal variables would be undesirable because the user needs to deal with internal variable names directly during operation of the system. Since MARKAL is rather complex, a significant training time must be planned for.

4.170 Comprehensiveness of model output. The output of MARKAL is potentially very large. The user can produce particular pieces of output according to his/her needs. Useful output options of MUSS include the cross comparison between cases and graphics of inputs and outputs.

4.171 Data intensiveness. Data intensiveness depends on the comprehensiveness of the particular case, and is a function of the number of technologies, demand sectors, and fuels being considered. For a major run for the state of New York, for example, data collection is estimated to take a full year.

4.172 Sophistication. Familiarity with Linear Programming is a prerequisite for fully understanding model inputs and results.

4.173 Transparency. Theoretically, a Linear Programming model is rather transparent, in particular if good use is made of the features provided by the LP solver. In practice, however, tracing the results of a large case back to its inputs can become tedious.

4.174 Robustness of results. LP models are known for their ability to generate significant changes of results as a consequence of only minor input variations. This characteristic must be taken into account during all steps of model usage to avoid misleading results.

4.175 Flexibility. Within the limits described below, MARKAL's flexibility is very high.

4.176 Applicability and limitations. MARKAL is best suited for studying energy supply scenarios as a function of varying assumptions about broad energy conversion technologies (energy extraction, imports, distribution, end-use devices, etc.). These assumptions include the availability (market penetration) of technologies, costs, and environmental impacts. Performance of the energy supply system is primarily measured in terms of costs, environmental impact, and resource consumption. This renders MARKAL particularly well-suited for estimating the potential benefit of future energy supply, conversion, and end-use technologies. Certain feedbacks of the supply system to energy demand development can be modeled, but general interrelations between the national economy, energy demand, and energy supply are not included. For this reason, a link between MARKAL and an economic model (Jorgenson) will be attempted in the near future at BNL. (In Japan, MARKAL was already linked with an Input-Output model 61/.) The present

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61/ Yasukawa, S., et. al., Progress in integrated Energy-Economy-Environment model system development, preprint for distribution to participants in the IEA/ETSAP/Annex III meeting held at Brookhaven National Laboratory, Upton, NY, 1987.

version of MUSS/MARKAL has been applied only in industrialized countries, although outreach activities, planned for the near future, will promote its use for developing countries. Some modifications to the model can be expected once these implementations generate new experience.

## MEDEE-S

### Model Description

4.177 The Modèle d'Evaluation de la Demande En Energie, or Energy Demand Evaluation Model (the "S" in MEDEE-S stands for South) is a long-term (15-20 years) final energy demand simulation system for intermediate income countries (World Bank nomenclature). It was designed and implemented by B. Chateau and B. Lapillonne at the Institute of Energy Policy and Economics (IEPE) of the University of Grenoble, France.

4.178 For this project only MEDEE-S was assessed. The relation between MEDEE-S and other MEDEE versions is shown in Figure 4.8 as a reference.

Figure 4.8: THE MEDEE FAMILY OF MODELS

| | | | |
|---|---|---|---|
| | | MEDEE-1 | |
| | MEDEE-2 | | MEDEE-3 |
| MAED | MEDEE-S | MEDEE-3/ME (conservation) | MEDEE-EUR<br>MEDEE-EUR/TROLL&KEOPS |

4.179 MAED corresponds to MEDEE-2, and is augmented by a feature that generates load curves for electricity demand. MAED is included in both ENPEP and MESAP (see 4.1 and 4.2), where it is coupled with the ELECTRIC (WASP) model for optimal expansion of the power system.

4.180 MEDEE-S is based on MEDEE-2, and is augmented by a user interface which enables the user to choose the structure of the energy demand system to be described. This enables the user to determine the level of model detail. MEDEE-S now exists in French (at the IEPE in Grenoble) and in English (at the AIT in Bangkok). Only the French version was available for testing in this project. The English version is more user friendly. 62/

4.181 MEDEE-2, MAED, and MEDEE-S are end-use accounting models. MEDEE-3 is a more complex and comprehensive mainframe version that includes simulation of behavior and socioeconomic dynamics. MEDEE-EUR and MEDEE-EUR/TROLL&KEOPS are developments of MEDEE-3, applied for the European Community as a whole.

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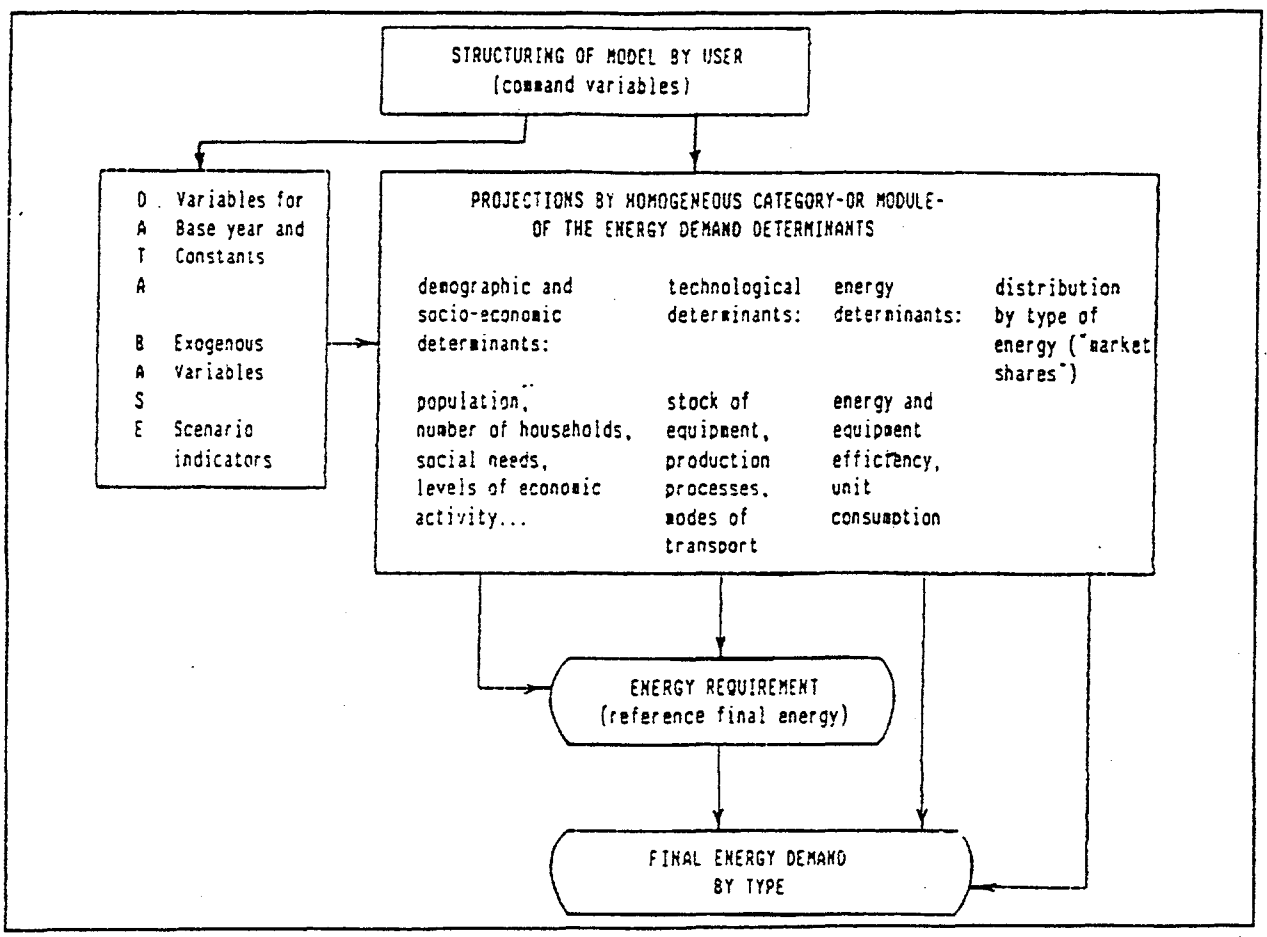
62/ Chateau, B., private communication.

4.182 MEDEE-3/ME was developed at the Agence Française pour la Maîtrise de l'Energie (AFME, the French Agency for Energy Conservation). It is particularly suited for calculating the effects of energy saving measures. The operating scheme of MEDEE-S is shown in Figure 4.9.

4.183 The main variables driving MEDEE-S are population and GDP, disaggregated into population groups and economic activities. A crucial variable is energy demand in the base year, since future energy demand is calculated relative to base year values. Other determinants of energy demand are technological data (e.g., information about the stock of energy consuming equipment, production processes, modes of transport) and assumptions about "market shares" of fuels. Model outputs are final energy demand projections by fuel type. The user can choose the amount of model detail within specific limits. Among the areas in which choices can be made are classes of households (rural and urban), the number of fuels, and optional demand sectors.

Figure 4.9: OPERATING PRINCIPLE OF THE MEDEE-S MODEL 63/




63/ United Nations Development Programme (UNDP) and Economic and Social Commission for Asia and Pacific (ESCAP) in collaboration with Commission of European Communities, MEDEE-S, An Energy Demand Model for Developing Countries, Regional Energy Development Programme (RAS/86/136), Bangkok, Thailand, 1989.

Future Plans

4.184 Work is in progress to recombine the different versions of MEDEE under the umbrella of the Grenoble-based ENERDATA consortium. The plan is to produce a commercial product, including an expert system, which assists the user in defining energy demand.

Applications of MEDEE-S in Developing Countries

4.185 The model description 64/ refers to 10 reports on MEDEE-S applications in 10 developing countries in Latin America, Northern Africa, and Asia. Typical applications generate projections of energy demand, and analyze the effects of demand-reducing policies.

4.186 Colombia. 65/ The importance of industrialization for the country's economic development puts industrial energy demand into the forefront of national energy planning. A version of MEDEE with a particularly comprehensive industrial part was used to project Colombia's future industrial energy needs.

4.187 Ecuador. 66/ In view of the rapidly decreasing reserves of crude oil, the effects of an energy policy directed towards demand management, including a more rational use of petroleum products, have been investigated for two scenarios of economic growth.

Model Classification

Classification by model characteristic. Energy demand model.

4.188 Classification by approach. Top-down (GDP, population) and bottom-up elements (specific consumptions, demand by economic agent) are combined.

Practical Aspects of Model Availability and Usage

4.189 Minimum computing requirements. XT or compatible, 512 kb of RAM; a hard disk is recommended but not necessary. A high density diskette will privide enough space for the programs and several scenario calculations.

Additional software required. None.

4.190 Price of the model. The present version of MEDEE-S is free. However, it is normally not transferred without prior training, which the user must finance. The future ENERDATA version of MEDEE will be sold commercially. The plan is to make this new version so user friendly that training will no longer be required.

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64/ ibid.

65/ ibid.

66/ ibid.

Support and training offered. Yes. See the previous item.

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4.191 Easiest access. There is apparently no easy access to the present version of MEDEE-S, i. e., no tutorial, no brochure, and no demonstration versions.

Model Evaluation

4.192 User friendliness. The French version of MEDEE-S is not friendly to the unexperienced user. But even the advanced user would appreciate more flexibility in preparing the model input, e.g., there is no room for additional comments in the input file. Except for a few headers, the correct places for input variables are given by short mnemonics. Apparently, the English version of the model has been considerably improved in this regard. Another problem with the French version is that in some cases, inconsistencies of input data are detected by the computer program but in other cases they are not. The model description 67/ is written in the style of program documentation. It contains many names of artificial variables which are not readily understandable and are hard to memorize. A tutorial would be helpful.

4.193 Comprehensiveness of model output. Energy demand per fuel and per sector for all years. Not all detail is printed out, e.g., results on industrial energy demand are subdivided only into large consumers and others. The experienced user can find further detail in the input file.

4.194 Data intensiveness. MEDEE-S is not very data intensive. Input consists essentially of a description of a country's economic sectors, development scenarios for macroeconomic indicators, the base year energy demand structure, technological indicators of energy demand (such as energy intensities), and assumptions about fuel mixes. Within limits, the degree of detail can be chosen by the user.

4.195 Sophistication. The model structure itself is of the accounting type. No particular methodological knowledge is required to run MEDEE-S.

4.196 Transparency. Theoretically, MEDEE-S is very transparent. In practice, however, the restrictive input formats make it difficult to profit from this transparency.

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67/ ibid.

4.197 Robustness of results. High. The model design largely prevents discontinuities and thus guarantees stable behavior.

4.198 Flexibility. Within the design limits of deliberately chosen simplicity, flexibility is rather high. A separate program exists to translate the user-defined structure of the energy demand system into a template for an input file. This feature is the highlight of the model's user friendliness.

4.199 Applicability and limitations. The most typical application is generating energy demand scenarios as a function of policy measures to improve efficiency and reduce consumption. The simplicity of the model is its strength, and probably explains its world-wide popularity. Especially in countries where energy consumption data are scarce, MEDEE-S can be used as a framework for collecting data and establishing a "snap shot" of the energy demand system. The model's deliberate simplicity, of course, leads to some limitations. One is that it lacks genuine dynamics. Practically all movement within the model is caused by changes in input parameters over time. Prices play only an implicit role, i.e., the user normally takes expected price developments into account when defining shares of fuels in a demand sector during his/her description of scenarios.

## APPENDIX A. OTHER PC ENERGY MODELS

1. This appendix describes models which for various reasons were judged to merit attention but were not selected for a detailed assessment. The descriptions are presented in abridged format, and no evaluation is included.

### COMPLEAT/ENERGY 2020

#### Model Description

2. The Comprehensive Model for Planning Least-Cost Alternatives and Technologies, (COMPLEAT), and its progenitor, ENERGY 2020, are systems-dynamics models of the economic system. COMPLEAT is particularly suited for electric utilities. Both models are used mainly in the U.S. and its subregions (states). According to one of COMPLEAT's promoters, the model could be applied straightforwardly to developing countries, and an organization in the People's Republic of China is preparing to do so. The model is typically used to forecast all-fuel demand and usage as a consequence of interacting demand and supply options.

3. Input is in the form of times seris of those variables that describe the history of a region's economy and of its supply of and demand for energy. From these time series, model parameters are calculated to produce historical values as accurately as possible (calibration). Central classes of variables include policy decisions (efficiency standards, subsidies, low-interest loans, environmental regulations, fuel prices, and so on) and narrowly defined "uncertainties" (primary energy prices, regulatory rulings, financial constraints, consumer response, technological change, and so on). A combination of one particular set of policy decisions and one particular set of uncertainties is called a scenario. COMPLEAT is designed to explicitly look into the differential evaluation of such scenarios.

4. The main model output is a set of dynamically calculated energy prices and their impacts. Confidence intervals on results are part of the output of the model.

#### Practical Aspects of Model Availability and Usage

5. Minimum computing requirements. The model authors recommend that the demonstration model should be run on a 386 PC with no RAM disk, a VGA monitor, and an HP-Laserjet II compatible printer. Other configurations are also possible.

6. Price of the model. The model is available without charge to U.S. and international organizations not involved with commercial consulting.

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Easiest access. Demonstration diskettes are available.

## COMPRAN

### Model Description

7. The Computerized Project Analysis (COMPRAN) model is an interactive computerized package designed as a tool for project analysis in developing countries. It enables the user to perform both financial and economic analyses, and provides the following alternative decision criteria:

- Net present value
- Internal rate of return
- Benefit-cost ratio
- Bruno-criteria
- Break-even analysis

8. The financial analysis measures the costs and benefits of projects in terms of private market values; the economic analysis is concerned with the social opportunity cost of the projects. The financial analysis is designed to serve private investors; the economic analysis to assist government agencies.

9. Depending on user-defined decision criteria, output reports can include the costs, benefits and cash flows for every year of the period under consideration (both current and discounted values); the net present value; the internal rate of return; break-even figures; benefit-cost ratios; or Bruno-criteria values. Results can be reported in either financial or economic terms, or both.

10. COMPRAN was originally developed as a mainframe computer model at Ohio State University; it was then refined, and adapted to the microcomputer, by Ohio State, with the help of the East-West Center (Honolulu) to assist energy planners in developing countries. Little is known, however, about the results of such applications. The model has been widely used as a teaching tool in research institutions and seminars.

COMPRAN's analysis options include:

(a) Financial analysis
-Debt service with varying amortization schedules
-Borrowing for operation and maintenance costs
-After-tax cash flow with straight-line depreciation

(b) Economic analysis
-Secondary effects (multipliers)
-Unemployed or under-employed inputs (shadow-priced input costs)
-Traded versus non-traded goods (shadow-priced imports)
-Traded capital (shadow-priced capital)
-Market price subsidy effects
-Externalities
-Income distribution impacts

(c) Sensitivity analysis
-Inflation rates
-Scaling factors on project inputs (costs) and outputs (benefits)
-Multipliers

Model Classification

Classification by model characteristics: Project analysis.

Classification by approach: "Tool box" (i.e. it can be used to evaluate any type of project).

Practical Aspects of Model Availability and Usage

11. Minimum computing requirements: IBM PC or compatible, 256 kb of RAM, two double-sided, double-density 5 1/4" floppy disk drives or one floppy disk drive and a hard disk.

12. Support and training offered: System documentation consists of a manual that includes the theoretical foundations of financial and economic analysis, a model description, and case studies.

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## ECCO

### Model Description

13. ECCO is a dynamic simulation model of a national economy, designed to calculate a country's development potential in the context of policy variables. It can also be used to identify scenarios of sustainable development. Unlike most other energy models, ECCO does not use monetary units to quantify economic activities. Instead, it is based on the resource accounting approach, in which embodied energy is used as a numeraire. This means that all inputs, investment, interactions, and outputs of an economy are measured in embodied energy; that is, the total amount of primary energy that had to be sequestered from the Earth's stores to deliver a good or service to the final consumer. Solar energy is counted only to the extent that harvesting it requires the use of a natural resource.

14. ECCO is a comparatively small model. Once the database is established for a particular country, the creation of alternative scenarios can be managed by a single person.

### Practical Aspects of Model Availability and Usage

15. Minimum computing requirements. IBM XT or compatible, DOS 2.2 or higher.

16. Additional software required. A Dynamo compiler, for which the ECCO manual directs the user to Pugh-Roberts Associates, 5 Lee Street, Cambridge, Mass. 02139, USA.

17. Price. The price of £200 includes the software, the user's manual, and an explanatory guide.

Contact:
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18. Easiest access. A stripped-down ECCO model ("MicroEcco"), offered for £25, is a development game in which up to five people, acting as a Cabinet, try to create a sustainable future for a hypothetical developing country.

## GEMS

### Model Description

19. The Generalized Equilibrium Modeling System originated in the early 1970s; the authors claim it is probably the only energy modeling approach that was born in the energy industry

68/. The first full-scale implementation using the underlying technique was the SRI-Gulf energy model 69/. This was followed by several other applications for the U.S., and by a world oil model. One of its most prominent current applications is the Gas Research Institute's (GRI) North American Regional Gas Supply-Demand Model, which is implemented on a microcomputer.

20. GEMS is designed for users who want to study particular markets in varying degrees of detail. Models constructed with GEMS are based on fundamental engineering-economic analysis 70/. Input data include detailed information on all costs related, on the supply side, to processes of energy production and conversion, and to price-dependent demand curves. The model output consists mainly of time series of market clearing quantities and prices.

21. Although most GEMS applications have been for industrialized countries, GEMS-based models have been applied also to Argentina 71/ and to the Republic of Korea 72/. In both cases, the documentation reports include questions asked of the model and its responses. A general discussion of quantitative methods for energy-economic planning in countries with market imperfections has been published by Ussher and Salerno 73/ at Decision Focus, Inc.

Model Classification

22. Classification by model characteristic. GEMS belongs o the class of demand-supply integration models.

23. Classification by approach. Generalized equilibrium approach.

Practical Aspects of Model Availability and Usage

24. Minimum computing requirements. The GRI model runs on a Compaq 386 personal computer. It requires DOS 3.3 or higher.

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68/ Nesbitt, D., History and Development of the GRI North American Regional Gas Supply-Demand Model and Underlying Methodology, Decision Focus Inc., Los Altos, September 1988.

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72/ Ahn, B. et. al., "Integrated National Energy Planning: A Case Study of the Republic of Korea," in The Energy Journal, Vol. 7, No. 2, International Association of Energy Economists, 1986.

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25. Additional software required. No additional software is required. However, interface programs (LOTUS 123, Harvard Graphics) can be used for facilitating input and output conversions.

26. Price of the model. The purchase price of US$ 60,000 includes a perpetual license, the FORTRAN source code, and one week of training. If additional support is purchased from DFI, the cost of the software can be lower.

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## APPENDIX C. GLOSSARY

1. Most terms defined here have already been used in the model descriptions; others are general terms from the field of energy planning. Unreferenced definitions are by the author.

2. "Bottom up" modeling. A modeling approach which arrives at economic conclusions from an analysis of the effect of changes in specific parameters on narrow parts of the total system 74/.

3. Dynamic. In the field of modeling, a dynamic model includes inter-temporal relations between variables. A model that does not include such relations is called static.

4. Dynamic programming. A method to find an optimal time path.

5. Endogenous variables. Variables determined within the system under consideration 75/.

6. Energy forms and levels. Primary energy is energy that has not been subjected to any conversion or transformation process. Secondary energy (derived energy) has been produced by the conversion or transformation of primary energy or of another secondary form of energy. Final energy (energy supplied) is the energy made available to the consumer before its final conversion (i.e., before utilization). Useful energy is the energy made usefully available to the consumer after its final conversion (i.e., in its final utilization)76/. Figure C.1 illustrates the different energy forms.

7. Engineering approach. A particular form of bottom-up modeling in which engineering-type process descriptions (e.g., fuel efficiency of end-use devices) are used to calculate a more aggregated energy demand. This term is particulary used in contrast to econometric models.

8. Exogenous variables. Variables which are determined outside the system under consideration. In the case of energy planning models, these may be political, social, environmental, and so on 77/.

9. Explained variable. A variable whose value is determined by the value of one or more other variables 78/.

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74/ The World Energy Conference, Energy Terminology - a Multi-Lingual Glossary, 2nd Edition, Pergamon Press, London, 1986.

75/ ibid.

76/ ibid.

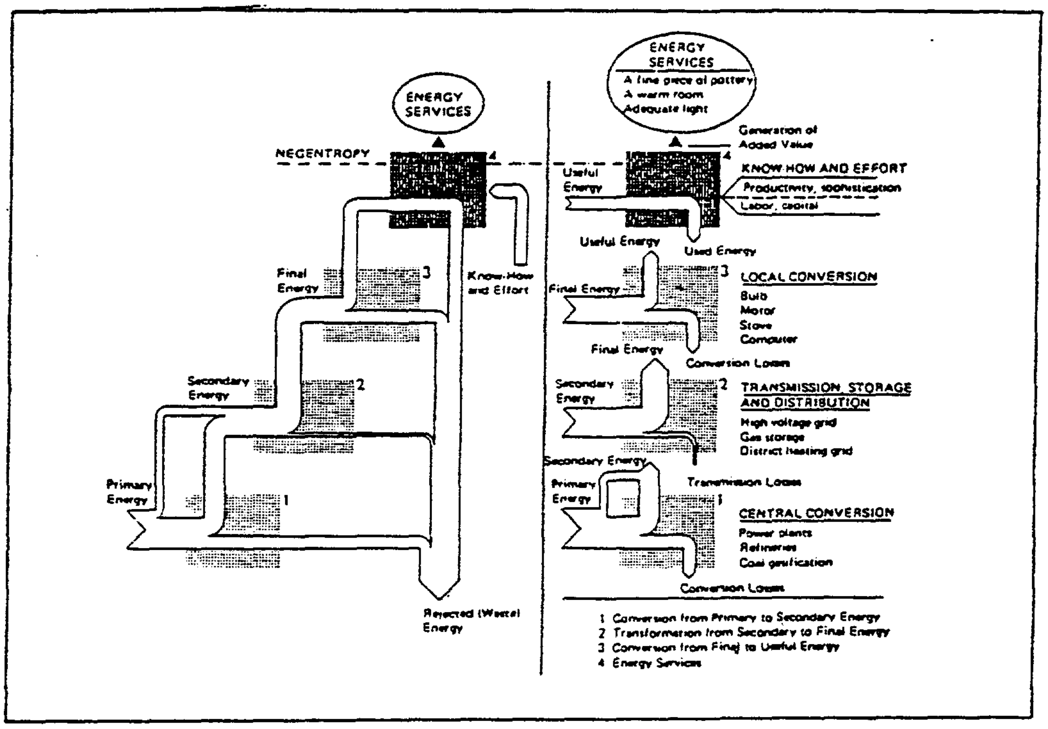
77/ ibid.

78/ ibid.

10. Explanatory variable. A variable whose value determines, either wholly or in part, the value of another variable 79/.

11. General equilibrium analysis. An approach which considers simultaneously all the markets in an economy, allowing for feedback effects between individual markets. It is particularly concerned with the conditions which permit simultaneous equilibrium in all markets, and with the determinants and properties of such an economy-wide set of equilibria 80/.

Figure C.1: ENERGY CONVERSION AND USE 81/




12. Input-output analysis. Method of investigating the interrelationship between the branches of a national economy in a specific time period. The representation, in the form of a matrix table, is called an input-output table. An input-output analysis allows the changes in total demand in related industrial branches to be estimated 82/.

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79/ ibid.

80/ Slesser, M., General Editor, Macmillan Dictionary of Energy, Macmillan Press, London, 1982.

81/ Energy Systems Program Group of the International Institute of Applied Systems Analysis, Wolf Hafele, Program Leader, Energy in a Finite World - A Global Systems Analysis, Ballinger, Cambridge, Massachusetts, 1981.

82/ World Energy Conference, op. cit.

13. Linear Programming. A practical technique for finding the arrangement of activities which maximizes or minimizes a defined criterion, subject to the operative constraints. For example, it can be used to find the most profitable set of outputs that can be produced from a given type of crude oil input to a given refinery with given output prices. The technique can deal only with situations where activities can be expressed in the form of linear equalities or inequalities, and where the criterion is also linear. That is, if $x_1$ and $x_2$ are inputs and y is the output, the technique applies only if their relationship is in the form $y \leq ax_1 + bx_2$, for example. 83/

14. Macroeconomics. The study of economic aggregates and the relationships between them. The targets of macroeconomic policy are the level and rate of change of national income (i.e., economic growth), the level of unemployment, and the rate of inflation. In macroeconomics, the questions about energy are how its price and availability affect economic growth, unemployment, and inflation; and how economic growth affects the demand for energy 84/.

15. Marginal costs. In a Linear Programming Environment, this term has the very specific meaning of change of the objective function value as a result of a change in the right-hand-side value of a constraint. If, for example, the objective is to minimize costs, and if the capacity of a particular energy conversion facility, such as a power plant, is fully utilized, the marginal cost in the LP sense expresses the (hypothetical) reduction of the objective function value (i.e., the benefit) of an additional unit of capacity.

16. Mixed-Integer Programming. An extension of Linear Programming in which binary (0-1) variables are admitted. Binary variables are a convenient way to model yes-or-no situations, such as whether or not to include a particular energy conversion plant in a system. In this way, variables that cannot reasonably assume any arbitrary (e.g. small) value - such as unit sizes of power plants - can be properly reflected in an otherwise linear model.

17. Optimization model. A model describing a system or problem in such a way that the application of rigorous analytical procedures to the representation results in the best solution for a given variable(s) within the constraints of all relevant limitations 85/.

18. Overall energy balance. A balance showing, in a consistent accounting framework, the stocks and flows of all forms of energy, from their origins through final uses, with quantities expressed in terms of a single accounting unit for purposes of comparison and addition. 86/

19. RAM disk. A virtual disk, usually defined to reside in a PC's expanded random-access memory.8

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83/ Slesser, op. cit.

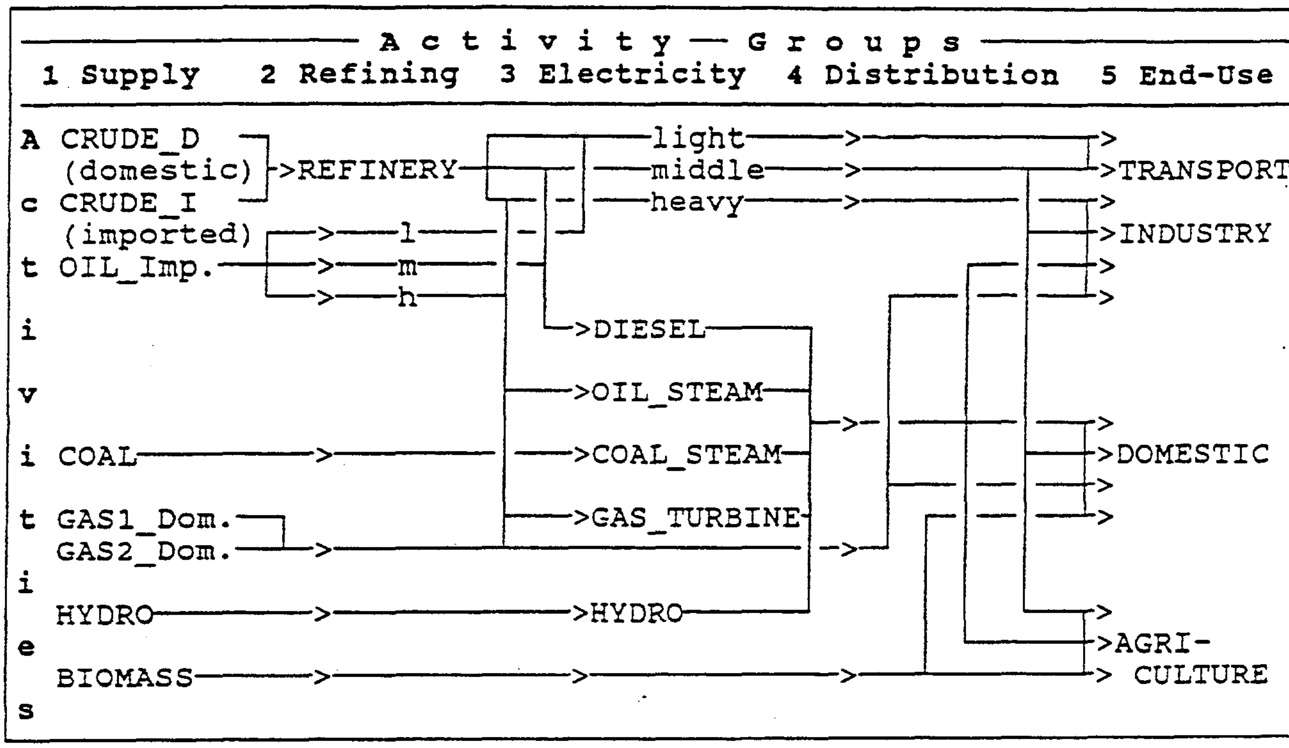
84/ Slesser, op. cit.

85/ World Energy Conference, op. cit.

86/ ibid.

20. Reference Energy System (RES). An RES network is a representation of the energy sector which shows physical energy flows at a single period in time. An example of an RES is shown in Figure C.2.

Figure C.2: AN EXAMPLE OF A REFERENCE ENERGY SYSTEM 87/




21. Regression analysis. Analysis of the mathematical relationship (often determined empirically) between two or more correlated variables, and the use of that analysis to predict values of one variable when given values of the other variables 88/.

22. Scenario. Coherent and plausible combination of hypotheses, systematically combined, concerning the exogenous variables of a forecast 89/.

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87/ ERL Energy Ltd and Halcrow Energy Associates, Energy Toolbox - A Decision Support System for Energy Planning, Users' Guide, Volume 1. ERL Energy Ltd., London, 1990.

88/ World Energy Conference, op. cit.

89/ World Energy Conference, op. cit.

23. Sensitivity analysis. A method of analysis which introduces variations into a model's explanatory variables in order to examine their effects on the explained variables 90/.

24. Simulation model. Descriptive model based on a logical representation of a system, and aimed at reproducing a simplified operation of this system. A simulation model is referred to as static if it represents the operation of the system in a single time period; it is referred to as dynamic if the output of the current period is affected by evolution or expansion compared with previous periods. The importance of these models derives from the impossibility or excessive cost of conducting experiments on the system itself 91/.

25. "Top down" modeling. A modeling approach that proceeds from broad, highly aggregated generalizations to regionally and/or functionally disaggregated details 92/.

26. User interface. All information, including push-button help texts, facilitating the technically correct operation of a computer program.

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90/ ibid.

91/ ibid.

92/ ibid.

## APPENDIX D. LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AEM | Argonne Energy Model |
| AFME | Agence Française pour la Maîtrise de l'Énergie (French Agency for Energy Conservation) |
| AIT | Asian Institute for Technology |
| AIX | (A version of the UNIX operating system) |
| ANL | Argonne National Laboratory |
| ASEAN | Association of South East Asian Nations (Brunei Darussalam, Indonesia, Malaysia, Philippines, Singapore, and Thailand) |
| AT | Advanced Technology (IBM microcomputer) |
| | |
| BALANCE | (Model for demand-supply integration; part of ENPEP) |
| BNL | Brookhaven National Laboratory |
| | |
| CAP | Calculator Program (Part of MESAP) |
| CEA | Commissariat pour l'Énergie Atomique |
| CEC | Commission of the European Communities |
| CGA | Color Graphics Adapter |
| COMPLEAT | Comprehensive Model for Planning Least-Cost Alternatives and Technologies |
| COMPRAN | Computerized Project Analysis Package for Developing Countries |
| | |
| DFI | Decision Focus Inc. |
| DOS | Disk Operating System |
| | |
| ECCO | (Simulation model based on the resource accounting approach) |
| EFOM | Energy Flows Optimization Model |
| EGA | Enhanced Graphics Adapter |
| ENERPLAN | UNDTCD's energy planning model |
| ENPEP | Energy and Power Evaluation Program |
| ESCAP | Economic and Social Commission for Asia and the Pacific |
| ESMAP | Energy Sector Management Assistance Program |
| ETB | Energy Toolbox |
| ETSAP | Energy Technology Systems Analysis Project |
| | |
| FEBT | Flexible Energy Balance Table |
| FORTRAN | Formula Translator (a programming language) |
| | |
| GAMS | General Algebraic Modeling System |
| GDP | Gross Domestic Product |
| GEMS | Generalized Equilibrium Modeling System |
| GRI | Gas Research Institute |
| | |
| HD | High Density |
| HGC | Hercules Graphics Card |

| | |
|---|---|
| IAEA | International Atomic Energy Agency |
| IBM | International Business Machines |
| ICARUS | Investigating Costs and Reliability in Utility Systems (part of ENPEP) |
| IDES | Integrated Demand and Energy Supply (predecessor model of BALANCE) |
| IEA | International Energy Agency |
| IEJE | Institut Economique et Juridique d'Énergie |
| IEPE | Institute of Energy Policy and Economics |
| IER | Institut fur rationelle Energieanwendung |
| INEP | Integrated National Energy Planning |
| JINEP | Jamaica Integrated National Energy Planning |
| kb | kilobyte (1024 byte) |
| LDC | Less Developed Countries (also the name of an ENPEP module) |
| LEAP | Long-Range Energy Alternatives Planning model |
| LP | Linear Programming |
| MAED | Model for the Analysis of Energy Demand |
| MARKAL | Market Allocation (energy supply model) |
| Mb | Megabyte (1024 kb) |
| MEDEE | Modèle d'Evaluation de la Demande En Énergie |
| MESAP | Microcomputer based Energy Sector Analysis and Planning System |
| MESSAGE | Model for Energy Supply Systems and Their General Environmental Impact |
| MIP | Mixed-Integer Programming |
| NEA | Nuclear Energy Agency |
| OLADE | Organizacion Latinoamericana de Energia (Latin American Energy Organization) |
| PC | Personal Computer |
| RAM | Random Access Memory |
| RES | Reference Energy System (also the name of an ETB module) |
| RSYST | (Data bank system, part of MESAP) |
| SADCC | Southern African Development Coordination Conference (member countries are Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe) |
| SEI-B | Stockholm Environment Institute, Boston Center |
| TEESE | TERI Energy Economy Simulation and Evaluation Model |
| TERI | Tata Energy Research Institute |
| UNDP | United Nations Development Programme |
| UNDTCD | United Nations Department of Technical Cooperation for Development |
| UNIX | (Computer Operating System) |

| | |
|---|---|
| VGA | Video Graphics Array (graphics card for microcomputers) |
| WASP | Wien Automatic System Planning (power system expansion model) |
| XT | Extended Technology (IBM Personal Computer) |

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