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ENERGY AND ELECTRICITY DEMAND FORECASTING FOR NUCLEAR POWER PLANNING IN DEVELOPING COUNTRIES

A REFERENCE BOOK

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FOREWORD

This publication of the IAEA is intended primarily for use as a training manual or textbook in the IAEA interregional training course on Electricity Demand Forecasting for Nuclear Power Planning in Developing Countries, as well as a source of reference for managers, economists, engineers and other professionals responsible for energy and electricity planning in developing countries.

The guidebook should serve to ensure that all participants of the above mentioned course possess or acquire the minimum core of knowledge and information on energy and electricity demand forecasting; thus, enabling them to extract the maximum profit from the course.

The overall organization of this training manual was discussed and agreed upon by the experts to Advisory Group Meetings on the subject matter convened by the IAEA at its Headquarters in Vienna in 1985 and 1986.

The Guidebook reflects the experience gained in conducting the first two Inter-Regional Training Courses on "Electricity Demand Forecasting for Nuclear Power Planning" at Argonne National Laboratory (ANL) in co-operation with the Government of the United States of America. The material was written mainly by the participants to the Advisory Group Meetings above mentioned.

This guidebook is published as part of a series of technical reports on Nuclear Power and its Fuel Cycle compiled by the IAEA's Division of Nuclear Power. Other documents already published in this series include:

Manpower Development for Nuclear Power: A Guidebook, Technical Reports Series No. 200 (1980)

Technical Evaluation of Bids for Nuclear Power Plants: A Guidebook, Technical Reports Series No. 204 (1981)

Guidebook on the Introduction of Nuclear Power, Technical Reports Series No. 217 (1982)

Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants: A Guidebook, Technical Reports Series No. 224 (1983)

Expansion Planning for Electric Generating Systems: A Guidebook, Technical Report Series No. 241 (1984)

Energy Planning and Nuclear Power Planning in Developing Countries, Technical Report Series No. 245 (1985)

Engineering and Science Education for Nuclear Power: A Guidebook, Technical Report Series No. 266 (1986)

Economic Evaluation of Bids for Nuclear Power Plants, 1986 Edition: A Guidebook, Technical Report Series No. 269 (1986).

Introducing Nuclear Power Plants into Electrical Power Systems of Limited Capacity: Problems and Remedial Measures. Technical Report Series No. 271 (1987).

The Division of Nuclear Power of the Agency would be grateful to receive comments from readers based on the study and use of the Guidebook.

ACKNOWLEDGEMENTS

The overall organization of this guidebook was discussed and jointly agreed upon by the authors, the members of an advisory group of experts coming from various countries and organizations, as well as staff members of the Economic Studies Section of the Division of Nuclear Power in the IAEA Department of Nuclear Energy and Safety. Messrs. J.P. Charpentier, J. Marques de Souza and P.E. Molina of the Economic Studies Section were the IAEA Technical Officers responsible for the preparation of this publication.

The structure of this guidebook relies heavily on:

a. the outline and the contents of conferences delivered by all lecturers to the first IAEA interregional training course on "Energy and Electricity Demand Forecasting for Nuclear Power Planning in Developing Countries", held at the Argonne National Laboratory (Illinois, USA) in 1985. The structure of this first training course on the subject was jointly agreed upon by Mr. J.P. Charpentier of the IAEA Economic Studies Section and Messrs. R. Cirillo, W. Buehring and T. Wolsko of the Argonne National Laboratory.

b. the work of the Agency Advisory Group of Experts on Energy and Electricity Demand Forecasting in Developing Countries. This group of experts met three times at the IAEA Headquarters in Vienna in December 1985, in June 1986, and in March 1987.

During its first meeting the group decided upon a suitable structure and contents of this guidebook and identified contributing authors who then drafted various chapters. On the occasion of the second and third meetings, the group of experts reviewed the various chapters drafted by the different authors and provided appropriate suggestions and recommendations in order to combine the various contributions within a comprehensive framework.

The International Atomic Energy Agency (IAEA) wishes to acknowledge the valuable contributions made by the members of the above mentioned advisory group as well as by Dr. T. Müller (an international energy consultant) who prepared this publication under a contract with the IAEA.

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INTRODUCTION

THE NEED FOR ENERGY PLANNING

Energy has always been an essential element of our civilization and ever increasing per capita consumption of energy has been experienced since the beginning of mankind through our days. Starting with the primitive man who mainly consumed energy in the form of food, followed by the hunting man who learned how to use fire to warm himself and cook his food, then the medieval man already using animals, windmills, water-wheels and little coal. The industrial revolution in the last century brought about the steam engine and a greater use of energy. Today's technological man with the increased need for mobility, machinery, goods and services has reached a level of consumption per capita many fold that of our primitive ancestors. Each evolutionary step of human society has been marked by an improvement in man's conditions of life as a results of his growing command over energy resources.

The above is true for the world at large even accepting that there is a great disparity in the pattern of energy consumption and in the standards of living of the population in industrialized and developing countries.

In the past decades the availability of abundant and cheap energy supplies encouraged intensive and extensive energy consumption patterns, as well as waste of energy since there was little incentive to save energy. The last decade with a disruption of this concept of cheap energy has brought about an increased motivation toward improved utilization of energy. Conservation measures and more rational use of energy without jeopardizing the overall standard of living or work productivity have become a goal for most countries.

Although petroleum continues to be the dominant source of primary energy, the overall demand for this product had been reduced mainly by saving and substitution, particularly in industrialized countries. Developing countries, with the exception of notable cases, do not have larger possibilities for oil savings and substitution since most of these countries need petroleum mainly for purposes which are difficult to be substituted, i.e. transportation. So these countries have experienced an erosion of their balance of payments as their oil bills increased. Even in today's world (1986/87) with again cheaper oil, most countries are aiming to increase the share of local energy resources in order to reduce their dependence from imported oil and the associated political risks.

Towards achieving these goals, an increased need for overall energy planning is present in most countries world-wide.

Decision-making at the national level is an increasingly difficult task in the complex world of today where so many different phenomena come into play. Links which may often be imperceptible or at least unapparent may transform the best intentions in one area into catastrophe in another.

Energy, with its many links with the various sectors of the economy, is one particularly sensitive area where any wise decision-maker must act with caution.

Almost all sectors of the economy are influenced by energy: transport, industrial manufacturing processes, even the private life-style, are affected by the availability of one or other form of final energy: liquefied petroleum gas (LPG), coal, electricity, etc. Each preferred life-style and every desired form of industrial or commercial development has one or more appropriate forms of final energy.

Furthermore, in the energy sector itself, the complexity of phenomena is greater still since there may be several possible types of primary energy for a given form of final energy. Electricity, for instance, is one possible form of final energy which can be generated from a number of primary sources: water, coal, oil, gas, uranium, solar radiation, etc.

Apart from the complex way in which energy interacts with all the sectors of economic and social life, there is a well-known but nevertheless formidable difficulty of the time factor faced by all decision-makers in this field.

The world of energy is dominated by substantial lead times between the taking of a decision and its implementation. Ten years is a time constant frequently encountered in the world of energy, and such a period often elapses between the discovery of a coal or uranium deposit and its commercial exploitation. The same order of magnitude applies to oilfields in difficult locations (which will increasingly be the case in the future) and for the time needed to construct a large electricity generating station.

It is no easy task to properly account for this time factor, since technical knowledge is constantly advancing. Taking a decision today on an investment which will become operational only ten years hence is a matter of experience, sound judgement and scientific analysis.

Lastly, another factor which further complicates the task of decision-makers in energy matters, especially at a time when many countries are suffering from a lack of capital, is the major financial impact of many of the decisions.

The interdependence between energy and other economic sectors, the need for a long-term view and the financial constraints require integrated long-term planning of the energy sector. This type of planning is a complex task requiring an iterative procedure.

Although there exists no defined sequence of how to carry out an energy/electricity planning study, it seems appropriate to proceed according to the following steps:

(1) Define the goals and objectives of energy and electricity demand planning in the broader context of development planning;

(2) Determine the planning approach and method to be taken;

(3) Establish the data base;

(4) Define possible solutions for achieving the goals and objectives identified in step (1);

(5) Carry out sensitivity analysis of the results obtained with regard, for example, to social and environmental compatibility;

(6) Define policies and strategies.

Reiterating the approach a number of times on the basis of hypotheses taken from the realm of the possible should lead to a firmer grasp of what is feasible.

Lastly, it should not be forgotten that planning is not an end in itself. The object and aims of the plan and the results achieved can be measured only against the final target set by the political decision-maker.

It is generally understood that no scientific methodology or approach can take the place of the decision-makers. One of the aims of this Guidebook, and of the methods it contains is to propose methods of analysis which may enable the energy authorities of a country to gain a better idea on energy demand planning in overall development planning.

I.1. History of the Guidebook

This Guidebook is the direct result of the experience gained during the Interregional Training Course on Electricity Demand Forecasting for Nuclear Power Planning organized by the IAEA and conducted at Argonne National Laboratory (ANL), USA. The course is part of the IAEA's role in providing technical assistance to developing Member States (as described in Section I.3). The course is open to all IAEA Member States, with special consideration to developing countries. Experts on energy and electricity planning from the IAEA and ANL, together with specialists from the World Bank, and from electric utilities, research organizations, universities, and private industry the world over, participate in conducting the course.

The course has generated a large volume of information and reference material. It was proposed that the IAEA organize the course material, prepare new material on several topics, and create a single document that could be used as the basic reference during future courses, and that would serve as a practical reference for energy/electricity planners. The IAEA with the assistance of numerous international specialists, have therefore developed this Guidebook in its present form.

I.2. Structure of the Guidebook

This Guidebook is designed to be a reference document to energy and electricity demand forecasting. It presents concepts and methodologies that have been developed to make an analytical approach to energy/electricity demand forecasting as part of the planning process.

The Guidebook is organized into 6 main chapters, each one presenting a major subject, and 3 appendices containing a summary of experiences with case studies in IAEA Member States, as well as additional material, including technical and economic data. A bibliography and a glossary complete the Guidebook.

Chapter 1 serves as a general background for the book and places energy demand analysis in the context of overall national economic and energy planning. The sensitive issue of adequate consideration of social needs (manifested through end-uses) in energy planning for developing countries is addressed. This chapter highlights the energy chain concept that commences with socio-economic needs and ends in resource requirements passing the useful, final and primary energy levels. The global and disaggregated approaches for energy demand analysis are introduced as well as the fine structuring of the disaggregated approach through modules.

Chapter 2 introduces energy demand analysis for forecasting and defines the scope of the remainder of the Guidebook: long-term energy and electricity demand forecasting. This chapter emphasizes the importance of energy demand analysis per se and the energy diagnosis as necessary pre-suppositions for appropriate forecasting. Furthermore, the establishment of an adequate energy data base is discussed, as well as the sectoral structure of energy demand and how it is normally decomposed for energy balances. The concept of energy diagnosis is presented in the light of regional considerations, the energy substitution process and the interaction between demand and supply.

Chapter 3 focusses on the concepts of electrical load curve analysis. It describes the several aspects connected to this analysis and the various forms (annual, seasonal, monthly, weekly, daily, hourly) of the load curve normally adopted for electricity planning. Considerations about differentiation of load curves at national, regional and sectoral and subsectoral levels are also made. The effects of policy decisions such as load management and tariffs on the load curve are also discussed.

Chapter 4 presents approaches and methods for energy/electricity demand forecasting. It discusses the global and disaggregated approach and introduces the normative and projective approach. Different methods used in energy (demand), forecasting, such as time series, econometric and simulation, are discussed. Emphasis is placed on the sectoral method used in electricity demand forecasting. Finally, the data retrieval problems are addressed in this chapter.

Chapter 5 describes energy and electricity demand forecasting techniques used in various organizations. Although it is not an exhaustive list, the Chapter reviews the most important examples of computer models and other techniques used in the world. These techniques are presented in a standardized form to allow the reader to make quick comparisons.

Chapter 6 describes the IAEA methodologies for energy and electricity demand forecasting. Methodologies used for projections at the world/regional level and projections used for specific country studies are identified.

The appendices complement the main text. Appendix A presents a summary of the experience with Case Studies carried out by the IAEA for some Member States. The other appendices cover mainly technical and economic data that may help in the conduction of energy/electricity demand forecasting analysis. The accuracy of such analysis is a direct function of the quality of the information used in its development. The planner should aim at obtaining the most up-to-date and accurate technical and economic data available particularly relevant for the country in analysis. This can be time consuming and is specially difficult during preliminary studies or when conducting training courses (such as the IAEA courses) but proves to be very important for the general understanding of the study. Appendices B and C provide typical information that can be useful to the planner to illustrate the scope and type of data required and to identify orders of magnitude until country-specific information is available.

A glossary defines terms used in the Guidebook, and a bibliography lists additional study material recommended by the various authors.

I.3. The IAEA's role in energy planning

In meeting its objectives of assisting developing Member States in the peaceful uses of nuclear energy, the Agency conducts an extensive and comprehensive programme of work in nuclear power planning and implementation, including economic assessments to determine the appropriate role of nuclear energy within the national energy plan of developing Member States. This programme includes three major types of interdependent and closely related activities:

(a) Development of appropriate methodologies specifically adapted to developing countries;
(b) Conducting training courses on energy and nuclear power planning techniques, based on methodologies developed by the Agency;
(c) Conducting energy and nuclear power planning studies in co-operation with the Member States requesting them.

In conducting this programme of work close co-operation has been established with other international organizations, for example the World Bank (IBRD) in joint IAEA/IBRD electric power sector assessment missions to developing countries.

I.3.1. Estimating future energy/electricity needs

One of the most important determinants of the future capacity mix of the electrical power system is the projected future demand for electrical energy. Experience showed that the information on electricity demand supplied by most developing countries was often not developed with a systematic procedure which would ensure internal consistency with the country's main economic and industrial development objectives and possibilities. The electricity demand projections therefore often proved to be a weak point in the resulting estimates of the role of nuclear power in a country's energy supply.

To improve estimates of future electrical energy needs, the IAEA developed the Model for Analysis of Energy Demand (MAED). This computer model (described in Chapter 6) provides a flexible simulation framework for exploring the influence of social, economic, technological and policy changes on the long-term evolution of energy demand.

I.3.2. Analysing the economics of electrical system expansion

Once the electrical energy needs are estimated, the electrical generating system must be planned to meet these long-range needs. To assist in this planning, the Wien Automatic System Planning Package (WASP) is provided by the Agency. WASP (referred to in Section 6) is a system of computer programs which uses dynamic programming techniques for economic optimization in electric system expansion planning.

The WASP model is structured in a flexible modular system which can treat the following aspects of an evaluation:

- Load forecast characteristics (electric energy, peak load, load factor, load duration curve),
- Different types of power generating plants (thermal using various fuels and hydroelectric power plants) and their individual characteristics (fuel and operating costs, heat rates, etc.), including the capital cost of those plants that are defined as candidates for system expansion,
- Power supply reliability criteria,
- Power generation system operation practices.

I.3.3. IAEA training courses in energy planning

To develop expertise within Member States which would enable them to undertake their own projections and planning, the Agency conducts three courses to train specialists from developing Member States in techniques for overall energy planning and for energy demand analysis and electric system expansion planning.

I.3.3.1. Training in overall energy planning

The major objective of the training course on Energy Planning in Developing Countries with Special Attention to Nuclear Energy is to familiarize energy specialists in developing countries with the fundamental elements of comprehensive national energy planning. The course emphasizes an understanding of the appropriate role for nuclear energy. It is not restricted to those countries already committed to using nuclear energy but is open to all developing Member States of the Agency and to participants interested in non-nuclear as well as nuclear energy technologies. The aim is to improve a country's ability to make a careful and objective choice among the various available energy options.

Even among energy planners, it is often thought that energy planning is only a question of economic analysis involving sophisticated computer models. This training course is designed to correct such a simplistic view and to show that good energy planning involves many aspects of technical as well as economic information. Particular attention is given to the link (too often disregarded) between the choice of the primary energy source and the end-use energy needs of the consumer.

In order to achieve this goal, the course combines a series of technical lectures on the subject matter and related aspects with round tables and panel discussions among the lecturers and participants. The last week of the course is spent on the analysis of case studies, about half of which are based on results of extended studies previously carried out in various countries. The other case studies are hypothetical problems which are analysed by working groups of five or six trainees guided by one or two lecturers.

Initiated in 1978 by the National Institute of Nuclear Science and Technology (INSTN) at Saclay, France, this course has been given four times in French (1978, 1979 and 1980 at Saclay, France, and 1987 at Rabat, Morocco), twice in Spanish (1981 at Madrid, Spain; 1985 at Bariloche-Buenos Aires, Argentine) and twice in English (1982 at Jakarta, Indonesia; 1983 at Ljubljana, Yugoslavia).

From 1978 through 1987 more than 250 senior engineer-economists from 60 countries were trained in energy planning. This course has been very successful, largely because Member States have always nominated highly qualified participants, but also thanks to the strong support of the contributing countries and organizations: Argentina, Brazil, France, the Federal Republic of Germany, Indonesia, Morocco, Spain, the United States of America, Yugoslavia, the United Nations Division for Natural Resources and Energy (DNRE), the World Bank (IBRD), UNESCO and, in particular, the National Institute of Nuclear Science and Technology (INSTN) at Saclay, France.

I.3.3.2 Training in energy and electricity demand forecasting

The objective of the IAEA's course on Electricity Demand Forecasting for Nuclear Power Planning is to train specialists in how to project future energy and electricity demand, the first step of any energy planning study. In particular, participants are trained in the use of the IAEA energy demand model MAED by conducting practical case studies based on their own country. During the course, attention is focussed on the overall problems involved in the energy planning field, stressing the problems related to energy/electricity demand forecasting. Other valuable approaches to energy and electricity demand forecasting developed and used in different countries and organizations are also described to the participants.

The two first sessions of this course took place at the Argonne National Laboratory (ANL), USA, in 1985 and 1986. During this period 63 engineers-economists from 20 countries were trained in energy/electricity demand forecasting. This figure does not include about 25 more specialists from developing countries who have been provided with training in the use of MAED as part of the conduction of Energy and Nuclear Power Planning Studies for interested Member States.

I.3.3.3. Training in electric system expansion planning

The objective of the Agency's course on Electric System Expansion Planning (ESEP) is to train specialists in planning the expansion of an electric generation system. It encourages the use of WASP for carrying out such planning, while pointing out that the WASP study is only part of an overall decision process, which should also include factors such as requirements for transmission, finance and manpower. In the period 1975-1985, more than 220 senior engineers and power system planners from 55 countries have been trained. From 1975 to 1977, training was carried out by the Agency at its Headquarters in Vienna. During 1978 to 1985, the IAEA training course, Electric System Expansion Planning (ESEP), sponsored by the US Department of Energy, was given seven times at Argonne National Laboratory, USA, with participation by 170 engineers and electric system planners from 48 countries. After completing the course, a trainee should be able to carry out studies to determine economically optimal expansion programmes including, in particular, the economically optimal share of nuclear power.

The main subjects of the ESEP course are:

- Principles of generation expansion planning,
- Interactions between electric system planning, overall energy planning and macroeconomic development
- Interactions between electric grid and generation expansion planning,
- Technical and economic characteristics of electric power plants,
- The WASP computer model, and
- conduction of a practical case study using WASP based on data for their own country.

I.3.4. Studies for energy and nuclear power planning

An Energy and Nuclear Power Planning (ENPP) Study is initiated only upon official request by a Member State of the IAEA and is carried out as a joint project of the Agency and the Member State. The objective is to assist the Member State in detailed economic analyses and planning studies to determine the need for nuclear energy and its appropriate role in the national energy plan. This requires both assessment in terms of economic plans and economic comparison with alternative energy sources. The analysis methodologies MAED and WASP are used during the studies, with improvements or changes as necessary, and are released to the Member State on completion of the study.

An ENPP Study has two specific objectives. One is to work with the requesting Member State to quantify future energy requirements, consistent with both national economic development plans and the expected share of electrical energy within the overall energy needs. The study then outlines an economically optimum electrical system expansion plan, including an assessment of the need for nuclear power and its role. These studies are based on the application of planning methodologies developed by the Agency, namely the MAED and WASP computer models. The second objective is to provide on-the-job training in the use of these methodologies to a local team of engineers and economists who conduct the study. Finally, within the framework of an ENPP study, the Member State receives the MAED and WASP models so that further energy, electricity and nuclear power planning studies can be undertaken solely by national experts.

As such studies are carried out in close co-operation with the requesting country, a joint team of specialists in energy planning is established. This joint team includes two or three IAEA staff members familiar with questions concerning energy planning and the different models that could be used as well as specialists from the Member State, at least five or six of whom are engineers and economists well acquainted with the electricity and energy situation in the country. It is recommended that the local team be composed of past participants in the three training courses as described previously (Section I.3.3).

Because of the importance of this type of study within the context of the present Guidebook, Appendix A describes in detail how an ENPP study is usually conducted and illustrates several studies carried out by the IAEA in cooperation with some of its Member States. In addition, Section 6.1 describes in detail the MAED methodology with reference to the other IAEA's planning model, WASP.

I.3.5. Need for long-range national planning for nuclear power and the Role of IAEA

Evaluation of the economic benefits from nuclear energy in a developing country needs a broad-based and in-depth analysis of the total effect of a nuclear power programme on the overall economic development of the country. There are three main points:

(a) The development of nuclear energy in a given country cannot be evaluated in an isolated way. Nuclear technology is only one among many means to supply secondary energy (e.g. electricity and heat), and nuclear power planning should be carried out in the context of all supply options. Nuclear power planning involves evaluation of the various types and forms of energy requirements, and should take into account the country's general plans for energy and economic development.

(b) Energy, electricity or nuclear planning can be undertaken rationally only by energy specialists of the country concerned. The Agency can provide advice and some methodologies but it cannot be a substitute for the local experts who must take final responsibility for planning the development of energy supplies in their country. Training to help develop local expertise can, if required, be obtained through the IAEA training courses. The Agency strongly emphasizes that the joint ENPP Study should be carried out mainly by the national team, supplemented by assistance from Agency experts. By this approach, a trained national team will be better able to understand the situation of its own country and will be able to follow up by itself the studies initiated in co-operation with the Agency.

(c) Finally, it must be accepted that economic studies such as those mentioned above are only a first step in the long process of nuclear power planning. Many additional studies and analyses should follow in order to determine whether nuclear power is a practical option and what would be the national implications of a decision to undertake a nuclear power programme. Complex problems such as impact on the balance of payment, financing constraints, manpower requirements and development, and the participation of local industry are involved; these are additional factors to be borne in mind when a country is evaluating the possibility of using nuclear energy.

Chapter 1

ENERGY DEMAND AND DEVELOPMENT

Energy demand planning is to be seen as an activity embedded in the broader frame of development planning. By that, energy demand and its respective planning come up to a certain importance for developing countries as the satisfaction of needs of the inhabitants and the demand for industrialization are both forces that will determine the decisions for the long term development.

The following sections stress this importance based on the special characteristics of developing countries and introduce important concepts which serve as a general background for the guidebook. In particular, one section discusses the energy chain concept as an adequate means to link socio-economic needs through the resource requirements passing the useful, final and primary energy levels. The demand forecasting phase within the energy planning process is also highlighted, introducing the two types of approaches commonly used for such purposes, i.e., the global and disaggregated approach. Finally, the chapter discusses the fine structuring of the disaggregated approach through the energy module concept and the sequential steps required to apply this concept. More detailed information about these concepts can be read in References [1] and [2].

1.1 Energy planning within development planning

1.1.1 The Role of energy planning within development planning

The aim of energy planning in developing countries cannot be found in the energy system itself but in its contribution to development jointly with other goods and services to satisfy the needs of the population. Consequently, the conceptual starting point will not be confined in any part of the energy sector (oil, coal, electricity, etc.) or even in the energy system taken as a whole. It will consist in a reflection on the nature of development and the way energy systems in developing countries relate to the development process.

Developing countries, with some exceptions, have a strong dependence on external economic forces, internal disproportionalities between sectors and between regions, inequalities between social groups, inadequate management of the ecosystems, etc. Therefore, developing a country means not only achieving economic growth but also realizing that structural changes are necessary to overcome these negative characteristics. In fact, the development process aims not only at increasing the amount of goods and services available to the society, it aims also at correcting structural imbalances specific to each country. Energy systems can play a role in this process.

Planning is not meant here as a centralized operation in which all economic decisions will be concentrated in the hand of a centralized government. It would rather be defined as a complex process in which various components (market forces, public authorities at all levels, consumers' behaviour) will have to play their role, hopefully in a concerted way. Institutional situations are very different from one country to the other, so that a document intended to cover all aspects in planning is bound to remain very general on this point.

Energy planning is part of overall development planning since the ultimate aim of energy planning is not to maximize the supply of energy (Joules or ton of oil equivalent) but rather to build up the energy system of the country to meet its socio-economic needs.

Energy planning involves organizations and other corporate bodies more directly concerned (Ministry of Energy, energy suppliers and other institutions in charge of specific energy aspects). But, more broadly, it should interest all individuals and institutions of the overall economic and social system for various reasons: because they consume energy (as final or intermediate consumption), because they produce or import goods needed by the energy system (inputs, capital goods, etc.), or because they compete for capital with the energy sector and other sectors of the economy (transport, schools, hospitals, etc.).

Therefore, in order to carry out energy planning more appropriately, methods are to be elaborated which could be used in a variety of developing countries where different organizations play different roles and are differently interrelated in the economic and social system (i.e. corporations which operate at least partly according to the laws of the various markets, public authorities at different levels, etc.).

1.1.2 The importance of energy planning for developing countries

In general, the necessity for timely and adequate energy planning may be seen in the following:

- Energy systems are relatively rigid to the dynamic needs of a country. Technology changes take place slowly and investments have usually a very long maturation time. More than most other sectors, energy planning is concerned with long term horizons (15 or more years) for which it is not always easy to get information and policy direction.

- In energy planning supply and demand are strongly interlinked. The relations between the energy systems and the overall economic systems are analyzed in an iterative or comprehensive manner. Comprehensive approaches, however, face quite often practical difficulties because of the complexities involved.

- In energy planning all energy forms of the energy system are equally important, no energy form is preferred per se. It means planning the various stages of the energy chain is required, implying that appropriate decisions are needed at the stage of the energy use as well as supply.

However, planning the energy system in developing countries requires also to consider appropriately the characteristics of the developing country energy system and its differences compared to developed country energy systems. Typical characteristics of the developing country systems are:

- The energy system in many developing countries is characterized by a biased energy consumption pattern, predominantly in rural areas, towards energy forms such as wood, charcoal, plantwaste, etc.; the over-use of which does have severe environmental impacts.

- In contrast to industrialized countries which have established energy systems, developing countries are in the process of developing these systems. Various alternatives are open to them, one of them in particular is the choice to be made on how energy requirements should be met: by expanding the centralized system (electricity network, gas grid, distribution of petroleum products) or by increasing decentralized production facilities (biomass, small hydropower stations, solar energy, etc.). The distinction between centralized and decentralized systems is essential for today's developing countries and the stakes are even higher for those which are currently setting up their energy systems.

The preceding reflections point towards the importance of a thorough understanding of the functions of the energy system and of its relationship to the economic and social system.

1.2 Energy demand in energy planning

1.2.1 The framework of energy demand forecasting

The importance of energy demand forecasting in the context of energy planning in developing countries should be seen in predominantly two facts:

- The demand to be anticipated is the one which will take place in 15 or more years from now. Even if it is admitted that market forces play an important role (to a different extent and in different conditions from one country to another), it would be very difficult to assume that the conditions existing at that horizon (absolute and relative prices, consumption patterns, income, technology, environment, etc.) will be similar to the ones prevailing now.

- The development process will effect structural changes which will influence future energy consumption.

Therefore what has to be analyzed is future energy consumption, not as it will emerge on a market similar to the present one, but rather future energy requirements*, i.e. the energy which is required to meet the socio-economic needs consistent with the objectives of the overall development plan.

Consequently, energy demand planning means to determine future energy consumption within a given set of policy assumptions, as explicitly described as possible, aiming at improving existing conditions both of the overall system and the energy system. Examples of such policies could be:

- overall policies (price policies, monetary policies, taxes, social policies, regional balancing, etc.)

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* When the word "energy demand" is used in this book, it will be used as synonym for the term "energy requirement".

- sectoral policies outside the energy system influencing energy consumption (transport policies, urbanization and housing policies, rural electrification, rural development policies, etc.)
- energy policies per se acting either upon the overall consumption or upon the substitution between energy forms (energy conservation, relative prices, etc.).

These sets of policies depend on the central government but other groups of the society or government (local governments, social groups, etc.) play also a role. Their participation in the planning process is very important. The plausibility and usefulness of the forecast will depend very much on the willingness of the various decision makers to state in factual terms their plans and policies.

Obviously, a realistic energy demand forecast should study a variety of assumptions (if possible incorporated in a set of coherent overall scenarios). Ideally, the choice of the scenarios to be studied and the assumptions to be included in each of them should not be left to the forecasters themselves but discussed and decided among the decision-makers concerned.

1.2.2 The energy chain concept

Historically, the energy chain concept refers to a global representation of the three successive stages: primary energy, final energy and useful energy, which indicate the physical flows of energy products through the extraction, transformation, transport, distribution and use stages.

In an energy demand forecasting approach as it is understood in this guidebook, this chain can be followed in the opposite direction to determine from socio-economic needs useful energy required for their satisfaction, final energy quantities, and then primary energy required and thereby work out the resources to be developed or exploited (Figure 1.1.1).

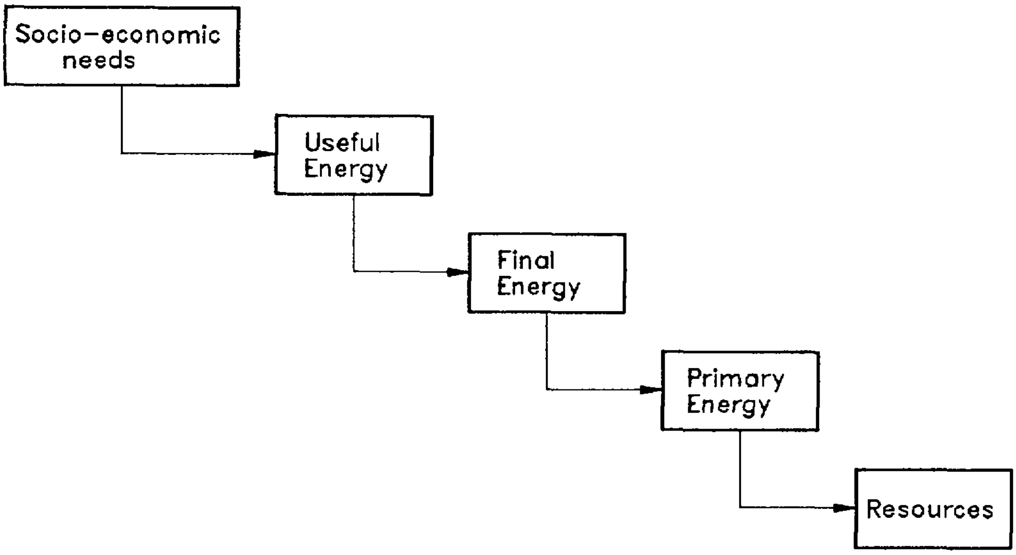

FIG. 1.1.1. The energy chain concept.

This concept is interesting because it maps socio-economic needs directly into operational energy categories (one of the central problems of energy economics). That is the problem of adequate balancing between resources and requirements, with the proviso that all resources, commercial and non-commercial, and all the requirements either actual or potential, are considered. This goes far beyond the balance between energy supply and demand. New sources of requirements are taken into account by extending the graph to include new elements in the energy chain. From a methodological point of view, forecasting and planning can therefore be seen as a selection of a few from among the whole combination of possible solutions.

In addition, the energy chain concept enables highlighting the energy efficiency of individual appliances used. Thus, this concept appreciates the rationality of an end use method in its entirety from primary energy to useful energy taking into account direct and indirect effects, as well as external and internal effects.

The energy chain concept may be extended by an economic, financial, environmental and manpower chain concept. These concepts would identify at each level of the energy chain all the economic activities involved in the energy transformation process such as for example capital and manpower requirements. Similarly an environmental chain concept would identify the emissions released during an energy transformation process. These concepts ultimately reintroduce a relationship with the energy system's surroundings. They prove particularly useful for examining the impacts of energy forecasting on investment, imports of products or equipment, introduction of new technologies, etc.

1.2.3 Social needs and energy requirements

The starting point for energy demand analysis, as indicated already in the previous section, is the concept of socio-economic, i.e., human, needs not defined by absolute quantitative norms but specific to socio-economic contexts. For planning purposes, the determination of future socio-economic needs will take into account the variety of external and internal objectives included in the developing strategies of each individual country. Obviously these needs will be related not only to material needs expressed in development styles, consumption patterns, quality of life, but also in more non-material values such as national autonomy, solidarity, social justice, cultural identity, etc.

The transition from the social needs concept to the energy requirements concept must be made carefully. The nature of energy requirements differ from for example food requirements. The latter give rise to the determination of certain minimum norms (in calories, proteins, etc.) which, with some qualification, may be used as guidelines for defining future minimum levels. It is not so for energy requirements for which abstract norms in terms of energy quantities (Joule per capita for example) make little sense. Energy helps to meet social needs both directly (as a component of final demand) and indirectly (as an intermediate input to productive sectors which themselves produce either goods and services satisfying social needs).

Energy end uses are the linking concept between the energy system's socio-economic dimensions and its physical dimensions.

Energy equipment is the technical corollary to the realization of energy end-use since no use is possible without a piece of equipment. The energy intensity of a given end use may be measured by useful energy which is the difference between final consumption and losses. The efficiency of the equipment used therefore has an influence on useful energy but directly effects final consumption. In addition to the quantitative level of energy consumed, the end-use approach must also specify the nature and quality of the energy used.

Referring back to Figure 1.1.1, a specific example is displayed in Figure 1.1.2 to illustrate the relationship between social need and primary energy requirement.

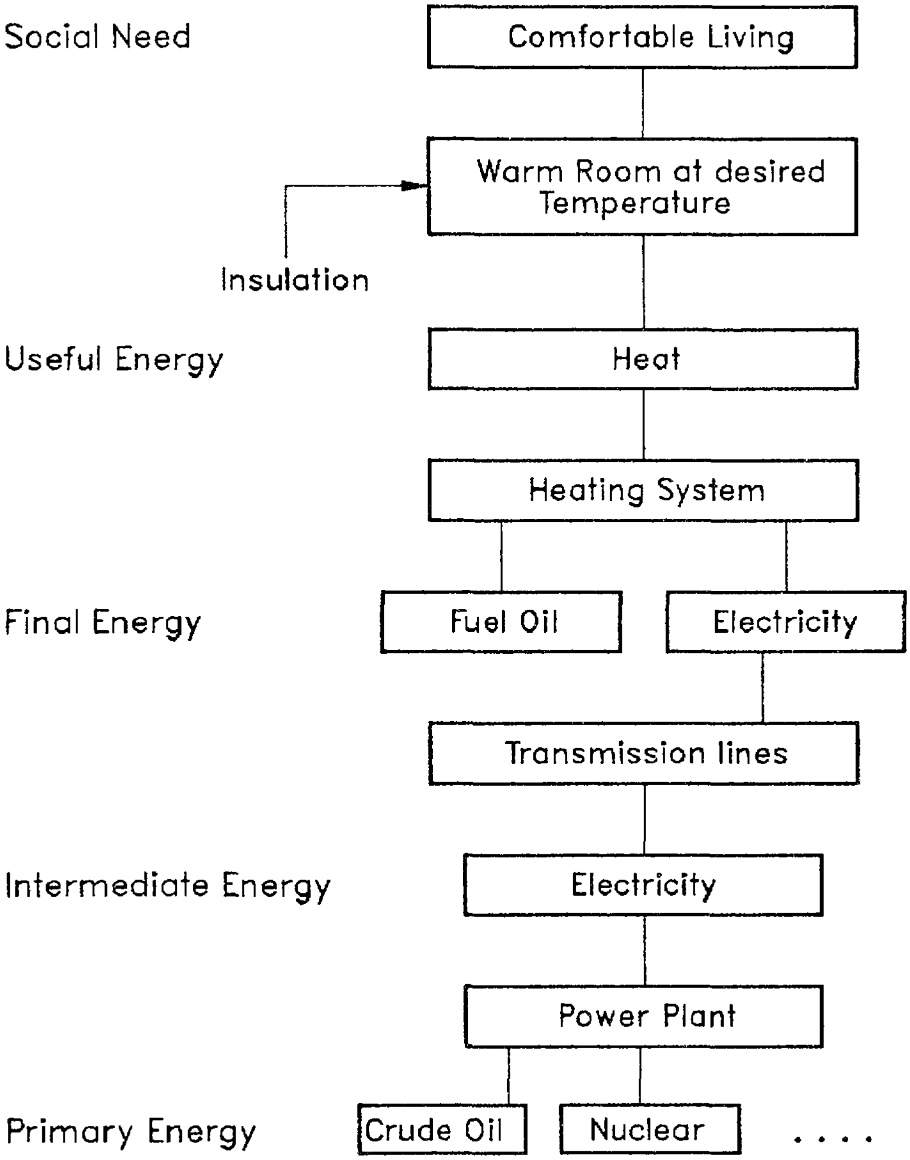

FIG.1.1.2. The social need — primary energy requirement chain.

1.3 The demand forecasting phase in the energy planning process

1.3.1 Adequacy of the disaggregated approach for energy demand planning in developing countries

It has been said that future energy systems should develop not only to promote economic growth but also to achieve structural changes that lead to better development. Furthermore, energy demand is not only considered in the market place but also as energy requirements consistent with socio-economic needs.

This would have direct bearing on the choice among methods available in order to analyze and forecast energy requirements. As a whole, even with the possible limitations due to the lack of appropriate information, preference should be given to a disaggregated over an aggregated approach. The disaggregated approach enables to analyze more appropriately the details of the socio-economic and energy requirement concept as compared to the aggregated approach.

To recall briefly, the aggregated approach is based on overall relations between energy consumption and economic factors. In its cruder version it reflects the prolongation of past trends. A more elaborated approach uses the elasticity concept. Specifically the concepts of the average income elasticity of demand and the average price elasticity of demand would be included in there.

Many ways of using elasticity concepts have been proposed. They are calculated by econometric methods and can be based on short run, medium run and long run elasticity calculations. The detailed discussion of the general validity of these concepts will not be entered in this chapter.

Using the aggregated approach, the planner faces the problem that whatever the degree of sophistication of the aggregated methods, they simplify the role of energy (as an input to economic growth) and usually forecast future relationships between the energy system and the national system consistent with what they were in the past. Using such a procedure makes difficult the appropriate consideration of the effects of structural changes on economic growth. In addition their general nature makes it difficult to identify the various policy actions which would be necessary in order to bring about the structural changes.

The way such aggregated methods have been used in the past has led in many cases to the building of systems which are not well adapted to real needs and resources of developing countries. Examples to be mentioned are disproportionate oil and electricity subsystems responding mainly to the requirements of the more affluent group in urban housing. Another example concerns the way in which rural electrification is often carried out, intensifying existing inequalities in favour of privileged minorities.

Having pointed to the limitations of application of the aggregated approach for energy demand planning in developing countries, the disaggregated method will be discussed. This type of approach takes better account of the heterogeneous nature of the energy systems of developing countries and their complex relationships with the economic and social systems.

The main features of the disaggregated method for developing countries are the following:

- Using the disaggregated method enables the planner to analyze features of the developing countries in a distinct way, for example the differences between urban and rural areas, formal and informal sectors, the central and marginal parts of the system. In endeavouring to define the energy requirements and the corresponding supplies for each of these parts within the energy system, it gives renewed importance to those parts which are generally neglected. Thus, changes in the proportions between these parts, and in the way in which they articulate, can be forecast. This analytical feature holds good for both requirements and supplies.

  From the provision (or supply) point of view, the analytical approach is necessary because of the heterogeneity which is also characteristic of energy production in developing countries. Very often a multiplicity of energy sources, traditional, conventional, and new ones, may well be envisaged to satisfy a particular use, and competition between these sources varies greatly from one region of a country to another. Although for measurement and aggregation a common unit is used (e.g. the Joule), it should be remebered that energy is not a homogeneous product, neither in an economic nor physical sense. Therefore, in each case, the type of energy necessary must be defined and it must be linked in the most appropriate way to supplies among the various energy sources.

- The disaggregated approach takes into account the characteristics common to all developing countries as well as those specific to each individual country. It is sensitive to structural changes implied by the various development styles and strategies chosen by these countries. It is flexible enough to be able to adapt to the different conditions in which the market, the state and civil society articulate. Therefore, account can be taken of needs which are not expressed in monetary terms.

- The analytical nature of the disaggregated method enables to define and analyze the links between energy requirements and socio-economic needs on the basis of variables generally measured in physical terms. However, this does not mean that the economic nature of the problem is ignored, nor that cost or price variables are put aside. These are taken into account at each stage of the process and particularly when substitutions between the various energy sources likely to meet a given use, are analyzed.

- In the disaggregated method a multiple set of relationships between the energy system and the global system (national, economic, social and cultural) is made more explicit. These relationships are not only examined at the beginning of the projection process (by a global GNP/energy consumption relationship) but at each successive stage of the energy chain. The articulations of the energy system with the global system is demonstrated at each link of the chain. By determining for a given future year the corresponding quantities at each point in the chain, one clarifies as much as possible the nature of the relationship.

1.3.2 The energy module concept

The practical realization of the disaggregated method leads to the application of the concept of energy modules. The objective of energy modules is to group together users whose behaviour now and in the future will be as homogeneous as possible, both because they have similar requirements and because they can be inserted into the economic, social and cultural system in the same way. Therefore, consumers can be grouped at the energy end-use level in categories on the basis of one or more criteria: social, economic, demographic, spatial, etc. An example of an energy module may be the rural population in a certain climatic zone with its specific energy requirements for agriculture, rural industries, households and local transport. For each module one can identify the determinants which will define future energy requirements in terms of levels, nature and type of energy source. By using the modular approach, the multiple set of relationships between the energy system and the global system (natural, economic, social and cultural) can be made more explicit.

However, the homogeneity of the sectors must not be understood in a static sense but rather according to the objectives of the projection method. In effect, the aim is to simulate the future behaviour of each unit. With this in mind, one seeks to represent the behaviour of each homogeneous group of users as determined by the macro-structural factors.

The disaggregation level to be adopted is not defined a priori. It varies according to the interplay of the various macro-structural factors and the way in which they influence the energy consumption of various user groups. Among those elements most often used for the breakdown into modules, the following may be quoted:

- the region's natural features which condition both energy requirements and the availability of energy sources to meet these requirements at a local level,
- the pattern of the economic activities,
- the location of the activity (urban or rural areas),
- the level of concentration of users (different size of towns, concentrated or scattered population),
- the type of technology used to consume energy, a factor which is linked to the user's socio-economic or cultural characteristics (income level, level of technical progress, size of enterprises, etc.).

Each of these aspects defines a part of the users' group in each sector by emphasizing a particular energy consumption pattern. By establishing a hierarchy among these various aspects a tree can be constructed which determines the place of each homogeneous module within the overall sector considered.

The breaking down of current energy consumption into modules is an important part of the energy diagnosis. The modular approach accounts for differences in the natural environment, production modes, and socio-cultural characteristics; it distinguishes between non-monetary requirements on the family or village level and energy demand in monetary terms on the energy market. It facilitates to introduce qualitative aspects of energy and to initiate structural changes.

For operational reasons, modules have to be grouped in blocks. A possible grouping might be: household sector, industrial sector, transport sector, agriculture and service (or commercial, institutional) sector. The energy system's own consumption is not treated in an energy demand analysis but in the respective supply analysis.

In other countries, it might be advisable to group together everything concerning the rural system. This would include not only the requirements for household purposes and for agricultural production but also specific requirements for rural industries.

Other key issues will be the choice of an industrialization strategy, e.g. satisfying social, domestic needs or integrating the local economy into the world market, using imported technology or developing national technology, promoting the modern or the traditional sectors, etc.

Summarizing the aforesaid, the modular approach is a transparent and flexible method which enables changes in parameters or coefficients to be introduced at any time if new information becomes available. If the case arises, it also means that the economic policy measures required to bring about the desired changes can be defined. Consistency between the energy system and the economic and social system is not obtained at the outset but rather in an iterative process which means that at each stage the results of one system can be introduced into the other. The validity of the hypotheses used at the start to define the global system of the future can be checked step by step. It may be added that as far as its application to energy planning is concerned, the process is not merely methodological. It can also reflect the actual movements of information and decision among the various actors who play a role in the planning process.

In order to carry out energy demand forecasting and planning in the specific case of a given country, a preliminary step is of utmost importance: that of the diagnosis of the energy system and of its relationships with the overall system (i.e. the economic, ecologic, social, etc.). Defining the future of the system is possible in a rational way only to the extent that the past and present situations are well understood.

When the diagnosis has been done, it is easier to define the energy requirements of the future horizon year. Conclusions of the diagnosis will provide useful orientations as they will narrow down possible alternatives and make it possible to identify the keypoints on which important decisions have to be made concerning both the level of energy requiredand the possible breakdown into various energy sources.

The diagnosis includes also the analysis of the supply side. In order to work out an iterative process of successive approximations, previous analytical work on past and present evolutions involving both sides, supply and demand, is a preliminary step before starting the projection phase.

1.3.3 Identifying the objectives

In order to design in each specific case an operational planning process, the overall orientation related to alternative strategies have to be expressed in terms of an actual set of objectives. For a more systematic presentation, these may be grouped under three headings: society, outside world, natural environment. Thus, the links between these objectives and the energy system can be identified at the global level of the overall economic and social system and through other sectors (industry, transport, etc.) themselves related to energy. The objectives can be grouped in three categories as follows:

- objectives related to society
    - . overall social structure (consumption pattern, income distribution, balance between rural and urban areas, cultural identity of each country, etc.),
    - . balance among the various regions in the country (this also concerns the environmental aspects),
    - . sectoral strategies and policies consistent with the overall objectives (i.e. strategies of integrated rural development, strategies of industrialization, housing policies, transport policies, socially oriented tariffs, etc.),

  The links with the energy system will have to be identified at the end use and at every step of the production process.

- objectives related to the outside world
    - . overall strategy: self-reliance aimed at progressively reducing the country's dependence, or integration within the world market,
    - . choice of external partners: regional or subregional integration, choice of partners from industrialized countries, relations to other developing countries, etc.

  The links with the energy system will appear at various levels: imports and exports of goods, exchanges of technology, know-how, training, etc. They are direct (energy sector itself) or indirect (other productive sector related to the energy sector through inputs or equipment).

- objectives related to natural environment
    - . overall objectives: proper management of the various ecosystems existing in the countries, strategy to control the rational utilization of natural resources (vegetation, minerals, water, etc.), pollution control, etc.

> The links with energy are both direct (use of fuelwood, production of possible fuels, use of water, environmental effects of electric power plants, etc.) and indirect (balance within agriculture between food crops and energy crops, environmental effects of energy use in industry, transport, etc.).

Obviously these three sets of objectives are interrelated. Some types of economic relations with the outside world may not be compatible with objectives of development styles or cultural identity. Some choices of industrialization strategies (or even individual industrial projects) will inevitably affect environmental conditions and insertion in the world market. One area is usually related to all three of them and should consequently be given special attention: the choice of technologies both in the energy sector itself and in the related sectors. Strategies and policies regarding the choice of technologies, include research and development, training, building up engineering capabilities and appropriate institutions, etc.

1.3.4 From social needs to useful energy requirements

As mentioned earlier (Section 1.2.2), the transition from the social needs to the energy requirements is a complex matter which refers to specific energy end uses and energy equipment.

The evaluation of useful energy consumption is the most adequate as it takes into account the efficiencies of end use equipment. Possible substitutions between various energy sources can be evaluated and compared. Very diverse solutions can be examined as regards the level of useful energy meeting the same socio-economic need. This is worthwhile in prospective studies and planning in order to evaluate the effects of a certain policy aiming at a more rational use of energy.

The energy module concept is a helpful tool in this context as it groups consumers according to their consumption behaviour in homogeneous sets which allows to analyze and identify the socio-economic driving forces in each sector of the system under study.

The choice of those variables among the socio-economic parameters linked to the future evolution of energy consumption is decided case by case in each of the sectors considered. One can say that such "explanatory" variables or energy consumption determinants are sometimes social and/or economic aggregates (population, Gross National Product, added value by sector, number of vehicles registered, etc.). Sometimes these parameters reflect the expected implementation of the selected strategies, i.e. change in income structure, correcting of imbalances between the urban and rural sectors, technological choices, relationships between the modern and traditional sectors, change in consumption patterns.

Useful energy requirements can be classified into two main groups:

- energy requirements associated with the various uses of final consumers: food, clothing, housing, transportation, etc.,

- energy requirements associated with the activity of production sectors: agriculture, industry, transport, services, etc.

Determining energy needs will consequently require definitions of overall (or global) objectives, i.e. consumption patterns, income distribution, dichotomy between the rural and urban regions, etc., and of objectives related to the various production sectors, i.e. agriculture, industry, construction, etc. and social sector, i.e. education, health, housing.

For the projection of energy requirements in the horizon year, two important features should be considered:

- the projection starts from the latest year for which the data base is adequate (base year). Breakdowns of the system and grouping into modules will primarily depend on two factors: the structure of the energy system to be studied and the availability of data for the base year,

- for each module the projection will include the total useful energy requirement and a breakdown into various energy sources. The future breakdown is determined on the one hand by the system's structure prevailing in the base year, and on the other hand by the anticipated structural development of the system. This implies that the breakdown is not static and can be modified during the planning process given the general planning objectives.

The overall objectives (related to the society, outside world and natural environment) are taken into account in the breakdown of the system into homogeneous modules (structure of the module system) and in the projection of each module's parameters. For instance, government policies concerning migration from countryside to cities will determine the proportion between rural and urban households. Transport policies will determine the respective role of private cars, trucks and buses, and bicycles. Government policies will also influence the energy demand of each module, for instance, temperature levels in public buildings, regulations for car's fuel use per kilometer, etc.

The projection of energy requirements in a given module may be made according to past trends or through plausible assumptions concerning the behaviour of economic agents, the technological evolution, ratio of penetration of energy sources, etc. It may also imply voluntary changes reflecting development strategy choices. Whatever the basis for the projection may be, modification of current relations should be accompanied by the explicit listing of policy measures which may incite such modifications.

1.3.5 From useful energy requirements to final energy

At this stage the efficiency of end use equipment is considered. Efficiency by use and by source is taken into account for each module in each sector. This gives room to the planner to introduce changes if desired. An improvement in the useful/final energy ratio may be an important factor in the transformation of energy systems.

This stage will include two main aspects:

- register all possible operations which will improve the efficiency of a given energy source for each use, and
- make choices concerning possible changes in the market shares of various energy sources.

All actions related to rational use of energy take place under the first heading. They include changes in the behaviour of the various energy users, improvements realized through better management of the equipment used, technical improvements of existing appliances or introducing new ones. Rational use of energy can be looked at module by module and specific measures recorded. Then measures at a global level could be considered. These might include action through regulations, fixing adequate prices and tariffs, incentives (subsidies, tax deductions, special interest rates, etc.), campaigns to explain to and educate people, training of specialized personnel, etc.

Examples of possible actions can be found in every end-use sector:

- increased efficiency of wood and charcoal for cooking purposes in rural areas through promotion of the use and production of adapted stoves,
- reduced consumption of coke per one ton of steel through improved technical processes and better management,
- decreasing the specific fuel consumption of cars through regulations and incentives directed at car users, and producers,
- policy of improving the efficiency of heating systems (insulation, heat pumps, etc.) through regulations, investment incentives, loans and tax reductions.

The second set of possible choices at this stage is related to changes in the market shares between various sources of energy in all uses where substitutions are possible. In developing countries one major aspect is the way wood and charcoal will be substituted by petroleum products, electricity, etc. or possibly by new energies (biogas, energy crops, solar, etc.). This is connected with the growth of centralized energy subsytems, in particular the expansion of the interconnected electrical grid. Electricity is an important factor in progress and modernization. However, too rapid electrification may commit too high portion of the available financial resources and may also be counterproductive to some political objectives, e.g. self-reliant development.

On the whole, increased efficiency for every specific use and a more critical rational combination of the various sources may lead to significant improvements in the overall ratio between energy consumption growth and economic growth. Possibilities depend very much on the stage of development of the country concerned and structural changes in the production sectors in a given period of time (share of industry in the Gross National Product, proportions between heavy and light industries, etc.).

Aggregation of all modules gives a vector of final energy requirements. Of course, due to the close interrelation between energy supply and energy demand this result is only a provisional one, corresponding to a first round in the iterative process of energy planning.

Normally, after the primary energy has been computed and the overall interactions of the energy system have been checked with the economic system, one may come across constraints and contradictions which make it necessary to undertake another step in the iterative process. This may lead to going again through the two stages which have been described in Sections 1.3.4 and 1.3.5. It some cases it may ultimately lead to the necessity of redefining the social objectives which had been set at the beginning of the planning exercise.

Figure 1.3.1 summarizes the previous sections and illustrates the energy planning process schematically. The objectives of the society, the outside world and the natural environment frame the energy system and influence the development of the energy chain (from useful to primary energy) on every level. The different technologies identify in the energy system the points of intersection between useful and final energy, i.e. use technologies, and between final and primary energy, i.e. product technologies.

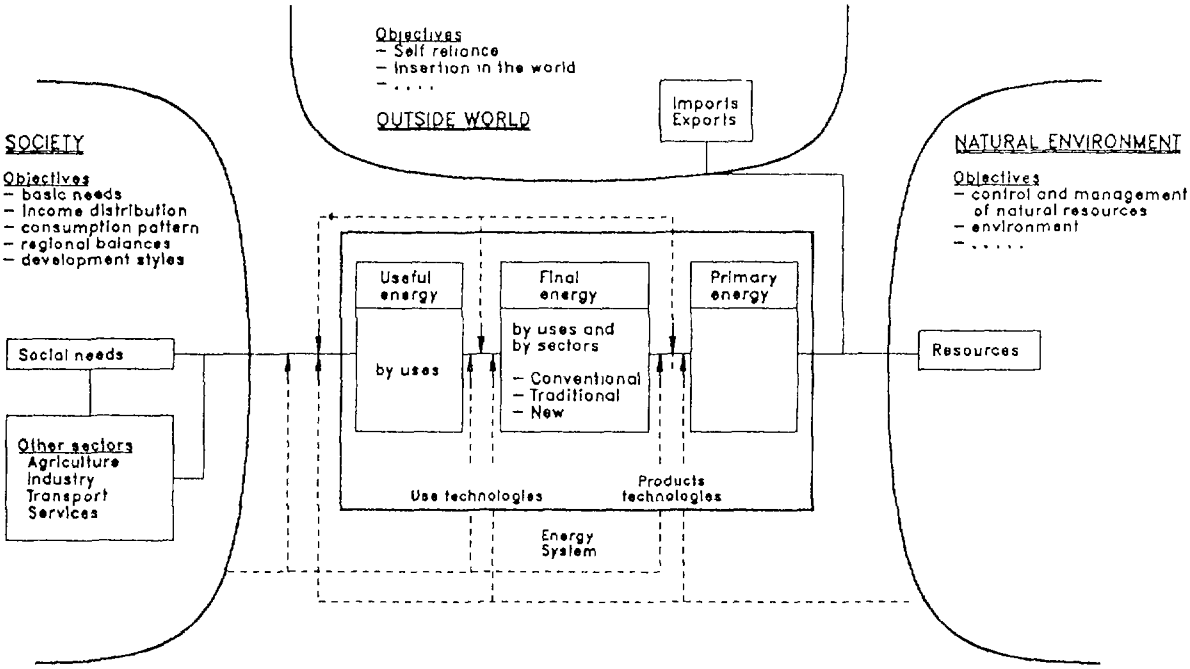

FIG.1.3.1. Scheme of the energy planning process.

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Chapter 2

ENERGY DEMAND ANALYSIS

The future development of energy demand (and supply as well) is subject to great uncertainties caused by a variety of factors. Actions and decisions in the energy sector have long term consequences which do not affect the energy system solely but the economic, social and ecosystem as well. In order to minimize uncertainties on future energy demand development and to relate the expected future demand most logically to the known systems of the past and present, it is necessary to have profound understanding of the framework of demand analysis, the main determinants of energy demand, and its interrelationships within the energy system itself as well as the surrounding systems, for example economy, society, ecosystem, etc.

There are different approaches to analyze the determining factors of energy demand for a given country. However, common to all approaches is the requirement of a careful assessment of the parameters describing the past and present situation. In this chapter, emphasis is placed on the assessment of parameters of the past and present energy system and its forms of presentation (i.e. overall energy balances, integrated energy balances, reference enegy system). In addition, great value is addressed to the energy diagnosis as an elaborated method of structured investigation of the system's most important determinants and as a framework for the establishement of a synthesis that enables to judge the working conditions of the energy system with regard, for example, in the light of energy substitution aspects.

2.1 Delimitation of the energy system

The features of the energy system are multi-dimensional, i.e. multi-facetted with regard to energy forms, complex in the consumption pattern, different with regard to the penetration time of fuel types within the system, etc. These factors are equally important for the energy system and have to be carefully considered for the system under study.

Energy demand analysis, as it is commonly carried out, focuses on non-animate and non-human energy forms, e.g. it excludes human and animal power from the analysis and henceforth from any energy management strategy. In spite of the fact that these energy forms play a significant part in the overall energy picture, especially in some developing countries, at the moment it appears very difficult to quantify these inputs to the energy system in terms of a common energy unit.

Energy demand analysis starts with the collection of relevant energy data which describe the energy system under study in the most representative way. However, due to the multitude of information, a systematical procedure has to be introduced and applied in order to structure the information set. A more general classification of energy is concerned with the different forms of energy available and used in commercial and non-commercial 'markets'. Furthermore, energy is usually not used in its naturally occurring form (e.g. coal, crude oil, natural gas, etc.). It passes several conversion processes before it reaches an energy form usable by the consumer for different purposes and this information must be taken into account in structuring the data base. Figure 2.1.1 displays the energy flow in the levels of the energy system.

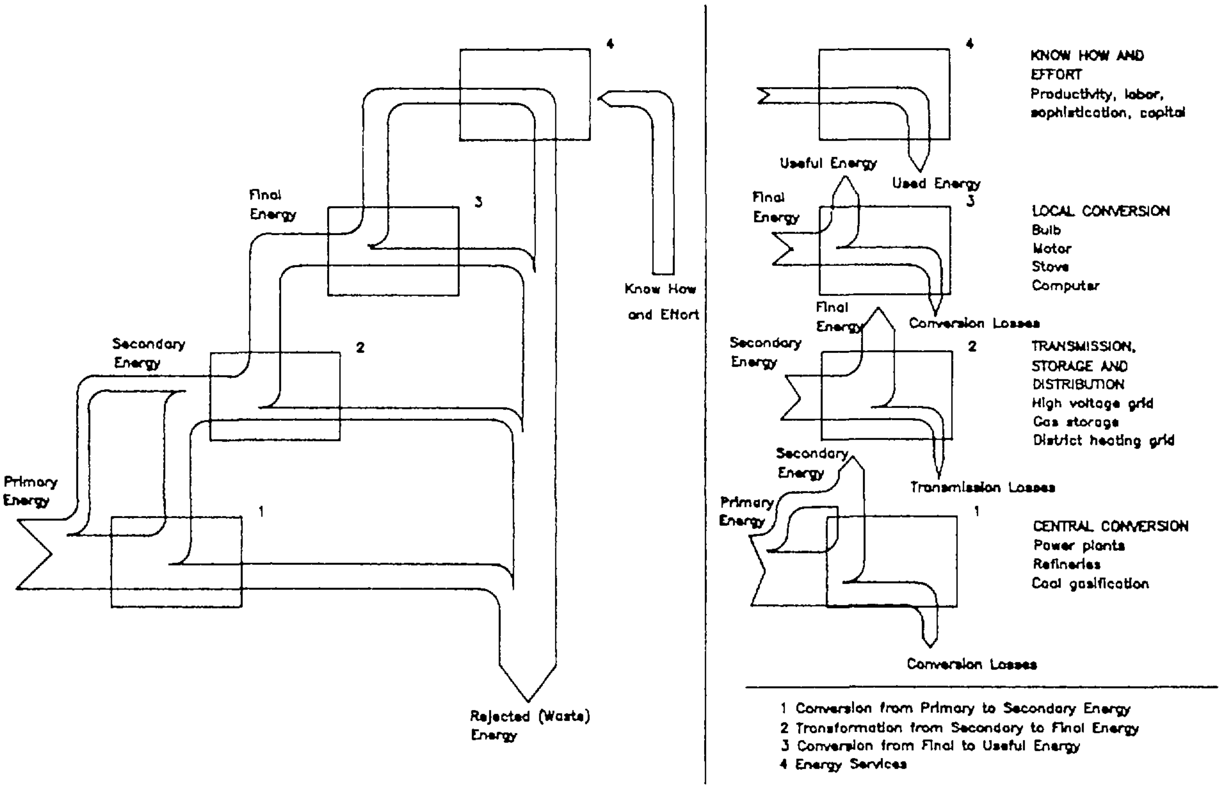

FIG.2.1.1. Energy conversion and use [1].

The primary energy forms of the energy input system are differently classified and the terminology used varies widely. A clear distinctiveness of the notion is important in order to avoid further confusion. Table 2.1.1 presents the primary energy forms classified according to different criteria commonly in use. This classification does not claim to be final. As technology and the fuel mix traded in markets are subject to changes, the scheme presented in Table 2.1.1 reflects the present status.

2.2 Energy demand data

2.2.1 Energy demand data base

In order to undertake retrospective analyses and to launch forecasting studies it is essential that data of the system under study are available. The data base is the basis for status-quo analysis. The energy demand data base consists of information related to the consumption pattern of the country under study, thus covering all energy forms which are used [2].

The formulation of an appropriate energy consumption data base should address primarily the collection, processing and categorizing of energy consumption data by quantity and energy type in different energy consuming sectors. Emphasis should be devoted to the collection of specific energy consumption ratios of the different consumption processes for all energy forms.

TABLE 2.1.1. CLASSIFICATION SCHEME OF PRIMARY ENERGY FORMS

Classification Criteria	Energy Form	Energy Type
Monetary transactions, Prices	Commercial	Crude oil, Natural Gas, Coal, Nuclear, Hydro, Geothermal, Heavy Oil, Tar Sand, Biomass
	Non-commercial	Biomass, Wind, Agricultural waste
	Classification dependent on country feature	Fuelwood, Biomass
Technology	Conventional	Crude Oil, Natural Gas, Coal, Nuclear, Hydro, Fuelwood, Agricultural Waste
	Non-conventional	Fusion, Heavy Oil, Geothermal, Tar Sand, Oil Shale, Wind, Tidal, Waves, Solar (direct radiation)
Physical Occurrence	Renewables	Solar, Hydro, Wind, Ocean Thermal Gradient, Biomass (fuelwood, agricultural waste, biogas), Tidal, Waves, Geothermal
	Non-renewables	Coal, Crude Oil, Heavy Oil, Natural Gas, Oil Shale, Tar Sands, Nuclear Fuels

Additionally, in order to obtain a broader data base, and hence a clearer picture on the manifold interrelations existent in the energy system, emphasis should be devoted on the following areas [3]:

- Collection of energy retail prices at final consumption level by energy types.
- Estimation of "suppressed or unserved demand", i.e. that part of the energy requirements or demand at existent prices which cannot be covered due to supply constraints.
- Estimation of non-commercial energy consumption in predominantly rural areas.
- Analysis for energy imports, by type of imported energy, quantities and prices, and degree of import dependence.
- Calculation of price elasticities for energy consumption.
- Establishment of consistent energy supply/consumption balances (see Section 2.3.1).

Although the information gathered pertaining to the energy demand (and supply) pattern forms the basis in the understanding of the energy system's linkages, energy demand is also driven by factors of different nature, such as, for example, economic, socio-economic, technical, environment factors, which are not immediately visible through the analysis of the energy system alone but which are closely interrelated with the energy system under study and 'steer' it to a certain extent. This leads to the energy diagnosis which will be discussed further in Section 2.4 [4].

A misrepresentation of the interrelation and interdependencies of the driving parameters of the energy system under study might lead to the establishment of inadequate energy demand policies and strategies.

The development of an adequate energy demand data base, suitable for demand planning, is not an easy task. Quite often the development is accompanied by a number of difficulties, for example inadequacy, lack or insufficiency of data, manpower and institutional problems. This subject will be discussed further in Section 4.4.

2.2.2 Sectoral structure of energy demand

Aggregate energy analysis on the national level alone does not provide enough information for appropriate energy policies and strategies. Therefore the energy system has to be disaggregated. Depending on the planning objectives, classification criteria for energy demand analysis could be:

- analysis per fuel type, e.g. coal, oil, gas, coal, electricity,
- analysis per economic sector,
- analysis of the energy content of materials used, manufacturing process applied, or end-use category.

From the energy demand point of view, the most appropriate approach would base the analysis on the end-use level. This approach defines the energy consumption pattern on the basis of the energy needed to produce materials and manufactured goods (e.g. glass -bottles, float or crystal-, etc.) or the production process. However, the multitude of information required for such an analysis makes this very detailed approach difficult at the moment.

A more practicable approach for energy demand analysis determines energy consumption according to the energy forms being used in the different sectors of the economy. The sectors of importance can generally be grouped into the following:

industry
agriculture
residential
commercial/institutional
transportation
rural communities

The interlacement of economic sectors and energy sources can be schematically displayed in a matrix (Figure 2.2.1).

	Industry	Households	Transport	Others
Coal				
Oil				
Gas				
Electricity				
Biomass and other renewables				
...				
...				
...				

FIG.2.2.1. Relationship between energy source and economic sector.

Energy demand analysis covers the entire matrix compared to electricity demand analysis that focuses predominantly on one energy form across the economic spectrum.

Each of these sectors has its own pattern of energy demand. The factors that determine energy use are different in each sector. Any analysis must consider the peculiarities of each sector separately. Table 2.2.1 lists typical useful energy demand categories for each sector. Each category can be subdivided to treat special problems; for example, industrial direct heat can be divided by temperature range to allow the analysis of potential penetration of low-temperature solar systems.

TABLE 2.2.1. TYPICAL USEFUL ENERGY DEMAND CATEGORIES [6]

Sector	Category
Industry	Indirect heat Direct heat – High temperature – Medium temperature – Low temperature Process electricity (i.e. electrolysis in the aluminium industry, etc.) Other electricity (i.e. lighting, etc.) Motive power Feedstock Off–road industrial vehicles
Residential/ Commercial	Space heat / air conditioning Water heating Cooking Lighting Electro–mechanical appliances
Transport	For intercity and intracity (urban) travel: Passenger travel (car, bus, rail, air, ship) Freight travel (truck, rail, air, ship, pipeline)
Agriculture	Motive power Off–road agricultural vehicles

2.2.2.1 Industry

The industrial sector is often the largest consumer of energy. It is also directly tied to economic growth patterns. The variables that are used in an energy demand analysis of the industrial sector are the growth by industrial subsector (e.g. food processing, steel production, chemical manufacture, machinery manufacture, etc.), production technology choice by subsector (e.g. use of open hearth or electric arc furnaces in steel making, use of wet or dry method in cement production, etc.), fuel choice by subsector (e.g. use of coal or fuel oil to generate steam, use of distillate oil or natural gas in ovens, etc.), and the efficiency of energy conversion equipment (e.g. boiler, ovens, furnaces, machinery, etc.). Reference is made to Appendix B that provides some information on specific final energy consumption characteristics in selected industries.

2.2.2.2 Agriculture

Apart from the manufacture of fertilizer and the processing of food (both which are generally treated as part of the industrial sector) and the distribution of agricultural products, agriculture is a relatively small user of commercial energy. The concern of this section is therefore primarily with commercial energy use of farm equipment (tractors, plows, harvesters, etc.) and irrigation pumps. Specific energy requirements for food processing and tractor use are given in Appendix B.

In some countries, energy use in powering fishing boats is included in this category.

The parameters used for developing a demand forecast in the agriculture sector are population growth, the projected growth in agriculture output, the arable land, the technical requirements to achieve the projected output, the choice of fuels for machinery and/or pumping, and the equipment efficiency.

2.2.2.3 Residential

Residential energy use follows a much different pattern than does industrial use. Although the concept of energy consumption and useful energy demand is the same, the parameters that influence the energy needs are different.

In the majority of developing countries, energy consumption in the household sector is primarily for cooking, with a small but important component for lighting. In the middle and upper income brackets, energy consumption for space heating forms a significant proportion of total consumption, especially in countries with severe cold climates. In countries with hot climate, air-cooling takes a remarkable share in the total. [6]

Various socio-economic and technological factors such as the level of income, population size, average size of homes, customs and habits of consumers, and efficiency of end use devices effect the consumption in this sector. The main difficulty often faced in the residential sector in analyzing energy demand is the availability of data, especially of end-use breakdowns of energy consumption. Due to the lack of data, aggregate analysis is undertaken more often than micro analysis. The aggregate energy demand is explained by macro variables such as population growth and per capita income, energy prices, penetration rates of electrical appliances, and some indicators of improvements in the efficiency of end-use devices.[6]

Energy needs for cooking are directly related to individual households' eating habits and these needs for a family may not change significantly as their income level increases. However, the switch of fuel sources from firewood or coal to commercial energy forms occurs significantly as the standard of living improves. [6]

The energy demand for electrical appliances and lighting depends first on the level of income (which could be identified through the ownership of electrical appliances), the average utilization per period of time and the efficiency of these appliances.

In the case of heating, useful energy demand is determined apart of the income level also by the need for a desired indoor temperature, the insulation characteristics of the dwelling, the volume to be heated and the free heat generated by occupants, the sun and the operation of the appliances. This requirement is translated into final demand for energy products which is determined by the efficiency of the heating equipment. But actually, the social and technical driving forces of energy demand for heating are masked and outbalanced on the final energy demand level by economic parameters, such as energy prices and income level.

The determinants of useful and final energy demand for heating can be illustrated as shown in Figure 2.2.2:

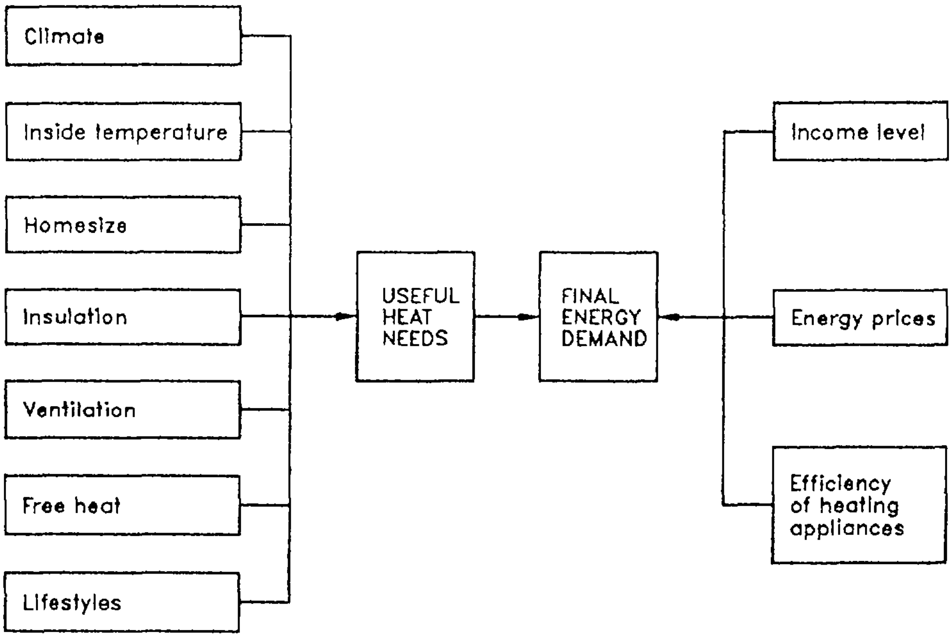

FIG.2.2.2. Determinants of energy demand for heating of a home or a building [10].

Due to the complexity of determining factors of useful and final energy demand, a comprehensive analysis of future residential energy requirements would need to address all those factors as they currently exist and as they are likely to change in the future.

2.2.2.4 Commercial/Institutional

The commercial/institutional sector includes shops, governmental and private offices, schools, hospitals and other such activities. Energy consumption is primarily from buildings. Some indicative specific energy consumption data by type of institution are given in Appendix B. The types of energy required in this sector are very similar to the residential sector: cooking, water heating, lighting, air conditioning, electromechanical. However, the primary parameter determining growth in this sector is the growth of the economy.

Although the energy use is very similar to residential use, different sub-parameters, apart from economic growth, require to deal with the service sector separately.

2.2.2.5 Transport

The transportation sector is predominantly tied to consumer's behaviour and requirements. The transportation sector can be classified according to the object being transported and the transportation mode. This interrelation is displayed in Figure 2.2.3.

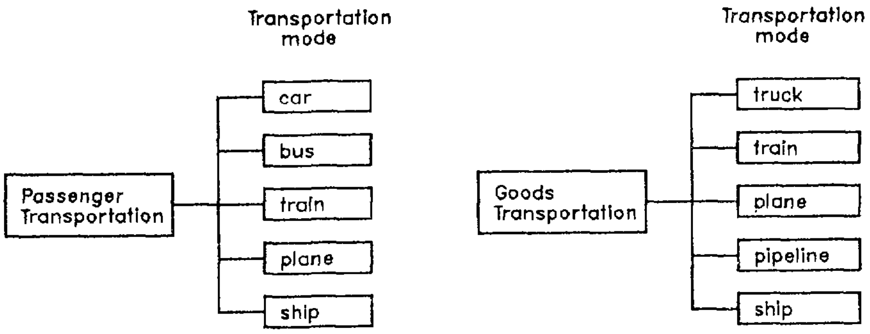

FIG.2.2.3. Clustering of the transportation sector according to the mode of transport used for passenger and goods transportation [9].

The energy required for passenger transport depends on the number of passengers traveling, the frequency and average length of trips, the distribution of trips among the various modes of transport and the technical characteristics of the carriers and their condition of use.

Energy demand for freight transport depends on the volume of goods, average distance of shipping, the modal structure of freight transport and the economic and technical characteristics of each transportation mode. Indicative specific energy consumption by transportation mode are given in Appendix B.

The estimates of passenger and freight transportation demands are the basic parameters of the analysis of energy use in the transport sector.

The difficulty in carrying out this approach on energy demand in the transport sector is the determination of characteristic values. Certain determinants can be and are recorded statistically; others can only be known through surveys and studies. The variables usually covered by statistical observations are population, development of transport modes, modal distribution, total public passenger traffic, and structure of the transportation system with regard to the transportation vehicle being used (e.g. cars, buses, trains, etc.). The demand for transportation measured in terms of passenger-kilometers traveled (PKT) and freight-kilometers traveled (FTKT), are usually statistically recorded values.

A detailed analysis has to be carried out on the energy requirements for the modes used to move passengers and freight, especially in those cases where there might be a possibility for substitution either between transportation modes (private car vs. public transportation system in urban areas) or within the transportation mode (gasoline vs. diesel cars).

2.2.2.6 Rural communities

Rural communities in developing countries must be considered separately when analyzing the energy demand picture. These communities have all the components of energy use of the other sectors (residential, agricultural, industrial, transport), but generally have little or no commercial sources of energy. They rely heavily on non-commercial fuels.

The analysis of energy demand in this sector must be considered in two separate parts. The first is an evaluation of the energy use in the sector from the perspective of traditional consumption patterns. For example, the use of fuelwood for cooking must be studied with the consideration of the availability of sufficient quantities of wood and the environmental damage from stripping woodlands. This perspective is based on providing rural communities with the basic energy necessities.

The second part is based on the projected demands for commercial energy that will come from rural communities as they change to more advanced stages. This second part must be analyzed in a totally different manner than the first part. In fact, the analysis of current energy use patterns in rural communities provides little insight into future demand for commercial energy. This is the case where the analysis is very strongly supply-driven.

Consider for example the case of a rural village that has just been added to the electric power grid. Prior to the electrification, the energy use follows traditional patterns of non-commercial fuel use. With the coming of electrical power, not only some of the energy-using functions converted from non-commercial fuel to electricity (e.g. lighting, water heating) but whole new uses of energy are stimulated (e.g. television, power tools). These new demands could not have been projected by simply extrapolating the traditional patterns.

For this reason, rural communities must be analyzed as sources of 'latent or suppressed demand' for commercial energy. As soon as the energy supply is made available, demand will increase in new areas. The only way to estimate the extent of this latent demand is to evaluate the pattern in communities that have already undergone the transition. This type of study is very rare and data are very sparse.

2.3 Representation forms of energy flows

The various different purposes for which structured information is needed may be summarized by saying that there is a need to know how primary energy forms have been used at the end-use level and to know, or rather to assess, the amount of primary energy forms needed to satisfy socio-economic needs or better say, needs that manifested in certain energy end-use requirements. An energy accounting framework should be suitable for meeting both types of needs [2].

Therefore the aim of the energy balance is to bring out the full significance of the table containing the energy data and to allow it to be read both per operation and per energy form [5].

2.3.1 Overall energy balances

Energy passes several stages of conversion from primary to useful energy. One method of visualizing the energy flow is in a version of a network. The presentation of an overall energy network in a single figure is rather difficult due to the manifold interrelations between energy form and end-use. Therefore, in Figure 2.3.1 the sector of the energy network concerned with resource production and conversion is presented as illustrative example.

In this representation of a network the circles represent allocation points of the different energy forms. The squares represent conversion facilities where one form of energy is converted into another. The triangles represent energy transport processes (e.g.

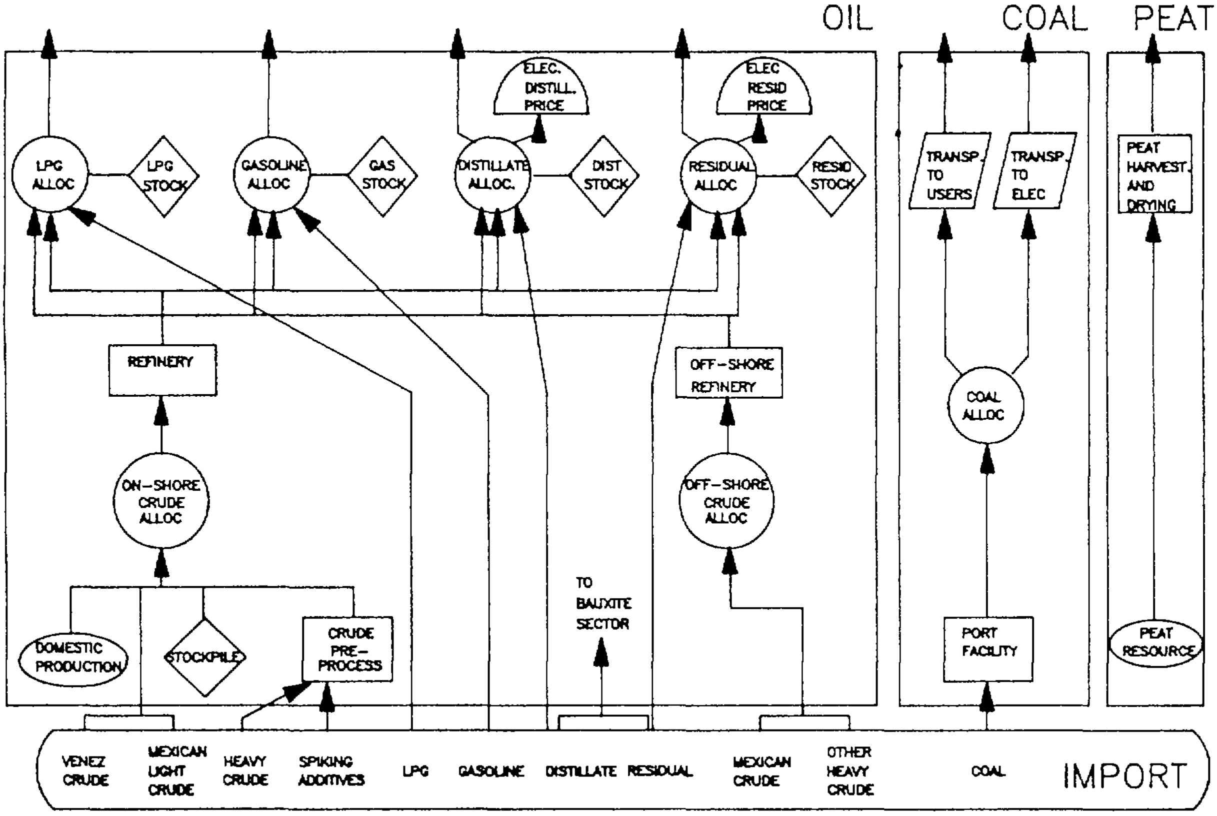

FIG 2.3 1. Typical energy network for energy resource sectors.

electricity transmission, oil pipelines). The half-circles represent possible allocation points depending on the market price of the energy form. The rhombus represent stock changes. The links represent flow of energy.

The objective of an overall energy balance is to structure the energy flow (that is to structure the energy network) and to display how final (useful) energy requested by end-users matches numerically with primary energy supplied by producers. Therefore, the construction of an overall energy balance is one major output of an energy analysis. The overall energy balance shows in a coherent accounting framework the stocks and flows of all forms of energy from their origin through to final uses [2]. Energy balances are displayed in overall balance sheets. These sheets record in a logical, systematic and consistent form the flow of energy from the primary energy to the useful energy and the uses per type and category. The balance should cover all commercial flows of energy as well as the non-commercial sources (see section 2.3.1.1.2).

2.3.1.1 Construction of the overall energy balance

2.3.1.1.1 Energy volume assessment

Energy is normally not consumed in the same form it is produced. There are one or more conversions which not only change the form but also the energy content and along with a conversion process conversion losses are occurring. However, with the aid of conversion coefficients (see Appendix B) it is possible to transfer data of original energy units on the basis of their net calorific value into a common unit, so that aggregations and allocation operations may be performed. The Joule is the reference unit internationally agreed upon to be used in overall energy balance sheets.

The definition of a conversion coefficient raises particular difficulties for electrical energy. Each form of energy has its own specific nature and is difficult to be directly or fully substituted. The most common and accepted approach to treat nuclear-based (and in a similar way hydro-based) electricity in an energy balance is to express the electricity produced in terms of the primary energy that would be needed if the same amount of electricity would be generated in a conventional thermal power station using fossil fuels (e.g. with a heat rate of 10 MJ(th)/kW.h(e)).

2.3.1.1.2 Overall energy balance sheet

Overall energy balance sheets have a matrix format of which the columns display the different energy sources used and the rows the energy transactions.

The overall energy balance sheet is made up of three principal parts:

- the <u>supply</u> section,
- the <u>conversion</u> section, and
- the <u>consumption</u> section.

Table 2.3.1 displays the overall balance sheet in the case of Brazil and is meant to illustrate the following descriptive sections.

TABLE 2.3.1. BRAZIL: ENERGY BALANCE, 1985 [8]

Unit: 10**3 toe

Primary Energy

		Petro-leum	Natural Gas	Steam Coal	Metal-lurgical Coal	Uranium U308	Hydro-power	Fire-wood	Sugar Cane	Other Primary Energy	Total Primary Energy
Supply	Production	27492	4987	2572	886	992	51694	31004	22653	660	142940
	Imports	27422			5838						33260
	Stock Variations			416	134	-992					-442
	Total Supply	54914	4987	2988	6858	0	51694	31004	22653	660	175758
	Exports										0
	Non-utilized		-1456								-1456
	Re-injection		-781								-781
	Gross Domestic Supply	54914	2750	2988	6858	0	51694	31004	22653	660	173521
											0
Trans-formation Centers	Total Transformation	-54580	-764	-980	-6804	0	-51694	-12527	-22653	-622	-150624
	Petrol. Refineries	-54580									-54580
	Natural Gas Plants		-609								-609
	Gasification Plants		-155	-9							-164
	Cooking Plants				-6804						-6804
	Nuclear Cycle										0
	Publ. Util. Power Plant			-950			-50812	-1			-51763
	Self. Prod. Power Plant			-21			-882	-60		-570	-1533
	Charcoal Plants							-12466			-12466
	Distilleries								-22653	-52	-22705
	Other Transformation										0
	Losses in distrib./stocks			-515	-63						-578
	Adjustments	-334	328	2	9			-2			3
		0	2314	1495	0	0	0	18475	0	38	22322
Final Consumption	Final Consumption	0	2314	1495	0	0	0	18475	0	38	22322
	Final Non Energy Consump.		615								615
	Final Energy Consumption	0	1699	1495	0	0	0	18475	0	38	21707
	Energy Sector		830								830
	Residential							11232			11232
	Commercial							112			112
	Public							30			30
	Agriculture							3117			3117
	Transport Total	0	0	13	0	0	0	1	0	0	14
	Highways										0
	Railroads			13				1			14
	Air Transp.										0
	Waterways										0
	Industry Total	0	869	1482	0	0	0	3983	0	38	6372
	Cement		6	985				4		38	1033
	Pig Iron, Steel		204	30							234
	Ferro Alloys										0
	Mining		60	18							78
	Non-ferrous							12			12
	Chemical		524	165				59			748
	Food & Beverages		9	107				1533			1649
	Textiles			5				133			138
	Paper & Pulp		15	132				740			887
	Ceramic		23	16				1076			1115
	Others		28	24				426			478
	Unidentified Consump.										0
											0

TABLE 2.3.1. (cont.)

Unit: 10**3 TOE

Secondary Energy

		Diesel Oil	Fuel Oil	Gasoline	LPG	Naphta	Kerosene	Gas	Coke	Uranium contain. in U02	Electricity	Charcoal	Ethyl Alcohol	Sugar cane Bagasse	Other Second. Energy	Non Energy Products	Total Second. Energy	Grand Total
Supply	Production																0	142940
	Imports	362	218	162	527	33	37		66		806				72	134	2417	35677
	Stock Variations	210	-335	-28	-497	424	-222		-30	1734			-1265		14	-509	-504	-946
	Total Supply	572	-117	134	30	457	-185	0	36	1734	806	0	-1265	0	86	-375	1913	177671
	Exports	-1184	-2241	-3668	-45		-772				-1	-2	-249			-192	-8354	-8354
	Non-utilized							-33						-1212	-344		-1589	-3045
	Re-injection																0	-781
	Gross Domestic Supply	-612	-2358	-3534	-15	457	-957	-33	36	1734	805	-2	-1514	-1212	-258	-567	-8030	165491
Transformation Centers	Total Transformation	16925	10972	9338	3983	4052	3183	1581	4878	-1734	55954	6103	7840	12078	2339	5086	142578	-8046
	Petroleum Refineries	17246	11583	8791	3191	5088	3183								2024	3130	54236	-344
	Natural Gas Plants			127	481	1											609	0
	Gasification Plants					-183		317									134	-30
	Cooking Plants							1264	4878						315		6457	-347
	Nuclear Cycle																0	0
	Publ Util. Power Plant	-324	-339							-1734	53412						51015	-748
	Self Prod. Power Plant	-83	-272								2542			-834			1353	-180
	Charcoal Plants											6103					6103	-6363
	Distilleries												7840	12912		1953	22705	0
	Other Transformation	86		420	311	-854										3	-34	-34
	Losses in dist./stocks							-24	-49		-6159	-610	-212				-7054	-7632
	Adjustments	1	-1	-2	1			1	-24			1	2	1		1	-19	-16
		16314	8613	5802	3969	4509	2226	1525	4841	0	50600	5492	6116	10867	2081	4520	127475	149797
Final Consumption	Final Consumption	16314	8613	5802	3969	4509	2226	1525	4841	0	50600	5492	6116	10867	2081	4520	127475	
	Final non Energy Cons.					4509							565	3299	372	4520	13265	13880
	Final Energy Consumpt.	16314	8613	5802	3969	0	2226	1525	4841	0	50600	5492	5551	7568	1709	0	114210	134917
	Energy Sector	343	1390		13		5	319			1547			4059	1300		8976	9806
	Residential				3547		190	155			9464	473					13829	25061
	Commercial	155	71		184			47			5373	3					5833	5945
	Public	110	65		16		1	6			4181	3					4382	4412
	Agriculture	2437	23								1310						3770	6887
	Transport total	12348	1640	5802	0	0	1882	0	0	0	328	0	5551	0	0	0	27551	27565
	Highways	11279		5748									5551				22578	22578
	Railroads	570	2								328						900	914
	Air transp.			54			1882										1936	1936
	Waterways	499	1638														2137	2137
	Industry total	921	5424	0	209	0	109	998	4841	0	28397	5013	0	3509	409	0	49830	55202
	Cement	27	83				2				712	709					1533	2566
	Pig Iron, Steel	51	464		45		14	912	4726		3416	3726			65		13419	13653
	Ferro Alloys								27		1208	411					1646	1646
	Mining	195	549		3		9				1625	38					2419	2497
	Non-ferrous		230		15			21	10		5359	120			297		6052	6064
	Chemicals	250	1657		93		6				3966	6			36		6014	6762
	Food & Beverages	143	571		14		11	14			2864			3509			7126	8775
	Textiles	2	283		4		4	3			1696	3					1995	2133
	Paper & Pulp	11	305		3		3	1			1942						2265	3152
	Ceramic	3	137		23			7			916						1086	2201
	Others	239	1145		9		60	40	78		4693				11		6275	5753
	Unidentified Consum.						39										39	39

a) The supply section

The supply section deals with the provision of primary and, for domestic purposes non-available or non-usable, secondary (or intermediate) energy sources and covers:

- net production of primary energies (commercial and non-commercial),
- exports of primary and secondary sources,
- imports of primary and secondary sources,
- bunkers of secondary sources, and
- stock of primary and secondary sources.

Net production of energy considers only that part of energy extraction that will enter the production chain. Natural gas being flared during oil extraction or re-injected for secondary recovery of crude oil, is not considered in this respect. However, in cases that the amount of flared gas is known, reference should be made in order to consider this energy potential in planning activities before new energy resources are tapped.

Conventional understanding of the terms bunkers refers to the provision of fuels for international shipping and aviation as both are viewed as energy consumption taking place outside national borders and not contributing to domestic activities. (Quite often the energy consumed by military uses is also accounted for in this section.) The term stock (or storage) describes the fuel keeping, voluntary or mandatory, that on the one hand has to be undertaken in order to counterbalance unexpected disruptions of fuel supply and which on the other hand occurs when energy products are difficult to market in the amount of their availability.

In the overall energy balance sheet, the supply section is completed by a row that provides at once the information of all primary energy forms available within the borders of the country for further usage and that sums up all secondary energy sources which are not available or not used for domestic purposes.

b) The conversion section

The conversion section of the balance sheet shows the facilities that process primary energy forms into a convenient form for the user, the energy forms that leave the energy system and are used as feedstock for non-energy purposes, and the conversion and distribution losses occurring during the transformation processes and during the dissemination of the derived energy forms.

This section can be composed of the following elements:

- Transformation facilities: Coal industry (coke-oven plants, coking plant, ...)
  Gas industry
  Oil industry (refineries, ...)
  Public-power plants
  Autogeneration of electricity by industries
  Others

- Consumption by energy producing industries
- Losses in conversion, transport and distribution
- Non-energy uses

The transformation section in the energy balance is completed by a row identifying the amount of final energy available for the consumer.

c) The consumption section

The consumption section finally displays the dissemination of fuels per consuming category. The most aggregate form clusters the consuming categories into industry, transport, households, agriculture and commerce. Further refinement of the categories may disaggregate the industrial sector according to energy intensive products for example into: iron and basic steel industries, non ferrous metal basic industries, chemical industry, mining and quarrying, construction materials, food industries and others. A disaggregation of the transportation sector according to the mode of transportation may lead to the sub-groups: road, rail, air, waterway and pipeline transport.

2.3.2 Improvements of the overall energy balance concept

2.3.2.1 Integrated energy balance

The Integrated Energy Balance (IEB) sheet opens up new measurement categories for resources and useful energy. The IEB is a means of describing step by step the complex set of energy chains which extends from resources to use and which is defined by the primary energy, final energy, useful energy sequence.

The IEB sheet endeavours to take into account certain aspects, such as production losses, quantities produced and not used, amounts reinjected into the strata, transformation plant for fuelwood, biomass, etc., which are important to developing countries. It defines an accounting framework within which these various headings have place.

Energy resources and reserves are considered in the IEB for commercial energies and a similar diagram for the non-commercials ones.

As useful energy can be explained as the difference between final energy and the losses occurring during final consumption, useful energy becomes an extension of primary energy and final energy, thus completing downstream the energy chain. The consideration of useful energy in the balance sheet facilitates the analysis of substitutions among energy sources as well as the analysis of the (overall) efficiency of the equipment used in the final energy stage [4].

Table 2.3.2 displays the Integrated Energy Balance for Argentina in the year 1980.

As in the usual type of balance sheet, the construction of the IEB presumes the definition of rules and conventions that are used in the overall balance accounting sheet.

TABLE 2.3.2. ARGENTINA: INTEGRATED ENERGY BALANCE, 1980 (1000 t oil equivalent)

Unit: 10**3 TOE

		Natural Gas	Petro-leum	Mineral Coal	Uran. U308	Fire-wood	Biomass Resid.	Hydro Power	Wind	Solar	Geo-thermal	Energy Crops	Total Primary Energy
Primary Energy Balance	Production	12801	24995	386	3602	1108	7128	4067	280				54367
	Imports	1939	2213										4152
	Exports												0
	Non-utilized	-3121					-6000						-9121
	Losses	-293											-293
	Stock Variations		-662		-2676								-3338
	Re-injection	-440											-440
	Total Supply	11326	26546	386	926	1108	1128	4067	280	0	0	0	45767
	Intermed. Consumption	-9965	-26459	-386	-926	-423	-74	-4067	0	0	0	0	-42300
	Final Consumption	1361	87	0	0	685	1054	0	280	0	0	0	3467
Primary Transfor-mation Centers	Natural Gas Treatment	-9965	-81										-10046
	Oil Refineries		-26378										-26378
	Coal Treatment			-386									-386
	Charcoal Plants					-423							-423
	Alcohol Distilleries												0
	Biogas Plants												0
	Nuclear Cycle				-926								-926
	Geothermal Treatment												0
	Subtotal	-9965	-26459	-386	-926	-423	0	0	0	0	0	0	-38159
Secondary Transfor-mation Centers	Gas Mining												0
	Petrochem. Refinery												0
	Cooking Oven												0
	Blast Furnaces												0
	Pub. Util. Power Plant								-4040				-4040
	Self Prod. Power Plant							-74	-27				-101
	Sub Total	0	0	0	0	0	0	-74	-4067	0	0	0	-4141

TABLE 2.3.2. (cont.)

Unit: 10**3 TOE

		Dry Gas	Network Gas	Liqu. Petrol. Gas	Refinery Gas	Naphta from Refin.	Aviat. Gasol.	Gasoline	Kerosene	Jet Fuel	Diesel Oil	Fuel Oil	Petrol. Coke	Commer. Coal	Coke	Coke-Oven-Gas	Blast Furnace Gas	Nuclear Fuels	Charcoal	Elect. Power	Non-energy Prod.	Total Second. Energy	Losses
Primary Transformation Centers	Natural Gas Treatment	8705		445				84														9234	372
	Oil Refineries			277	539	435	21	5174	640	803	7533	8062	649								983	25116	1262
	Coal Treatment													297								297	89
	Charcoal Plants																		239			239	184
	Alcohol Distilleries																					0	
	Biogas Plants																					0	
	Nuclear Cycle																	643				643	283
	Geothermal Treatment																					0	
	Subtotal	8705	0	722	539	435	21	5258	640	803	7533	8062	649	297	0	0	0	643	239	0	983	35529	2190
Secondary Transformation Centers	Gas Mining	-8705	8773	-62	-6	-435																-435	
	Petrochem. Refinery		-114	-25	-38			179	-33												448	417	18
	Cooking Oven												-8	-569	355	113			-1		34	-76	76
	Blast Furnaces														-128		158		-30			0	
	Pub. Util. Power Plant		-1948								-698	-2336		-241				-671		3068		-2826	6866
	Self Prod. Power Plant		-411								-249	-441	-11			-15	-16			347		-796	897
	Sub Total	-8705	6300	-87	-44	-435	0	179	-33	0	-947	-2777	-19	-810	227	98	142	-671	-31	3415	482	-3716	7857
Secondary Energy Balance	Production	8705	8773	722	539	435	21	5437	640	803	7533	8062	649	297	355	113	158	643	239	3415	1465	49004	
	Imports			338				209	83		13			639	44					2	22	1350	
	Exports										-218	-1124	-244								-22	-1608	
	Non-utilized				-8																	-8	
	Losses		-553		-12		-4		-9	-45	-62			-81			-3		-20	-431		-1220	
	Stock Variations			34			1	-51	-11	-21	-128	578	-172	119	28			28	-14			391	
	Re-injection																					0	
	Total Supply	8705	8220	1094	519	435	18	5595	703	737	7138	7516	233	974	427	113	155	671	205	2986	1465	47909	
	Intermed. Consumption	-8705	-2473	-87	-44	-435			-33		-947	-2777	-19	-810	-128	-15	-16	-671	-31			-17191	
	Final Consumption	0	5747	1007	475	0	18	5595	670	737	6191	4739	214	164	299	98	139	0	174	2986	1465	30718	

TABLE 2.3.2. (cont.)

Unit: 10**3 TOE

		Natural Gas	Petroleum	Mineral Coal	Uranium	Fuelwood	Biomass Resid.	Hydro Power	Wind	Solar	Geothermal	Energy Crops	Total Primary Energy	Dry Gas	Network Gas	Liqu. Petrol. Gas	Refinery Gas
Balance of Net Energy Consumption by Sources	Total Net Consumption	1361	87	0	0	685	1054	0	280	0	0	0	3467	0	5747	1007	475
	Own Consumption	-1361	-87										-1448	0	-364	-10	-471
	Final Consumption	0	0	0	0	685	1054	0	280	0	0	0	2019	0	5383	997	4
	Non-Energy Consumption												0				
	Total Energy Consump.	0	0	0	0	685	1054	0	280	0	0	0	2019	0	5383	997	4
	Urban Domestic												0				
	Rural Domestic												0				
	Total Domestic	0	0	0	0	441	96	0	14	0	0	0	551		1799	959	
	Rural Production					3	1		266				270				
	Mining												0				
	Industry					211	957						1168		2949	4	4
	Construction												0				
	Transport					7							7				
	Services					23							23		635	34	

	Naphta from Refin.	Aviat. Gasol.	Gasoline	Kerosene	Jet Fuel	Diesel Oil	Fuel Oil	Petrol. Coke	Commer. Coal	Coke	Coke-Oven-Gas	Blast Furnace Gas	Nuclear Fuels	Charcoal	Elect. Power	Non-energy Prod.	Total Second. Energy	Global Totals
Total Net Consumption	0	18	5595	670	737	6191	4739	214	164	299	98	139	0	174	2986	1465	30718	34185
Own Consumption			-17	-11	-8	-268	-1721	-97	-67		-7	-91		-1	-106		-3239	-4687
Final Consumption	0	18	5578	659	729	5923	3018	117	97	299	91	48	0	173	2880	1465	27479	29498
Non-Energy Consumption								-50		-44						-1465	-1559	-1559
Total Energy Consump.	0	18	5578	659	729	5923	3018	67	97	255	91	48	0	173	2880	0	25920	27939
Urban Domestic																	0	0
Rural Domestic																	0	0
Total Domestic			25	656		39								164	766		4408	4959
Rural Production			35			1409									83		1527	1797
Mining																	0	0
Industry				3		50	2133	67	97	255	91	48		9	1490		7200	8368
Construction																	0	0
Transport		18	5518		729	4288	748								22		11323	11330
Services						137	137								519		1462	1485

2.3.2.2 Reference energy system

The Reference Energy System (RES) visualizes in an extensive flow diagram the path of each energy commodity from its origin through each transformation process until the stage of final energy consumption. The system indicates a reference conversion process that contains all information used in the overall energy balance sheet and associates additionally efficiencies of reference technologies used to accomplish the energy conversion. The major advantage of the RES is that losses in conversion and utilization are explicitly shown at each stage for each energy chain. The RES serves as a structured data base with which it is possible to examine the effects of specific policies, typically short-term or supply-demand related [16]. A RES is displayed in Figure 2.3.2 for the case of Nigeria.

Values in Mtoe

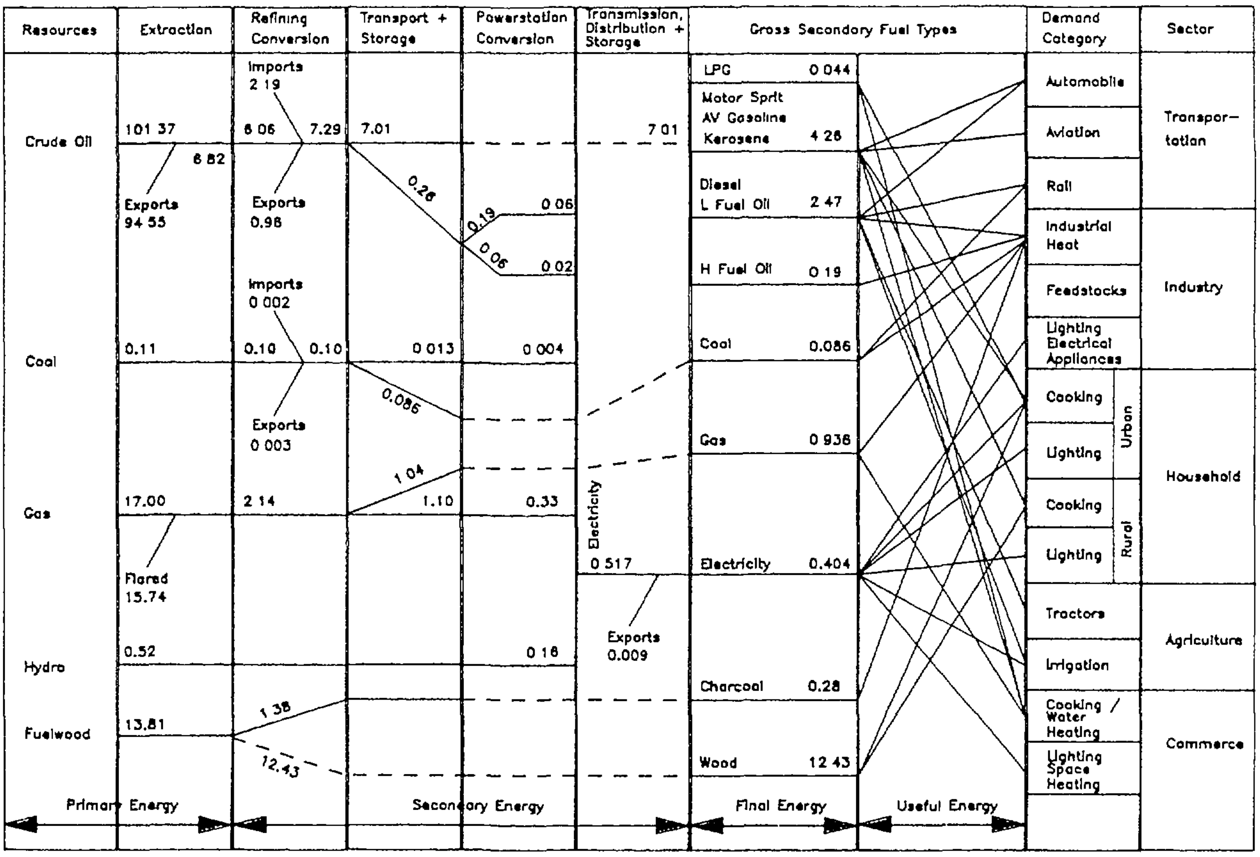

FIG.2.3.2. Nigeria: Reference Energy System, 1980.

2.4 Energy demand diagnosis

2.4.1 Concept of energy diagnosis

Although the construction of a balance sheet is an essential, preliminary stage it is not enough to fully describe an energy system and indicate its main characteristics. However detailed the balance sheet may be, it does not show all the date needed to clarify questions which arise or interpret phenomena observed, i.e. it does not provide information on the operation of the system.

A methodological framework can be elaborated so that the full significance of all information is brought out and more systematic thought can be given to what the analysis of an energy system should entail, in the energy consumption and the production modes, in the working of the energy sector and in its relationship with other economic sectors.

Energy diagnosis should be understood as a method of structured investigation whose aim is to identify the energy system's most important characteristics and establish a synthesis so as to be in the position to judge its working conditions [4]. The presentation of numerical results as well as the construction of tables can not always present the system under study sufficiently. This is not due solely to insufficient data but rather to the absence of a framework in which these data could be positioned and related to each other. This framework must be large enough to cover all the relationships between energy and the various components of the economic and social system.

Although diagnosis is mainly concerned with the present situation, explained by an analysis of the past, it is also oriented towards the future. It must isolate the conditions required for a more favourable situation (action variables, margins of freedom) so that any interventions in the development in the future system are made advisedly. The diagnosis forms part of the planning process which itself attempts to orientate previously observed trends in a direction in agreement with development objectives expressed in the preferences of the various actors in economic and social life [4].

The energy diagnosis of a country or region cannot be complete until all aspects that determine the system have been considered and until it is possible to formulate opinions on the working of the system. But that is going outside the domain of methods because such a comprehensive solution can only be envisaged using concrete examples. It must be emphasized that all diagnosis is necessarily dated, that it is related to a given period of time and must be periodically updated if it is to keep up with the evolution of the energy system.

In the following discussion, specific areas are addressed that are not covered by an energy balance but in the energy diagnosis.

2.4.2 Analysis of influence on energy demand by final user

It has been said that the energy system is embedded and linked with other different systems. In fact, it is the final consumer whose consumption behaviour is influenced by the different systems. The energy demand diagnosis endeavours to analyze the relationship of consumption groups and the different systems in order to get to know the driving factors of energy demand.

Some energy demand driving factors, mostly macro-economic and energy supply-technology are only marginally influenced by final users. On the other hand, there are factors, predominantly socio-economical ones, that are sensible to consumer's behaviour. Table 2.4.1 qualitatively hints consumer's possibilities to influence economic, socio-economic, and technical parameters that are driving forces in energy consumption. This exercise of influence by the final user can be limited or significant depending on the specific cases.

TABLE 2.4.1. EXERCISE OF INFLUENCE BY FINAL USER

Economic and Socio-economic parameters	Technical parameters	Exercise of influence by final user
Retail price structure Posted prices Subsidies and/or taxes Operating and/or capital cost of transformation centers Lifetime of transformation centers and facilities	Electric Power Station – Load factor – Capacity factor – Thermal eficiency – Fuel type consumption – System losses Refinery – Capacity – Structure – System losses	Limited
Households – Rooms per unit – Number of people per family – Number of occupied units – Demand for warm water – Food intake Transportation – Passenger's preferred mode of transport – Number of passengers per transportation mode – Average amount of kilometers driven by passenger and per vehicle – Average amount of kilometers of goods transported per vehicle	Households – Insulation coefficient – capacity of appliances Transportation – Specific energy consumption per passenger transported – Specfic energy consumption per good transported – Average consumption of fuel per vehicle Agriculture – Average consumption of fuel per type of machinery (tractors, pumps, etc.)	Significant

2.4.3 Energy substitution aspects

Energy substitution is the synonym for the interchange of energy forms that render a similar energy service to the consumer (e.g. kerosene by electricity for lighting purposes). The energy substitution must be carefully analyzed because it can contribute to modify the growth rate of consumption of fuels. That implies different economic consequences in the future for consumers and countries. Energy substitution will result from decisions taken by different actors, considering only impacts on the demand side at four levels:

- government policies [9],
- prices,
- producers of secondary energy (however, not considered in the context of this guidebook),
- consumers of final energy [10]. The commercial and non-commercial aspects of fuels constitute a potential amount of substitutions.

At the stage of final energy demand, substitutions of energy forms are to be related to their availability and price. Useful energy needs and final energy forms are both considered relevant to the efficiency of conversion devices for energy substitution.

The demand of final energy is relatively easy to determine in countries with an open and free market and with sufficient offer of goods. However, the substitution of energy can be limited in countries whose economy is concerned with shortage. Substitution of final energy forms, with its impacts on primary energy and conversion facilities, will depend on the economic situation of the countries because the interchange of energy forms requires sometimes new capital investment.

The substitutions of energy forms will be triggered by multidriving factors. These driving factors will essentially be acting at the four levels of decision previously mentioned. The main determinants which will lead or will impose substitutions must be investigated in the frame of each country. Some examples, however, can be given:

- for the final energy consumer:
    - to counteract an unacceptable price increase of an energy commodity,
    - to maintain the energy service but at lower energy costs through introduction of a new equipment with better efficiency or by using cheaper fuels,
    - to increase the energy service maintaining the energy costs through introduction of a new equipment with better efficiency.
- for the government:
    - to reduce energy import dependencies,
    - to support development of a diversified energy demand system in order to avoid too heavy reliance on one kind of fuel,
    - to eliminate negative effects on the environment, e.g. acid rains on forests.

Substitutions which took place in the past in developed countries (currently under way in developing countries) concerned substitutions of non-commercial energies with commercial ones. In developed countries, a further substitution process, namely the replacement of "dirty" energy forms (e.g. predominantly coal and oil) by "clean" energy forms (mainly electricity), takes place and leads to changes in the energy consumption mix [11], [12]. Another impact of energy substitution is related to the improvement of efficiency values of conversion processes delivering useful energy from final energy.

In the following sections, the aspects of energy substitutions in different energy consuming sectors will be addressed.

2.4.3.1 Industry

The industrial sector uses fuel as heat and mechanical source as well as feedstock. Only the substitutions for heat production purposes will be considered here. Thus it is useful to forecast and to promote the use of the most efficient energy sources on both technical and economical grounds [13].

Before the first oil price shock, industries including the secondary energies producers, largely drew benefits from low cost oil.

But right after, the situation was radically changed for big oil consuming industries for which the cost of oil represents up to 40% of the total production costs. This is generally the case for iron and steel, and the lesser for pulp and paper, cement, brick and metal melting industries and for those involved in chemical, food and drink productions. In 1984-85, because of coal prices were nearly 50% below those of oil, energy substitution concerned the use of coal instead of oil in those cases where there were no constraints for coal storage or handling. However, in the future the industrial sector may use coal, electricity, nuclear and geothermal steam for processes and motive power purposes and other specific uses related essentially to lighting, space and water heating. For the last uses, energy substitutions carried out will not differ from those for the main activities. In addition to the economic advantage of energy substitution, the fuel switching often leads to energy 'savings' in the order of one-third to half of the total energy consumed.

Two ways can be considered for energy substitution, the first one relying on the use of another energy form only and the second one on the change of process, that is changing the consuming technology and, eventually, along with it, the energy form that can be used more efficiently. In the case of substitution of final energies the comparison of the consumption cannot be made on the basis of their equivalent thermal energies but in terms of primary energies. For example when electricity is considered, it can be assumed that the production of 1 kW.h(e) requires about 2.5 kW.h(th) of primary energy given the efficiency of 40% for a thermal power plant. In this condition a new industrial process using electricity is less energy intensive if it consumes less than 1/2.5 times of equivalent fossil primary energy consumed by the previous process.

The effects of energy substitution on energy conservation and financial savings will be shown for two cases. Although both examples reflect cases that occurred in a developed country, their principles are also valid for developing countries.

The first example relates to a saw-mill factory which intended to double its production but faced the question how the additional demand for energy could be balanced. The status-quo situation was characterized by the fact that 50% of the power needed was supplied by the national utility, and the remaining share through autogeneration by an oil generator. The company's energetic, technologic and economic survey led to the decision to install a new power generating system using the wood waste produced by the saw-mill itself. The final energy bill could be diminished by 800 MW.h(e) per year, equivalent to 175 toe per year. The total investment cost including all expenses were equivalent to the expenses for electricity that would have to be taken from the national utility instead (that is without substitution) for a period of three years.

The second example presents the case of a company specialized in the transformation of rolled iron into bars and punched pieces used for car manufacturing. In order to decrease its energy expenditures, the industrial oven, fed by a blended heavy and light oil, was replaced by an electrical induction heating device. The substitution diminished the energy consumption from previously 5000 kW.h(th) per ton of iron to a mean consumption of 565 kW.h(e). The investment costs of the new device were recovered after 1.5 years.

As substitutions yield profit in a number of cases, energy substitution must be taken into account to forecast final energy demand.

It is not always economically acceptable to switch permanently from one energy source to another. It can be advantageous to have the possibility of consuming alternatively one or two final energies. This concept for example is used for alternative stand-by electricity systems in case of outage of the main supplying utility.

2.4.3.2 Residential and Commercial

Both sectors are remarkable consumers of both non-commercial and commercial energy. Owing to the constantly reducing supply of non-commercial energies together with the increasing income levels and the emerging accelerated demand for commercial energies both serving the same purpose, the analysis of energy substitution possibilities becomes imperative.

In developing countries the energy demand is more related to elementary needs of people than it is in developed ones. Other determinants of useful energy are related to the geographical and climatic location of countries. The substitutions of energy forms will be greatly dependent on the social cost-benefit analysis, the technical characteristics of the introduced appliances, and the price of the equipment and the commercial fuel. It would be necessary to devote special attention to the importance of the energy market and in particular the energy mix offered to meet the useful energy demand. However, in general it can be stated, that choices of energy forms of the higher income classes are made in accordance with their convenience and availability while the lower income classes will mainly seek cheap fuels. Thus, the increase of income will lead to fuel substitutions from hitherto non-commercial energies to charcoal and kerosene and at the final stage to gas and electricity.

Before giving some practical details about consequences of energy substitution in developing countries, it is necessary to briefly review the incentive actions taken by governments in order to increase the use of certain kinds of energy forms.

Governments can lever prices of energy forms and in that way discourage or favour the consumption of some energy resources. They can also give financial help in direct fund addressing to firms developing new devices, or reduce the income tax of private individuals in order to promote the installation of new systems, i.e. heat pumps, solar devices or to insulate dwellings.

Before the first oil price shock, developed as well as developing countries, both on a different scale, were not as much concerned as presently about the kinds and quantities of energies they were consuming. However, the forecast of energy consumption is becoming now both a challenging matter and a necessity for all countries especially for those seeking growing economic development.

The results of a case study of energy consumption of the residential sector in Tunisia illustrate the above stated, in particular related to the needs of household equipment expressed as a general wish for refrigerator and television [14]. Table 2.4.2 shows the ratio of useful energies to final energies for basic needs in different uses like heating, cooking, and lighting.

Table 2.4.2 displays the important variance of efficiency values of different conversion processes. in general they are lower in rural compared to urban areas. This is essentially linked to the fact that in rural areas, a major part of the energy consumed is non-commercial energy which is used in less efficient devices. Table 2.4.3 gives the percentages of the commercial and non-commercial energy consumption in rural and urban areas.

TABLE 2.4.2. RATIO OF USEFUL ENERGIES TO FINAL ENERGIES IN TUNISIA (including non-commercial fuels) [4]

Conversion Processes	Urban Area	Rural Area
Bread cooking	0.15	0.14
Cooking	0.25	0.21
Water heating (traditional means)	0.31	0.24
Heating	0.63	0.49
Lighting	0.93	0.37

TABLE 2.4.3. PERCENTAGE DISTRIBUTION OF COMMERCIAL AND NON-COMMERCIAL ENERGY CONSUMPTION IN TUNISIA [4]

	Rural Area	Urban Area	Total
Commercial energy	35 % 21 %	65 % 74 %	100 % 40 %
Non-commercial energy	85 % 79 %	15 % 26 %	100 % 60 %
Total	65 % 100 %	35 % 100 %	100 % 100 %

2.4.3.3 Transport

The transportation sector is probably the sector in which substitution of energy forms, predominantly oil, is the most difficult to achieve because the adequacy of the high energy density of petroleum derivatives required in thermal energy combustion engines. Another aspect is related to safety and to the easy transportation and handling of petroleum derivatives. Nevertheless, potential for energy substitution exists in different countries and must be carefully analyzed.

The main experiences in substituting petroleum derivatives by another fuel exist for Brazil where ethanol replaces gasoline at an increasing rate in the energy consumption pattern. The remarkable success resulting from the implementation of the PROALCOOL programme is reflected by the share of ethanol in total final energy consumption during the period 1970-85. From a level of 1.1% in 1970 it jumped to 20.1% in 1985 (the respective totals are: 13 million toe in 1970 and 26.7 million in 1985). However, the PROALCOOL programme faces also reservations by many sectors of the society arguing issues like:

- the cost of alcohol and the subsidies involved,
- the worsening effect on the income distribution,
- the replacement of food crops by sugar cane in the vicinity of populated centers,
- the removal of soil nutrients by the sugar cane [15].

Despite these obstacles, such programmes might attract countries with fertile unused land that can produce ethanol which is not competitive with gasoline at prevailing crude oil prices and by that, can contribute to reduce or avoid oil import expenditure and saving hard currencies. The uses of liquified petroleum gases and liquified natural gas are being developed. For the specific collective urban transportation, the use of batteries could provide a satisfactory solution on both standpoints environmental pollution and oil import financial load depending on the electrical generating system. This is an incentive for a predominantly hydropower system. At the present time, however, the trend is to develop engines using less gasoline per kilometer. This solution is presently more attractive than to develop new types of engines.

Furthermore, it should be noted that there are other substitution options in the transportation sector, different from energy forms, which are concerned predominantly with the mode of transportation. Such substitution options include for example land vs. water and road vs. rail transport. More detail on this subject has been devoted to already in Section 2.2.2.5.

2.4.4 Regional considerations

In the previous sections, emphasis has been put on the energy demand analysis on the national level. However, it might be that for certain cases that the approach to energy demand evaluation from a different angle is more appropriate as the peculiarities of the country under study are more adequately represented. In such cases a classification into regions of the country under study might be opportune. Generally speaking, such grouping can be undertaken with or without incorporation of the neighbouring countries. In both cases, criteria for such a disaggregation could be politically, socially, environmentally, or topographically based. The energy demand configuration and magnitude is different in all such cases.

The objectives of disaggregated energy plans have to be consistent with the national goals in energy (demand) planning so that recommended energy strategies valid for the partial system are not counteracting the overall strategies.

Three perspectives for regional subdivision will be highlighted as follows.

2.4.4.1 Homogeneous environmental regions

The most important characteristica of this classification criterion concern the non-existence of national boundaries and the natural environment. Elements of a natural environment are defined as [4]:

- climate-air (temperature, rainfall, humidity, etc.),
- abiotic substrate (geological structure, soils, relief, surface and underground water, etc.), and
- abiotic substrate (vegetation, fauna, etc.).

These elements interact with each other and characterize the homogeneous region within an energy system to be studied, independently of the political or administrative divisions.

Regions for which a classification according to geographical characteristics might be appropriate, could be:

- Archipelagoes, such as Indonesia and the Philippines,
- Partially deserted countries, such as Algeria, Libya, China and Sahalian zone countries, and
- Sub-continental countries like India, Brazil and China.

2.4.4.2 Rural urban dichotomy

A peculiarity of developing countries is the different energy consumption pattern, predominantly of the household sector, in rural and urban areas. Energy distribution and consumption is biased with commercial energy hardly flowing to rural areas although in some countries the majority of people live there. Owing to the differences in the income structure of rural and urban inhabitants, energy consumption inequalities are not merely in the amount but also in the form [16].

Different forms of energy, e.g. electricity, oil, coal, fuelwood and charcoal, have different costs, and the poorer the sector of the society, the cheaper the energy source it uses. The poorest sector of developing countries uses mainly non-commercial energy for their survival. This non-commercial energy can be gathered at zero private cost but at high environmental cost through deforestation, soil erosion, desertification, loss of nutrients and valuable fodder in the case of burning dung and agricultural residues. In addition, this behaviour could cause damage to health if, for example, poorly designed indoor stoves are used [16].

Energy demand analysis for rural areas is a rather difficult task due to the meager availability of data on energy consumption patterns in the household sector or agriculture, transport and rural industry sector. The good assessment of non-commercial energy consumption structure is of great importance in the formulation of appropriate and environmentally sound approaches to solve rural energy problems. Environmentally sound approaches are viewed as processes that are directed towards:

- satisfaction of basic human needs in order to achieve reduction of inequalities within a country,
- indigenous self-reliance through social participation and control, and
- harmony with the environment.

Within the rural village, most energy needs may be classified as one of the basic requirements: heat, light, shaft and other mechanical power, fertilizer and communication. The five basic requirements fulfill all the village/household end-use energy needs, ranging from cooking to plowing, grinding and transport [17]. Thus, in rural areas exist a 'permanent suppressed demand' for commercial energy carriers and, related herewith, the satisfaction of basic needs. This energy demand is marginally income driven but more influenced by socio-economic and technical parameters. However, with industrialization progressively penetrating in rural areas, the household income will become the major driving force of energy demand.

Urban household consumption profiles are primarily a function of household income. These profiles include both energy consumed directly and energy as it appears in the form of material consumable and delivered services. They also contain information on the modes used to deliver the services or goods and the functional relationship between delivery modes, end use devices, and energy form specifications and total energy inputs. In urban as well as in rural households it is the relationship between energy end-use and basic human requirements which are of particular interest to the analyst [18].

2.4.4.3 Rural electrification

A country has some obligations from a socio-economic point of view, to bring electricity to remote areas so that the development and industrialization processes in such areas will be adequately supported [16]. Rural electrification, however, is rather difficult to achieve as most people live in small villages with low standard of living. Thus from the supplier point of view, any electrification programme for rural areas implies high investment and running costs for installation and operation of an adequate power supply unit and electricity grid. Another important characteristic of rural areas is the low load factor (see section 3.3). All that adds to the electricity unit costs charged to the final customer, which he might, due to low income, not be able to afford unless subsidies are given.

The electricity demand in rural areas is primarily driven by the energizing of pumps, the need for lighting and the mechanization of rural small industries. However, the required data base on energy demand and the respective economic and socio-economic determinants are often insufficiently existent in developing countries.

With regard to the actual energy consumption pattern and the human activities related herewith, the most appropriate data collection process bases on interviews tailored for rural surveys. The future electricity demand might be assumed on the basis of socio-economic requirements being best supported by electricity, the amount of suppressed demand and new markets created by usage of electrical appliances (radio, television, air-cooler, etc.).

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Chapter 3

ELECTRIC LOAD CURVE ANALYSIS

Energy demand analysis encompasses the entire spectrum of the energy mix at the consumers' level and treats each energy form as an equally important component of this pattern, which means that no accentuation is given to one energy form per se. However, in the view of the IAEA, a special consideration should be devoted to the electricity sector as electricity usage opens a variety of applications to satisfy socio-economic and economic needs and its provision exposes the ecosystem to a minimum of encumbrances, especially in the case of nuclear energy. Along with the analysis of electricity demand has to come the analysis of how demand is to be 'steered' in order to minimize oscillations, that is to study the load variation for defined time intervals. The following sections are addressed to the analysis of the electric load curve and also introduce other important concepts for electric power systems, such as reliability, reserve margins, etc. The effects of policy decisions, such as load management and tariffs on the load curve, are also discussed in the final sections of this Chapter. For a more detailed description of these aspects the reader is referred to the publications in [1] to [5].

3.1 Definition of terms

3.1.1 Load and load duration curves

An Electric Load Curve shows the amount of power (load) needed to be delivered at a given point on an electric system, plotted against chronological time of occurrence. The total electricity consumed during the specified time is obtained by integrating the area under the load curve. The measure generally used for electricity is the kilowatt hour (kW.h).

A System Load Curve is the total of the independent loads of various classes of customers: residential, industrial and commercial. Each class of customers exhibits different load characteristics which are determined by lifestyle, economic development, climate and operating pattern.

Daily Load Curves (or weekly, monthly, etc.) may differ between days of the week (months of a year, etc.) and from season to season. Figure 3.1.1 displays as an illustrative example two daily load curves for the island of Java.

A Load Duration Curve is a curve that describes the duration of time in % or in hours during which particular load levels occur or are exceeded. It shows the cumulative frequency distribution of system loads. The energy consumed during the period of time is represented by the area below the curve. The shape of the curve will directly affect the mix and operation of generating capacity. As the peak is reduced, the need in predominantly thermal systems for turbine peaking units decreases and, as a result, oil and/or gas consumption decreases. As the load duration curve flattens out, better use can be made of base load thermal plants [2].

Figure 3.1.2 displays a typical load duration curve. System load is shown in power units (MW(e)) on the vertical axis and in hours or in percentage on the horizontal axis. The period involved can be a year, a three or four month period, a month or even a week with corresponding annual, seasonal, monthly or weekly load duration curves.

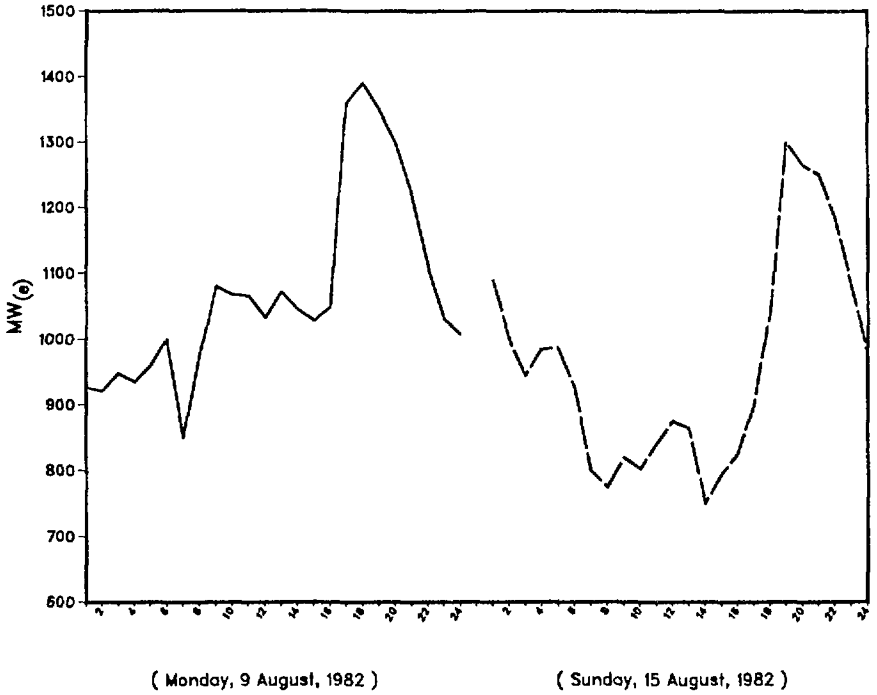

FIG.3.1.1. Two daily load curves for the Island of Java, August 9 and 15, 1982.

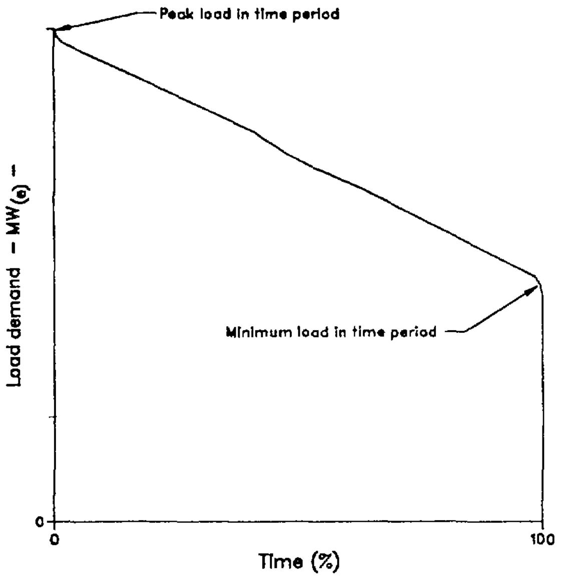

FIG.3.1.2. Load duration curve.

3.1.2 Peak load

Load is the amount of power needed to be delivered at a given point to an electrical system. Peak Load is the maximum load in a certain period of time. Peaks may vary considerably depending on the day of the week, month of the year and the season. Sometimes a pattern in the variability of weekdays peaks may be observed (higher peaks during the first part of the week due to industrial customer's operational pattern); or in some other cases the day of the peak is due to random occurrences, such as weather, or even the television broadcast of a national/international sporting event.

3.1.3 Load factor

The Load Factor is the ratio of average load to peak load. The higher the load factor the flatter the load curve. A very low load factor reflects a high peak in relationship to the average power over the period of interest.

Load factors vary greatly from system to system depending on climate, mix of customers, saturation of electrical devices, etc. A few examples of annual load factors for selected utilities are:

- Ontario Hydro	0.68
- Hydro-Quebec	0.60
- Florida Light and Power	0.54
- Tennessee Valley Authority	0.66
- Federal Republic of Germany	0.69

3.1.4 Diversity and losses

Diversity is the ratio of the sum of (individually metered) customer loads at the time of system peak load and the sum of the peak loads of all the customers regardless of whether they coincide with the time of system's peak or not. Since individual customers may experience their peak loads at diverse times, the sum of their peak loads will be greater than the sum of their actual loads at the time of the system peak and therefore the value for diversity is always less than or equal to one.

$$\text{Diversity} = \sum_{i=1}^{n} \text{cust}(i,T) \;/\; \sum_{i=1}^{n} \text{Max}[\text{cust}(i,t)] \leq 1 \qquad (3.1)$$

where

cust(i)	represents the loads of individual customers in kW
t	the 1-hour time intervals over evaluated period
T	the time of the 1-hour system peak
n	number of customers.

Diversity is a function of the timing of end-use utilization and is affected by social patterns and weather conditions. Note that the concept of diversity is used when considering peak and not energy demand.

Losses are the electrical losses incurred in transmitting and distributing the electricity from the generating stations' terminals to the customers. This is evaluated by taking the difference between the system demands measured at the generating stations and the measured customers loads.

Both power and energy losses have two components: a load dependent and a load independent part. The load dependent losses are proportional to the electrical current squared and are caused by the resistance of wires, transformers, etc. The load independent part is caused by such factors as magnetic losses of transformers and is proportional to the voltage squared.

Recent studies indicate that transmission and distribution losses in an efficient system should be between 4% and 8% of total annual generation and between 7% and 12% of peak power. Higher losses could be due to technical problems in system components, metering errors, billing and collection problems, theft and statistical error, and long transmission lines.

3.1.5 Reliability

The overall goal of electric system planning is, broadly, to provide a system that adequately meets the demand for electricity at the lowest possible cost. A reliable generation system usually has enough reserve capacity to keep random equipment failures (outages) from causing service interruptions to customers.

In the context of overall systems, the supply of reliable electric service to customers depends not only on the generating system but also on transmission and distribution systems. Customers may consider a utility system reliable only if it supplies them with the quantity and quality of electricity they desire when they require it. Therefore, all three of the subsystems (generation, transmission, distribution), which can fail for any number of reasons and at any time, are critical. Although distribution outages are usually the most frequent, they are local in nature and normally of short duration with minimal cost impact to the utility. However, generation shortages due to major contingencies or significant deviations in load forecasts affect the entire system and last for long periods of time, with major cost impacts not only to the utility, but also on customers by way of lost production, etc.

Historically, electric utilities have approached generation, transmission and distribution reliability planning as separate and sequential functions, an approach which is due in part to the considerable complexity of evaluating the reliability of each subsystem. Target goals for overall system reliability are typically established on the bases of historical patterns and practices. In several cases, these targets are related to the quantities of unsupplied energy as measured by the frequency of providing reliable supply.

Distribution and transmission reliability also play key roles. In the case where a surplus of energy is available, it is the distribution and transmission systems which act as the weak link in the system. In the case where supply is insufficient, generation reliability may play the pivotal role. The composition of the local infrastructure must be studied to determine where resources should be spent in maintaining or improving reliability.

3.1.6 Installed reserve margin

Reserve Margin is a measure of the installed generating capacity available above the amount nedded to meet the system load requirements. The reserve margin is defined as the difference between the total installed generating system capacity and the annual peak system load, divided by this peak system load, i.e. it is the excess of the installed generating capacity over annual peak load expressed as a fraction (or in percentage) of annual peak load.

For example, a system with a total installed capacity of 11 500 MW(e), and which experiences a peak load of 10 000 MW, has a reserve margin of 15%.

While this deterministic reliability index does not directly reflect system parameters such as generation mix, unit size and forced outage rates, it does provide a reasonable relative estimate of reliability performance when parameters other than reserve margin remain essentially constant.

The generation reliability of power systems will vary greatly depending on their size, interconnections, type of capacity mix, variations in unit sizes, age of plant and transmission network. A large, predominantly hydraulic system could have a reserve margin target of around 10% or less whereas a large, interconnected predominantly thermal system with similar reliability have an installed reserve margin target of around 25%.

Reserve margin criteria has been widely used for electric system expansion planning and has been lately combined with probabilistic techniques, such as loss of load probability (mainly valid for thermal systems), expected unserved energy, probability of positive margin, loss of energy probability, etc. [2].

3.2 Characteristics of load curves

3.2.1 Regional load curve analysis

Regional load duration curves are appropriate in a country composed of separate areas having distinct electricity characteristics, such as electricity consumption due to climatic conditions or else, transmission and distribution losses peculiar to a given area, or distinct hydroelectric sub-systems with different hydrological characteristics. In such cases, a regional consideration of the specific problem could provide better indicators for electricity planning purposes than a national level analysis.

Regional load duration curves would also be needed when interconnection between separate regional systems is expected. Regional load duration curves can then be aggregated to obtain the national load curve. Most often, the national curve can be directly obtained by considering all the regions together. Also here, there are diversity of peak loads and the overall peak load of an integrated system is usually smaller than the sum of the peak loads of different subsystems.

3.2.2 Sectoral load curve analysis

Power expansion planning deals with the long term because of the long lead time required for the building and commissioning of power stations. Structural changes in economic activities, will result in changes in daily and seasonal variation in load and, consequently, the shape of the load duration curve will evolve.

The sectoral approach is best suited when considering the differences between economic sectors in terms of the impact on the electricity consumption pattern and, consequently, the load duration curve. In the industrial sector, disaggregation is based on classifying companies according to their size, the nature and capacity of production, and the structure of the electricity end-uses. In the residential sector, numerous socio-economic and regional parameters are taken into consideration to classify households into relevant consumption categories.

The economic prospects of each sector and subsector can be considered individually in determining the respective growth in future electric consumption. Nevertheless, it must be understood that the individual sector scenarios must be consistent with the scenario forecasted for the country as a whole. Section 4.2 discusses this issue further.

3.2.3 Temporal load curve analysis

Seasonal Load Variations

Electric energy demand varies seasonally depending on meteorological changes and/or social and economic activity variations. To estimate this seasonal variation, the time series decomposition technique which will be discussed in Section 4.1 is appropriate.

Load Variation according to the Type of Weekday

Economic activities and the related electricity demand are not the same for all weekdays. Therefore, a division of weekdays into several day types has to be undertaken. One distinguishes between normal working days and holidays and intermediate days, e.g. Saturdays in the Western World, Fridays in the Islamic World.

The hourly load curve is determined for every day type and every sector. As an illustrative example, Figure 3.2.1 gives the overall hourly load curves of an electric system in Algeria normalized with respect to a normal working day (Monday to Wednesday); Saturday is a variant of the working day.

Hourly Load Variation of a Working Day

To facilitate load calculations, the hourly load variation during a working day is normalized as follows: for every hour of the same working day, the ratio between load during a specific hour and the average daily load is generated.

A great diversity in the shapes of hourly load curves are observed when comparing economic sectors. Figure 3.2.2 illustrates two peculiar curves with extreme shapes. The first reflects the load in the

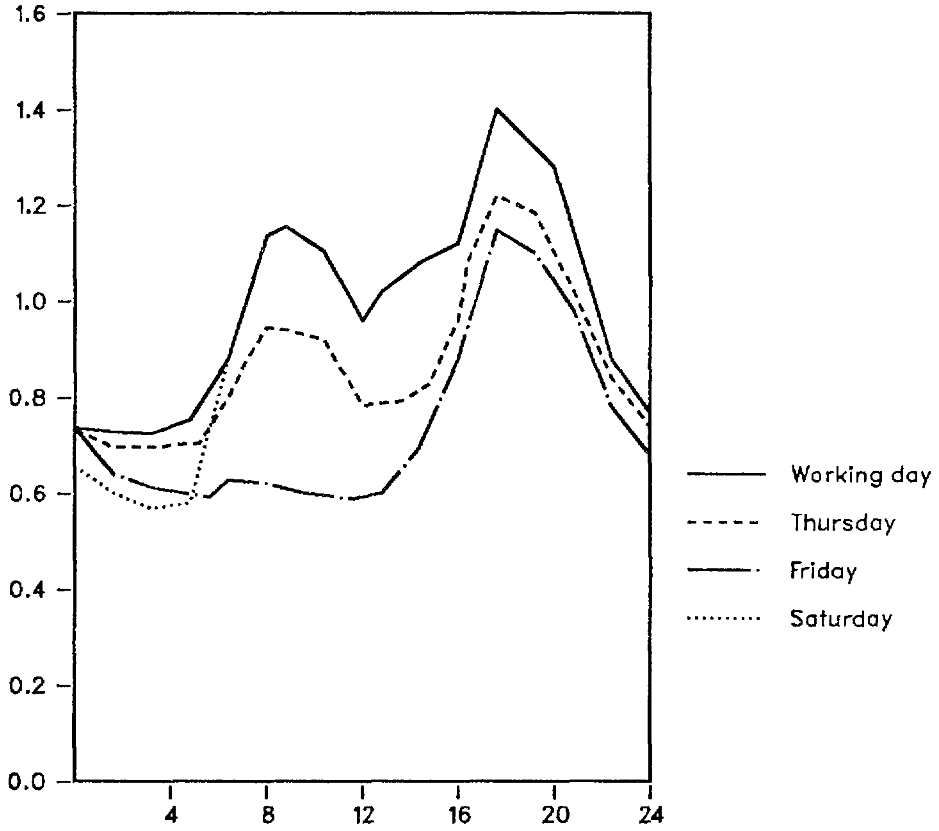

FIG. 3.2.1. Algeria, load variation curve according to weekday type — normalized curve for the working day.

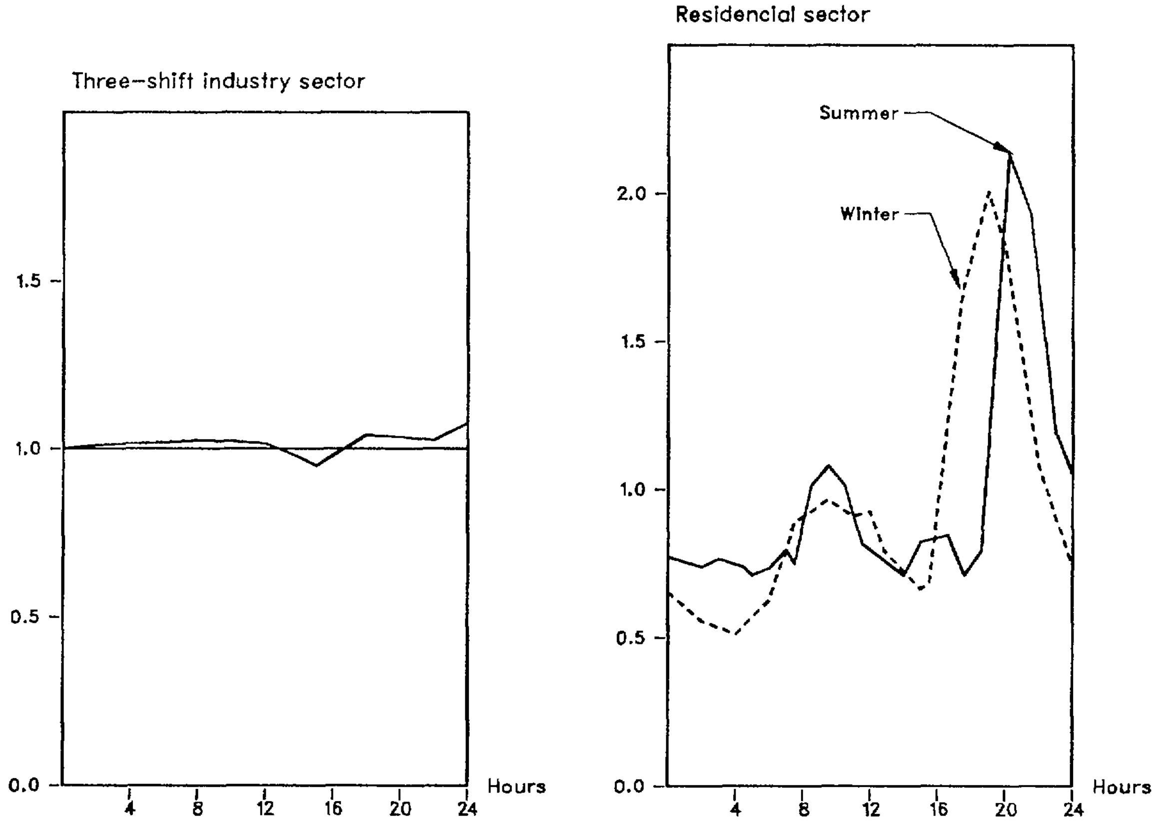

FIG. 3.2.2. Algeria, hourly load variation of a working day (normalized curve).

heavy industry sector where plants run continuously. The second shows the load of the household sector in Algeria in both, summer and winter. The very sharp right peak is due to lighting.

3.3 Load management and electric power pricing

Electric power pricing policy in most countries has been determined mainly on the basis of financial and accounting criteria, e.g., raising sufficient sales revenues to meet operating expenses and debt service requirements while providing a reasonable contribution towards the capital required for future power system expansion [4]. But electricity pricing can also be used for demand management purposes, presupposing that demand responds to price changes to some extent.

Any modification of demand for electricity may require changes in the supply system developed to meet it. Therefore, it is essential to consider the demand-supply system as a whole and to seek how to control the total system in order to reach the optimal benefit for the community.

A customer tends to choose the least cost solution, for instance to select one kind of energy among others, or a more or less efficient way of using electricity, which requires different levels of investment. Accordingly, if electricity prices reflect the costs of supply, the customer will choose the least cost solution for the community by choosing the least cost solution for himself. Therefore, the customer should be informed through tariffs and incentives about the costs in the supply system resulting from changes in his consumption pattern.

As a matter of fact, the overall optimization of the system can be represented as a closed loop mechanism as suggested in Figure 3.3.1.

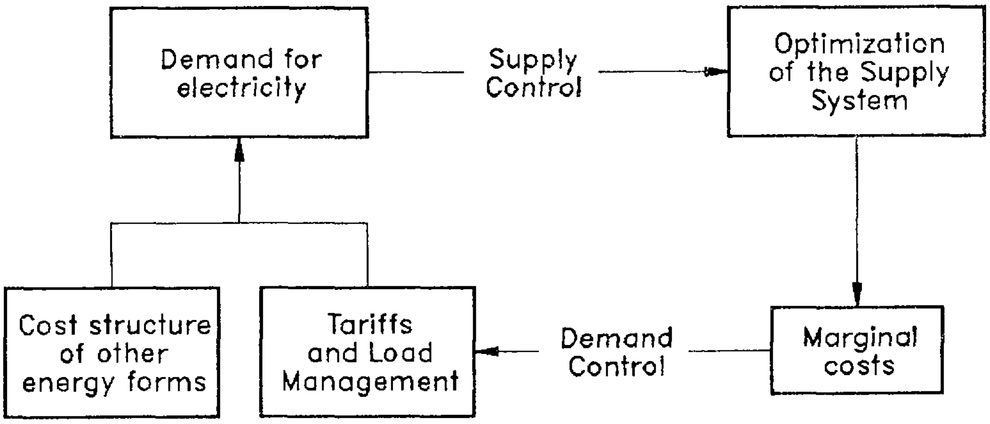

FIG.3.3.1. Overall optimization of the electricity system.

There are basically two measures that may control electricity demand:

- load management, and
- electric power tariffs.

It should be pointed out that to be successful the measure to be taken must be accepted by the final consumer. Additionally, the system must be large enough and should consist of different consumer types so as to allow the use of the time dependent behaviour of the different clients. For example, assume that a potential user is carrying out or receiving an important social need during the evening time. In this case it makes no sense to the consumer if the evening lighting peak is cut by switching off, as it would leave him in a similar position as before electrification that is without the possibility of satisfying his need.

3.3.1 Load management [2]

Load management refers to any means by which load curves may be made flatter in shape, i.e. increasing the system load factor. The benefits of this activity are:

- for a given level of energy production, greater utilization of generating equipment will result in lower capital investment, and
- less need to generate energy with high fuel cost peaking generation since the peaks are reduced.

There are several methods of increasing the system load factor of thermal systems:

- Differentiated rates could be introduced to encourage off-peak loads, perhaps facilitated by user-supplied energy storage devices. Similarly, seasonal usage may also be controlled by incentive rates.
- Staggered working hours and holidays for factories and offices can lower peak loads.
- Automatic "time control of utilization" equipment can be used to restrict power consumption during periods of anticipated peak loads. The utility can offer a financial incentive to customers in return for being able to install a device that allows the utility to turn off that device for a certain period every hour. This is mostly used in heating processes with storage capacity.
- The utility itself may want to consider developing pumped storage hydro-electric plants if the topography permits such an installation. This scheme can be very effective in flattening the load curves, by, in effect, storing some power at off-peak hours that will be used during peak hours.

3.3.2 Electric power tariff

A quite sensitive issue, especially in developing countries, is the establishment of an economically and socially "justified" electricity pricing system for the economic sectors of the country. Tariffs cannot reflect all cost differences or the cost of all kinds of supply. Simplification of the tariff structure is required if one wants to avoid excessive complexity in tariffs and high metering costs.

The final user expects the utility to supply: - electric generation and transmission capacity, and - electrical energy, and these at any time upon consumer's requirements.

The costs associated with electric power generating plants and systems are of two categories:

- capital investment cost, expressed in $/kW (the $ is used for convenience, although any currency can be used) of installed capacity, which denotes the capital outlay necessary to build a power plant, and

- power generation costs, expressed in mills/kW.h (a mill is defined as 1/1000 of a monetary account) of generation, that represent the total cost of generating capacity. Power generation costs consist of the cost associated with the initial capital investment in a power plant (fixed investment charges), fuel costs, and operation and maintenance (O&M) costs. These costs can be divided into two broad categories: fixed costs and variable costs [2].

In addition to the electric generation costs, the power tariff should include another component so that sufficient revenues would be accumulated in due time in order to meet future financial requirements.

The development of a tariff structure that considers appropriately both electric generation costs and future financial requirements, based solely on a "fixed" pricing system, i.e. by charging a lump sum per month independent of the real consumption, or a "variable" system, i.e. by charging on a unit basis only, would provoke negative effects of different kind on both sides, consumers as well as suppliers. (A fixed pricing system for example could lead to unstable and unexpected high electricity demands insufficient to recover utilities economics; a variable pricing system could put much pressure on low income groups).

Therefore the objectives of a fair tariff have to be:

- easy measurement of electric parameters (power, energy, reactive power, ...) keeping in mind to minimize the costs of calibration and electric meters,
- credibility and understanding by the consumer,
- straightforward rules for use (i.e. not 10 different tariff periods)
- true reflection of the economic costs of energy production
- affordability by all the different members of the society

A two component tariff may provide the answer to the above requirements:

- a fixed amount depending on the time of consumption,
- a variable amount depending on the energy consumed.

In order to raise the load factor during the periods of low demand it is appropriate to include one or two different tariff periods.

Especially different tariff periods, that try to tackle adequately different electricity consumption levels, should be handled carefully. If too many time periods are included, it has the effect that just before the tariff switches to the low cost period the load will decrease as final consumer intends to save money by switching off electric power until the lower tariff comes into operation. And just after the switching time t_s the load will increase very fast. This effect is illustrated in Figure 3.3.2.

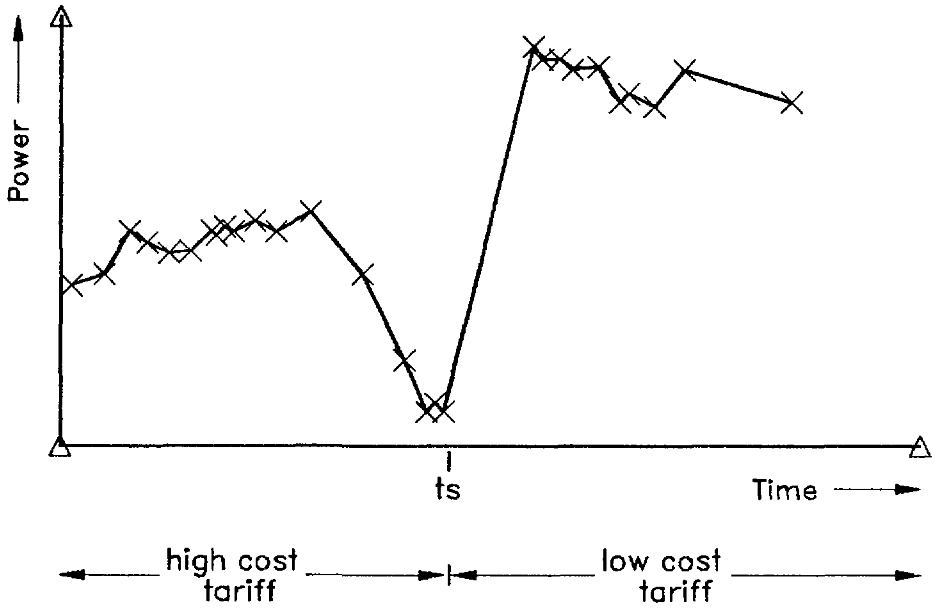

FIG. 3.3.2. Effect of tariff switch on load.

There obviously would be some conflicts between the needs of the consumer and the supplier on an electricity pricing system. The Long-Run Marginal Costs (LRMC) approach to price setting is said to have the analytical rigor and inherent flexibility to provide a tariff structure [3] which is responsive to both consumer and supplier requests. The reader is referred to the references on this subject.

The LRMC based tariffs are concerned with the amount of future resources used or saved by the consumer. Supply costs increase if existing consumers increase their demand or if new consumers are connected to the system. Therefore, prices which act as a signal to consumers should be calculated on the basis of the true economic present and future value of the production factors.

In order to preserve the economic efficiency of the tariff, departure from marginal costs could be rather important for energy supply to customers having the lowest price elasticity but should be small for customers with high price elasticity. A reason for deviating from the strict LRMC approach arises in cases when prices elsewhere in the economy do not reflect marginal costs, especially in the case of substitutes and complements of electric power. For example, in rural areas alternative energy may be available cheaply in the form of subsidized kerosene and/or firewood. In this case, pricing electricity below LRMC may be justified, to prevent excessive use of the alternative forms of energy. Also, pricing electricity at LRMC does not normally result in exactly the revenues needed by the utility (e.g. because of historical costs that are different from current costs).

In order to give some understanding of the economics of peak load energy pricing, a brief discussion on the subject is presented subsequently.

For electricity generation, the marginal opportunity cost of supply consists of segments that represent base-load and peaking generating units, ordered from the least costly to the most costly. A cost curve is illustrated in Figure 3.3.3. If the marginal cost curve MOC is compared with the electricity demand curve for all hours in the year D_d, the optimal electricity price is P_d and the optimal quantity of electricity generation is Q_d. A generation system with capacity Q_d is only large enough to meet base-load requirements but not peak load requirements. To insure that peak demand will be met, the demand for electricity must be represented separately for the peak and off-peak hours. Using the peak demand curve D_{pk} results in the price P_{pk} for electricity generated during the peak period. Price P_{pk} is sufficient to ensure enough capacity to meet peak load requirements [1,5].

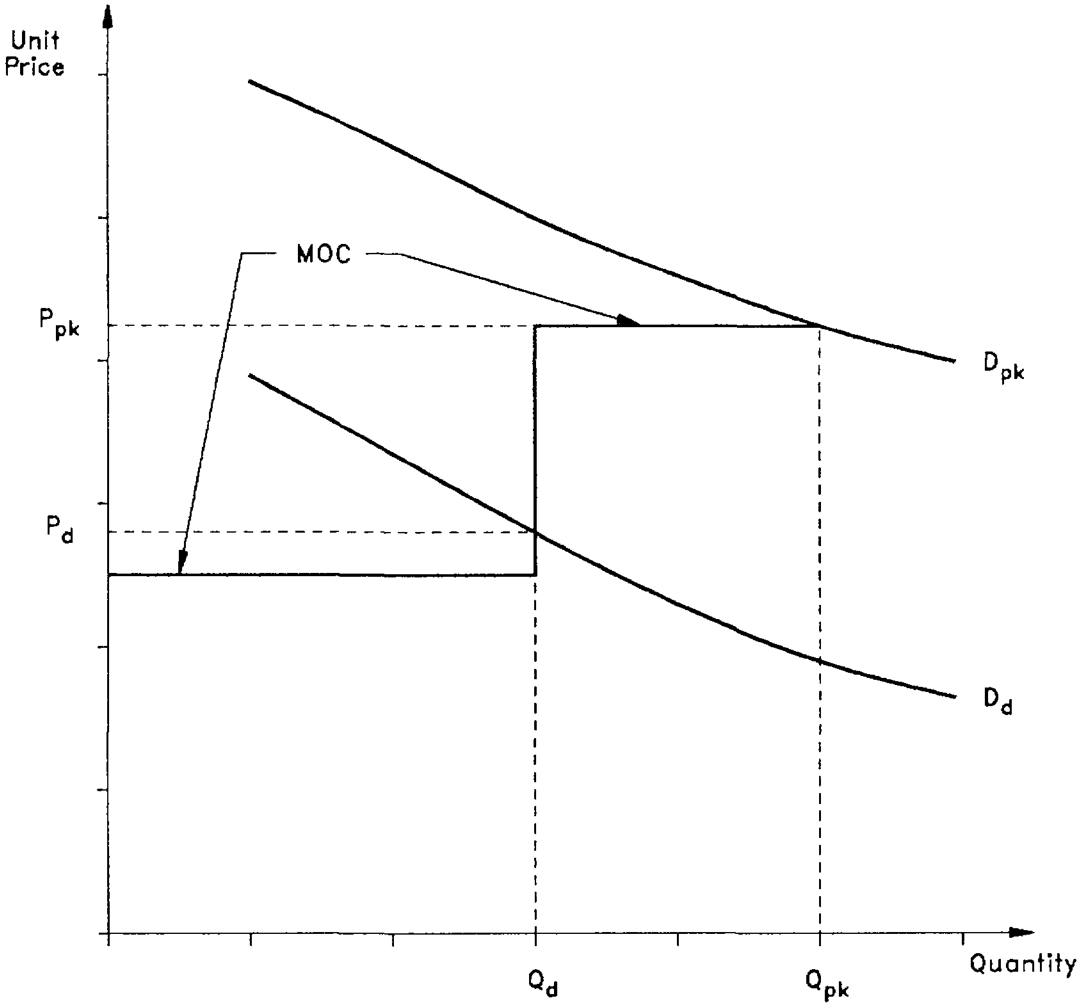

FIG.3.3.3. Peak load pricing.

Figure 3.3.4 illustrates the shortcoming of pricing electricity at average cost rather than at marginal opportunity cost, when marginal costs are rising. Pricing electricity at average cost results in a larger peak demand Q_{av} and a larger system capacity than is optimal, Q_{pk}. This results in wasted resources that could be devoted to more productive uses elsewhere in the economy.

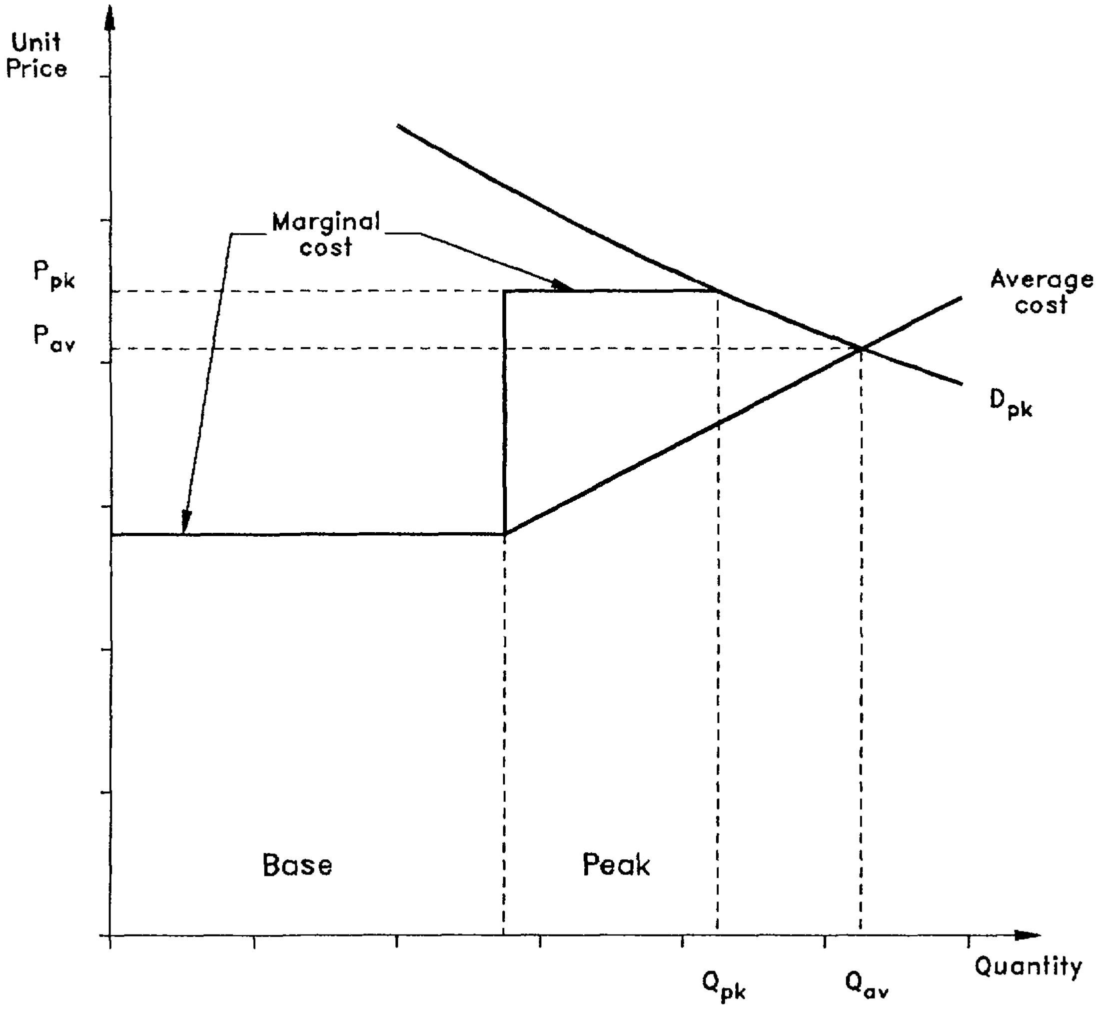

FIG. 3.3.4. Capacities based on average and marginal costs.

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Chapter 4

ENERGY AND ELECTRICITY DEMAND FORECASTING

The actual choice of tool to be used for energy and electricity demand forecasting is an important consideration for the forecaster. Several methodologies are available and the forecaster should be aware of the costs and benefits of each one based on his own particular situation and needs. Criteria to be considered include: the purpose of the forecast, data availability, forecasting horizon and cost of implementation. These criteria are stressed in the following sections while presenting different approaches and methods for energy and electricity demand forecasting. The particular problems related to data retrieval to conduct this forecasting are highlighted at the end of the Chapter.

4.1 Approaches and methods for energy demand forecasting

4.1.1 Approaches to forecasting [1]

4.1.1.1 The global versus the disaggregated approach

The global and disaggregated approach has been introduced already in section 1.3.1. However, it seems appropriate at this place to return to these approaches to recall the problem addressed in selecting an appropriate energy demand forecasting approach.

The global approach may be best characterized by the following: Economics treat energy demand much like demand for any other good or service, by exploring the price/quantity relationship. For an economy as a whole, total energy demand is seen as a function of population, income and energy prices. Energy price differentials are introduced in cases where energy demand should be distinguished in different individual fuels [2].

For the purpose of projecting future energy demand, it is important to keep in mind that the parameters of the function identified before have been estimated from past data and that the historical relationship between economic activity and energy demand may not remain constant in the future. This is a particularly important consideration for developing countries where rapid development may drastically alter the determinants of energy consumption. Of course, the Gross National Product (the macro-economic parameter to measure the 'wealth' of a country) of a country will naturally grow as population increases. More workers, no matter how well or poorly they are employed will result in income. Whether this growth in income keeps pace with population development, depends on the productivity of labour and how wealth is distributed in a society [3].

The disaggregated approach looks into the fine structure of the sectors of an economy. By that the planner is in the position to analyze specific features of the country and to come up with detailed strategies tailored to the needs of the country. This approach enables to define the links between energy requirements and socio-economic needs on the basis of variables generally measured in physical terms. Since energy demand is specific to sector and process, the opportunities for energy conservation and substitution can be examined properly in a detailed approach. Cost and price variables are taken also into account in particular for cases that tackle energy substitutions effects between various energy sources in order to meet a given use.

While the global approach provides general information useful for policy directions, the disaggregated approach provides further detailed information and guidelines useful for formulating specific energy policies. In many cases both type of approaches should be carried out jointly and in parallel as they may supplement each other.

In anticipation of Section 4.1.2 (Methods to forecasting), it may be said that for energy demand forecasting using the global approach often the econometric method is favoured (Section 4.1.2.2) whereas for the disaggregated approach use is made of the simulation method (Section 4.1.2.3).

4.1.1.2 The projective versus the normative approach

The energy demand pattern of the future can be approached in two different ways:

- projective, or
- normative.

The former approach is primarily concerned with predicting the future while the latter is concerned with how a desired future can be attained.

The projective forecasting approach is based on the historical interrelationship of the energy consumption driving forces and their respective evolution over time and derives the future energy demand pattern by extending the traditional pattern.

The normative forecasting approach formulates a priori targets of different nature, e.g. social, environmental, economic, etc., for a future point in time and their possible relation to energy demand and derives the future energy demand pattern by establishing a consistent framework around them. However, determining the future energy demand pattern without referring to the ways of how to achieve the desired targets is a fruitless exercise. Therefore, normative forecasting is related with a backcasting procedure [4] which implies the backward operation from the future end-point to the starting point of the exercise in order to determine the policies required to reach that future point.

Projective and normative forecasting approaches are not exclusive approaches and any forecasting activity may include both elements. For example, an electric utility may engage in forecasting with the intent of finding out what electricity prices should be charged to promote economic efficiency. However, because the electric utility cannot control the demand of every consumer in every sector of the economy, it must engage in projective forecasting to predict the aggregate response of consumers to alternative electricity pricing structures, which it may consider implementing. In the sense that the utility would like to know the "best" prices to charge in the future, but must also forecast how electricity demand will change in response to prices, this forecasting problem has both normative and projective aspects.

Projective and normative forecasting approach can span a wide range of results of the possible energy demand pattern in the future. In order to narrow the border lines and derive at a limited number of computational exercises, scenarios are introduced.

4.1.2 Methods of forecasting

Forecasting can be of [5]:
- descriptive, or
- quantitative nature.

Descriptive methods are subjective and intuitive, depending on the judgment and expertise of the forecaster rather than on statistical and mathematical relationships. The use of the expert judgment is sometimes the best possibility for a quick and recent estimate.

Quantitative forecasting is based on mathematical and statistical tools and models. This type of method seems appropriate when the scope of the analysis and the interrelationships of the parameters involved are rather complex, numerical results within confidence intervals are required and a sound basis for decision-making activities is necessary. Results are best obtainable when the following two conditions exist:

- a reliable, sufficient and consistent data base, and

- a quantifiable mathematical formulation of the past and future relationships among the factors under study.

Quantitative methods can be further categorized as:

- time series methods,
- econometric or causal methods, and
- simulation methods.

4.1.2.1 Time series method

Simple curve fitting

The distinguishing feature of time series analysis is the assumption that all the information required to produce the forecast is contained in the series itself. No attempt is made to bring in other explanatory variables. This is both the most convenient feature and the most serious shortcoming of time series analysis.

On the one hand, data collection requirements are the simplest of any forecasting method used. This translates into minimum time requirements to prepare a forecast, ease of understanding, and lower cost than the other forecasting techniques.

On the other hand, the accuracy of the forecast depends critically on the stability of historical trends and patterns. Simple extrapolation of past trends may produce grossly incorrect results if some events disturb the historical behaviour of the series. Blindly fitting a model to data without due consideration to extraordinary or one of a kind events can lead to unreasonable forecasting results.

Because of the underlying assumption, that historical patterns will continue into the future, time series analysis is more likely to be reasonably accurate in the short-term.

The simplest time serie model uses the trend technique as forecasting tool. The statistical methods are easy to implement sincethey require no other data than the time series of the variable to be projected itself. If E denotes the energy consumption, t the time and a, b and c fitting parameters, possible relationships are:

- Straight line: $E = a + b * t$ (4.1)
- Quadratic curve: $E = a + b * t + c * t^2$ (4.2)
- Logarithmic curve: $E = a * \log(b * t)$ (4.3)

The use of time as the sole explicative parameter implies that this variable combines the possible effects of both technical progress and economic change.

Exponential smoothing

When the variable to be forecast is very unstable, it is sometimes useful to smooth some of this variation in order to get at the underlying trend. This can be accomplished by transforming the original time series data by means of a filter capable of reducing this unwanted variation. As an example, an exponentially decreasing set of weights (which gives more weight to more recent values) can be assigned to the variables to be forecast. This technique can be represented by the following algorithm:

$$E(t+1) = a*E(t) + a(1-a)*E(t-1) + a(1-a)^2*E(t-2) + \ldots \qquad (4.4)$$

$$0<a<1$$

Decomposition

Most time series exhibit a trend, or long-term movement, as well as regular variations around this trend. For example, electricity consumption is lower on weekends than on weekdays; crude oil stock piling is higher in summer than in winter. The essence of decomposition is to isolate these various components so that their effects can be considered separately. The forecaster can, therefore, obtain a better handle on what is an overall increase (decrease) in demand and what is only a temporary fluctuation. Time series data can be decomposed into systematic (seasonal, cyclical, trend) and a non-systematic random component. One decomposition method which is widely used is the Census X-11 method [6]. In principle, this method decomposes original sales data in the following way:

- Seasonal factors (e.g., high rating loads during winter) are obtained by calculating the ratio of the original data to a moving average.
- Random movements are identified and smoothed.
- Cyclical movements (e.g., business cycle effects) are identified by extracting the seasonal and random factors.

- The underlying trend is obtained by filtering out the above 3 factors.
- The relative importance of each of the above factors can be determined and future behaviour predicted.

Holt-Winters method and Box-Jenkins analysis

More sophisticated versions of exponential smoothing, which make explicit allowance for trend and seasonal patterns in the data, are the Holt-Winters Method and Box-Jenkins Analysis [7].

The Box-Jenkins method can provide the most accurate results for complex time series where the underlying behaviour is not readily apparent. This technique allows the forecaster to follow an iterative procedure to make sequential improvements to his model and thus optimize his forecast.

The Box-Jenkins technique postulates a mixed Auto-Regressive Moving-Average model to be used to explain the bahaviour of the data series to be forecasted.

$$X(t) = \overbrace{O(1)X(t-1) + O(2)X(t-2) + \dots + O(p)X(t-p)}^{\text{auto-regressive}} + \underbrace{e(t) - A(1)e(t-1) - A(2)e(t-2) - \dots - A(q)e(t-q)}_{\text{moving average}} \tag{4.5}$$

where

X(t)	represents the forecast value
X(t-1), ... , X(t-p)	past time series observations
O(1), ... , O(p)	autoregressive coefficients
e(t), ... , e(t-q)	errors between actual and forecast values for past periods
A(1), ... , A(q)	moving average coefficients.

The correlations with past data give a direct indication of which time lags are important and, therefore, what is the seasonality or cyclical behaviour in the data. The next step is to determine if the error terms are randomly distributed. Any correlation in the error terms would indicate that not all seasonality or cyclical behaviour in the data has been picked up, and that terms must be added or changed.

Bayesian forecasting

This method allows the analysts to specify a range of models for the data, rather than a single model, with associated probabilities. As more data becomes available the model parameters and probabilities are updated using a technique known as Kalman Filtering. This method potentially includes both exponential smoothing and Box-Jenkins models as special cases. However, it requires a very high degree of analytical sophistication and experience. A detailed discussion of the application of this technique can be found in [8].

4.1.2.2 Econometric or causal method

Regression (or causal) models are based on the assumption that the behaviour of the variable to be forecast is affected by one or more other factors, represented as independent (or explanatory) variables [9,10,11]. The modelling effort in regression is an attempt to formulate the relationship between the dependent variable, E, and the independent variables, X1,..., Xn.

$$E = f(X1, \ldots, Xn) \qquad (4.6)$$

The measure of quality of the relation between dependent and independent variables requires a knowledge of basic statistical summary statistics such as the regression coefficient, t-statistics, SSEs, etc. (see glossary).

Causal models are superior to time series analysis in that they are valuable in helping to understand why changes in demand occur. This would be very important in the situation where fundamental changes were expected to occur in the causal variables. Since such changes would only have an impact in the longer term, causal methods assume greater importance the longer the time period under consideration. However, there is a cost to gathering information about causality. Firstly, these methods require more time to prepare since data on several variables have to be collected. Secondly, the forecaster must estimate the relationship between the dependent and independent variables and this requires an understanding of the underlying structure of the relationship. The forecaster must then determine forecast values of the independent variables and use these in the estimated relationship to predict future values of the dependent variables. This all adds to the cost of the forecasting exercise.

Multiple regression techniques rely on the specification of a single equation relating the dependent variable to a number of independent ones. For the target year of the study, the independent variables are forecasted and the calculated relationship is applied.

4.1.2.3 Simulation method

Simulation methods (also known as end-use models or process-engineering models) are used to construct in detail the most realistic replica of a system and the interrelation of its various components.

Energy simulation models are engineering oriented models which derive energy demand from a 'bottom up'approach. These models study energy consumption at the detailed and disaggregate level of end-uses such as space heating, lighting and cooking. The interdependencies of variables are captured to simulate the system's structure. In its simplest form, an energy simulation model is a basic accounting model which adds up the demand created in each energy end-use category.

In the case where the real system to be analyzed is at equilibrium or at a fixed point in time, the simulation model is of static nature. In the case that the variable time is inherent in the process, the model is called dynamic. The mathematical formulation of a dynamic simulation model is given by:

$$X(t)=f_t[Z(t), Z(t-1), \ldots, Z(t-n), X(t-1), \ldots, X(t-n)],U \qquad (4.7)$$

with Z indicating the variables specified outside by the user (exogenous),
X the variables calculated by the program itself (endogenous),
U the stochastic disturbance term, and
t the time.

If some or all variables of the above equation are random variables, the simulation method is called stochastic otherwise, it is deterministic. The error term in stochastic simulation methods accounts for measurement errors, or variability from other uncontrolled random elements.

The usefulness of simulation models can best be understood in terms of the historical events which led to their development. Prior to the oil embargo of 1973, even simplistic approaches could be used to capture the steady growth in demand trends. Hence, the detailed nature of the subsequent conservation progress required assessments of demand for specific end uses of energy. Traditional energy demand models are much too aggregate to reflect the impacts of progress that in some cases are specific to end-use by fuel, sector, and geographical area. The traditional models are not capable of analyzing the structural change that many demand options (co-generation, load management, etc.) aim to achieve. Demand forecasts based on end-use methodology are not only capable of providing the needed level of disagregation, but can also incorporate the dynamics of changing energy demand.

As would be expected, data requirements increase significantly with the level of detail and sophistication used by the forecaster. A typical model could easily be based on the order of 8000 assumptions or estimates. Therefore, while a simple simulation accounting model may not pose a large demand on resources, a more realistic model would require significantly more computing capabilities such as increased computer capacity and advanced computational techniques.

The MAED model (Model for Analysis of the Energy Demand) is a simulation model designed by the IAEA to evaluate medium- and long-term demand for energy on the end-use level. This model and its application is presented in detail in Chapter 6 and Appendix A, respectively.

Table 4.1.2 summarizes the attribute of the basic forecasting methods discussed here. Because models differ so greatly with each of these categories, these general attributes may not apply in specific cases. They do, however, point to what one can expect from the majority of these techniques.

4.1.3 Framing factors of appropriate methodologies

A number of general factors and constraints will have a direct impact on the choice of the forecasting tool used, independent of the specific features of the country under study. Some of these factors are:

- forecasting horizon,
- data availability and reliability,
- computational capabilities,
- forecasting cost, and
- time as a constraint.

TABLE 4.1.2. GENERAL CHARACTERISTICS OF FORECASTING METHODS [10]

Characteristics	Time series	Econometric	Simulation
Best forecast horizon	Months to a few years	1 to 10 years	10 to 10 years
Data requirements	Minimal energy/load data only	8 to 12 year time series for several independent variables	Proportional to desired detail of model
Computer requirements	Trivial for trend models; significant for complex models	Moderate – many models can be run on microcomputers	Most models can be run on microcomputers
Specialized skills	Trivial for trend models; significant for complex models	Relatively easy to build models – experience and training needed to detect/solve problems	No specialized training except for optimization models
Suitability for analysis of system shocks/scenarios	Poor	Good for variables explicitly in model	Generally the best method of all

Forecasting horizon

The forecast horizon is particularly crucial. Methods that suit short-term forecasting differ from those for long-term forecasting. A forecast is called short-run (or short-range, in some cases) if it involves statements about the near future. If the statements are regarding a distant future, then the forecast is called long-run. A situation in between will be considered as middle-run. It is apparent from the way these definitions were made that there is no precise definition of what constitutes a short, middle or long-run. This more than anything will depend on the variable to be forecast, type of available data and other specifics of the circumstances. In econometric modelling (see 4.1.2.2), for example, the terms short and long run have generally accepted connotations, although imprecise ones. The short-run generally refers to a time frame in which existing capital stock is assumed to be fixed. The long-run refers to a time frame in which capital stock is assumed to be variable and all eventual adjustments to capital stock are possible.

In energy forecasting, indicative ranges are: short-run 1 - 5 years; middle-run is 5 - 10 years; and long-run is beyond 10 years. For the short-run, time series and/or a blend of autoregressive and causal modelling approaches are used. The periodicity is monthly, although hourly models have been developed for weather correction and load shape analysis purposes.

Short-run forecasting is necessary for rate design, planning of power system operation and distribution facilities, crude oil stock piling and analysis of the impact of short-term marketing programmes. Long-run forecasts are used mainly in planning the means of satisfying future generation and transmission requirements of the electrical system and energy requirements demanded by the society to perform social needs.

Data availability and reliability

Although a given forecasting technique may have attractive theoretical features, it must be noted that quantitative techniques rely on the existence of appropriate data bases. Generally speaking, the amount of data required will increase with the level of sophistication of the model used. For example, when using multiple regression or econometric models, data on several variables must be collected. As the number of explanatory variables increases, so does the size of the data base required.

Further, data must be reasonably accurate and consistent to be useful. Even in countries where detailed data exist, measurement errors or aggregation can cause problems. In some cases, data may not be available or cannot be measured. These difficulties are compounded for countries lacking sound statistical data. The data retrieval problem will be discussed further in Section 4.4.

In terms of data requirement, time-series techniques require the least amount of data. Causal model requirements are generally moderate, depending on the level of detail. Simulation models have the largest data requirement.

Computational capabilities

The forecasting techniques used and the data requirements determine the computational capability. Although very basic models can be satisfied with minimal computer time, more 'realistic' models are more detailed and require significantly more computing capability such as increased computer capacity and familiarity with advanced computational techniques. This translates into investment in computer technology and trained professional staff.

Forecasting cost

Forecasting techniques will vary in their cost for development, implementation and maintenance.

Intensive gathering and manipulating of data, the carrying out of surveys, the establishment of different scenarios, the formulation of a forecasting methodology suitable for the objectives of the country under study, etc., result in significant costs the deeper the matter is penetrated.

The hidden costs of forecasting should also not be overlooked. For example, there are costs of manpower internal to the organization doing the forecast, costs of consultants to gather data (possibly), costs of computer and other hardware (microcomputer and otherwise), costs of training the staff on the use of the software, cost of retraining the staff in the event of staff turnover, cost of preparing the forecast in a form suitable for the presentation to decision makers, etc.

Depending on the forecasting technique used, a trade-off between the cost factor, in terms of money and time, and benefit factor, in terms of accuracy, has to be achieved. As long as the benefits to be gained outweigh the costs, the technique may still be viable. Nevertheless, the bottom line cost factor will make some of these models unsuitable for the forecaster with limited resources.

Time as a constraint

Another constraint may be the time needed to develop and implement a forecast. Simpler models take less time to generate results, while more sophisticated ones will take longer. If there is a time problem, due to the unavailability of manpower or too large a workload, simpler models may be the solution.

4.2 Electrical load curve forecast

The rate at which energy is supplied by the power system (kW.h, MW.h, or GW.h) frequently presents significant variations through the day, the week and the year. Because of these variations, supply costs are higher than they would be if that rate remained constant, since supplying loads higher than the average requires additional investments and entail higher transmission losses and other operating costs. Hence, the analysis and forecast of such load variations pattern, called the load curve, is necessary for operation and planning purposes.

Operating and planning of electrical systems require load curve forecasts given as a function of such factors, that enable the evaluation of possible pattern changes, that are conducive to supply cost reduction either by direct means, such as supply restrictions to specific loads, or by indirect ones, such as rate penalties or incentives.

4.2.1 General features

The electrical load curve forecasting methods presented below should be adequate for any area or any time horizon; they were conceived, however, for the forecasting of the load curves of comparatively developed areas, comprising a considerable number of loads of different classes.

Since both the present volume and this particular set of methodologies are intended for planning purposes and therefore aim at the medium and long-run, some variables that are relevant for daily or weekly forecasts, such as daily temperature, humidity and cloud cover are not considered. These methods require a large data base in terms of electricity demand including typical load curves for different days of the years for individual consumers and for different levels of consumption aggregation.

Depending on the detail level of available data and the time horizon of the studies, different methodologies may be adopted. For long-run studies, the sectoral method is better suited; for the short-run purposes, more simplified criteria, either standard statistical methods, such as Holt-Winters and Box-Jenkins are usually used.

4.2.2 Sectoral method

4.2.2.1 Principles of the sectoral method

The load curve of the total system is a superposition of all individual load curves of the different consumer sectors, e.g. industry, household, manufacturing, etc. The principle of sectoral modelling is to analyze the single consumer sector's load curve. The sectoral load curve can be defined by the annual electricity consumption (in GW.h) and the shape of the load curve. The load curve's shape reflects the behaviour of this particular sector during a given period of time, e.g. a day, week, or month. Thus, the future evolution of the total load curve can be linked to:

- the evolution of the general level of electricity consumption,
- the evolution of the shape of the different sectors in the total electricity consumption, and
- the evolution of the load diagram of any sector.

The general approach is to derive a given day's hourly load values from the respective year's electrical energy demand for a given sector. The process for obtaining the hourly demand for each day from annual energy demand is based on modulation coefficients typical for the particular sector (as illustrated in Figure 4.2.1). Such coefficients

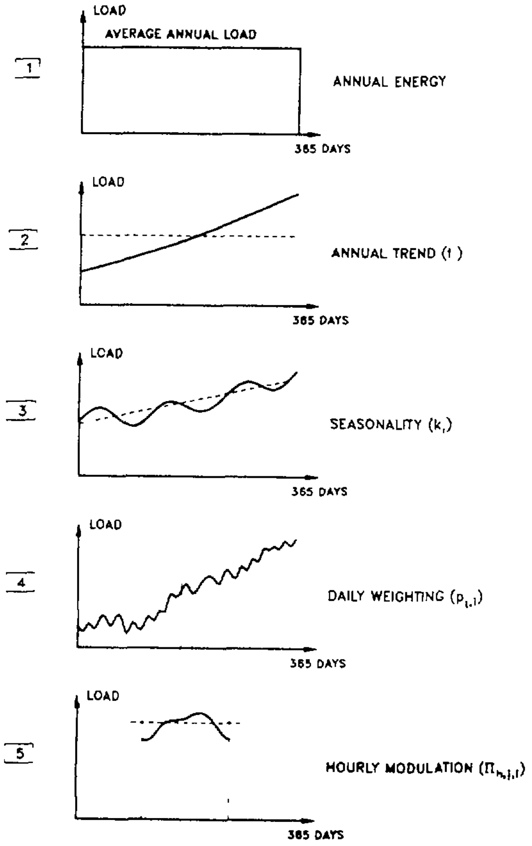


FIG.4.2.1. Step calculation of hourly load.

are determined by means of statistical methods from recorded load curves and also from the sample measurements and studies.

The use of modulation coefficients as derived from recorded load variation patterns is based on the assumption that some inherent patterns, described by such modulation coefficients, remain constant throughout the forecasting period.

4.2.2.2 Selection of the consumer sectors

The adequate selection of consumer sectors is essential for the quality of the results. The model accuracy and the quality of simulation results will depend on this choice. The following requirements should be fulfilled:

- sectors should be homogeneous in terms of their component load curves,
- sectors should be well defined in terms of their load curve coefficients and their share in global annual energy consumption.

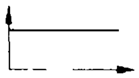
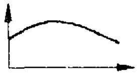
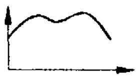
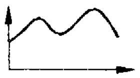
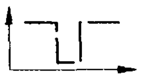
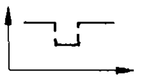
Since one sector is defined as a residual of all other sectors with respect to the global load curves, this sector should be as small as possibly no assumptions can be made regarding its future behaviour.

Sectoral aggregation criteria apply either to a kind of clientele (domestic, professionnal, industrial) or to a kind of usage (premises heating, air conditioning, lighting, etc.) for which the nature of information is in general different and complementary. Due to the fact that a sectoral split based solely on the clientele or the usage basis is difficult to be carried out (the load diagrams of the 'clientele' are hard to apprehend with preciseness, and the annual aggregate consumption of the 'usage' are less well known), in practice the sectoral model may be a compromise of both.

Statistical methods for data analysis such as typology, cluster analysis and automatic classification, provide a compromise between economic characteristics and load curve types. An example provided by statistical methods is the typology for high-voltage loads (supplied at 69 kV and above) presented in Table 4.2.1. This table shows that a major group of industrial consumers (mainly metallurgy), 60.9% of the consumers have a flat demand curve. These consumers are responsible for 74.4% of the total demand of the group [13].

In order to obtain this typology it is necessary to recover consumer's load curves and to set up measurement programmes in order to obtain representative load samples of consumers for which records are not available.

TABLE 4 2 1 BRAZIL, TYPOLOGY OF HIGH VOLTAGE LOADS [22]

ECONOMIC ACTIVITY TYPE	 FLAT			 MODULATED			 OVER-MODULATED			 DOUBLE-PEAK			 HIGH RATE SENSITIVITY			 SMALL RATE SENSITIVITY			TOTAL CONSUMPTION (MWh)
	% OF CONSUMERS	CONSUMPTION		% OF CONSUMERS	CONSUMPTION		% OF CONSUMERS	CONSUMPTION		% OF CONSUMERS	CONSUMPTION		% OF CONSUMERS	CONSUMPTION		% OF CONSUMERS	CONSUMPTION		
		(%)	(MWh)		(%)	(MWh)		(%)	(MWh)		(%)	(MWh)		(%)	(MWh)		(%)	(MWh)	
METALLURGY	60 9	74 4	11992395	5 8	1 1	186201	3 5	0 6	93322	0 0	0 0	–	27 6	23 5	3787233	2 3	0 4	67116	16125267
CEMENT	61 7	54 1	1476785	4 3	3 5	94781	0 0	0 0	–	0 0	0 0	–	31 9	41 4	1130624	2 1	1 0	26569	2728759
CHEMICALS	91 3	95 1	6242144	0 0	0 0	–	0 0	0 0	–	0 0	0 0	–	8 7	4 9	324262	0 0	0 0	–	6566106
TRANSPORT EQUIPMENT	30 4	34 3	585954	21 3	26 7	410476	21 8	21 7	333612	4 3	2 7	40726	8 7	2 8	42637	13 0	7 8	119955	1356360
ELECT & COMUNIC EQUIPMENT	50 9	73 9	214171	20 0	5 6	16445	10 0	5 6	16299	0 0	0 0	–	10 0	9 3	27088	10 0	6 2	18044	292047
NONMETAL MINERAL PRODUCTS	66 7	70 5	335460	22 2	13 6	65010	0 0	0 0	–	0 0	0 0	–	11 1	15 9	75592	0 0	0 0	–	476062
FOOD AND DRINK	95 8	81 9	372408	0 0	0 0	–	0 0	0 0	–	0 0	0 0	–	4 2	18 1	82288	0 0	0 0	–	454695
MECHANICAL	20 5	22 0	53545	50 0	40 3	97856	10 0	24 8	60204	10 0	6 6	16017	0 0	0 0	–	10 0	6 3	15300	242922
TEXTILES	89 7	93 0	1276588	0 0	0 0	–	0 0	0 0	–	6 9	3 5	48600	3 1	3 5	47442	0 0	0 0	–	1372630
OTHERS	55 1	86 7	6174944	13 5	2 7	190724	8 3	1 5	106054	23 1	9 1	650902	0 0	0 0	–	0 0	0 0	–	7122624
TOTAL	65 0	77 9	28727394	9 1	2 9	1061493	5 0	1 6	608491	8 7	2 0	756245	10 6	14 9	5517166	1 6	0 6	246984	36917773

Source Analysis of the Load Curves of the Electrical System of Brazil, DNAEE/MME – Nov 1983

4.2.2.3 Coefficients of the method

The sectoral model requires the total consumption been split into sectors with homogeneous load curves. Splitting yearly electricity consumption of a given sector [W(n,s)] into weekly, daily and hourly consumption, i.e. into a load curve, is done by means of a set of coefficients:

- the trend coefficient "t" of the week i, derived from the growth rate T of average demand in year n and from the position of the given week i with respect to the middle of that year:

  $$t = [\ 1 + (T\ /\ 100)]^{(i-26.5)/52} \qquad (4.8)$$

- the seasonal coefficient "k" which is the ratio of week i average working day's electricty consumption to the year's average working day electricity consumption,
- the daily coefficient "p" which is the ratio j of the average electricity consumption in day type "j" with respect to the average electricty consumption of a working day of that week; week-days are usually differentiated into working days, Mondays, Saturdays and Sundays; for a working day the value of p is 1,
- the hourly coefficient "ii" which represents the ratio of electricity consumption of each hour to the average electricity consumption of the respective day,
- the number of equivalent working days "N" in year n, which is given by:

  $$N(n,s) = \sum_{j}^{TD} t(i,n,s) * k(i,n,s) * p(j,i,n,s) \qquad (4.9)$$

where TD is the total number of days in the year so that the electricity consumption during N working days is equal to the electricity consumption during year n.

Hence, the load curve P for a specific sector, year, week, day and hour is given by:

$$P(h,j,i,n,s) = \frac{W(n,s)}{24*N(n,s)} * t(i,n,s) * k(i,n,s) * p(j,i,n,s) * ii(h,j,i,n,s) \qquad (4.10)$$

More detailed description is found in Chapter 6 and in the MAED Users' Manual [14].

4.2.2.4 Load forecasting

Once the sectors have been chosen and the respective coefficients calculated, it is possible to simulate the total load pattern as a function of total electricity demand growth and its sectoral evolution.

The forecasting phase consists in converting the expected development of consumption and structure into hourly demand figures. By dissociating the forecast of annual electricity demand from the different modelling coefficients, a large flexibility in the simulation of the future is obtained.

Changes in the aggregate load curve depend on changes in the structure of consumption that is, on the changes in the relative importance of the different sectors that were initially selected. The load curve is also affected by the introduction of new sectors, with different load curve patterns.

Significant changes in the load curve pattern of well defined sectors are not usual but may happen, requiring corresponding changes in the respective coefficients.

4.2.2.5 Input and output of the approach

The sectoral approach requires the following input data for each sector s and each year n:

W(n,s)	energy demand in a given year for sector s
W(n-1,s)	energy demand in the previous year
k(i,n,s)	weekly seasonality in the given year
p(j,i,n,s)	daily weighting for each week of that year
ii(h,j,i,n,s)	hourly modulation for each week day type

Besides that, the approach requires the initial and final years of the period to be studied and whether such years are real or theoretical ones, i.e. those that begin, by definition, on a Monday. Such years present some convenience for computation and may be adopted for intermediate calculations.

The output of the approach is an hourly demand set. Such data are organized into daily load curves, for all days of the years of the period that is being studied, for each sector and for the sum of all sectors.

From this file, several outputs may be obtained, according to the user's needs such as selected load curves listing and patterns, maximum yearly load, etc. Hence some generally used features of the load curve, like the load factor or the load diversity among different sectors can readily obtained.

Table 4.2.2 presents a calculation of future electricity demand in Brazil (September 20, 2000, 3rd Wednesday of the Month, 38th Week of the Year), given the demand structure and sectoral load curve characteristics.

TABLE 4.2.2. BRAZIL, FUTURE ELECTRICITY DEMAND (September 20, 2000; 3rd Wednesday of the month; 38th week of the year)

SECTOR	ANNUAL ENERGY DEMAND (GWh)	GROWTH RATE IN YEAR 2000	N^{s} 2000	AVERAGE WORKING DAY ENERGY DEMAND-W_d/N (MWh)	TENDENCY COEFFICIENT FOR 38th WEEK	SEASONAL COEFFICIENT FOR 38th WEEK	DAILY WEIGHT COEFFICIENT FOR 38th WEEK	ENERGY ON 2000/09/20
HIGH VOLTAGE								
FLAT	93.6	6 26	352	265.9	1 0135	1 000	1 000	269.5
RATE SEN.	62 4	6 26	349	178.7	1 0135	1 000	1 000	181 1
MEDIUM VOLTAGE	150.8	6 26	345	437 0	1 0135	1 000	1.000	442 9
LOW VOLTAGE	207.9	6 26	343	606 1	1 0135	1.000	1 000	617 4
TOTAL	514 7	6 26	–	–	–	–	–	–

4.2.3 Global methods

4.2.3.1 General concept and appropriate use

Global methods are better suited for short-run forecasts. There are instances, however, when longer run forecasts are required but only aggregate demand load records are available and estimates of sectoral load curves are not feasible. In such cases, global procedures may be adopted; they are, however, different from those used for the short run.

4.2.3.2 Methodology and forecasts calculation

For the short-run, standard methods like Box-Jenkins and Holt-Winters are usually employed; for long-run forecasts, one may use the same formulation as already described in Section 4.1.2.2, but restricted to a single global sector. Hence, the hourly load curve is given by:

$$P(h,j,i,n) = \frac{W(n)}{24*N(n)} * t(i,n) * k(i,n) * P(j,i,n) * ii(h,j,i,n) \qquad (4.11)$$

Following the procedures described in Sections 4.2.2.3 and 4.2.2.4, the following characteristics are obtained from the records: annual trend, weekly seasonality, daily weighting, and hourly modulation.

From the past values of these coefficients and the expected general features of future demand, such coefficients' future values may be estimated and future load curves forecasted. The same computing facilities as used for the sectoral approach may be employed in this case, for the analysis of recorded series as well as for forecasting resulting load curves.

4.2.3.3 Rough simplifications - load factor

In some cases, the only information available about a load during a given period, is the amount of energy required and the maximum value attained by that load during a standard time interval, such as the hour (MW.h/h).

The ratio between average and maximum loads is the load factor. Its evolution may help to evaluate peak requirements in coming years. The next important information is the hour at which maximum demand has occurred. Minimum load value and the time at which it was recorded is also important.

For planning purposes, an approximation to the load curve may be obtained by sample measurements, estimates gathered from different sources, researches on electricity usage habits, etc.

It is usually recommendable to define a load curve, even if roughly approximated, in order to organize all information and have a feeling about the most likely evolution of its major characteristics, such as the load factor. This could be forecast using the correlation with the structure of global demand, in terms of its main consumption classes (industry, residential, etc.) when no information about the load curves are available.

4.3 Treatment of uncertainty

The imprecision inherent in any forecasting process and the uncertainty of events the forecasters are trying to predict unavoidably produce a forecast which is uncertain to a greater or lesser degree. While the techniques discussed in Section 4.1 can be used to produce a 'most likely' forecast (i.e. a forecast using what is considered to be the most realistic set of parameters given present expectations of the future), the recognition that other directions are possible means that a range or band of possible outcomes rather than a single estimate should be provided.

Five methods of analysis to estimate the level of uncertainty associated with a line forecast are discussed in the next subsections.

4.3.1 Types of analysis

4.3.1.1 Scenario analysis

This is by far the easiest and most common analysis used [15,16] in which alternative scenarios are postulated, each characterized by a different set of assumptions for the explanatory variables. The same forecasting model used to produce the line forecast is used to simulate the different conditions and obtain forecasts for each alternative scenario.

The scenario approach usually involves the use of high, low and median estimates of explanatory variables to obtain a high, low and most-likely forecast. Although the median estimate generally results in the most-likely forecast, this is not always the case. Consider, for example, the case of electricity use in a rural area where electricity presently is not available. The most likely case may, in fact, be the one in which electricity is not provided through a rural electrification program. This would, of course, be the low growth electricity scenario. Depending on the forecasting method used, the high scenario could consider such factors as higher economic and/or higher population growth, higher saturation and usage of appliances as well as more rapid penetration of new devices, lower energy prices, high energy intensities, low energy efficiencies, etc. as compared to the assumptions of the most likely scenario. The low scenario could attach opposite characteristics to the above variables.

The scenario approach also provides an effective tool for policy analysis by measuring the effect of a proposed policy or government measure. Policies of interest might be the government decision to ban future inefficient cooking stoves in the household by introducing other means of cooking, to lift subsidies from energy products by implementing an appropriate tax scheme favouring poorer incomes, to reduce dependency on imported energies, to ban coal or other fossil fired plants in order to control acid rain, to analyze the impact of subsidy suspension of energy prices on the energy demand pattern, to encourage substitution of non-commercial energies by commercial ones, etc.

There are, however, a few shortcomings with the scenario approach. When producing an alternative scenario, it is imperative that a reasonable relationship between explanatory variables be maintained. Judgment must be exercised to ensure that the explanatory variables used to build a scenario form a consistent set. For example, if higher GNP growth is postulated, one would expect lower, not higher unemployment rates (unless, of course, there is higher population growth due to immigration, etc.). There is also a difficulty in quantifying a probability range between scenarios since the scenarios describe mutually exclusive events.

4.3.1.2 Monte Carlo method

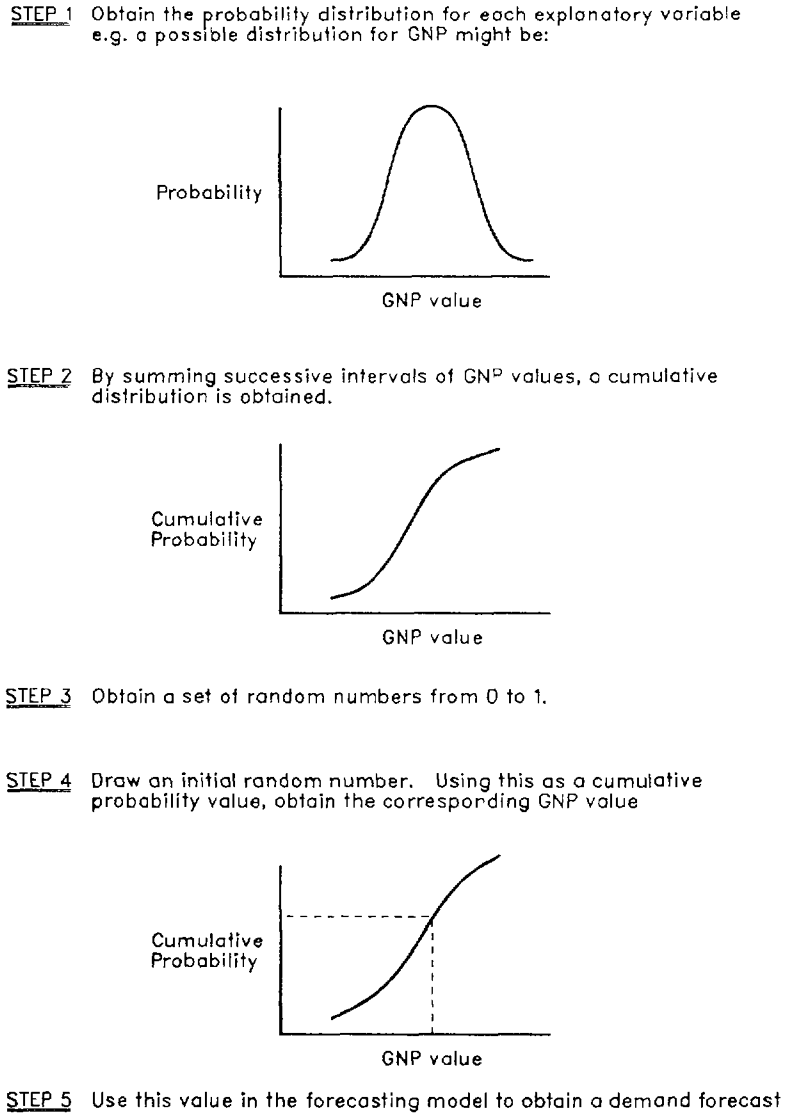
In the Monte Carlo method [17,18], uncertainty about the values of the explanatory variables are directly addressed (see Figure 4.3.1). From the range of possible values (Step 1 and 2) values for the explanatory variables are randomly selected (Step 3), such that the probability of selecting a given value is defined by the probability distribution of that variable (Step 4). The probability distribution for each variable can be obtained in a number of ways depending on the availability of data.

For each complete set of randomly selected explanatory variables, a demand forecast is produced using the forecast model used to produce the line forecast (Step 5). This process is performed a large number of times (500-1000 trials) and a frequency distribution is produced for the resulting forecasts. It is then possible to produce a probability distribution for the forecast. The distribution of forecasts gives the forecaster an indication of the effect of uncertainty in the explanatory variables on the forecast itself.

4.3.1.3 Error modelling

Error Modelling looks at the forecast errors made in the past as a way of dealing with future uncertainty [19].

Forecast errors may be caused by many factors. Some of these factors are: error in the forecast of energy prices, economic growth, marketing efforts, government policy, and the rate and penetration of technological improvements. In addition to these unforeseen shifts in exogenous variables, errors also reflect differing methodologies used in preparing the forecast. The forecast error is thus a convenient summary index of uncertainty in the forecast.



STEP 1 Obtain the probability distribution for each explanatory variable e.g. a possible distribution for GNP might be:

STEP 2 By summing successive intervals of GNP values, a cumulative distribution is obtained.

STEP 3 Obtain a set of random numbers from 0 to 1.

STEP 4 Draw an initial random number. Using this as a cumulative probability value, obtain the corresponding GNP value

STEP 5 Use this value in the forecasting model to obtain a demand forecast

FIG. 4.3.1. Monte Carlo process.

The first step in using this approach is to calculate the percentage error for each year forecasted in the past. For a forecast produced in year t, the error for the first year forecasted (t+1) is termed the first year forecast error, the error for the second year forecasted (t+2) is termed the second year forecast error. By looking at a number of historical forecasts, a probability distribution can be obtained for the first year forecast error, the second year forecast error, etc. Each distribution is characterized by a mean and a variance.

The next step is to model these variances against time. The model results are then used to determine uncertainty limits for each year forecasted.

4.3.1.4 Probability tree

The mechanics of this method [20] can be best understood by viewing the steps in Figure 4.3.2.

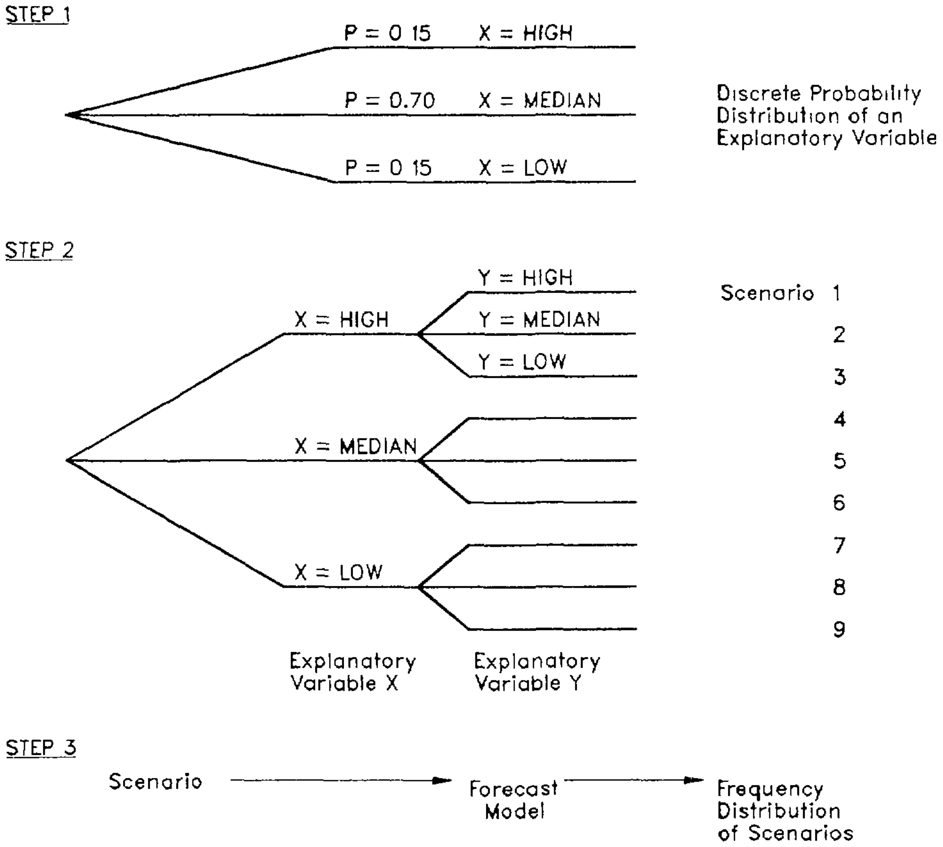


FIG 4 3 2 Probability tree analysis

First, the probability distribution for each explanatory variable used in the forecasting model is obtained. This is usually chosen to be a simple discrete distribution with high and low values each having a 15% chance of occurring and the median value with a 70% chance.

Next, a set of possible future scenarios is generated using the method shown in Step 2. The future is thought of as a probability tree with each route through the branches (characterized by a certain set of explanatory variables) as one possible scenario.

Finally, demand forecasts for each scenario are produced. The probability of occurrence for each scenario (branch) is determined by using the multiplicative probability rule. Using this method, a forecast probability curve can be approximated.

Note, however, that this exercise can become quite unwidely as the number of explanatory variables, and therefore, probability branches increases.

4.3.1.5 Sensitivity analysis

An important criterion of any model's performance is its sensitivity to such factors as simulation period, small changes in estimated coefficients, and small changes in the explanatory variables.

This can best be understood in terms of the following example. (Note that this is an example only and should not be interpreted as necessarily factually.)

$$\ln y = a + b1 * \ln(Pe) + b2 * \ln(Pg) + b3 * \ln(GDP) + b4 * \ln(LDV) \qquad (4.12)$$

where

y	represents electricity demand	--- explanatory variables
Pe	price of electricity	
Pg	price of natural gas	
GDP	gross domestic product	
LDV	lagged dependent variable	
b1	own-price elasticity	--- estimated coefficients
b2	cross-price elasticity	
b3	income elasticity	
b4	long-run multiplier	

Note: Elasticities are an important concept in economics. The concept of elasticities is devised to indicate the degree of responsiveness of the quantity demanded to changes in the market of prices or income. It depends upon percentage changes and is independent of the units used to measure the quantity and the price. See for that subject Ref. [5,8] and Glossary.

If this model were estimated over the period 1945-1980, the sensitivity to initial period could be tested by starting the model simulation at various years. If the model is well specified, then similar results should be obtained regardless of the starting year of the simulation. Another test of sensitivity would be to vary the estimated coefficients by a little bit (less than 1 standard error). Again, the simulation performance should not be very different from the base simulation. The same reasoning holds true for the exogenous variables used.

4.3.2 Error modelling technique as carried out by Ontario Hydro

The following is a discussion of the Error Modelling Technique used by Ontario Hydro to estimate annual forecast uncertainty. It is presented to illustrate the actual application of a technique and the complexities involved in its implementation. This particular technique relies heavily on the availability of extensive historical data and would not be appropriate, therefore, for a situation where this would not be the case.

The forecast error et,k is defined as the relative difference between a forecast made in year t for a year k time periods ahead (ft,k), and the actual demand in year t+k (at+k):

$$et,k = (ft,k - at+k) / at+k \qquad (4.13)$$

The forecast error has two attributes: 1) it is always greater than or equal to -1, and 2) empirically it has been found to exhibit an underlying exponential behaviour. It is appropriate, therefore, to study the transformed variable $X_{t,k}$ given by:

$$X_{t,k} = \ln (1 + e_{t,k}) \qquad (4.14)$$

The transformed variable $X_{t,k}$ is characterized by a normal distribution about the value 0 with a variance σ^2.

$$X_{t,k} = N\ (0,\ \sigma^2) \tag{4.15}$$

The variance σ^2 is given by the following formula:

$$\mathrm{var}\ (X_{t,k}) = \sigma^2 = E[X_{t,k} - E[X_{t,k}]]^2 = \sum_{t=1}^{n} x_{t,k}^{2}/n \tag{4.16}$$

where E[ ] = expectation value

$x_{t,k} = X_{t,k} - \bar{X}_{t,k}$ where $\bar{X}_{t,k}$ is the sample mean of the population.
n = number of observations of k year-ahead forecast errors.

Letting $(S_k)^2$ represent the variance estimated for a given population sample, it is assumed that $X_{t,1}$ has a mean growth rate g and a variance $(S_1)^2$. Hence:

$$X_{t,1} = g + u$$

$$X_{t,k} = kg + u^1 \tag{4.17}$$

where:
$u = N(0,S_1^2)$ (normal distribution)

$u^1 = N(0,kS_1^2)$ (normal distribution)

The k year-ahead variance for $X_{t,k}$ (S_k^2) is given by kS_1^2.

If the variance of $X_{t,k}$ were to show no growth, then $S_k/\sqrt{k}$ would be a measure of the square root of the "within trend" mean squared error as well as the square root of the total mean squared error. However, the variance does exhibit growth and the following linear regression is used to explain this behaviour:

$$S_k/\sqrt{k} = \alpha + \beta k \tag{4.18}$$

For the purpose of illustration, sample fitted results for a particular Ontario Hydro System for the above equation are given below:

k	S_k	k	S_k
1	0.028420	11	0.262942
2	0.048534	12	0.285680
3	0.069660	13	0.308842
4	0.092235	14	0.332431
5	0.116313	15	0.356448
6	0.141864	16	0.380892
7	0.168839	17	0.405761
8	0.197182	18	0.431053
9	0.218709	19	0.456763
10	0.240622	20	0.482889

$\alpha = 0.02252$
$\beta = 0.00590$

The uncertainty limits around the forecast for k years ahead is generated by the preceding table and the following equation:

$$\text{limits} = F_t \exp [\pm Z_{\alpha/2} * S_t] \tag{4.19}$$

$$\Pr\}F_t \exp (Z_{\alpha/2} * S_t) \leq F_t \leq F_t \exp (-Z_{\alpha/2} * S_t)\}=1-\alpha$$

where F_t = forecast for period t
$Z_{\alpha/2}$ = normal deviate at the $\alpha/2$ probability
Pr = probability

The distribution of the uncertainty bounds has a log-normal shape. There is, therefore, no possibility of negative values being encompassed by the uncertainty limits.

Using the above example,

$$\text{limits} = F_t \exp[\pm Z_{0.02252/2} * S_t] = F_t \exp[\pm 2.28 * S_t]$$

k	S_k	limits
1	0.028420	$0.937 F_t \leq F_t \leq 1.067 F_t$
5	0.116313	$0.767 F_t \leq F_t \leq 1.304 F_t$
10	0.240622	$0.578 F_t \leq F_t \leq 1.731 F_t$

In each of the above ranges, the probability of the forecast being within the range specified is equal to 98.9% ($=1 - \alpha/2$).

In actual practice, a narrower range is often specified with correspondingly lower probability. Standard statistical theory can be used to make this transformation.

4.4 Data retrieval problems

4.4.1 Data adequacy and control of their origin

Energy demand analysis and forecasts require reliable and sufficient data, besides adequate methodologies and reasonably coherent scenarios. In the short run, insufficient availability of data may be an important limitative factor in the choice of forecasting methodologies, a situation that can be eliminated or at least diminished in the long run.

Due to the multitude usage of energy in different processes, energy consumption studies have a considerably broad scope which implies the involvement of a large variety of variables. But the methods used in order to capture the interactions of the energy system under study with the economic and socio-economic system set limits to the number of variables that can be treated. In consequence, certain simplifications in the representation scheme of the energy system are required to suit the input requirements of the forecasting method selected. However, these simplifications, coupled with uncertainties regarding assumptions and basic data, concur to the lack of precision of the results obtained from their use.

Data required for energy demand studies correspond to variables pertaining to the energy sector, i.e. the annual electricity and fuel consumption, etc., to the economy, i.e. value added per manufacturing sector, etc., or the socio-economic sector, i.e. transportation preference of final consumers. The nature and the origin of the data present different problems in terms of retrieval, consistency, adequacy for the model under consideration, periodicity, reliabilityand checking possibilities,among others.

4.4.2 Steps in the retrieval process

Two basic steps in the data retrieval process may be identified:

a) from the sources of origin , i.e. oil refinery, central bank, ministry of transport, etc., to the energy forecasting agency's files, and
b) from these files to the forecasting model's programmes.

In the first step, the receiving-end depends on the activities of the sending-end with regard to completeness, quality and timely reception of required data. The transmission of data on magnetic tapes seem to be the most appropriate as it minimizes, to a certain extent at least, the transcription of errors. However, it should be realized that often, in developing countries at least, mechanical transference of data is not possible at all stages of the process. In all instances, the receiving-end should check the incoming data in terms of their consistency. This requirement should always be fulfilled in order to avoid that grossly distorted figures are accepted in the files, jeopardizing the validity of the studies in which they are used.

The second step, that is the internal data retrieval process, depends on the equipment available in terms of hardware and software, and on the needs of the methods for which such data will be an input.

4.4.3 Systematic and sporadic retrieval

Energy demand studies may be recurrent at different times. In such cases the energy data base has to be updated and, eventually, revised. For that purpose, energy data are systematically or sporadically retrieved depending on the importance for the study.

The core of the data are mostly systematically retrieved, i.e. fuel sales, electricity consumption, etc., as they form valuable information of the consumer's energy behaviour for an oil (or coal/gas) company's or electric utility's energy supply strategies. Therefore, the statistical data on the energy (sales) mix should be permanently updated and at disposal.

Sporadic retrieval is concerned with those statistical data that are either difficult to obtain through "simple" accounting or similar methods, or regarded as relatively stable over a certain period of time.

In these cases micro censi are carried out, but sparsely and not frequently. The value of such censi is difficult to estimate as often the composition of the group under study is subject to changes, so that the development of a representative information pattern on the commercial and non-commercial energy consumption structure is difficult to obtain.

4.4.4 Institutional and manpower problems

Statistical offices may face several kinds of institutional problems in their effort to collect and evaluate data. The term institutional is taken here to mean anything that is related to the organizational aspect that could be changed, modified or altered through instituting any form of organization.

In order to be able to provide statistical information needed by other governmental (or non-governmental and international) bodies, Central Statistical Offices have been established that are required to collect and process representative data. To carry out this task requires close co-operation with local governmental and non-governmental bodies which can not be achieved merely through legal and executive orders [21].

For the energy sector in particular, the information quite often is scattered among different producing companies of the electricity and oil industry. The statistical data of the companies and utilities usually present the supply of energy from their point of view which often leads to inadequate information concerning a specific consumption pattern of energy in the country under study. Additionally to the incompatibility of statistical data, it is the lack of historical data that hampers the appropriate analysis of the development of fuel consumption.

More frequent institutional problems arise when certain data are regarded as confidential such as the crude oil or petroleum derivatives stock piling of industries, and are not disclosed to the statistical offices.

Along with the institutional problems, it is quite often the lack of trained professional staff and the transfer of trained staff to other duties that hamper the successful implementation of a relevant data base and guarantees the appropriate carrying through of the task. [22]

Manpower requirements and training in energy data retrieval is a subject that cannot be treated in isolation from the fundamental issues of energy planning; it rather should be fully integrated in the planning process itself. The problems related to the subject reach very deeply into the fundamental issues of technologies and development. Failure to provide local manpower capable of understanding data retrieval constraints and the respective handling, will leave data offices dependent from outside experience which might lead to a difficult situation in its forecating activities when foreign expertise is not anymore available. [23]

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Chapter 5

ENERGY AND ELECTRICITY DEMAND FORECASTING TOOLS USED IN VARIOUS ORGANIZATIONS

The structural problems encountered in energy and electricity demand forecasting as well as the general concept and in the planning field were outlined in the previous chapters. Given different objectives in energy and electricity demand planning of developing countries, the materialization of the general concept led to different approaches. The aim of this chapter is to present some representative model approaches applied in the field of energy and electricity demand planning in order to highlight the various possibilities to tackle energy and electricity demand problems.

5.1 Introduction

5.1.1 Brief history of energy modelling

Although the development of energy models began in the early sixties, it was the growing awareness of the energy problems originating from the first oil crisis in 1973 that forced an explosion in the development of energy models.

The energy models developed in the sixties focused mainly upon the supply and demand of a single energy form such as electricity, oil or natural gas. Petroleum companies for example have developed and applied large allocation models in order to deal with the complex problem of optimal allocation and routing of crude oil and oil products between different oil sources, refineries and demand centers, as well as to optimize the production process in the refinery. Another example of such model application relates to the analysis of electric utility operations and of system expansion planning. Several models using the optimization or simulation approach have been developed and are used to evaluate the optimal expansion strategy of the power plant system required to satisfy an increasing electricity demand.

Both areas of model application, allocation and expansion, focus on the energy supply side, and on the best way to satisfy an assumed demand. This demand, however, is an exogenous input to these models and often provided by econometric models.

In order to grasp better the interactions of the entire energy system, energy system models were developed, describing the energy flows from different primary sources through various conversion and utilization processes to different end use demands.

Likewise the energy models mentioned earlier, energy demand in energy supply system models is ussually treated exogenously. Thus, energy supply system models do not allow for demand adjustments due to higher energy prices or to changes in GDP growth caused by raising energy cost and limited energy supplies, or to changes in the socio-economic structure and the consumption behaviour.

Therefore, in order to capture the energy economy interface more appropriately, Energy-Economy models were mainly developed in the past.

Such models link the energy sector with the rest of the economy. This model type has been developed originally for application in developed countries where the market mechanisms are more or less well established. The ever increasing expansion of energy-economy models in order to comprise all the major market phenomena and technological characteristics of developed countries in a single model led to complex, highly sophisticated and data intensive modelling tools.

Some kind of re-orientation with regard to simplicity, transparency and easy handling, of modelling tools can be seen in the technique-oriented models. Such models focus on the technical feasibilities in an assumed economic frame. These models are, however, like the energy economy models, very data intensive.

5.1.2 Classification of planning tools

Depending cf the planning problem to be studied, the energy model will be chosen out of one of the groups presented in Figure 5.1.1.

Energy Planning Models	Purpose	Methodology
Macroeconomic Growth Model	Determination of composite or sectoral economic growth	Econometrics Input–Output System Dynamics
Energy-Demand Model	Analysis and assesment of demand variables and demand structures	Econometrics Engineering-Process Approach
Energy-Supply Model	Identification of fuel and technology mix	Simulation Optimization
Energy-Economy Model	Analysis of impact and feedbacks between energy sector and the rest of the economy	Simulation Optimization Econometrics Input–Output

FIG.5.1.1. Classification of energy planning models.

For each category of models (demand, supply, etc.), different methodologies are used (econometrics, simulation, optimization, etc.).

Macro-economic growth models refer to the economy of a country or region and deal with the consumption and production of aggregated producers and consumers in the economy. Macro-economic growth models analyze the sectoral economic activity growth prospects of an economy, taking into consideration the factors of production like capital, labour, land, material and energy or investment, consumption, imports and exports, technological progress, etc. Energy in macro-economic growth models is not treated separately but together with other production parameters in conglomeration. From the methodological point of view they are econometric models, including any kind of behavioural function, they use statistical methods like regression and correlation analysis, or they use input-output analysis, or system dynamics methods.

Energy demand models analyze the sectoral energy demand in one of the following levels:

- final energy demand,
- useful energy demand,
- energy service demand.

Among the energy demand models, the simulation method and econometric techniques are most common.

Energy supply models focus either on single energy forms and sectors (sectoral supply model), or the energy system as a whole (energy supply system models). A major criticism made to a single fuel model is that it treats the development of the fuel in question in isolation from the rest of the overall energy and economy situation. Energy supply system models represent the energy supply system by an oriented network such as, for example, the one shown in Figure 2.3.2.

Energy supply models use the simulation as well as the optimization method with linear programming or other optimization algorithms.

Energy-economy models were developed to explicitly model the linkages and interrelationships between the energy sector and the economy in terms of capital, labour, material and other requirements. There are integrated energy-economy models which explicitly describe the interactions within a single network of equations and model sets which consist of a separate economy module and a separate energy module.

Recent developments in energy modelling concentrate on the development of integrated sets of models, which may serve a variety of planning tasks. The links between the different models are performed by a data management system.

5.1.3 Modelling issues for developing countries

The socio-economic, economic and energy systems of developing countries are in many ways different from those of developed nations. The production systems in many of these countries are poorly organized and the economic infrastructure in most cases underdeveloped. Due to the specific nature of developing countries, the problem areas differ from those of industrialized nations and in consequence the economic, energetic and socio-economic goals of any planning activity. Hence, the development of any energy model which will be used for planning the energy system in developing countries, must be based on the recognition of this distinction in addition to representing the issues which are peculiar to these nations.

When dealing with energy models, one should recognize, that there is not a single "best" model or methodology. Rather the appropriate model depends on the application and the questions that need to be addressed in consideration of the resources available in terms of time, manpower, computer resources, etc. A progressive approach from simple manual or interactive microcomputer-based schemes to more comprehensive automated ones will ease some of the modelling and computational bottlenecks prevailing in developing countries and will enable the planner to commence with energy modelling even given a rather weak data base. Furthermore, such a procedure enables to improve data base and model/computer configuration in parallel.

Energy modelling tools should be flexible and modular due to the following reasons:

- The economic and energy policy environment in developing countries undergo rather rapid structural changes. Any changes in supply-demand configuration can require a restructuring of the energy system representation. A flexible and modular energy model can be more easily adapted to structural changes than "one-body" energy models where the model configuration is difficult to change in response to structural changes [1].
- The energy product markets of developing countries could exhibit a variety of market characteristics and, in general, more government interventions and controls. This inherent variety of market characteristics does require flexibility in the energy system representation and its accompanying modelling and integrating logic [1].
- Quite often in developing countries the private industries use sectoral energy models. The modularity of the energy system would allow to accommodate these already existing models as a whole or, in an equivalent reduced form, in an integrated model.

Particular modelling issues for developing countries are to be reflected in the adequate consideration of the following features:

- rural/urban dichotomy because the most important difference between the energy system in developing countries and developed ones stems from the fact that non-commercial fuels play a large role in the former and is mot accounted for in normal cash transactions,
- role of renewable energy sources because limitations in introducing commercial fuels into rural areas provide the ground for utilization of small scale renewable energy sources, such as hydropower, solar energy, wind, tidal, geothermal, biomass, etc. in the short and medium term,
- regional imbalance in energy supply and consumption because most developing countries are characterized by heterogeneous spatial economic development and as a result, the supply of energy to some regions develops usually in a different way compared to other areas of the country,
- management of depletable resources because the optimal utilization of resources and development of proper resource pricing policy will aid either the increase in foreign exchange revenue from export of these resources or the decrease in imports of energy resources and consequently less foreign exchange requirements.

- interaction between energy and economic development because the realization of any energy supply plan will influence the economy as well.

5.1.4 Interaction between energy demand and energy supply

Actual energy markets are characterized by the interaction between energy demand and energy supply. Therefore, when analyzing energy demand, one major problem addresses the adequate consideration of the feedbacks from the energy supply system. On the other hand, when modelling the energy supply system, the problem has to be faced of how to deal with the price induced demand changes and price induced conservation and substitution. Figure 5.1.2 illustrates the connection between the energy system and the economic system in an modelling approach pointing to the problem of energy supply and demand balancing in the energy market.

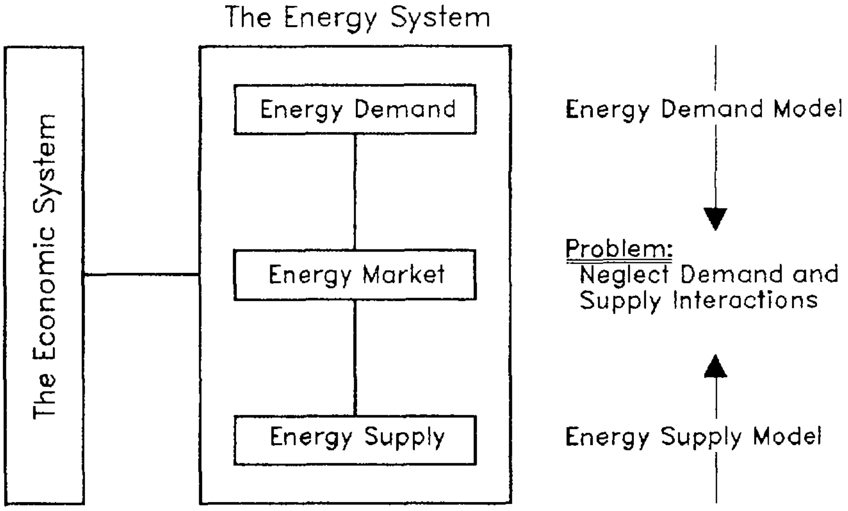


FIG.5.1.2. The energy-economy system.

In energy supply system models the exogenous input of the demand may be in terms of final energy (electricity, petroleum derivatives, fuelwood, etc.), useful energy (process heat, mechanical energy, etc.) or energy service demand (tons of steel produced, kilometer traveled, etc.) or is composed of combinations of these. Energy demand can either be given as a fixed value for each point in time, or in price dependent terms by using a demand function, i.e. an own price elasticity function of demand. Energy demand inputs to a supply model on the three energy demand levels, e.g. final, useful and energy services, are specified in Figure 5.1.3.

There are some basic differences between the various demand representations, which the user of the model should be aware of:

- on the final energy demand level:

The exogenous specification of final energy demand inputs means, if the demand is fixed, that price responses due to price increases or decreases of the fuel in question cannot be taken into account; that there are no possibilities for interfuel substitution, which means that the demanded fuel cannot be substituted by another technically feasible one; that there are no possibilities to treat conservation efforts on

		Exogenous Input of the demand to the Supply System model in terms of		
		Final Energy	Useful Energy	Energy Service
Demand is fixed for each point in time	Interfuel Substitution	—	X	X
	Efficiency Improvements of End-Use Devices	—	X	X
	Conservation Efforts	—	—	X
	Behaviour of Consumer	—	—	—
Demand is given in price dependent terms (Demand functions)	Interfuel Substitution	—	X	X
	Efficiency Improvements of End-Use Devices	it is not clear what caused the effect on the demand	X	X
	Conservation Efforts		it is not clear what caused the effect on the demand	X
	Behaviour of Consumer			X

FIG.5.1.3. Demand treatment concept.

the end-use side; and that there are no possibilities to take into consideration improvements in the efficiency of the end-use device.

If the final energy demand is given in price dependent terms, it is not clear, by what means the price response has been achieved, whether by conservation efforts, by improvements in the efficiency or by reducing the energy service demand.

- <u>on the useful energy demand level:</u>

The exogenous specification of useful energy demand input means in the case of fixed demand, that interfuel substitution as well as the possible improvements in the efficiencies of the end-use devices can be modelled. However, the price determined behaviour on the consumer side including the conservation efforts cannot be considered.

If the useful energy demand is given in price dependent terms, interfuel substitution and possible improvements in the end-use device are considered. Also the behavioural changes in the demand for useful energy with respect to the useful energy price can be modeled, with an implicit treatment of conservation.

- <u>on the energy service level:</u>

The exogenous specification of the energy service demand input means for cases with fixed demand, that the consumers reaction to changing prices of the energy service like for example to lower the room temperature, to reduce the size of the flat or house cannot be considered but an explicit treatment of energy conservation can be modeled.

If the energy service demand is given in price dependent terms, it describes the behaviour of the consumers in respect to demand adjustments due to price changes, including the explicit treatment of conservation efforts. If, for example, the price of energy increases, possible reactions of the consumers are: to lower the room temperature, to drive slower, or to change other behavioural factors. The problem is that price demand functions for the energy service demand are not available yet. Also their representation would increase the size of the supply system model substantially and the computer capacity might be the bottleneck for this application especially when microcomputers are used, which is more and more the common practice.

Especially the actual realization of the demand representation might be beyond the possibilities (financially, infrastructurally and concerning the available data base) of many countries.

5.2 Energy and electricity demand forecasting tools

5.2.1 Introductory notes to energy and electricity demand models presented in the Guidebook

The endeavour has been made in the previous sections to present the theoretical frame of energy and electricity demand planning from different aspects. In order to visualize how such theoretical frame can be transformed into applicable forms, different energy and electricity demand models were selected as examples of how different methodologies have been implemented. A complete list of every available model is impossible and is not attempted, but rather a sampling of models that have followed different approaches. These models are presented in detail in Sections 5.2.2 to 5.2.4. These planning tools can be distinguished into three groups:

- Integrated Demand/Supply Models,
- Energy Demand Models,
- Electricity Demand Models.

It could be argued that the spectrum of the models presented is too restrictive and only limited representative, given the multitude of energy and electricity demand models in use. However, it should be kept in mind that this Guidebook serves primarily the purpose to present the IAEA energy and electricity demand models. In this context, the presentation of other models is meant to display the variety of possible approaches in the field of energy and electricity demand planning.

This section is not meant to compare the features of the different models, as every model serves its specific purpose and is therefore unique in its structure and characteristics. In fact, this section should be viewed as a short overview of the variety of different modelling approaches on energy and electricity demand planning applied for developing countries.

The models have been described by the authors or responsible person themselves, so that the content of each model description is the sole responsibility of the respective author(s).

5.2.2 Integrated demand/supply models

5.2.2.1 ENPEP: ENergy and Power Evaluation Program

General Information	Name of model:	ENergy and Power Evaluation Programme (ENPEP)
	Institution:	Energy and Environmental Systems Division Argonne National Laboratory Argonne, IL 60439, USA
	Contact Person:	Thomas Wolsko
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	Long-term demand and supply projections; to determine energy demand from the economic growth prospective; to develop load forecasts for the electric sector and perform an electric system expansion planning optimization using the WASP model; to describe resource and environmental impacts associated with any energy expansion plan
Model Specifications	Modelling Technique used:	Optimization for electric system expansion planning Simulation for demand/supply balances Spreadsheet type calculations
	Temporal frame:	Time horizon: 20-30 years Time intervals: 1 year (down to one month for some modules)
	Spatial frame:	National with possibilities for regional and sectoral disaggregation
	Level of disaggregation:	Consuming sector Fuel type
	Level of energy demand calculation:	Useful/Final

Model Specifications

Information requirements:
(type of data needed, number of exogenous and endogenous variables, etc.)

The model can be disaggregated into up to 72 useful or 38 final energy demand categories; information required is entirely dependent upon the users level of disaggregation or approach to energy planning; characteristic parameters required at minimum are at least for one energy sector and one final energy demand category.

Information generated (model output):

ENPEP has 7 modules, each produces specific output:

MACRO	formats forecasts for specified macroeconomic variables in either percent growth per year over the study horizon or in absolute values of growth,
DEMAND	calculates energy demand as a function of the macroeconomic parameters; information generated at minimum: final energy demand projections by category; maximal number of generated information in each demand category: useful energy demand by category,
PLANTDATA	provides basic information about thermal and hydro electric generating facilities for the ELECTRIC and BALANCE modules,
BALANCE	calculates the price and quantities of energy consumed or produced at all points in the energy system,
LOAD	generates seasonal load duration curves,
ELECTRIC	is the microcomputer version of WASP III,
IMPACTS	calculates the resources (capital, labour, materials, fuel) requirements and environmental impacts (air, water, solid waste, land, radiation) associated with an energy plan.

Computer Specifications

Programming language:	Combination of FORTRAN and BASIC
Hardware:	IBM PC/AT or compatible
Storage capacity.	approximately 20 Megabytes
Operating system:	Microsoft-DOS 3.1 or above
Compiler used:	Microsoft FORTRAN and BASIC
Peripheral requirements:	Printer, color pen plotter
Commercial software:	Framework II, DBase III plus (optional), Graf Talk
CPU-time needed:	Most modules execute in only a few minutes, but some ELECTRIC submodules can require several hours for the first iteration
Implementation of the Microcomputer possible:	Yes

Application, Future Development, Comments	Example(s)/Country(ies) of application Jamaica (other countries for specific modules of ENPEP)
	Future development: - MAED will be added, - Transmission and distribution simulation module
	Additional comments:
Documents	[2]

5.2.2.2 ETA-MACRO: Energy Technology Assessment

General Information	Name of model:	Energy Technology Assessment (ETA-Macro)
	Institution:	Department of Operations Research Stanford University
	Contact Person:	Alan S. Manne
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	Long-term supply and demand projections; allows for price induced conservation, interfuel substitution between electric and non-electric energy; designed to cover only broad outlines of the long-term issues
Model Specifications	Modelling Technique used:	Optimization Econometrics
	Temporal frame:	Time horizon: 1975-2050 Time intervals: 5 years
	Spatial frame:	National
	Level of disaggregation:	Fuel type: Electric and Non-electric energy (Nuclear fuel cycle may be analysed at several levels of detail)
	Level of energy demand calculation:	Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) for the energy sub-model: - natural resources (petroleum, natural gas, coal, uranium, hydroelectric, etc.), - energy conversion technologies (light water reactors, solar electricity plants, coal-based synthetic fuels, etc.), - energy costs supplied from the MACRO component of the model
	Information generated (model output): by the energy sub-model: - electric and non-electric energy (non-electric energy combines liquids and gases on a BTU basis)
Computer Specifications	Programming language: Fortran also GAMS/MINOS Hardware: Storage capacity: Operating system: Compiler used: Peripheral requirements: Commercial software: CPU-time needed: Implementation of the Microcomputer possible: Yes, IBM XT/AT
Application, Future Development, Comments	Example(s)/Country(ies) of application: USA, Canada, Mexico, OECD Europe, Israel, Taiwan, Japan, Korea and Total OECD
	Future development:

Application, Future Development, Comments

Additional comments:

Figure 5.2.1 provides an overview of the principle static linkages between the energy and the macro sub-models.

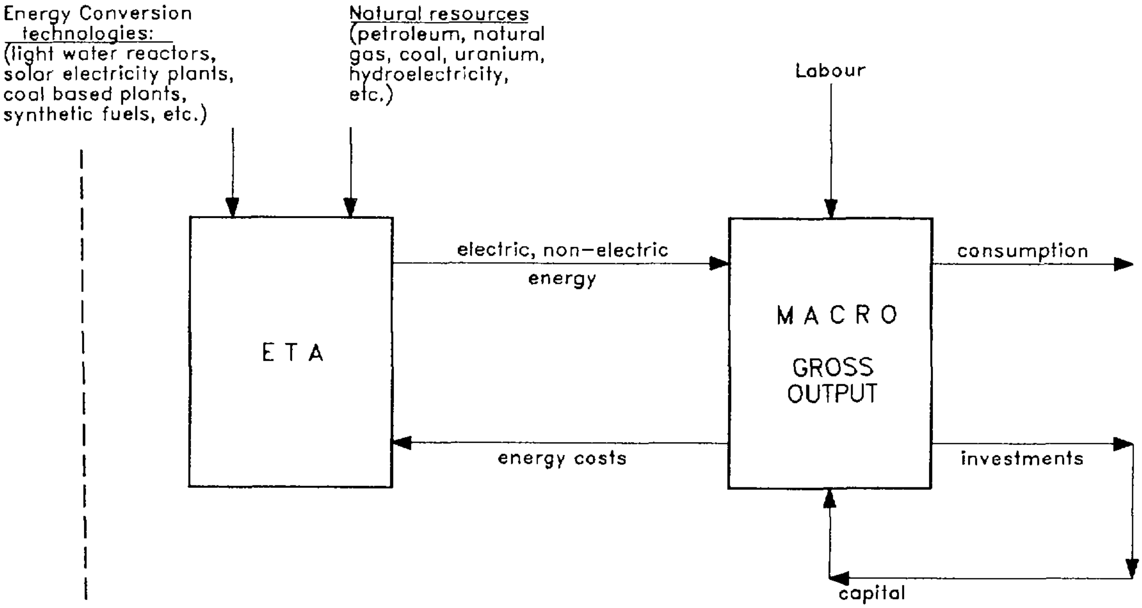


Figure 5.2.1 ETA-MACRO

Documents

[3]

5.2.2.3 MESAP: Microcomputer based Energy Sector Analysis and Planning system

General Information	Name of model:	Microcomputer based Energy Sector Analysis and Planning System (MESAP)
	Institution:	Institut fuer Kerntechnik und Energiesysteme (IKE) University of Stuttgart Pfaffenwaldring 31 D-7000 Stuttgart, FRG
	Contact Person:	A. Voss, A. Reuter
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	MESAP is a microcomputer based integrated energy planning tool to analyse the energy system, to establish structural data bases, and to provide an interactive training medium.
Model Specifications	Modelling Technique used:	Optimization for supply model MESSAGE Simulation for demand model MAED Econometrics for household model HMOD Regression, Trend extrapolation
	Temporal frame:	Time horizon· flexible
	Spatial frame	National with regional disaggregation
	Level of disaggregation:	Consuming sector Fuel type Household types (Level of disaggregation in the supply model depends on user's specification)
	Level of energy demand calculation	Useful/Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) MESAP has 5 modules, each requiring specific inputs: MAED see separate description of MAED in section 6 HMOD demographic data, income, prices of fuels, efficiencies, income elasticities, own and cross price elasticities, wage rates MESSAGE energy demand, resource-, import-, export-, restrictions, conversion-, transportation-, storage-technology data (costs, lifetime, etc.) other modules depend on the problem addressed.
	Information generated (model output): MAED see separate description of MAED in section 6 HMOD energy demand per fuel type, technology, house type over the time horizon MESSAGE "optimal" energy supply structure including resource extractions, imports exports, activities and capacitities of conversion technologies, cost of the system, environmental impacts, etc. other modules depend on user's specification
Computer Specifications	Programming language: Fortran Hardware: Mainframe and Microcomputers Storage capacity: approximately 20 Megabytes Operating system: independent (UNIX, MS, etc.) Compiler used: Fortran Peripheral requirements: Graphic terminal (Printer, Plotter) Commercial software: None CPU-time needed: depends on problem size, dialogue oriented system Implementation of the Microcomputer possible: Yes
Application, Future Development, Comments	Example(s)/Country(ies) of application: Nigeria, Iran

Application, Future Development, Comments

Future development:

Modelling: Inclusion of an energy-economic module, sector specific modules (electricity)
Computerization: Menu guide, implementation on other microcomputers, graphic presentation of balances in form of colored flow diagrams

Additional comments:

The relationships between the modules of the MESAP system is shown in Figure 5.2.2.

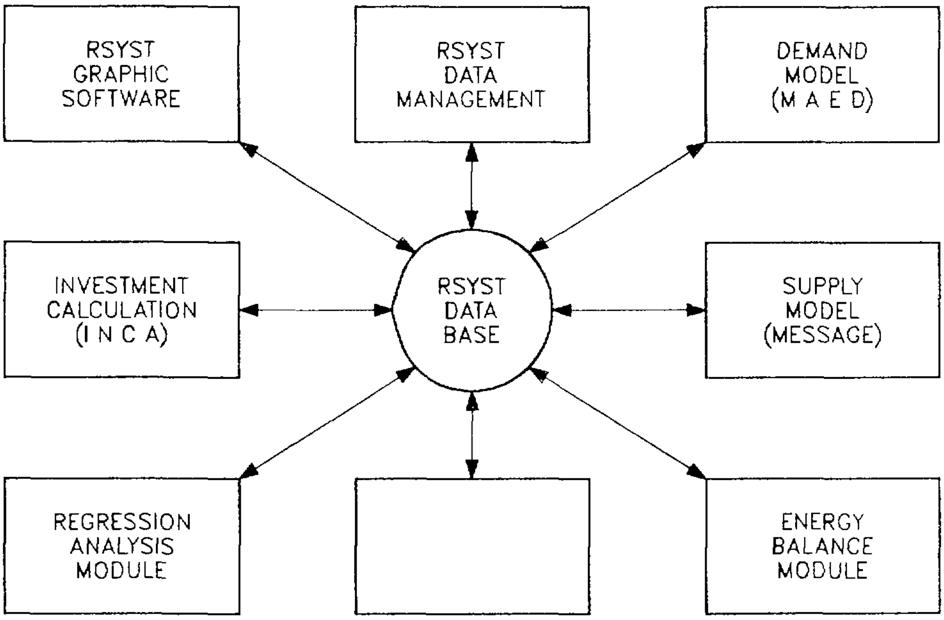


Figure 5.2.2 The MESAP System

Documents

[4]

5.2.3 Energy demand models

5.2.3.1 WISCONSIN model

General Information	Name of model:	WISCONSIN Model
	Institution:	Energy Systems and Policy Research Program Energy Research Center University of Wisconsin 1402 University Avenue Madison WI 53706, USA
	Contact Person:	Wesley K. Foell
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	Determining energy demand on the end-use level; disaggregation of energy demand into five sectors;
Model Specifications	Modelling Technique used:	Simulation Scenario-approach
	Temporal frame:	Time horizon: flexible Time intervals: ususally 1 year
	Spatial frame:	National, Regional, Sectoral
	Level of disaggregation:	Consuming sector Fuel type End-use process
	Level of energy demand calculation:	Final/Useful

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) The WISCONSIN model has 5 major components: - Socio-economic activity model, - End-use energy demand model, - Energy conversion and supply model, - Environmental impact model, - Preference and decision model. Inputs to the energy demand model are: Socio-economic variables, socio-economic and technical development parameters, population, demographic characteristics, Gross Domestic Product, income, output of the productive sectors, employment, energy prices, energy appliances indicators, etc.
	Information generated (model output): Energy indicators on the end-use level per fuel type and consuming sector
Computer Specifications	Programming language: Fortran and/or Basic Hardware: Mainframe and Microcomputers Storage capacity: Operating system: PC-DOS (MS-DOS) for IBM PC, CP/M for Osborne. Kaypro, etc., Apple-II DOS 3.3 for Apple, Radio Shack TR-DOS for Radio Shack TRS-80 Series Compiler used: Peripheral requirements: Commercial software: Lotus 1-2-3 for IBM-PC, VisiCalc for Apple II series, VisiCalc and Multiplan for Radio Shack TRS-80 Series CPU time needed: Implementation of the Microcomputer possible: Yes
Application, Future Development, Comments	Example(s)/Country(ies) of application: Indonesia, Tunisia, Mexico, Philippines, GDR, USA, Switzerland, Austria
	Future development:

Application, Future Development, Comments	Additional comments: A simplified diagram of overall information flow within the systems of models is given in Figure 5.2.3.

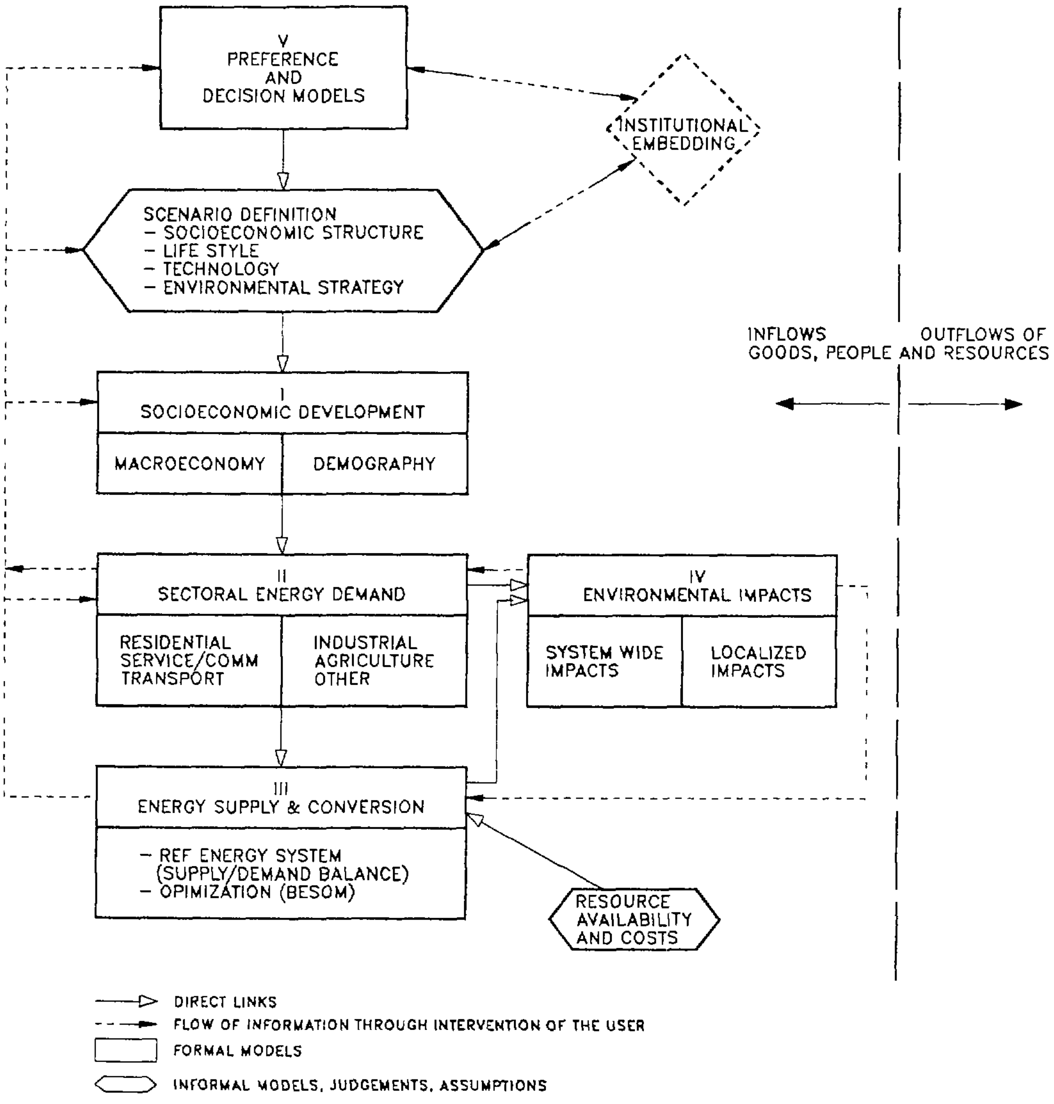


Figure 5.2.3 WISCONSIN Model

Documents	

5.2.3.2 PVDR: Pays en Voie de Developpement Résidentiel

General Information	Name of model:	Pays en Voie de Developpement Residentiel (PVDR)
	Institution:	Commissariat a l'Energie Atomique Departement des Programmes 31-33 rue de la Federation Paris (XV), France
	Contact Person:	S. Amous, A. Ouerghi
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	To analyze the energy consumption in the residential sector of a country; to determine the driving forces of energy demand (socio-economic, economic, etc.); to forecast energy demand evolution in the residential sector, taking into account the loacal context and using a data base based on user suveys; to support energy substitution analyses.
Model Specifications	Modelling Technique used:	Simulation with scenario approach
	Temporal frame:	Time horizon:
	Spatial frame:	Sectoral
	Level of disaggregation:	End-use process
	Level of energy demand calculation:	Final/Useful

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) 1. Constitution of the data base by means of surveys. The surveyed population is typically 1/1000th of all households distributed throughout the country. This total sample is selected and structured according to the most representative factors of the study. Design of the questionnaires ensures that information is collected from the concerned households on all use of energy (except transportation) and all other forms of energy (including non-commercials). 2. Identification of the main determinants of household energy demand for use in modeling Apart from the data on energy consumption and corresponding household expenditures, the PVD-R survey supplies data on numerous other variables. Many of these are socio-economic variables. The PVD-R method uses component analysis, a form of multivariate analysis, which identifies new, synthetic determinants as linear combinations of the basic variables.
	Information generated (model output): The PVD-R model uses the analytical approach. Using the input information, the country's population is distributed into a number of classes, each of which is uniform in terms of energy consumption and associated uses. The results is a graph as in Figure 5.2.4. associated with the energy characteristics of the various classes.
Computer Specifications	Programming language: SAS (Statistical Analysis System) Hardware: IBM 3081 Storage capacity: 1 track Operating system: OS/MVS Compiler used: no Peripheral requirements: Unit 3380/SYSDA Commercial software: SAS Institute CPU-time needed: 2.7 seconds Implementation of the Microcomputer possible: Yes
Application, Future Development, Comments	Example(s)/Country(ies) of application: Tunisia
	Future development:

Application, Future Development, Comments

Additional comments:

Other applications of the model:

a) The PVD-R model can be used to analyse the mechanisms of substitution between different forms of energy.

b) The model can be employed in econometric analysis of household decision concerning procurement of various sorts of energy-use equipment and the corresponding levels of consumption, integrating quantitative, i.e. income, and qualitative variables, i.e. standard of living.

The model structure is given in Figure 5.2.4.

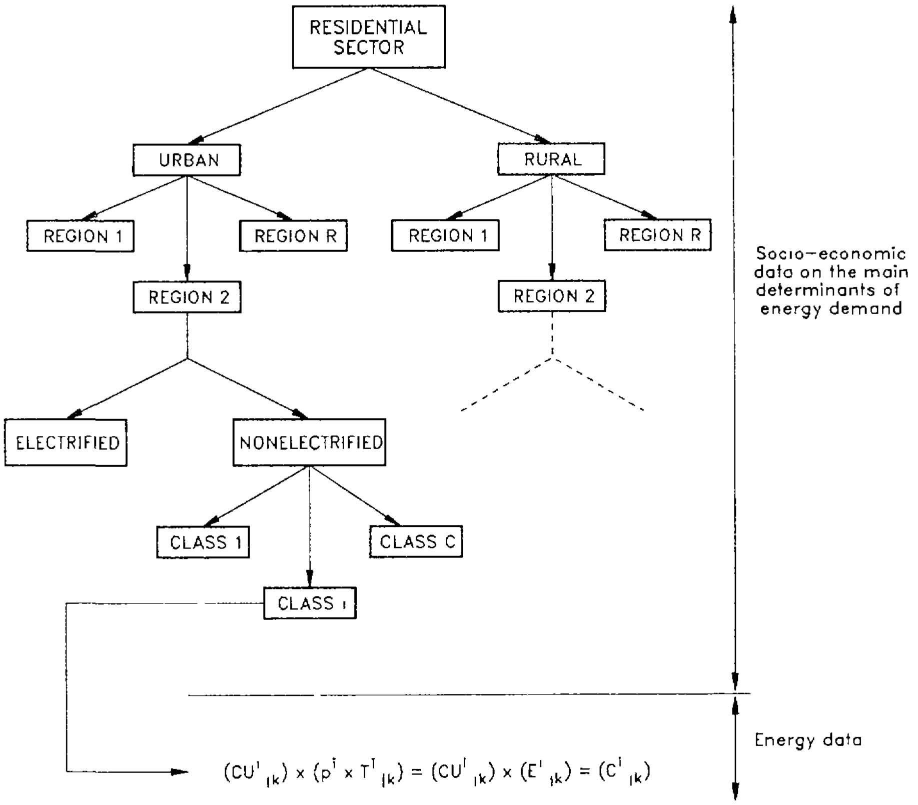


Figure 5.2.4 The PVDR model structure

Documents

5.2.3.3 MEDEE-S: Modèle d'Evaluation de la Demande d'Energie pour les Pays du Sud

General Information	Name of model:	Modele d'Evaluation de la Demande d'Energie pour les Pays du Sud (MEDEE-S)
	Institution:	Institut Economique et Juridique de l'Energie (IEJE) BP 47 X F-38040 Grenoble Cedex, France
	Contact Person:	Betrand Chateau and Bruno Lapillonne
	Availability of Model:	Restricted
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	Long term energy demand forecasting and planning
Model Specifications	Modelling Technique used:	Simulation and Accounting
	Temporal frame:	Time horizon:
	Spatial frame:	National with regional and sectoral disaggregation possibilities
	Level of disaggregation:	Consuming sector Fuel type End-uses
	Level of energy demand calculation:	Useful/Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) Socio-economic data: - value-added per sector and branches - physical output for intensive industries - demography, stock of energy dwelling, equipment of dwelling, etc. - traffics, stock of vehicles, etc. Technical data: - unit consumption of energy per appliance, end use, transport mode, etc. - efficiencies of energy transformation appliances.
	Information generated (model output): Evolution of energy demand determinants Useful energy (relative) requirements Final energy demand
Computer Specifications	Programming language: Fortran Hardware: IBM or compatible with 526 k and 20 Megabytes Storage capacity: approximately 20 Megabytes Operating system: Compiler used: Peripheral requirements: Commercial software: CPU-time needed: Implementation of the Microcomputer possible: Yes
Application, Future Development, Comments	Example(s)/Country(ies) of application: Argentina, Ecuador, Brazil, Colombia, Venezuela, Costa Rica, Nicaragua, Thailand, Mexico, Greece, South Korea
	Future Development: Modelling Computerization Application
	Additional comments: MEDEEE-S belongs to the set of energy demand models which have been developed within the framework of the MEDEE method. It has been designed especially

Application, Future Development, Comments

for application in a wide range of countries, because

- its flexible structure and its specifications allow for copying with numerous various situations in terms of energy end-uses, economic activities and information availability,
- its computerization allows for easy transfer to any kind of computer.

Table 5.2.5 Structure of the MEDDE-model

	STANDARD SUB–MODELS	SUPPLEMENTARY MODULES
INDUSTRY	analysis by branch and end–uses motor fuel uses thermal uses specific uses of electricity	steel energy intensive products (by type of products)
HOUSEHOLD	distinction urban/rural and according to classes cooking (and other thermal uses) lighting (and other electrical uses)	heating water heating electrical appliances cooling
TERTIARY SECTOR	analysis by sub–sector thermal uses specific uses of electricity	heating cooling public lighting
TRANSPORT	distribution between passenger transport freight transport international transport	urban transport
AGRICULTURE	analysis by end–use, or by equipment	

Documents

[5]

5.2.3.4 DEMI: DEmand Model for Indonesia

General Information	Name of model:	Demand Model for Indonesia (DEMI)
	Institution:	- Kernforshungsanlage Juelich (KFA) Systemforschung und Technologische Entwicklung Postfach 1913 D-5170 Juelich, Federal Republic of Germany - Lahmeyer International GmbH Lyoner Strasse 22 D-6000 Frankfurt/M 71
	Contact Person:	M. Kleemann, D. Sievert (KFA) H. Pape (Lahmeyer International)
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	Final and useful energy demand forecasting scenarios for Indonesia
Model Specifications	Modelling Technique used:	Simulation
	Temporal frame:	Time horizon: 30 years Time intervals: 1 year
	Spatial frame:	National with regional and sectoral disaggregation possibilities
	Level of disaggregation:	Consuming sector Fuel type
	Level of energy demand calculation:	Useful/Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.)	- Input-output table - For each demand sector: historical energy consumption data by type of energy carrier and by end-use categories - Final-useful energy conversion efficiencies
	Information generated (model output):	- Economic development scenarios - Energy demand scenarios in terms of useful energy or in terms of final energy by type of energy carrier. Demand estimates are provided on a sectoral and regional level.
Computer Specifications	Programming language:	Fortran
	Hardware:	IBM Mainframe and Microcomputers
	Storage capacity:	less than 0.5 MBytes RAM
	Operating system:	VM
	Compiler used:	Fortran
	Peripheral requirements:	Terminal, printer
	Commercial software:	None
	CPU-time needed:	Minutes
	Implementation of the Microcomputer possible:	Yes
Application, Future Development, Comments	Example(s)/Country(ies) of application:	Indonesia
	Future Development:	Modelling Computerization The model will be extended to include demand management strategies (pricing of energy carriers, regulation and the like)
	Additional comments:	The present version of DEMI is tailored to the Indonesian requirements. The model has been programmed such that it can be easily changed to be used for other countries.

Application, Future Development, Comments

Figure 5.2.6 shows the schematic description of the energy demand approach

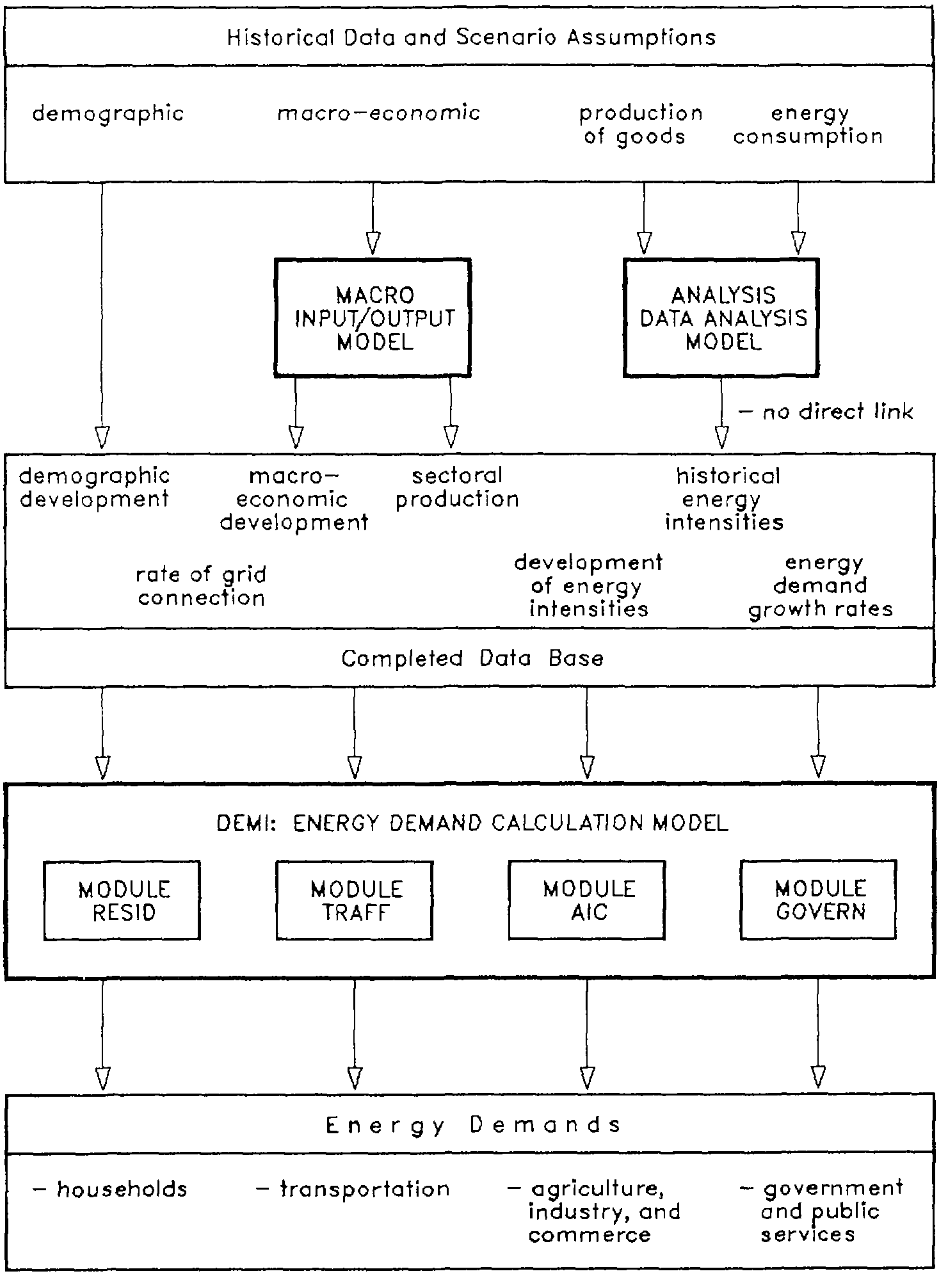


Figure 5.2.6 The DEMI-Approach

Documents

5.2.3.5 MAED: Model for Analysis of Energy Demand

General Information	Name of model:	Model for Analysis of Energy Demand (MAED)
	Institution:	International Atomic Energy Agency (IAEA) NENP P.O.Box 100 A-1400 Vienna, Austria, Europe
	Contact Person:	
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	MAED is a model for evaluating the energy demand implications (in the medium and long term) of a scenario describing hypothesized evolution of the economic activities and of the life-style of the population
Model Specifications	Modelling Technique used:	Simulation
	Temporal frame:	Time horizon: flexible Time intervals: flexible
	Spatial frame:	National with regional and sectoral disaggregation possibilities
	Level of disaggregation:	Consuming Sector Fuel type End-uses
	Level of energy demand calculation:	Useful/Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) The MAED model consists of 4 modules each having the following specific requirements: Module 1 (Energy Demand) requires socio-economic and technological information concerning the activities and energy split in sectors: household, services, industry, mining, construction, agriculture, transport Module 2: (Hourly Electric Power Demand) converts the global annual electricity demand of each consuming sector on an hourly basis Module 3: (Load Duration Curve) transforms the hourly load curve into the format required by the WASP model (IAEA energy supply model) Module 4: (Load Modulation Coefficients) may be used for determining the various load modulation coefficients (trend, seasonal, daily, hourly) characterizing a consuming sector, a group of consumers, etc.
	Information generated (model output): Each module of the MAED model has its own output: Module 1: Final energy results by sector and energy form (fossil, soft solar, electricity, motor fuel, coal, feedstocks); socio-economic and economic variables (e.g. transportaiton activity level, value added, GDP formation, etc.); energy intensities and load factors Module 2: Specific coefficients of the electricity sector on the basis of day, client types and per season, etc., and the typical hourly load of each sector and the total power system Module 3: Load duration curves of the system for each period into which the year has been subdivided, etc. Module 4: Energy growth trend coefficients per week; hourly load coefficients for each hour and per calendar day; etc.
Computer Specifications	Programming language: FORTRAN Hardware: IBM 3081/3032 Storage capacity: Operating system: MVS Compiler used: Peripheral requirements: Commercial software: LIBRARIAN, TELL-A-GRAF (dispensable) CPU-time needed: Implementation of the Microcomputer possible: Yes

Application, Future Development, Comments

Example(s)/Country(ies) of application:

Algeria, Indonesia, Jordan, Malaysia, Thailand, Turkey, Tunisia, Venezuela

Future development:

Microcomputer version under developement using Microsoft-FORTRAN

Additional comments:

Figure 5.2.7 displays the interconnection between the modules of the MAED model.

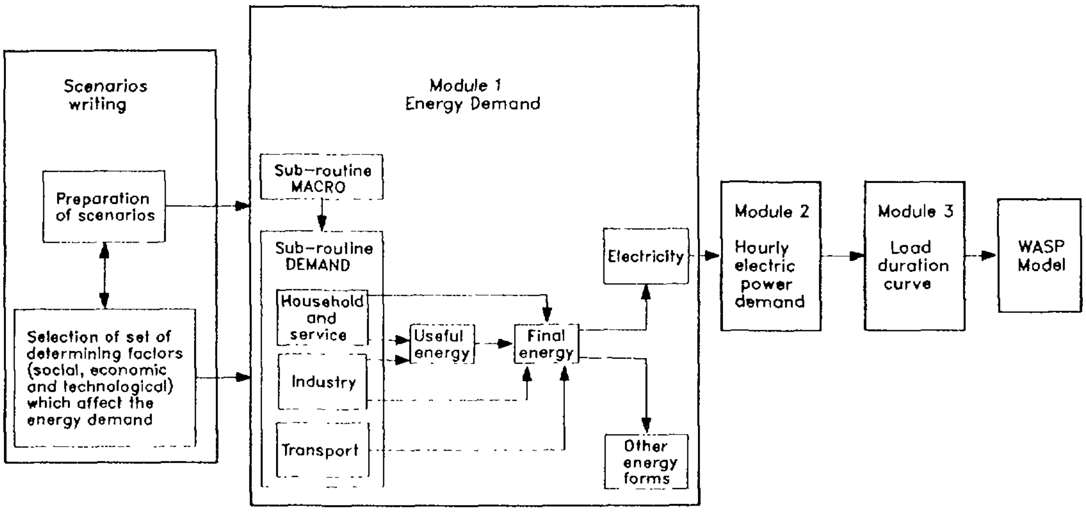


Figure 5.2.7 Interconnection between MAED modules

Documents

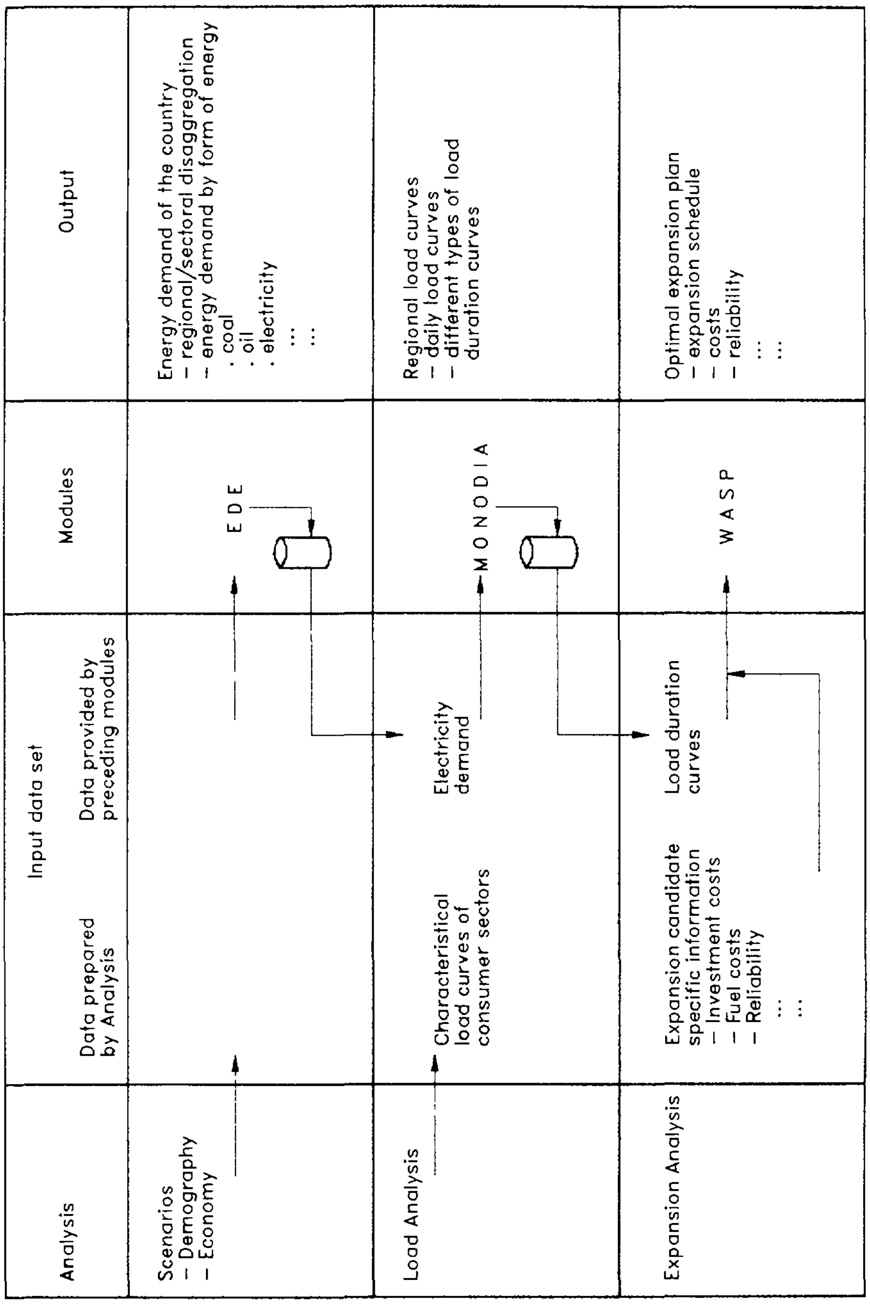
see section 6.1

5.2.3.6 EDE: Energy Demand Evaluation

General Information	Name of model:	Energy Demand Evaluation (EDE)
	Institution:	International Atomic Energy Agency (IAEA) NENP P.O.Box 100 A-1400 Vienna, Austria, Europe
	Contact Person:	
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	Long-term energy demand forecasting in different regions of a country; adequate consideration of non-commercial forms of energy in the energy planning process
Model Specifications	Modelling Technique Used:	Simulation
	Temporal frame:	Time horizon: flexible Time intervals: flexible
	Spatial frame:	National with regional disaggregation
	Level of disaggregation:	Consuming sector Fuel type End-uses
	Level of energy demand calculation:	Useful/Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) The EDE model requires socio-economic and technological information concerning the activities and energy split in sectors: household, services, industry, agriculture, transport
	Information generated (model output): *The output of the EDE approach is as follows:* final energy results by sector and energy form (fossil, soft solar, electricity, motor fuel, coal, feedstocks); socio-economic and economic variables (e.g. transportation activity level, value added, GDP formation, etc.); energy intensities and load factors The output of the EDE model serves as input to the electrical load curve synthesis model MONODIA (see section 6.2)
Computer Specifications	Programming language: FORTRAN Hardware: Mainframe and Microcomputers Storage capacity: approximately 5 Megabytes Operating system: Compiler used: Peripheral requirements: Graphic terminal (Printer, Plotter) Commercial software: None CPU-time needed: depends on problem size, dialogue oriented system Implementation of the Microcomputer possible: Yes
Application, Future Development, Comments	Example(s)/Country(ies) of application: Algeria
	Future development:

Application, Future Development, Comments	Additional comments: The relationship between the modules of the EDE system is shown in Figure 5.2.8.



Analysis	Input data set: Data prepared by Analysis	Input data set: Data provided by preceding modules	Modules	Output
Scenarios – Demography – Economy			E D E	Energy demand of the country – regional/sectoral disaggregation – energy demand by form of energy . coal . oil . electricity ... ...
Load Analysis	Characteristical load curves of consumer sectors	Electricity demand	M O N O D I A	Regional load curves – daily load curves – different types of load duration curves
Expansion Analysis	Expansion candidate specific information – Investment costs – Fuel costs – Reliability	Load duration curves	W A S P	Optimal expansion plan – expansion schedule – costs – reliability ... ...

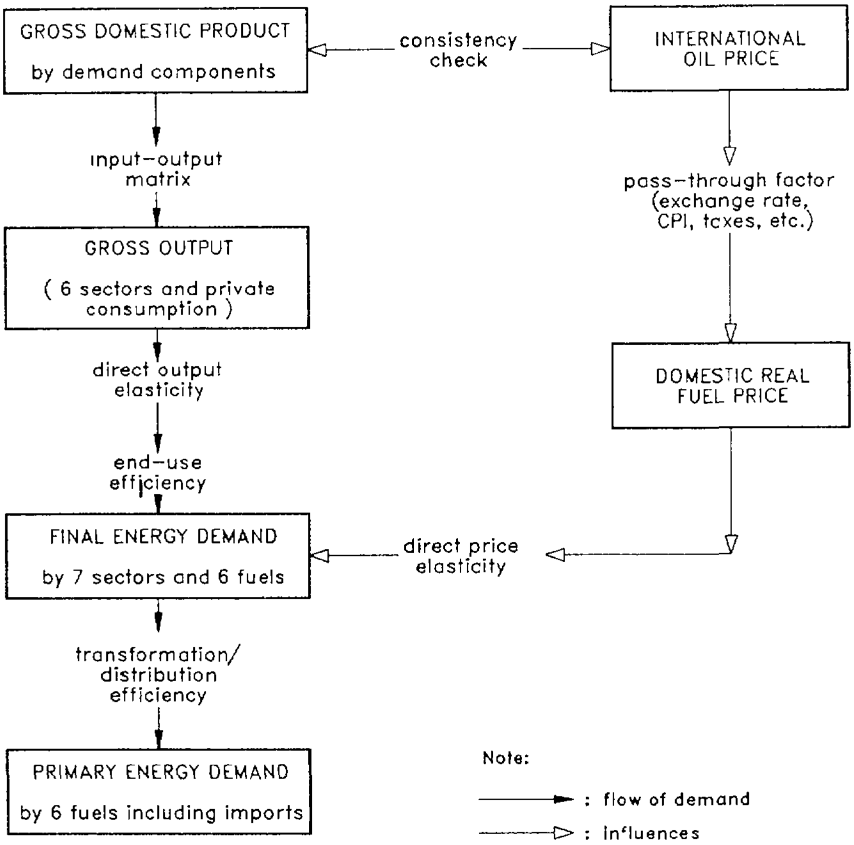
Figure 5.2.8 The EDE System

Documents	see section 6.2

5.2.3.7 Minimum Standard model (The World Bank approach)

General Information	Name of model:	Energy Demand in Developing Countries A Minimum Standard Model
	Institution:	ATW-Forschung Geiersbergweg 7 D-8400 Regensburg, FRG
	Contact Person:	Lorenz Jarass
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms (including biomass)
	Purpose and Subject addressed:	Projections of energy demand by fuel type on national level on the basis of data from input-output and engineering analyses with econometric estimates.
Model Specifications	Modelling Technique used:	Simulation Econometrics
	Temporal frame:	Time horizon: Time intervals:
	Spatial frame:	National by consuming sectors
	Level of disaggregation:	Consuming sector Fuel type
	Level of energy demand calculation:	Useful/Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) Components of Gross Domestic Product and their growth rates; energy balance, disaggregated into sectors and fuels for the base year; economic development for the time horizon; energy prices and efficiencies of energy transformation processes (primary --> final, final --> useful/energy services)
	Information generated (model output): Time development of demand for final and primary energy, disaggregation into 6 fuel types including biomass and into 7 consuming sectors; development of end-use efficiencies and transformation efficiencies
Computer Specifications	Programming language: Hardware: Storage capacity: Operating system: Compiler used: Peripheral requirements: Commercial software: CPU-time needed: Implementation of the Microcomputer possible: The program can be run on an IBM-PC using Fortran IV or Pascal
Application, Future Development, Comments	Example(s)/Country(ies) of application: Brazil, India, USA, FRG
	Future Development: The model will be extended including a separate breakdown of the rural energy consuming sectors.
	Additional comments: The model has been developed on behalf of the World Bank Economic Projections Department and can be used for industrialized and non-industrialized countries. The basic structure of the model is given in Figure 5.2.9.

Application, Future Development, Comments	 * Note that output, price, end–use efficiency and energy demand are in the form of rates of change Figure 5.2.9 Basic structure of Model
Documents	

5.2.3.8 RESGEN: Reference Energy System GENeration

General Information	Name of model:	Reference Energy System Generation (RESGEN)
	Institution:	IDEA Inc., Suite 1020 900 17th street NW Washington DC 20006, USA
	Contact Person:	P. Meier, J. Lee
	Availability of Model:	General
	Energy spectrum covered:	All Energy Forms
	Purpose and Subject addressed:	Microcomputing based Modelling System for Energy Analysis in Developing Countries
Model Specifications	Modelling Technique used:	Simulation
	Temporal frame:	Time horizon: flexible, typically 5-20 years Time intervals: 1 year
	Spatial frame:	Flexible, user determined
	Level of disaggregation:	Consuming sector Fuel type (User determined - can be used for a simple model of rural fuelwood to complex, multi-regional, multi-sectoral and multi-fuel models of national energy use.)
	Level of energy demand calculation:	Useful/Final

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) RESGEN is not a fixed model as much as software to develop models. Any system that can be visualized as a network can be handled. Typical application for electricity planning would require user specified projection equations for demand, technical parameters for generation, fuel costs, etc.
	Information generated (model output): Typical output might include national energy balance, optimal dispatch of electric system, investment and debt service requirements.
Computer Specifications	Programming language: Hardware: Microsoft-DOS Storage capacity: 384 k RAM Operating system: Compiler used: Peripheral requirements: Printer, color pen plotter Commercial software: CPU-time needed: Implementation of the Microcomputer possible: Yes
Application, Future Development, Comments	Example(s)/Country(ies) of application: Sri Lanka, Uruguay, Haiti, Indonesia, Thailand, Dominican Republic
	Future Development:
	Additional comments:
Documents	[6,7,8]

5.2.4 Electricity demand models

5.2.4.1 PVDE: Pays en Voie de Développement Electrique

General Information	Name of model:	Pays en Voie de Developpement Electrique (PVDE)
	Institution:	Electricite de France (EdF) Etudes Economiques et Tarification 68 rue du Faubourg Saint-Honore F-75008 Paris, France
	Contact Person:	P. Launay
	Availability of Model:	General
	Energy spectrum covered:	Electricity
	Purpose and Subject addressed:	Short-, medium- and long-term electricity demand forecast; to model the electrification process; to model the spatial and socio-economic differences within the consumer base; to model the interface between electricity and other forms of energy
Model Specifications	Modelling Technique used:	Simulation on scenario basis
	Temporal frame:	Time horizon: 20 years Time intervals: (N, N+1...N+5, N+10, N+15, N+20)
	Spatial frame:	National with sectoral breakdown
	Level of disaggregation:	Consuming sector

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) Data concerning macroeconomics, demography, housing, energy usage and policy, the electric power system and electrification
	Information generated (model output): Forecast of electric energy demand: - in the residential sector - in the industry sector - in the tertiary (service, commercial) sector - total Forecast of required electric power production Forecast of total consumption and regional production for each electric power subsystem
Computer Specifications	Programming language: SAS (Statistical Analysis System) Hardware: Storage capacity: Operating system: Compiler used: Peripheral requirements: Commercial software: CPU-time needed: Implementation of the Microcomputer possible: Implementation underway (Any computer system compatible with SAS language can be used)
Application, Future Development, Comments	Example(s)/Country(ies) of application: Senegal, Ivory Coast, Argentina, Egypt, Reunion Island, Guadalupe, Martinique
	Future development:

Application, Future Development, Comments

Additional comments:

PVDE is a 'master' model in a family of computer models designed for electricity industry forecasting on behalf of utilities, public authorities, etc.

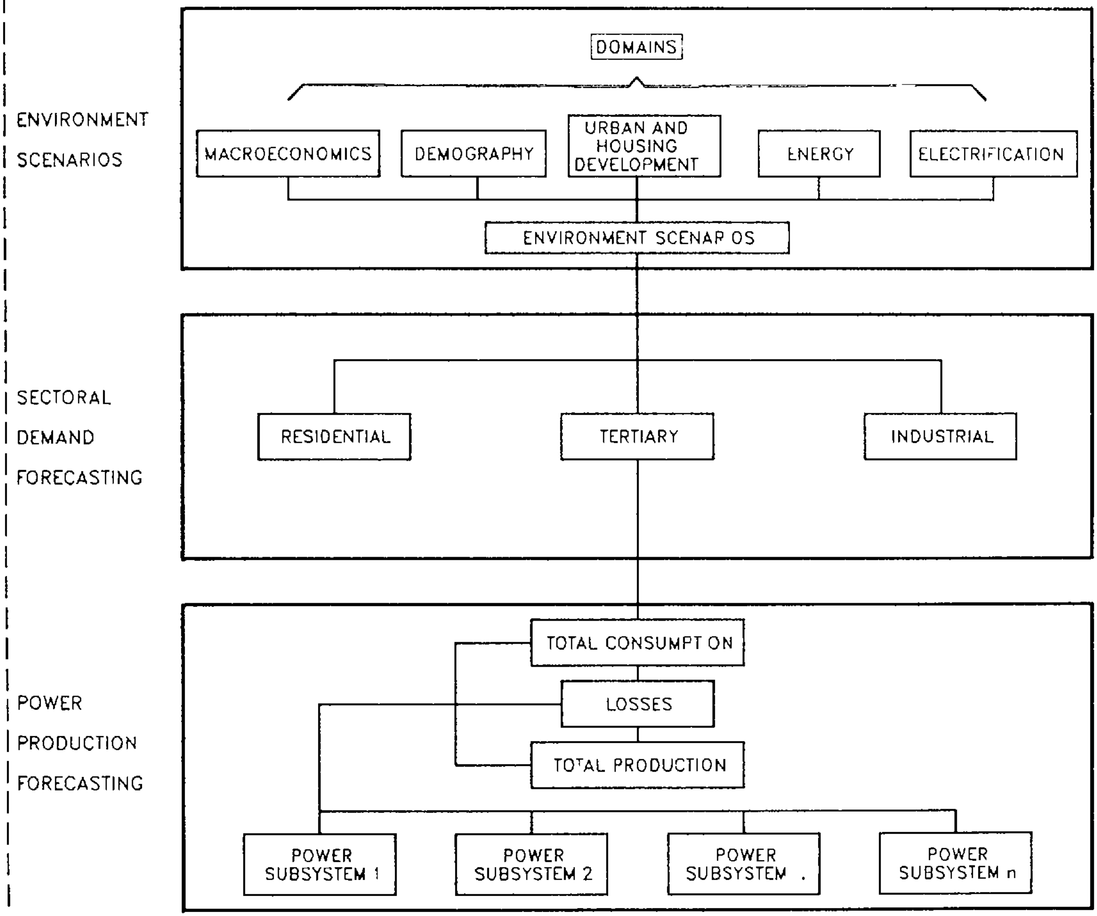


Figure 5.2.10 The General Organization of the Model

Documents

5.2.4.2 SPM: Electricity Demand Forecasting System

General Information	Name of model:	Electricity Demand Forecasting System (SPM)
	Institution:	Eletrobras Escritorio Central Av. Presidente Vargas 642-10 20.079 Rio de Janeiro, Brazil
	Contact Person:	Paulo de Vilhena Brandao
	Availability of Model:	General
	Energy spectrum covered:	Electricity
	Purpose and Subject addressed:	Power system planning for the entire country
Model Specifications	Modelling Technique used:	Simulation
	Temporal frame:	Time horizon: 20 years Time intervals: as requested
	Spatial frame:	National, Regional, Sectoral
	Level of disaggregation:	Consuming sector

Model Specifications	Information requirements: (type of data needed, number of exogenous and endogenous variables, etc.) Historical series of consumption per consumer classes, number of residential consumers (households), number of houses, etc. GNP and industrial production
	Information generated (model output): - Annual Consumption (MWh) for each consumer class and for their total - Number of residential consumers (households) - Annual growth rates - Demand structure tables
Computer Specifications	Programming language: Fortran Hardware: IBM 4381 Storage capacity: 16 Megabytes Operating system: MVS Vs. 1.3.4 Compiler used: Fortran enhanced Peripheral requirements: Video terminal, Printer Commercial software: ADABAS CPU-time needed: depends on problem size Implementation of the Microcomputer possible: This will require some modifications of the programmes and routines that integrate the system.
Application, Future Development, Comments	Example(s)/Country(ies) of application: Brazil
	Future Development: This will include system improvements for other applications, such as economical studies and integration to micro computers

Application, Future Development, Comments

Additional comments:

The diagram of the demand forecasting procedure is presented in Figure 5.2.11.

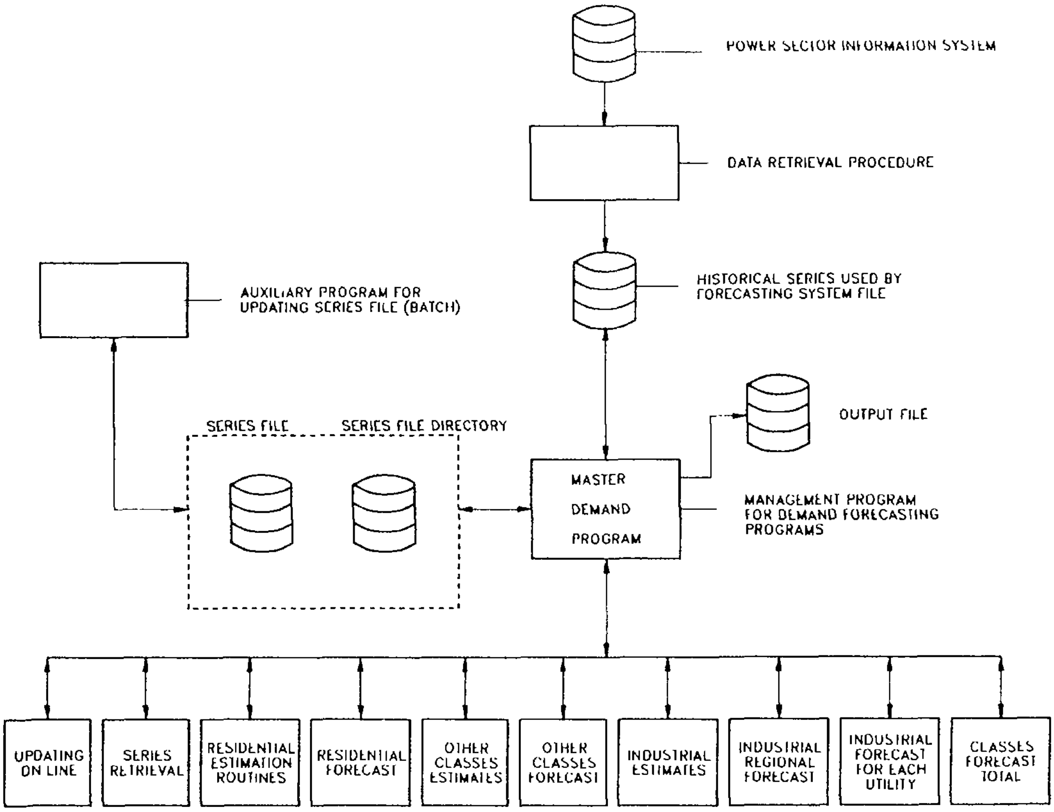


Figure 5.2.11 Demand Forecasting Program Diagram

Documents

5.3 Multilateral efforts

In addition to specific modelling approaches, as outlined in Sections 5.2.2 to 5.2.4, there are more general approaches tackling energy demand and supply planning not from the country point of view but globally by interconnecting the national energy planning activities.

Two approaches in this context, those of the World Energy Conference and the Commission of the European Community, are presented subsequently.

5.3.1 WEC: World Energy Conference

5.3.1.1 Characteristics of the WEC

The WEC is an international organization with the characteristics:

- non-governmental; its role is to bring together technicians, scientists, members of the academic community, business leaders and politicians,
- world-wide in scope; it operates through a network of some 80 Member Committees representing most of the major energy producing and consuming countries in the world; most of the international organizations concerned with energy problems are directly associated in the work of the WEC,
- multi-energy in its outlook; all types and sources of energy fall under its purview,
- strictly limited with budgetary resources; its work is supported essentially by the voluntary contributions of its Member Committees and associated organizations.

5.3.1.2 Characteristics of WEC's approach to forecasting

The methodological principles which constitute the approach to the problem, can be characterized as follows:

- studies are made on a long term basis; beginning with its first report (1974-1977), the horizon of its forecasts has been set at 2000 - 2020,
- they are in the form of cross section analyses that do not take into consideration annual trajectories,
- they present a global (or semi-global) picture of energy needs to the exclusion of detailed analyses,
- forecasts are based on scenarios, a necessity for long range forecasting,
- they are basically expressed in quantities, prices being introduced implicitly in the framework of the different scenarios,

- they are concerned with primary energy sources without any specific reference to secondary ones or the analysis of different sectors (in relation to final uses or to useful energy),

- they are regional, divided up by the major regions of the world without having recourse to national studies (or at least not publishing them),

- the studies are open and in constant evolution: the WEC has not used one sole model in its forecasting, but rather a whole series of different models and approaches that have been successively used in accordance with the objective sought,

- they are multinational in conception: all studies have been inspired and coordinated by a central team of specialists, and submitted to the Conservation Commission itself for control at each step; they are revised by panels of Conference experts; Member Committees are kept informed and participate in the making of these studies.

5.3.1.3 Evolution of studies

A brief review of the different Congresses displays the evolution of the subjects treated and the methods used.

Istanbul, 1977

The first really meaningful global forecast was presented by a team of specialists of the Cavendish Laboratory at Cambridge University (United Kingdom) and employed a computerized model to explore a number of different scenario based on a variable economic climate, with the constraint of a maximum overall world energy supply of 1000 Exa-Joule in the year 2000. [9]

The abundance of the results obtained led to a selection of a few representative scenarios based on two series of high and low projections.

The study treated the problems of adjusting supply and demand as well as the different main regions of the world. A number of forecasts, in particular the prospects held out to the developing countries have been more closely investigated by a team of experts from the University of Stockholm and an alternative scenario have been developed. In parallel, a series of special studies devoted to the estimation of the ultimate reserves have been carried out by the Institut Francais des Petroles. [10]

Munich, 1980

The insufficient knowledge of the problems concerning developing countries led to a study carried out by a team of French specialists. This study examined the developing countries in ten different regions by means of a centralized overall approach using two contrasting development scenarios derived from two of the scenarios in the OECD Interfutures project. It was devoted solely to forecasting consumption. Particular attention was paid to two points:

- the estimation of non-commercial energy sources which for the first time were integrated into a general world-wide study,
- the development of an original method for forecasting the income elasticities, introducing the evolution of a series of qualitative and quantitative sectoral factors, classified and weighted. [11]

New Delhi, 1983

In order to update the results presented in the pilot study at Istanbul, a decentralized approach was favoured making the most comparative advantage of the studies carried out by Member Committees.

Ten regional working groups created especially for this purpose brought together some 50 experts from 20 different Member Committees and 10 international organizations. Each working group, using guidelines provided by the central team, was charged with the responsibility of forecasting energy consumption, production and exchanges in their region for the period 2000 - 2020, making use of two scenarios of economic development, one high, the other low. [12]

This approach made possible the use, depending on the region, of all the different forecasting methods possible, from the highly sophisticated models of simulation to the use of intuitive models, based on personal experience as well as informal discussions within the working group. Seventeen meetings were held in different parts of the world during the preparation of this report, and the final results were harmonized and rendered coherent by the central team. [13]

Cannes, 1986

The focal point of the Congress concerned the comparison of the evolution of energy demans with the stock of different fuel reserves, in particular non-renewable sources.

The exercise itself consists in calculating total consumption of the four types of non-renewable energy (coal, petroleum, gas and uranium) for five reference regions between 1980/1985 until 2060 by twenty year subdivisions. The compilation of the data makes it possible to define eleven regions or zones and to compare, for each region and each energy source, total accumulated consumption with corresponding reserves, classified by relative costs.

To these basic assumptions were added a number of strategic variants, in particular the gradual introduction of breeder reactors, the imposition of possible environmental constraints on the use of nuclear energy (moratorium), or firewood or fossil fuels (CO_2, NO_x).

The WEC has not hesitated to make use of varied and imaginative methods (theoretical work on global approaches, research concerning the key variables such as the elasticity of energy consumption/revenue, or non-commercial energy sources) with a constant concern for providing as complete and relevant an overall view of the world situation as possible.

5.3.2 CEC: Commission of the European Communities

5.3.2.1 Introduction to the CEC approach

The CEC has undertaken a multilateral effort to develop a method for energy demand forecasting. It is carried out mainly by 12 energy research institutes from Europe and developing countries. This programme, supported by about 4 million US$ during 1980-1986, was launched in 1980 and involves some 50 researchers.

The research undertaken has been oriented towards the elaboration of action and understanding tools appropriate to the situation in developing countries. It comprises three main topics: data collection and processing, case studies at local level, particularly in rural areas, and the preparation of an analysis and forecasting method for energy requirements and provisions. These methodological tools are now used in forecasting studies, energy planning operations and energy policy choices.

The energy problems of developing countries and the elaboration of specific methods to be used in economic analysis and energy forecasting and planning in order to combat these problems arouse increasing interest. A lot of research in universities and specialized institutes has been devoted to them. They were discussed at numerous international, regional and world-wide conferences. They gave rise to national, bilateral and multilateral specialist training programmes and to the elaboration of development plans.

Energy problems are complex because of the role played by energy in the economy. It is linked to the satisfaction of all consumers' social needs and is an input in the production process of all branches of the economy. In the developing countries which are still putting their energy systems together, the choices to make concerning basic development strategy options will have long-term effects which will extend far beyond the boundaries of the energy sector itself.

This is why the CEC and the institutes participating in the current research are preoccupied with the numerous relationships existing between the energy system and the economic and social system as a whole and the possibilities thus afforded for alternative development strategies and policies. This forms one of the main lines of the approach.

A few comments on the work undertaken are called for:

- Research was carried out within a network comprising several institutes in Asia, Africa and Latin America and in Europe which acted as coordinator and Liaison officer with the European Communities Commission. Furthermore, the CEC and the network centers are in contact with different organizations in the respective regions, the project therefore made possible both a continuous South-South and North-South cooperation.

- The participating institutes were given complete academic freedom in their research which has itself fenefited from the multifarious nature of the network.

- From the beginning the aim was to harmonize the points of view of the various participants as regards the basic questions; it is a joint effort which has been broadly accepted by all the participants, although they may differ on points of detail.

- Finally, and this must be emphasized, this joint approach has concentrated on research into analysis, forecasting and decision-making tools and methods specially adapted to the specific nature of the energy situation in developing countries and to their development objectives.

The CEC and the network members put into practice the analysis and forecasting tools either in national energy exercises or more comprehensive forecasting exercises. The methodological research itself will benefit from these practical applications and the present results will be reappraised, studied in depth and developed.

Beyond the published results [14], the joint project has enabled the formation of a real network which has given rise to a permanent collaboration between the participants.

5.3.2.2 Key-elements of the approach

a) <u>The notion of an Energy System</u>

- <u>Physical system and socio-economic system</u>
  Energy is an element in a physical system subject to the laws of thermodynamic. But it certainly can not be used alone and its uses penetrate various sectors of the economic and social system.

  The CEC approach considers energy as a component of the economic and social system, that is a product which along with other goods and services contributes to the satisfaction of man's social needs.

  A complete description of the energy system and particularly its insertion into the economic and social system as a whole requires the use of tools which identify the economic flows expressed by values and prices. From this point of view energy is part of a complex set of national accounts: input/output tables, economic tables, flows of funds tables.

- <u>The energy system's surroundings</u>
  The energy system is a sub-set forming part of the economic and social set and articulates on other subsets: rural and urban, agriculture, industry, transport, services, housing, etc. The links between them must be examined from two angles: the energy requirements of the other subsets and the requirements of the energy system as regards all other goods, particularly capital goods. A significant part of the CEC approach consisted in understanding how the energy system responded and responds to the variety of requirements in the past and present (energy diagnosis) and how it might respond to them in the future (forecasting).

As the links between the energy system and the surroundings are multiple and complex, an attempt has been made to carry out a more detailed and precise analysis of the relationship between the elements of the energy and the economic system.

A consideration of various interactions with agriculture and industry (as well as with transport, building and services) could lead to energy choices very different from those resulting from a calculated optimization of the energy system alone according to traditional methods.

- Internal components

  An energy system is more than just a set having complex links with the outside world and playing a diversified role in an even larger set. It is also a set with all its present and potential articulations.

  Internal energy system articulations cover the relationship between the various sources and the possibilities of substitution between energies and energy transformation. This is not limited to energy forms already in use but must also include new energies. The interdependence of these various energy sources is particularly important for developing countries; it will often be one of the basic elements of any future changes in their energy systems.

b) Methods and concepts used

- The concepts employed

  In order to succeed in elaborating a coherent methodological line, a certain number of concepts had to be used with the same acception throughout various stages. This set of concepts goes beyond the elementary observation stage and avoid describing energy consumption and production modes by means of an inappropriate economic theory. It is through these specific concepts that one will really be able to grasp the internal workings of the energy system and its relationship with the other systems.

  Furthermore, these concepts form the basis of methodological developments and constitute points of reference along the line followed, they are also of use in the implementation and use of these methods. These concepts make the adequate consideration possible of the successive stages from observation to representation and from representation to model building that is regarded by the CEC as important in the analysis.

- Socio-economic needs and energy requirements

  The first idea to be given prominence is that of needs. Without taking sides in the controversies which raged at one time as regards human and basic needs, it may be said that man's personal, family and social activities necessitate the availability of certain quantities of material goods, and the creation of certain psychological, cultural and spiritual conditions. The term socio-economic needs (or more simply social needs) will be used to express the fact that these needs are not defined by absolute quantitative norms but may be satisfied differently in various socio-economic contexts.

The transition from the social needs concept to the energy requirements concept must be made carefully. One avoids talking of energy requirements in the same way for example as food requirements. Whereas food requirements can be determined in certain minimum norms, energy requirements do not exist either in terms of quantity or in terms of source as energy is not required in itself but in connection with the satisfaction of other needs.

Energy has a role to play on the one hand in liaison with the different final, individual or collective, consumption items and on the other hand in liaison with the production sectors which are themselves oriented towards the satisfaction of social needs. Therefore energy helps meet social needs both directly and indirectly through the production of other goods and services.

- Energy end uses and useful energy

  Socio-economic needs which require energy use in order to be satisfied materialize through energy end uses. Energy use can be seen as a linking concept between the energy system's socio-economic dimension and its physical dimension. It is the category which expresses or specifies the need and which makes possible a definition of its various physical components, particularly the thermodynamic one. It is this category which opens up the possibility of using quantitative methods of energy analysis.

  Energy equipment is the technical corollary to the realization of energy end use as it may be said that no use of energy is possible without a piece of equipment, however basic. As to the use intensity it may be measured by useful energy. It is therefore related to the efficiency of the equipment used. Depending on the methods and type of equipment used, the same level of need satisfaction can be obtained with very different physical quantities of energy.

  It is not merely the quantitative level achieved by final energy consumption which defines a given economic sector or consumer group. The nature and quality of the energy used must also be specified (high or low temperature heat, mechanical force, light radiation, etc.) and this is not only possible by reference to the various energy end uses listed.

- Energy modules and chains

  These two concepts have an essentially operational significance for description, analysis and forecasting.

  An energy module is defined with regard to a given end use and groups together a homogeneous set of consumers on the basis of one or more criteria: social, economic, demographic, spatial, etc.

  The energy chain concept refers to a global representation of the three successive stages primary, final and useful energy which indicates the physical flows of energy products through the extraction, transformation, transport, distribution and uses stages. In this procession one seeks to take into account all the energy resources and energy means which must be put into play in order to supply each module with energy.

- Models and model building techniques
  A model can only be of use if it provides, albeit in a simplified form, a fairly faithful representation of reality. The specific features of developing countries require the development of energy systems. These models to be used must be specifically designed so as to take into account specific realities and objectives of the country concerned. These models should be sufficiently broken down in order to simulate new relationships differing from the past ones (for example in consumption patterns, technology choices, income distribution, etc.). They should also be sufficiently transparent so as to enable those relationships one wishes to change to be easily identified.

  Another advantage of this idea of model building, particularly for planning, is that is associates expected changes in behaviour with those energy policy measures which make them possible. For example the introduction of a change in specific energy consumption in a particular industrial branch will only be justified if one anticipates those investments necessary for corresponding technological changes.

  Although these models can in no way replace decision-making which remains a discrete process and is often a political act, they may have their place in a methodology which aims at helping the decision-making process. Formalization will be sought in a systematization of data gathering and presentation (both energy and non-energy data) and in the linking of calculation procedures.

c) The principal research line

The principal research line concerns data, case studies and forecasting methods.

- Data
  At a national level energy balances for a certain number of developing countries were worked out and analyzed.

  The Integral Balance sheet (Section 2.3.2.1) was elaborated with the idea of going beyond some of the limitations in the conventional balance sheet, and expanding and gathering of data relating to operations upstream of production (resources, reserves, and potential) and downstream of final consumption (useful energy). It is a means of sorting and representing which is more suited to describing energy system than conventional balance sheets, whilst being used as a basis for forecasting and analysis work.

  In this context also specific research was undertaken to define a method for evaluating renewable energy potential, basically biomass products, which would take account of competition between energy and non-energy crops and those factors limiting their expansion (land availability, technology, etc.).

- Case studies

  An understanding of the national energy system is essential but is not enough on its own. It must be supplemented by a more detailed analysis illustrating the different use methods at a local level in various geographic, social, cultural and production contexts, and assessing a category of problems which are not inmediately obvious in a purely national context. The spatial dimension and the close interdependence of various factors ofetn play a dominating role which is difficult to explain on too large a scale.

  A significant part of the CEC programme was devoted to the realization of case studies which mostly concern the rural system in several countries. The diversity of the situations studied, fishing village, cattle breeding area, mountain villages practicing a self-reliant type of economy or a region with coexisting small-scale industry and agricultural activities, provides fairly contrasting insights and conjures up a large variety of problems concerning the way in which lifestyles, production types and resource availability control energy consumption modes.

  These studies are not appendices, nor are they the lip service paid to some vague ethnological idea. On the contrary, they help to illustrate that the different levels of analysis, action and intervention cannot be seen in isolation of each other.

- Forecasting methods

  The last main line of research concerns forecasting methodology. This comprises thre sub-parts: energy use forecasting methods, energy supply forecasting methods, and methods for adequating supplies to uses. The general directions consist in restructuring an Integral Energy Balance starting from an evaluation of useful energy requirements within each module and determining the final energy necessary using use efficiencies and energy substitution hypothesis. Primary energy quantities to be made use of - production, imports, exports - as well as the reserves to be built up, are calculated in various ways.

  The adequation between the forecasting of uses and the forecasting of supplies is sought when the two previous stages have been concluded, via a more or less rapidly converging movement of successive approximations in which the forecaster will exercise his judgement, or if the method is to be used for planning, in which social preferences will be indicated by the appropriate authority.

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Chapter 6

IAEA METHODOLOGIES FOR ENERGY AND ELECTRICITY DEMAND FORECASTING

For many years the International Atomic Energy Agency has been involved in the execution of studies aiming at the determination of the future role of nuclear power as a source of energy. In addition, the Agency conducts a comprehensive programme of work in nuclear power planning and implementation to assist its developing Member States (see Section I.3).

To perform these activities the Agency used, along the years, different approaches and methodologies, and sometimes had to develop its own models. This chapter presents some of the models for energy and electricity demand forecasting developed by the IAEA. Prior to this discussion it is, however, necessary to introduce the history of these developments.

In earlier years, the economic assessment of nuclear power consisted simply in comparing total annual generation costs of nuclear power plants against alternative generating plants operating at base load (provided that the size of the electric power grid was large enough as to permit this mode of operation). However, it was soon realized that the development of nuclear power could only be analyzed as part of the overall expansion of the electric power system in which all available types of energy resources were considered, thus introducing the concept of integrated expansion system analysis.

For this type of analysis, the IAEA developed the WASP computer program (Wien Automatic System Planning Package) and a related methodology [1] designed to find the economically optimal generation expansion policy for an electric power system within certain constraints specified by the user. WASP was first used in 1972-73 by the IAEA for the execution of global studies [2, 3] and later, during the period 1974 - 1977, at special request of some of its Member States, to carry out individual Nuclear Power Planning (NPP) studies[4].

The experience gained in the use of WASP from the execution of such studies has led to the development of improved versions of the model. The latest version, WASP-III [5], is considered by electric utilities worldwide and international organizations (e.g. IBRD) to represent the state-of-the-art model for electricity expansion planning.

Although the WASP methodology has been recognized as suitable for carrying out NPP studies, some criticisms have been raised to these studies, specially concerning the electricity demand forecasts used in each case, which in fact constitutes part of the main input information required for the execution of a WASP study.

Until recent years, these forecasts had been usually carried out by means of econometric models. A large variety of models were applied in the past, ranging from simple extrapolations of historical trends to the more sophisticated techniques including co-relation of the energy demand to macro-economic indices of the country such as the GDP or GNP. However simple or sophisticated, all these models were based on the search for an invariant parameter to be related to the energy demand and the link between both was supposed to be a constant or of universal nature, or both at the same time.

Consequently, the main criticisms encountered in using electricity demand forecasts based on econometric approaches for the conduct of NPP studies were:

- that the relation between electricity consumption and macro-economic parameters (for example GDP per capita) is unclear, particularly in the present context of the international energy situation;
- that the hypothesis used by econometric models, i.e. the invariability of econometric relations, is rarely satisfied;
- that econometric models do not permit identifying which factors determine the demand for electricity; and finally
- that the future development of the electricity sector in general, and of nuclear power in particular are not autonomous or independent from external influence; thus an appraisal of this development within a global energy framework is required.

In the last few years, however, energy planners have been introducing new methodologies for the analysis of the energy demand. In this respect, different approaches have been tested with various degrees of success. The so-called "scenario" approach constitutes one of these new methodologies. According to this approach, energy demand is determined by a set of parameters describing a possible future situation of the country or region under consideration with respect to demographic, economic, social and technological factors which are recognized to have a strong influence on the demand for energy. Thus, the set of determining factors describes a "scenario" of development for the country (or region). Besides, they are the driving force behind the models based on this approach since very few assumptions are made as to the relationships linking energy demand and the set of "scenario" factors. Some of these factors can be assumed to follow historical trends or patterns observed in another more advanced country or region, whereas the evolution of other factors is rather uncertain so that a wide range of possibilities (or "scenarios") must be analysed.

The main objective in applying a scenario approach for the analysis of the energy demand is not to remove from the results all the uncertainties which were recognized in the resulting projections provided by econometric models, but mainly to examine the spectrum of the energy demand under varying possible "scenarios" of development.

Following the recommendations of several experts in energy planning, the IAEA has developed a methodology for estimating energy demand based on a scenario approach: The MAED Model (Model for Analysis of the Energy Demand). MAED is intended to be applied by the Agency in conjunction with the WASP code for carrying out energy and nuclear power planning studies (ENPP) for its Member States. Section 6.1 describes the MAED methodology and Appendix A summarizes some of these studies.

Other models developed by the IAEA based on the scenario approach are also described in this Chapter, indicating their main differences with respect to the MAED model. These models, the TUV model (section 6.2) and EDE-MONODIA model (section 6.3) are not intended to be used for conducting detailed studies by the Agency, but mainly to produce quick estimates of energy and electricity demand for a country or region.

To assess the future share of nuclear power in the world energy supply, the IAEA still applies a very simple technique combining trend extrapolation and human judgement (see Section 6.4). Although the Agency uses this modified trend extrapolation method to project the evolution of nuclear energy supply, this approach is sometimes used to obtain quick and rough projections of a country's energy or electricity demand.

6.1. MAED: Model for Analysis of Energy Demand

6.1.1 Introduction

The IAEA has developed an integrated planning approach in which nuclear power planning is carried out within the context of all supply options, considering also the country's overall energy, economic and general development policy. In particular, in the area of long term energy and electricity forecasting, only through such an integrated approach can structural modifications in the economy be reflected and possibilities of electricity substitution and conservation policies assessed.

In the IAEA's work of assisting requesting Member States in carrying out Energy and Nuclear Power Planning (ENPP) Studies, it was often encountered that the electricity demand forecasts supplied by developing countries were not obtained in a systematic procedure which would ensure internal consistency with the main economic and industrial development objectives and possibilities. Thus, the electricity demand projections often proved to be a weak point in the resulting estimate of the role of nuclear power in the country's energy supply.

To develop coherent projections of future energy and electricity needs for improving the estimates of future electrical energy requirements, the IAEA in collaboration with the Institute for Economic and Legal Aspects of Energy (IEJE, Grenoble, France), the International Institute for Applied System Analysis (IIASA, Laxenburg, Austria) and Electricité de France, developed the computer model MAED (Model for Analysis of Energy Demand). MAED is based on the MEDEE model (Model d'evolution de la demande d'energie) originally developed by Messrs. B. Chateau and B. Lapillonne of the IEJE [6]. In fact, the MAED model is very similar to the simplified MEDEE-2 which was adopted to the needs of IIASA [7] [8].

Presently there are two versions of MAED at the IAEA: MAED-1 and MAED-2. Both models utilize the same methodology. This section describes the MAED methodology, the present state of development of MAED-1 and the main features of the modified version MAED-2.

6.1.2 MAED methodology

The MAED-1 model is a simulation model designed for evaluating the energy demand of a country or region in the medium and long term.

As already mentioned in the introduction, MAED belongs to the family of MEDEE models which are based on the scenario approach. In the MAED/MEDEE approach a "scenario" is viewed as a consistent description of a possible long-term development pattern of a country, characterized mainly in terms of long-term direction of governmental, socioeconomic policy. Following this approach, the planner can make assumptions about the possible evolution of the social, economic, and technological development pattern of a country that can be anticipated over the long term from current trends and governmental objectives.

In summary the methodology comprises the following sequence of operations:

(1) Producing a consistent breakdown of the country's final energy consumption into a multitude of end-use categories. This breakdown should start by decomposing the country into several economic sectors (e.g. Agriculture, Construction, Mining, etc.) followed by a further decomposition into the principal categories of end-use in each sector as illustrated in Figure 6.1.1 for the Agriculture sector;

(2) Identifying the social, economic and technical factors influencing each category of final energy demand as illustrated in Figure 6.1.1 for the Agriculture sector;

(3) Specifying (in mathematical terms) the functional links between energy consumption and the factors governing it;

(4) Constructing (consistent) scenarios for socio-economic and technical development;

(5) Evaluating the energy consumption corresponding to each such scenario.

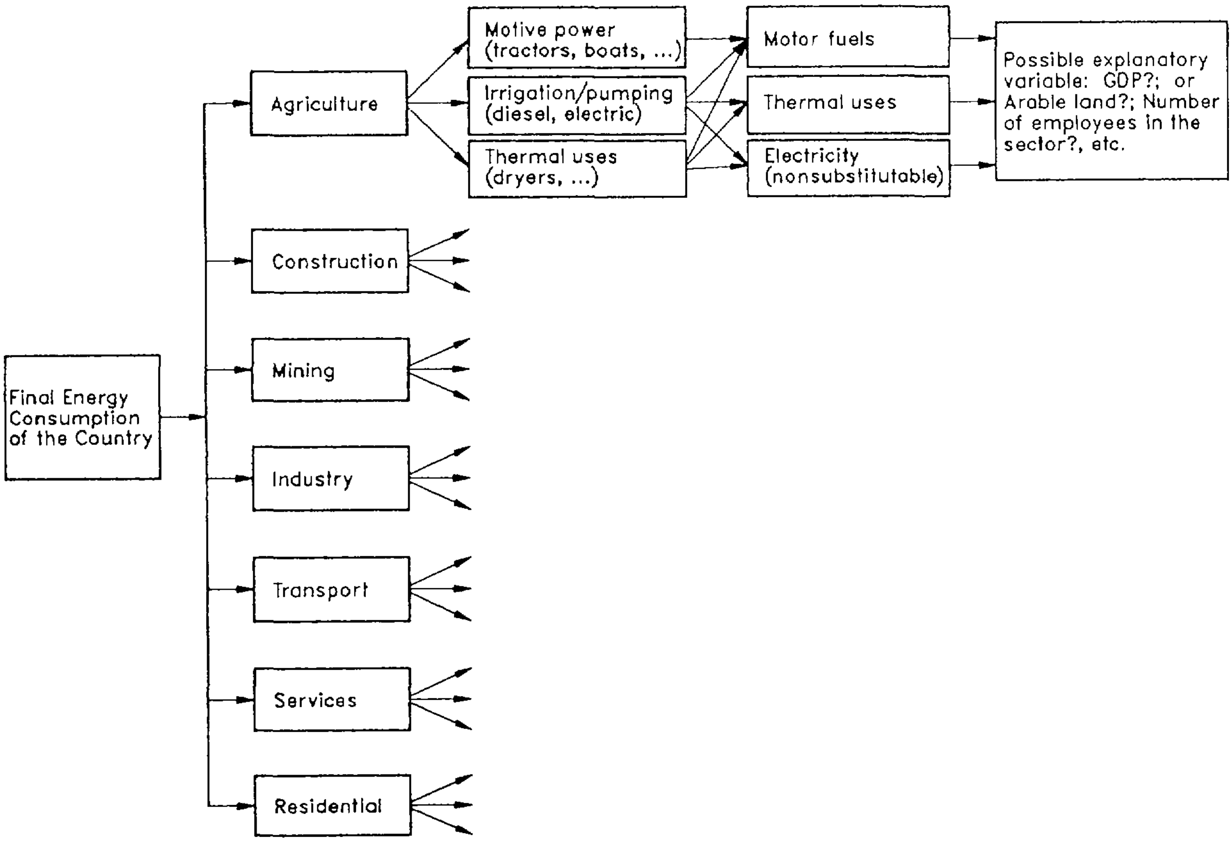


FIG.6.1.1. Illustration of decomposition of final energy consumption of a country.

The energy demand from final consumers is, as far as possible, always evaluated in terms of useful energy, i.e. in terms of service rendered and not only in terms of the amount of energy supplied. This differentiation between energy expressed in useful terms and in final terms makes it easier to study the interchangeability of various energy forms and the effects of technical improvements in the appliances used by final consumers.

The MAED model includes modules for converting annual electricity demand to hourly consumption, i.e. to the power demand imposed on the grid. In this way, the MAED results can be fed into the IAEA's WASP model (Wien Automatic System Planning) [5] which is used to study the optimization of the electricity generating sector.

The MAED model is designed to reflect (see Figure 6.1.2):

(1) Structural changes affecting medium- and long-term energy demand by means of a detailed analysis of the social, economic and technical system. This approach takes into account, in particular, the changing social needs of individuals, including heating, household equipment, transport, etc., according to the area in which they live (town, country); the industrial policy of the country (more or less rapid development of various types of industry); policies with regard to transport and other matters; and technological progress.

(2) Trends in the potential market for each final energy form: electricity, coal, gas, oil, solar energy, etc.

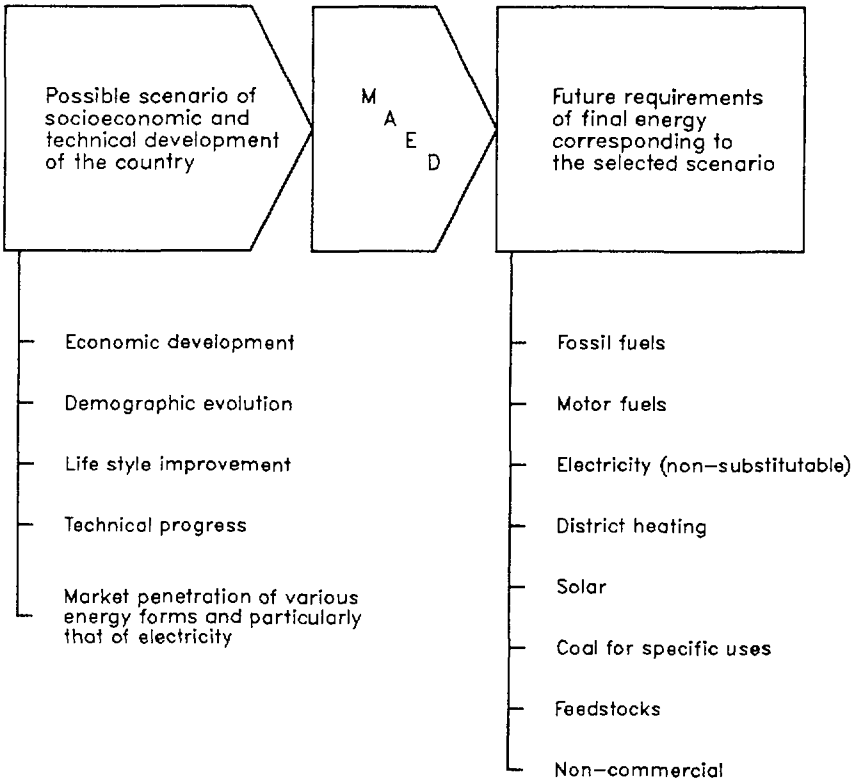


FIG. 6.1.2. Simplified scheme of calculation of final energy demand by MAED.

Substitutability of energy forms is not calculated automatically from the trends in prices for each energy form and the coefficients of elasticity, but from the analysis which is carried out when the scenarios are constructed. This may be seen as a drawback of the model, but it must be remembered that in the present economic situation, where prices are continually changing, economists have no technique for determining the impact of price trends on demand. As is demonstrated by the considerable discrepancies between the results of many studies concerning price elasticity, the traditional method of dealing with elasticity is no longer satisfactory. Moreover, such elasticities were calculated on the basis of past experience, i.e. of times when energy prices were stable or even tended to fall, and they can no longer be applied to the present energy situation.

For these various reasons, the MAED model does not calculate trends in energy demand from the direct trends in prices; for instance, the demand for petrol is not deduced from a hypothetical petrol price. The price is simply reflected implicitly in the construction of the scenario, serving as a backdrop in varying future trends in data on the number of cars per inhabitant or the number of kilometres travelled each year by car. In this case, the model calculates the demand for motor fuel solely as a function of the socio-economic parameters: the number of cars, the average distance travelled, etc.

The following paragraphs give a general description of the MAED model in its MAED-1 version as presently used by the IAEA [9].

6.1.3 Description of the MAED-1 model

The general structure of the MAED-1 model is shown schematically in Figure 6.1.3.

Module 1 ("energy demand") calculates the final energy demand by energy form and by economic sector for each reference year on the basis of the various parameters describing each socio-economic and technical development scenario.

Module 2 ("hourly electric power demand") is used to convert the annual demand for electricity of each sector to the hourly demand imposed on the power grid.

Module 3 ("load duration curve") ranks the hourly demands on the grid in decreasing order of magnitude and provides what electrical engineers term the "load duration". This curve forms a basic input to the optimization study of the electricity generating sector using the WASP model [5].

MAED also includes an additional module (not shown in the figure), Module 4 ("load modulation coefficients") which is considered as an auxiliary tool of the model. This module can be used to calculate the load modulation coefficients characterizing the consumption behaviour of a given client.

Module 1 forms an essential part of the MAED-1 model because it determines the annual demand for energy in all its forms; it will therefore be described in more detail than the other three modules.

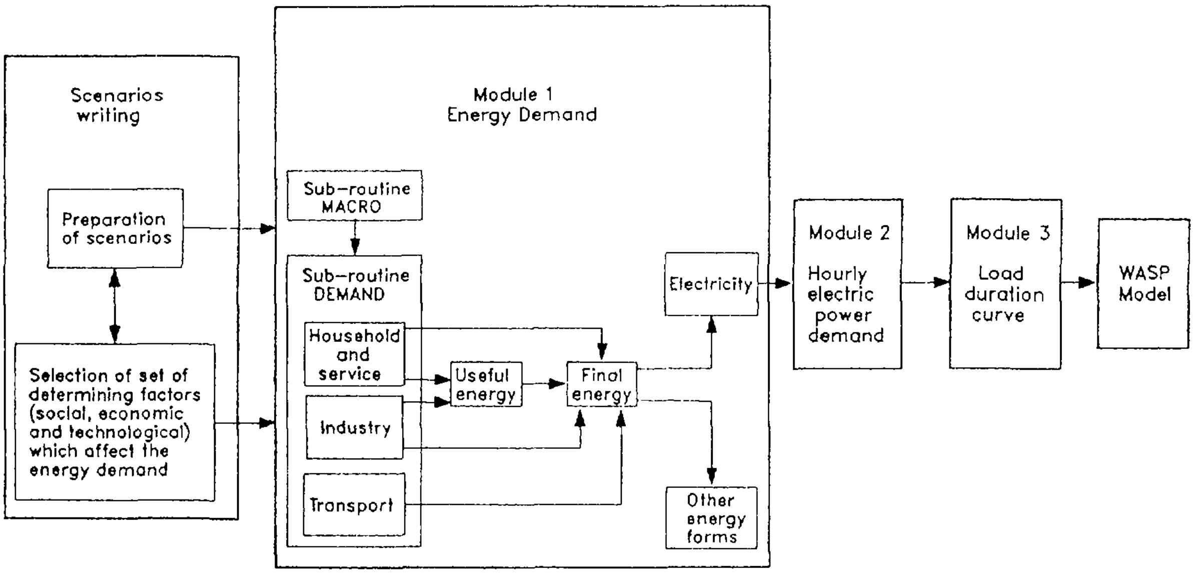


FIG.6.1.3. General structure of the MAED-1 model and interconnection with the WASP model.

6.1.3.1 Module 1: Energy demand

In the MAED-1 model, the energy demand is calculated according to a scenario of possible development. This scenario is subdivided into two subscenarios (see Figure 6.1.4):

- One is linked to the socio-economic system and describes the basic features of the social and economic development of the country;
- The other relates to the technical factors which must be taken into account when dealing with energy, e.g. the efficiency of final energy utilization or the share of the market held by the various energy forms.

The consistency of the scenario is a very important consideration of the methodology in order to guarantee attainment of sound results. Such consistency is to be exercised by the planner while formulating possible scenarios of development (i.e., in the scenario writing process) following a logical procedure as described in subsection 6.1.3.5.

Module 1 incorporates two subroutines: a macro-economic subroutine (MACRO) which calculates the level of activity in the production sectors taken into account, and another (DEMAND) which calculates the energy demand for each final use category. The demand by category is estimated separately for three major sectors of economic activity: Industry/Agriculture, Transport and Household/Services. Of course, the various individual demands are combined at the end of the program in order to obtain the overall demand for the country as illustrated in Figure 6.1.5.

These two subroutines combine to form a systematic framework through which the effect on energy demand of any economic, technical or social change can be quantified and evaluated.

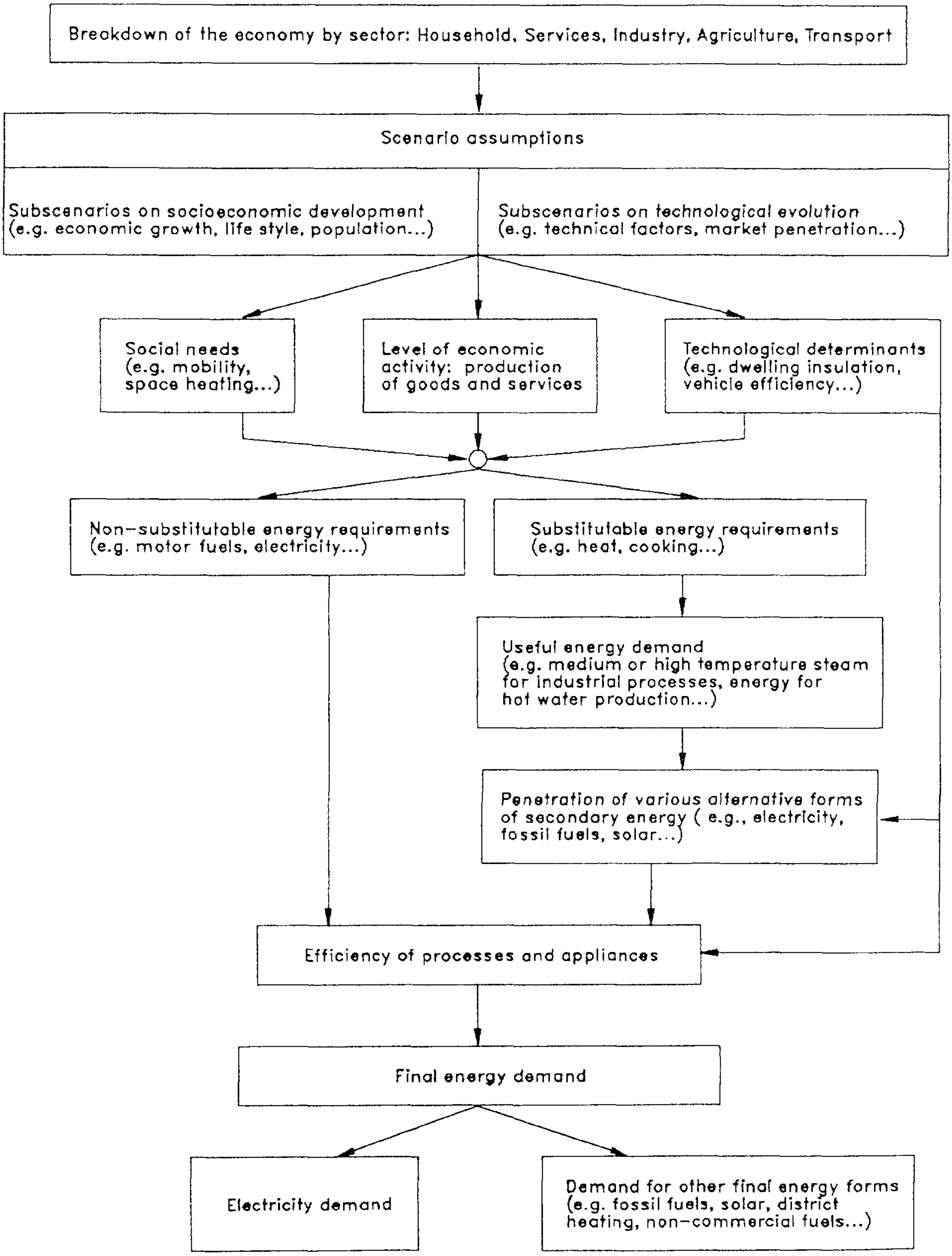


FIG. 6.1.4. Module 1 of MAED. Scheme used to project useful and final energy demand.

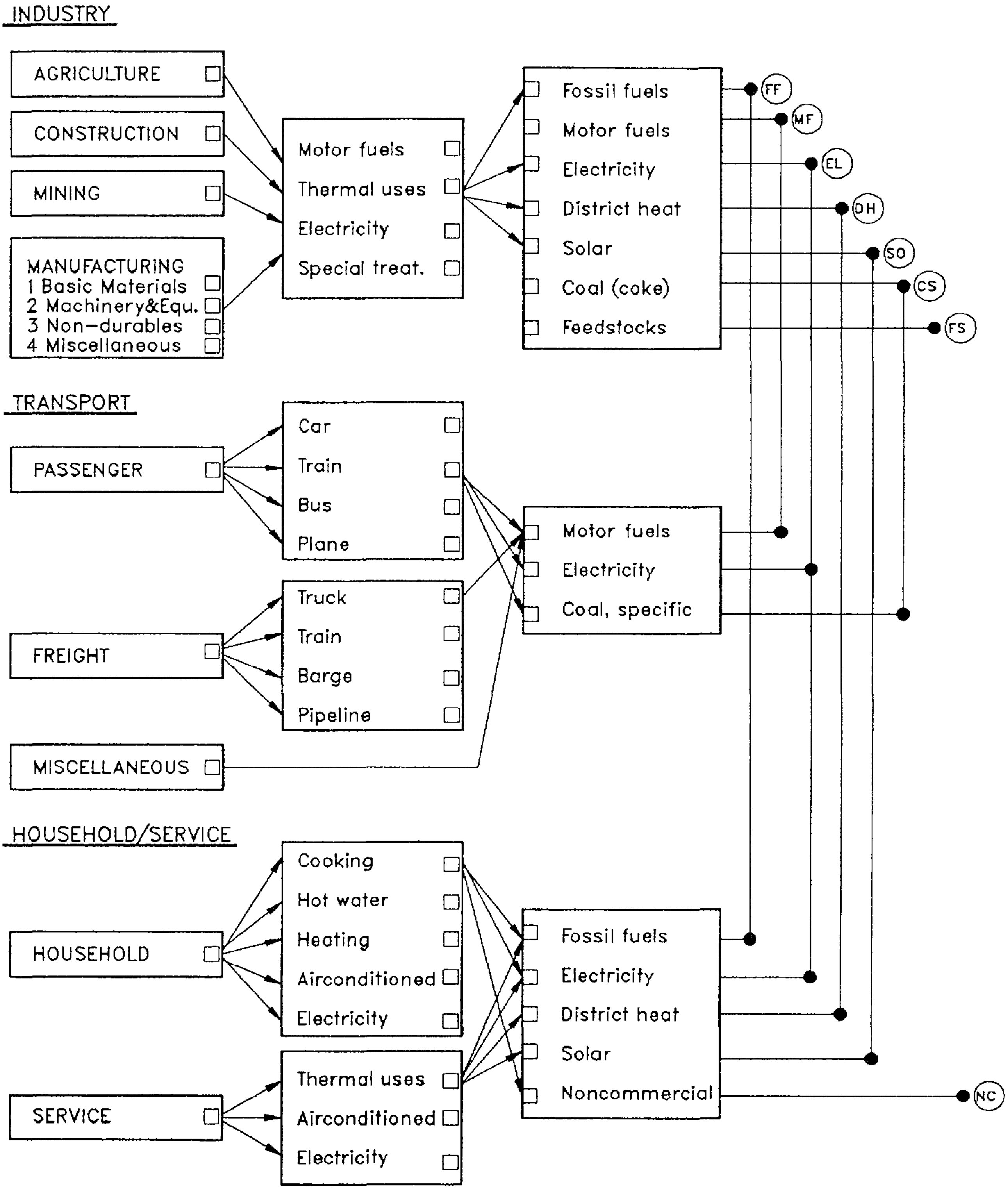


FIG. 6.1.5. *Composition of total final energy in the MAED-1 model.*

When various forms of energy, e.g. electricity, solar energy or fossil fuels, compete for a given final use category, the demand is first calculated in terms of useful energy and then converted into final energy, taking into account both the scenario parameters for penetration of the various competing energy forms and their efficiencies.

Fossil fuel demands are estimated globally and are not disaggregated into coal, gas and oil, since the breakdown depends on the supply situation and on the relative prices of these fuels, two factors which are beyond the scope of the model. The replacement of fossil energies by "new" forms of energy (e.g. solar energy, for certain electrical applications or district heating) is nevertheless considered in view of the future importance of such structural changes. Since these developments will essentially depend on central policy decisions, they are taken into account in the construction of the scenarios.

Non-substitutable energy uses such as motor fuels for cars, electricity for specific uses (electrolysis, electrical appliances, etc.) are calculated directly in terms of final energy.

For each end-use category the demand for useful or final energy is linked to the socioeconomic and technical determining factors. In particular, the demand for electricity is the result of trends in these factors, some of which are endogenous to the model whereas others are exogenous and therefore reflected in the scenarios.

With this in mind, the general equation used by the model for determining the energy requirements (E) of a sector -is- for a given end-use category -ic- in year -t- is:

$$E_{is,ic,t}(\text{useful or final}) = SPEC_{is,ic,t} * [SCEL]_t$$

where $SPEC_{is,ic,t}$ represents the specific consumption of energy for a given category (for example: kcal/monetary units of value added) in year -t-, and $SCEL_t$ the value of the scenario element (i.e. determining factor or explanatory variable for this consumption; for example the sector's value added) in the same year.

Within the model the above equation is treated somehow differently. In fact, the first step in the application of the MAED model consists of reconstructing, by means of the model, the structure of the energy consumption of the country for the so-called base year of study. The future energy requirements are then calculated by the model based on the energy structure established for this year and the changing scenario parameters from year to year. Thus, the general equation used by the MAED-1 model is:

$$E_{is,ic,t}(\text{useful or final}) = SPEC_{is,ic,0} * CHSPEC_{is,ic,t} * [SCEL]_t$$

where:

$SPEC_{is,ic,0}$ = specific energy consumption for the given category in the base year; and

$CHSPEC_{is,ic,t}$ = change in this specific energy consumption in year -t- relative to that in the base year.

The above equation is used to determine the demand for useful or final energy for each end-use category with the requirement that the respective $SPEC_{is,ic,0}$ must also be specified in the same terms.

For substitutable energy uses the determination of the final energy demand for a given energy form (ie) requires to break down the total useful demand into the various competing forms, e.g.:

$$E_{is,ic,ie,t}(final) = E_{is,ic,t}(useful) * MP_{is,ic,ie,t} / EFF_{is,ic,ie,t}$$

where:

$MP_{is,ic,ie,t}$ =	market penetration of the respective energy form in the given sector and energy use in year -t-; and
$EFF_{is,ic,ie,t}$ =	factor combining the efficiency of the energy form and of the equipment or appliances used for the same sector, energy form, category of use and year.

MACRO: Macro-economic subroutine

The purpose of the MACRO subroutine is:

- Firstly, to reflect, in quantitative terms, trends in the growth of each major economic sector defined in the qualitative scenario;
- Secondly, to ensure consistency between the development of each economic sector and the overall economy of the country.

Six economic sectors are considered in MAED-1: agriculture, building and construction, mining, manufacturing industries, services (including transport) and energy. The manufacturing industry sector is itself subdivided into four subsectors: the basic materials industries (steel, construction materials, chemicals, etc.), the capital goods (or durable goods) industries, the consumer goods industries (food, textile, etc.), and the various other industries which essentially comprise all other kinds of industries, including craft trades.

Since the structural development of the gross domestic product (GDP) is one of the most important factors governing the model, it may be either entered directly with the scenario data or calculated by means of a set of macro-economic accounting equations on the basis of the structure of gross domestic product expenditure.

The macro-economic development scenario for the country may therefore be constructed either in terms of value added per sector or in terms of investment in fixed assets and expenditure.

The result of this subroutine is the contribution to total GDP by each economic sector (i.e. the sectors' Value Added) as illustrated in Figure 6.1.6.

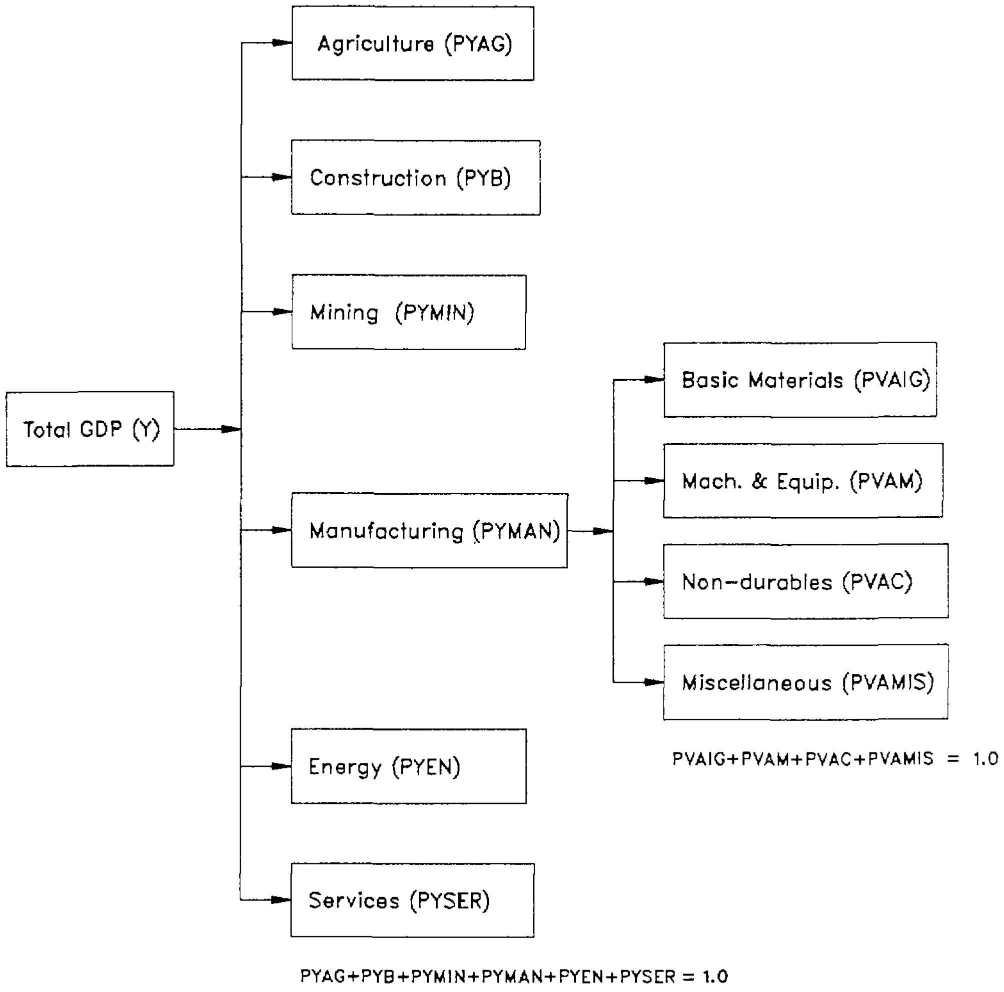


FIG.6.1.6. GDP contribution by economic sector.

DEMAND: Energy demand subroutine

The demand for energy from the various final consumers is calculated separately by grouping them together in three main "consumer" sectors: industry (including agriculture), transport, and households/services.

The demand from each sector is determined by the same method: each category of final energy use is driven by one or more socio-economic and technical factors, the values of which are defined in the scenarios.

A. Industrial sector

The industrial sector includes the following economic activities: agriculture, construction, mining and manufacturing industries. Manufacturing is broken down into four subsectors: basic materials (steel, chemicals, etc.); durables (machinery and equipment); consumer goods (food and textiles) and miscellaneous industries, which comprises all other types of industry, including craft trades.

Generally speaking, the energy demand in each sector is essentially determined by the level of economic activity in the sector, as evaluated in terms of its value added. The level of economic activity in each sector is either derived from the macro-economic subroutine or built into the scenario.

Within each sector, energy demand is calculated separately for three categories of end-use: electricity for specific uses (lighting, motor power, electrolysis, etc.), thermal applications (space heating, hot water, steam generation, furnaces and direct heat), and motor fuels. Coke used in steel production and chemical feedstocks are treated separately.

Of these categories of energy use, motor fuels and electricity for specific uses are considered non-substitutable forms. On the other hand, substitution possibilities exist for the thermal uses, in particular of fossil fuels (mainly oil), and especially in manufacturing owing to the high level of concentration of these activities. Agriculture, construction, and mining are much more decentralized, thus leaving little opportunity for the substitution of fossil fuels which can be easily transported and stored.

In order to analyse the substitution process, the thermal energy demand in manufacturing is broken down in three temperature ranges: low temperature (space heating, hot water, and steam for process temperatures between 80 to 120 ^{o}C); medium temperature (steam for process temperatures higher than 120^{o}C); and high temperature (furnace and direct heat). For each manufacturing subsector, or at least for the manufacturing sector as a whole, the scenario parameters must specify the breakdown of thermal uses into these temperature ranges.

The energy intensities per category of use (i.e., the consumption of motor fuels, electricity and thermal energy per unit value added) of each sector must be specified as scenario parameters due to the fact that these energy intensities are characteristics of each country and depend on the equipment used.

For non-substitutable uses (i.e., electricity for specific uses and motor fuels) energy intensities are specified in terms of final energy per unit value added, and for substitutable uses (thermal uses) in terms of useful energy per unit value added. In consequence, these two categories of energy use are calculated directly in terms of final energy whereas that for thermal uses are expressed first in terms of useful energy.

The thermal energy demand (for substitutable energy forms) is then converted from useful into final by means of the scenario parameters related to the market penetration of each alternative energy form. The efficiency of each energy form and of the equipment used comes into play at this stage.

The activities included in the industrial sector and the various end-use categories and alternative energy forms are summarized in Figure 6.1.7 and Table 6.1.1. Figures 6.1.8 through 6.1.10 and Table 6.1.2 illustrate the calculations performed by MAED-1 for evaluating the energy demand of the industrial sector.

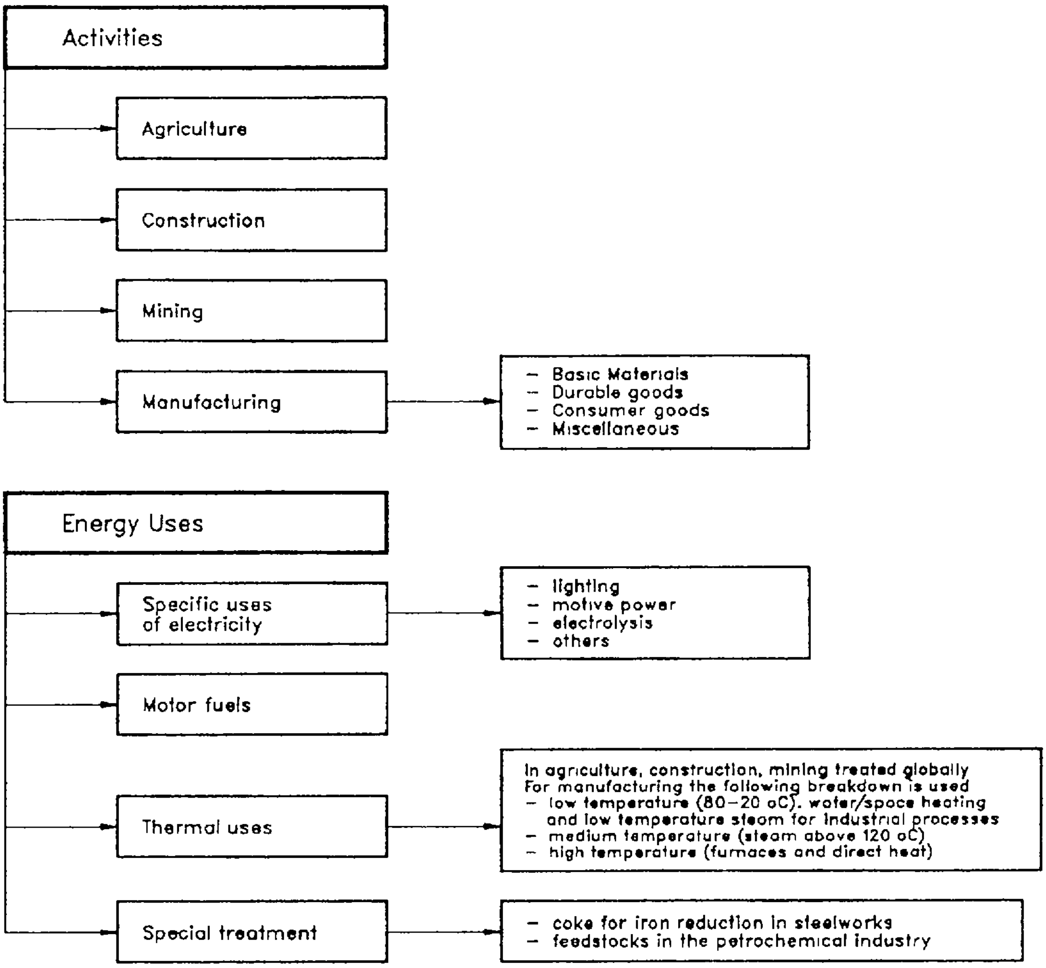
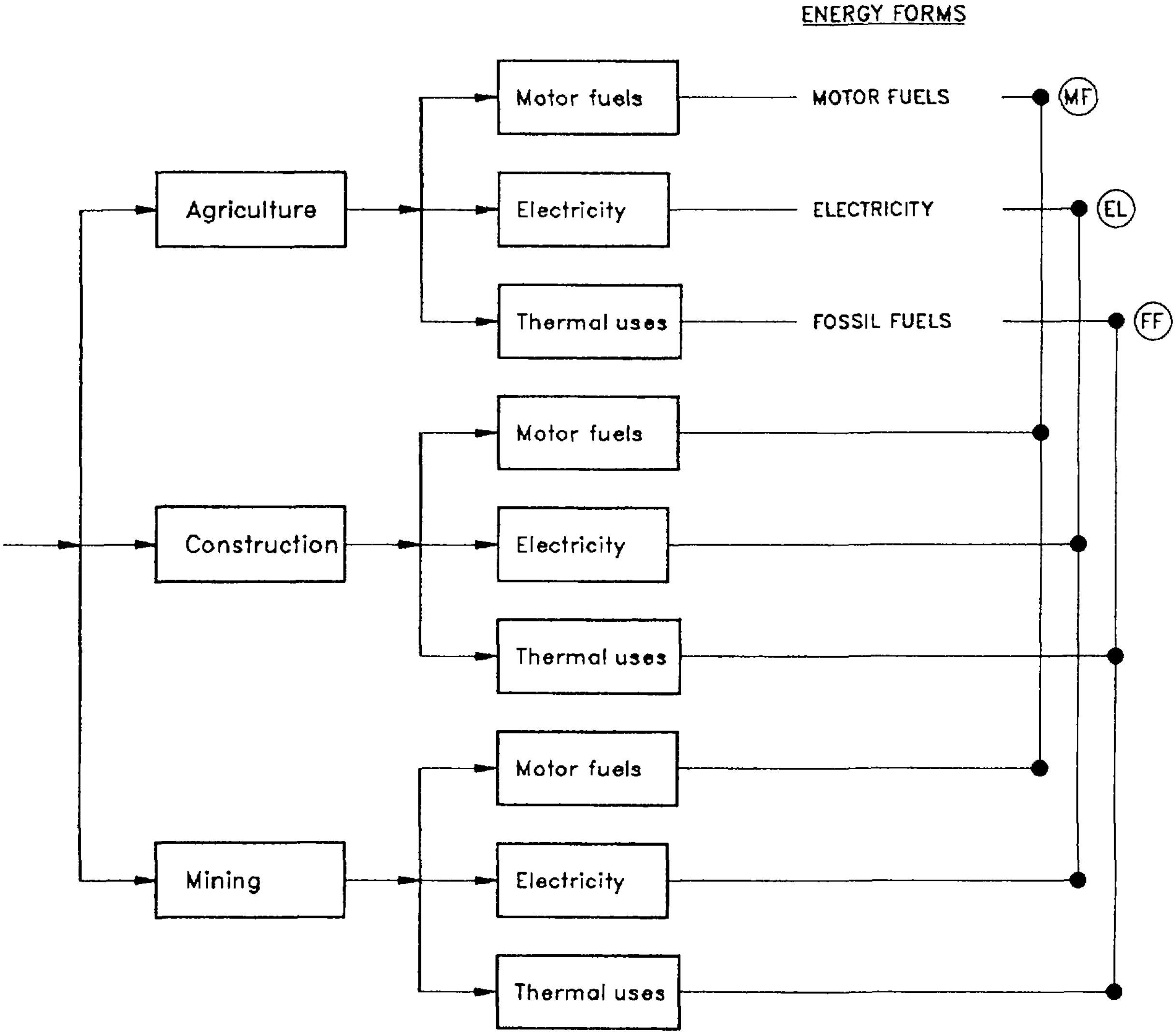


FIG. 6.1.7. Industrial sector· description of activities and categories of energy use considered.

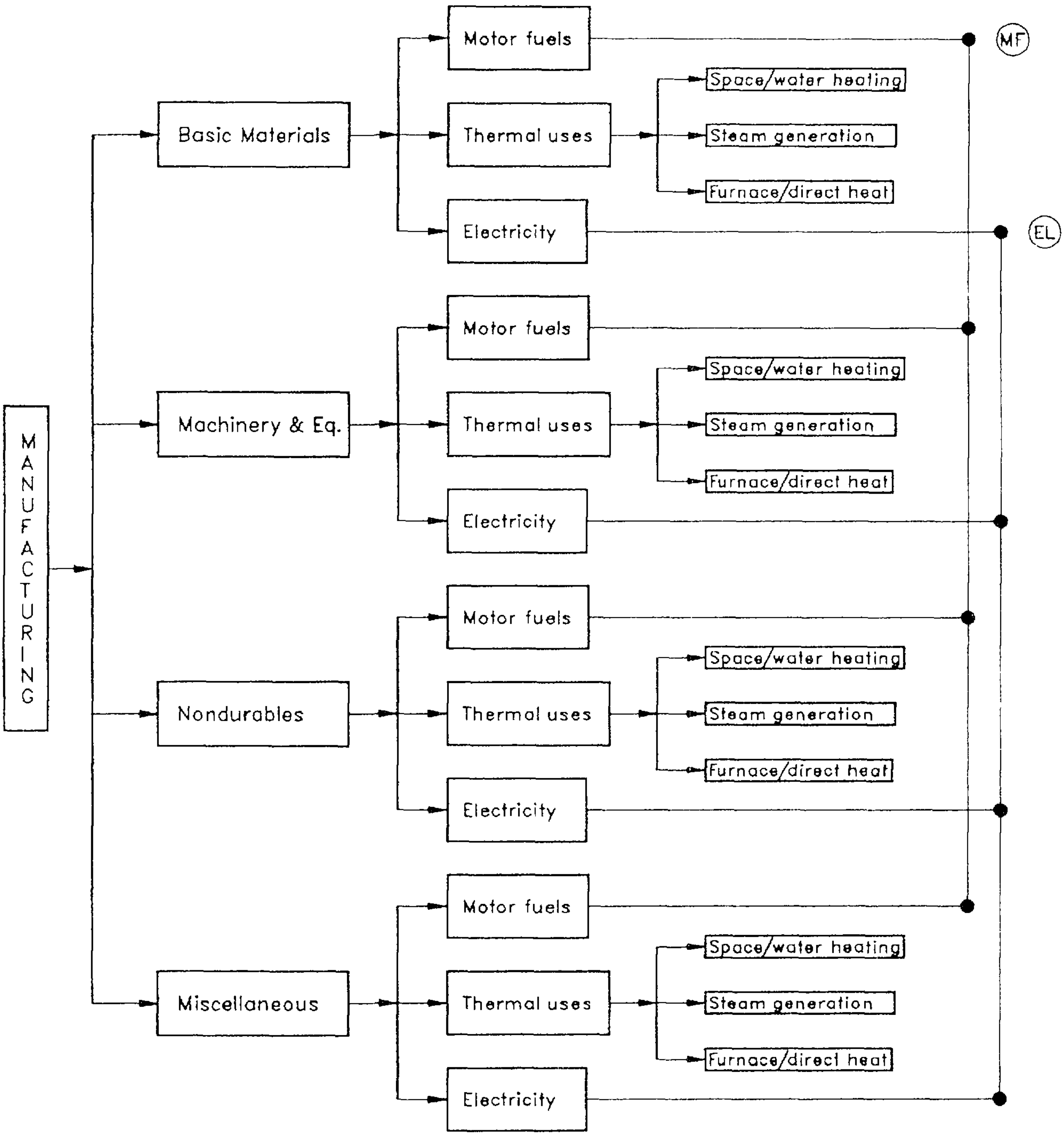
TABLE 6.1.1 INDUSTRIAL SECTOR: ALTERNATIVE ENERGY FORMS BY END-USE CATEGORY

SUBSECTORS / ENERGY FORMS	Agriculture	Construction	Mining	Manufacturing				
				Specific uses of electricity	Conventional motors	Thermal uses		
						Low Temp	Medium Temp	High Temp.
Fossil fuels (coal, gas, oil)	X	X	X			X	X	X
Electricity (conventional)	X	X	X	X		X	X	X
Electricity (heat pump)				X		X	X	
Motor fuels	X	X	X		X			
Distric heating						X	X	
Cogeneration						X		
Soft solar systems						X		



DEMAND FOR: MOTOR FUELS, ELECTRICITY, OR THERMAL USES	=	SPECIFIC ENERGY CONSUMPTION PER UNIT OF VALUE ADDED OF SECTOR FOR GIVEN USE IN BASE YEAR	X	RATIO OF ENERGY INTENSITY OF SECTOR IN CURRENT YEAR RELATIVE TO THE BASE YEAR	X	VALUE ADDED OF THE SECTOR IN CURRENT YEAR

FIG. 6.1.8. Computation of energy demand for agriculture, construction and mining sectors.



DEMAND FOR: MOTOR FUEL, ELECTRICITY	=	SPECIFIC ENERGY CONSUMPTION PER UNIT OF VALUE ADDED OF THE SUBSECTOR FOR GIVEN USE IN THE BASE YEAR	X	RATIO OF ENERGY INTENSITY OF THE SUBSECTOR IN CURRENT YEAR RELATIVE TO THE BASE YEAR	X	VALUE ADDED OF THE SUBSECTOR IN CURRENT YEAR

FIG. 6.1.9. Computation of energy demand in the manufacturing sector.

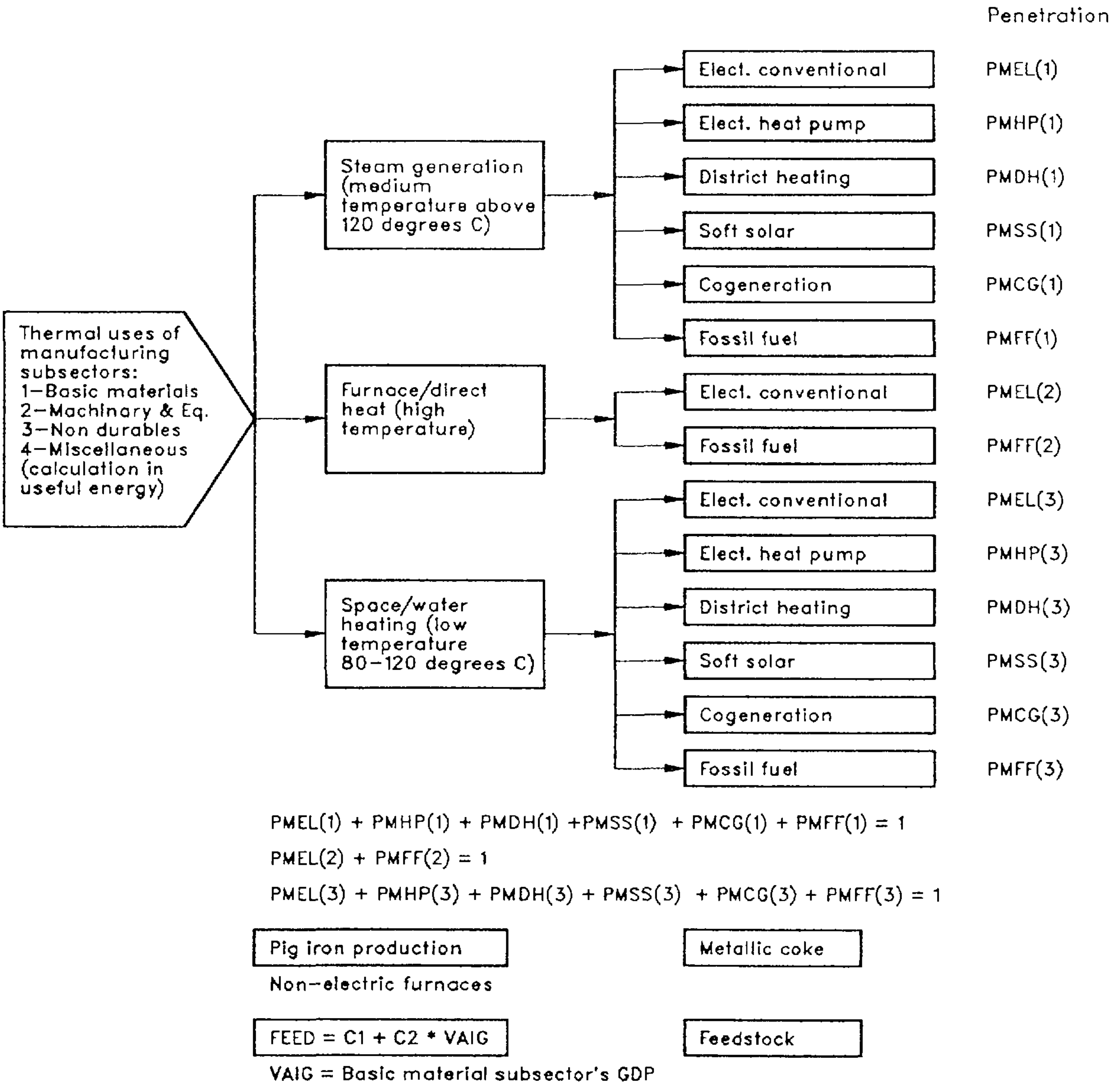


FIG. 6.1.10. Computation of energy demand in manufacturing subsectors.

TABLE 6.1.2. COMPUTATION OF ENERGY DEMAND OF EACH ENERGY FORM FOR EACH MANUFACTURING SUBSECTOR

| Useful energy demand for each temperature range (e.g. low temperature) for each manufacturing subsector (e.g. basic materials) | = | Specific energy comsumption per value added of the subsector in the base year (thermal uses) | x | Ratio of useful energy intensity of the subsector in current year relative to the base year | x | Value added of the subsector in current year | x | Share of the temperature range in thermal uses in manufacturing subsector |

| Amount of useful energy demand for each energy form (e.g. electricity, solar, fossil fuels , etc.) for each temperature range in each manufacturing subsector | = | Useful energy demand for each temperature range (e.g. low temperature) for each manufacturing subsector (e.g. basic materials) | x | Penetration of that energy form in that temperature range of that manufacturing subsector |

| Amount of final energy demand for each energy form (e.g. electricity, solar, fossil fuels, etc.) for each temperature range in each manufacturing subsector | = | Amount of useful energy demand for each energy form (e.g. electricity, solar, fossil fuels, etc.) for each temperature range in each manufacturing subsector | / | Efficiency of conversion from final to useful energy for that energy form |

B. Transport sector

The demand for final energy in the transport sector is determined as a function of the requirements for transport of freight and passengers, the breakdown per mode of transport (car, train, plane, etc.), the specific energy needs of each mode of transport and the load factors applying to each mode.

The total requirements for transport are calculated separately for freight (ton-km) and passengers (passenger-km) according to macro-economic and life-style factors. For freight transportation, these requirements are calculated as a function of the GDP contribution by the productive sectors, i.e. agriculture, mining, manufacturing and energy sectors. The requirements for transport of passengers are determined from total population and the average distance travelled by person. The latter considered to be a scenario variable since it is certainly dependent on disposable personal income and cost of travel, and also on consumer habits.

Since the trends in the proportional use of the various modes of transport are essentially influenced by government policy, all changes relative to past trends are introduced exogenously via the scenarios. If no change is introduced, the distribution of the various modes of transport is calculated on the basis of functions adjusted according to past trends.

With the exception of the car, where substantial improvements in specific consumption may be expected in the future, the specific consumption figures for the other modes of transport are deduced from past trends. Furthermore and in order to allow for differences in the specific consumption of certain modes depending on the distance involved, some distinctions are made for both, freight and passenger transport. For freight, distinction is made for transportation of goods by trucks for short hauls and long distances. For transport of passengers, distinction is made for urban (intracity) and intercity transport by bus and cars.

The load factors which depend on transport policy are included as specific scenario components.

In addition, the transport sector includes the category of consumption called Miscellaneous. This category is used to account for energy consumption for international transport as well as for the remaining consumption in the transport sector, such as military transport, that cannot be classified in the other subsectors. The energy demand for Miscellaneous is determined as a linear function of the total GDP. The coefficients of this function are deduced from past trends.

The types and modes of transport, together with the alternative energy forms considered for the transport sector, are listed in Figure 6.1.11 and Table 6.1.3. Figures 6.1.12 and 6.1.13 and Table 6.1.4 illustrate the computation of energy demand in the transportation sector.

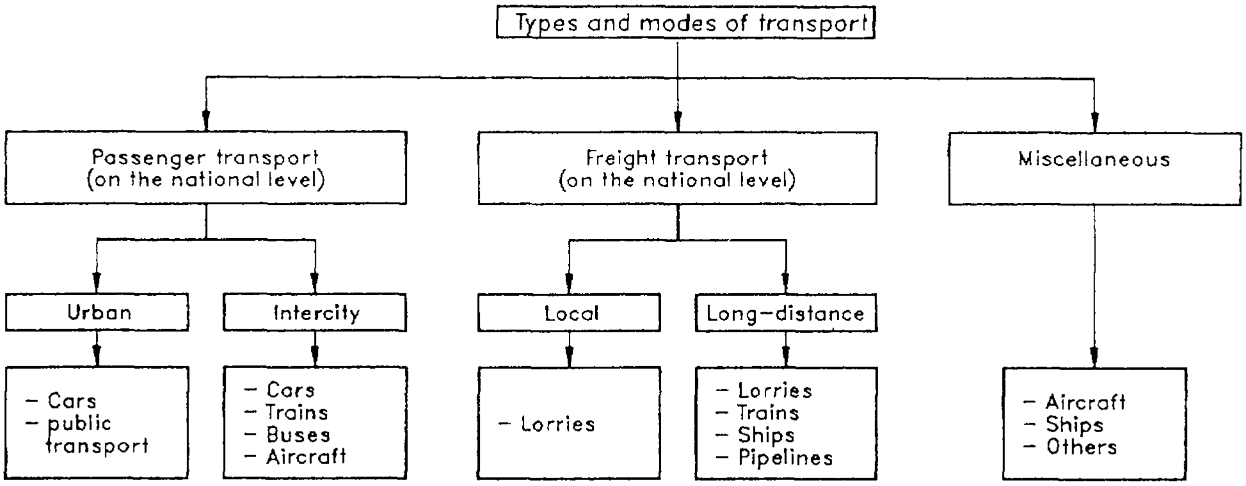


FIG. 6.1.11. Transport sector: types and modes of transport.

TABLE 6.1.3. TRANSPORT SECTOR: ALTERNATIVE ENERGY FORMS FOR EACH MODE OF TRANSPORT

Mode of transport	Motor Fuels	Electricity	Other fuels (mainly coal)
Cars	X	X(1)	
Urban public transport	X	X	
Trains	X	X	X
Buses	X		
Lorries	X		
Aircraft	X		
Ships	X		
Pipelines	X		X

(1) For urban transport only

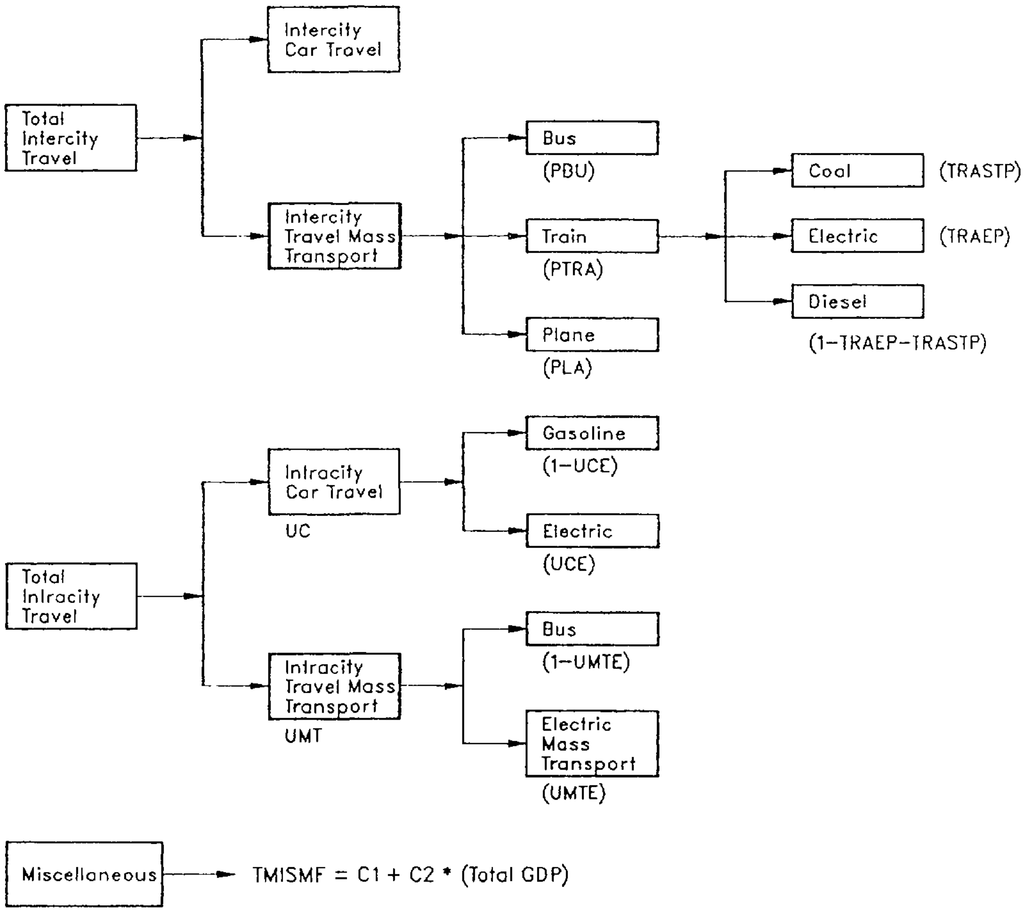
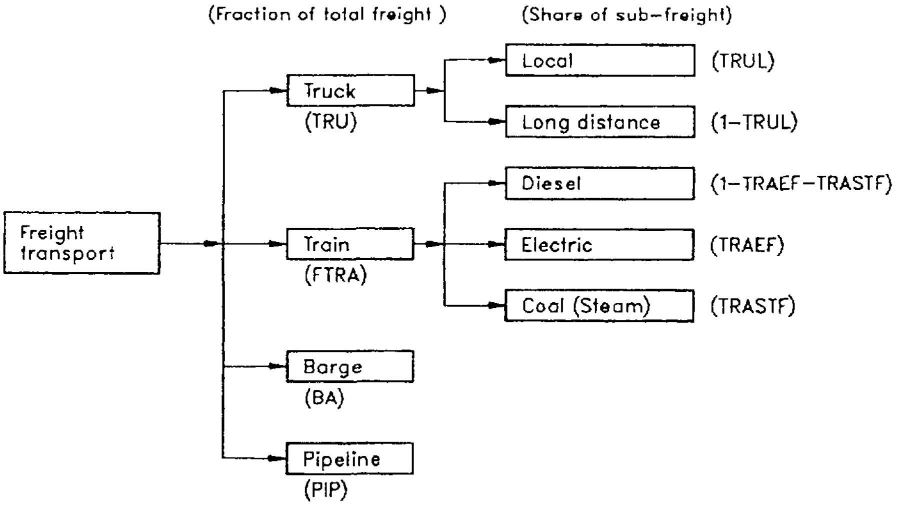


FIG. 6.1.12. Computation of energy demand in the transportation sector.



TRU + FTRA + BA + PIP = 1

Total freight (ton−km) = C1 + C2 * (Total GDP − construction GDP − service GDP)

Fuel consumption by each mode of freight transport	=	Total Freight transported	x	Share of transport by that mode of freight transport	x	Energy intensity of that mode of freight transport

FIG. 6.1.13. Energy demand for freight transportation.

TABLE 6.1.4. EXAMPLE FOR CALCULATING FUEL CONSUMPTION FOR PASSENGER TRAVEL

Passenger-km for intracity (urban) travel by car	=	Average urban distance travelled per person per day	x	Share of population living in large cities	x	Total population	x	Share of cars in the total demand for urban passanger transport
PUC		DU		(1- POLC)		PO		UC

Gasoline consumption by car for urban travel	=	Passenger-km urban travel by car	x	Share of gasoline car in urban travel	x	Specific gasoline consumption of car in urban travel	/	Average load factor of car in urban travel
TGUC		PUC		(1–UCE)		GUC		LFUC

C. Household and service sector

Although they come under the same heading, the household and service sectors are in fact treated separately since their determining factors are not the same: the demand of the household sector is driven chiefly by demographic factors (population, number of households, etc.), whereas in the service sector the main factor is economic activity.

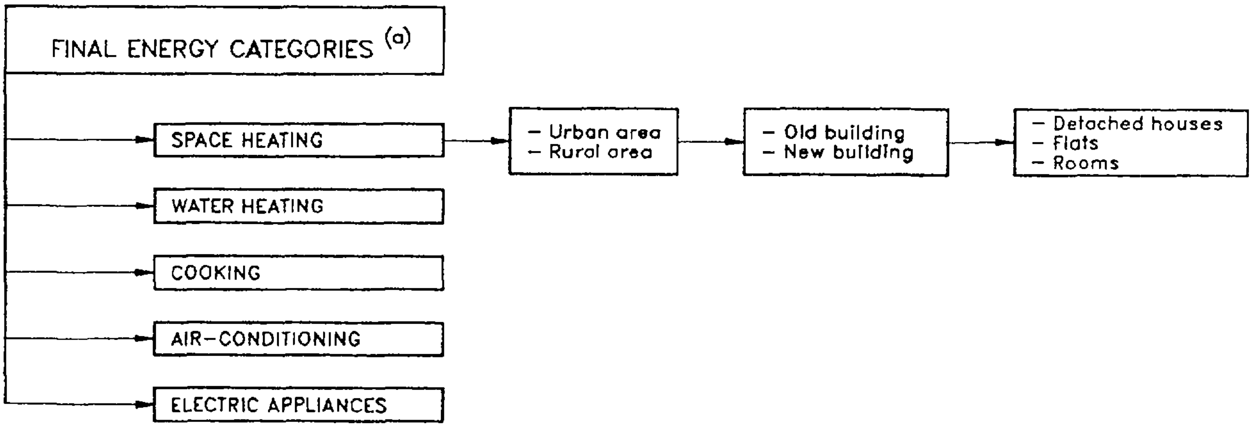
The final energy uses considered in the household sector include space heating and air-conditioning, water heating, cooking and the use of electrical equipment (household appliances, lifts, etc.).

These estimates take into account the place of residence: large town with high population density or the countryside; the type of building: "old" (traditional) or "new" (complying with modern insulation standards); and, finally, the type of residence: detached house, flat or room. This approach is intended to achieve a better representation of the individual's specific needs and thus to provide a clearer definition of the markets for the various forms of final energy.

Energy utilization in the service sector is broken down into: thermal applications (essentially space and water heating), air-conditioning and use of electric appliances (small machine motors, computers, etc.). The type of building (traditional or new) is also taken into account in calculating space heating and air-conditioning for this sector.

When there are several forms of energy which can be used to satisfy the same needs, the estimates are expressed in terms of useful rather than final energy. The final energy is then calculated by means of the scenario parameters related to the market penetration and efficiency of each alternative energy form, following a procedure similar to the one already explained for the Industry/Agriculture sector.

The various final use categories and the alternative energy forms considered by MAED for the household and service sectors are summarized in Figure 6.1.14 and Table 6.1.5. Figures 6.1.15 and 6.1.16 and Table 6.1.6 illustrate the calculations of energy demand for the Household/Service sector.



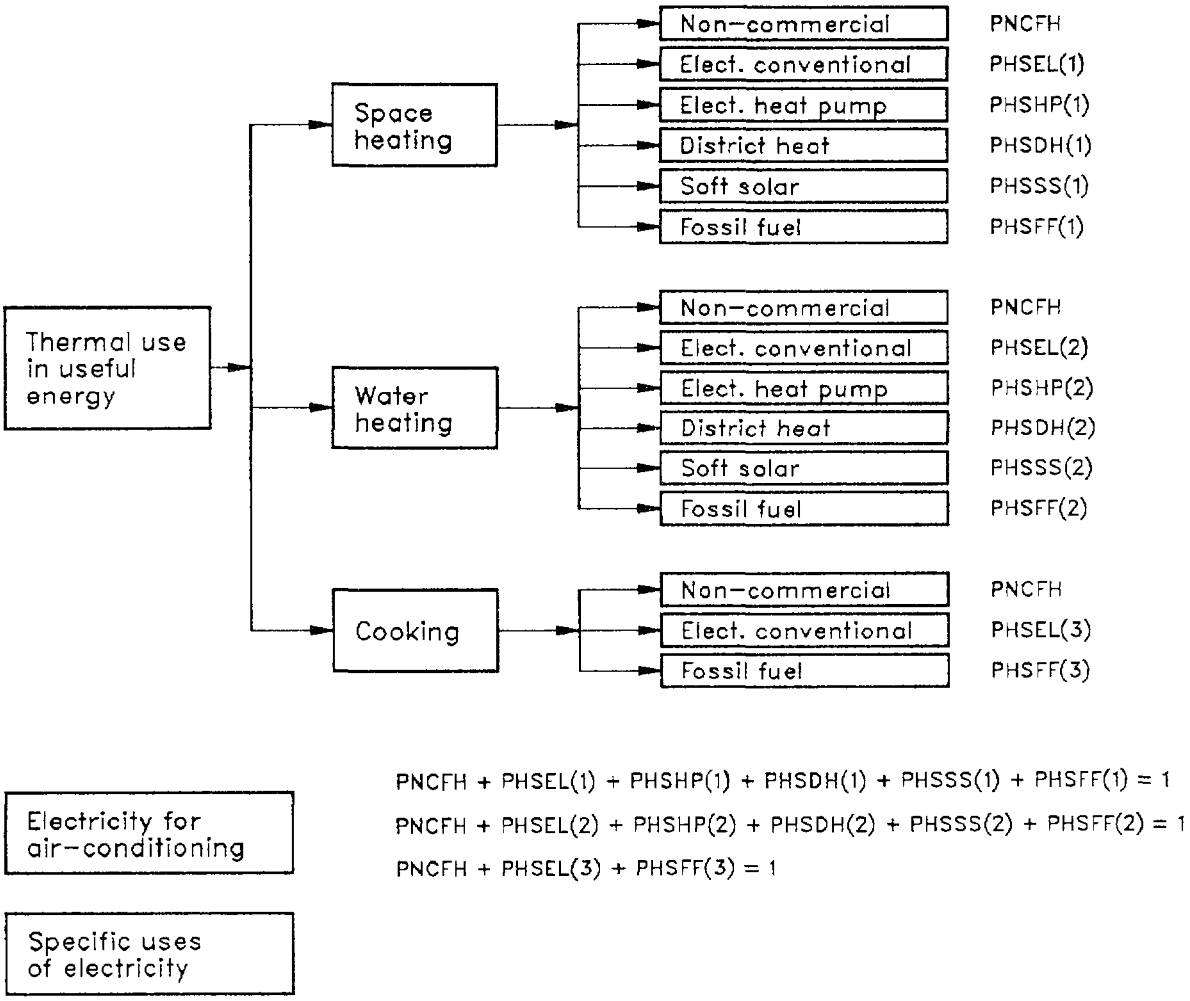
(a) The categories for the service sector are thermal uses, air conditioning and electrical appliances

FIG. 6.1.14. Household and service sector: main categories of final energy use.

TABLE 6.1.5. HOUSEHOLD AND SERVICE SECTOR: ALTERNATIVE ENERGY FORMS FOR EACH END-USE CATEGORY

Energy forms \ Energy uses	Household					Service		
	Space heating	Water heating	Cooking	Air-conditioning	Electrical appliances	Thermal uses	Air-conditioning	Electrical appliances
Non-commercial fuels (wood, etc.)	X	X	X					
Fossil fuels (oil, gas, coal)	X	X	X			X		
Electricity (conventional)	X	X	X	X	X	X	X	X
Electricity (heat pump)	X	X				X		
District heating	X(1)	X(1)				X(1)		
Soft solar system	X(2)	X				X(3)		

(1) only in large cities
(2) only for 'new' single family (detached) houses
(3) only for 'new' low-rise building



$$\mathrm{PNCFH} + \mathrm{PHSEL}(1) + \mathrm{PHSHP}(1) + \mathrm{PHSDH}(1) + \mathrm{PHSSS}(1) + \mathrm{PHSFF}(1) = 1$$

$$\mathrm{PNCFH} + \mathrm{PHSEL}(2) + \mathrm{PHSHP}(2) + \mathrm{PHSDH}(2) + \mathrm{PHSSS}(2) + \mathrm{PHSFF}(2) = 1$$

$$\mathrm{PNCFH} + \mathrm{PHSEL}(3) + \mathrm{PHSFF}(3) = 1$$

FIG.6.1.15. Energy demand in the household sector.

TABLE 6.1.6. EXAMPLE FOR CALCULATING ENERGY DEMAND IN THE HOUSEHOLD SECTOR

Commercial fossil fuel for water heating in household sector	=	Specific useful energy consumption for water heating per person per year	x	Average household size	x	Share of dwelling with hot water facilities
		HWCAP		CAPH		DWHW

x	Total stock of dwellings	x	Penetration of fossil fuel for water heating	/	Efficiency of converting final energy to useful energy
	DW		PHSFF(2)		EFFHS(2)

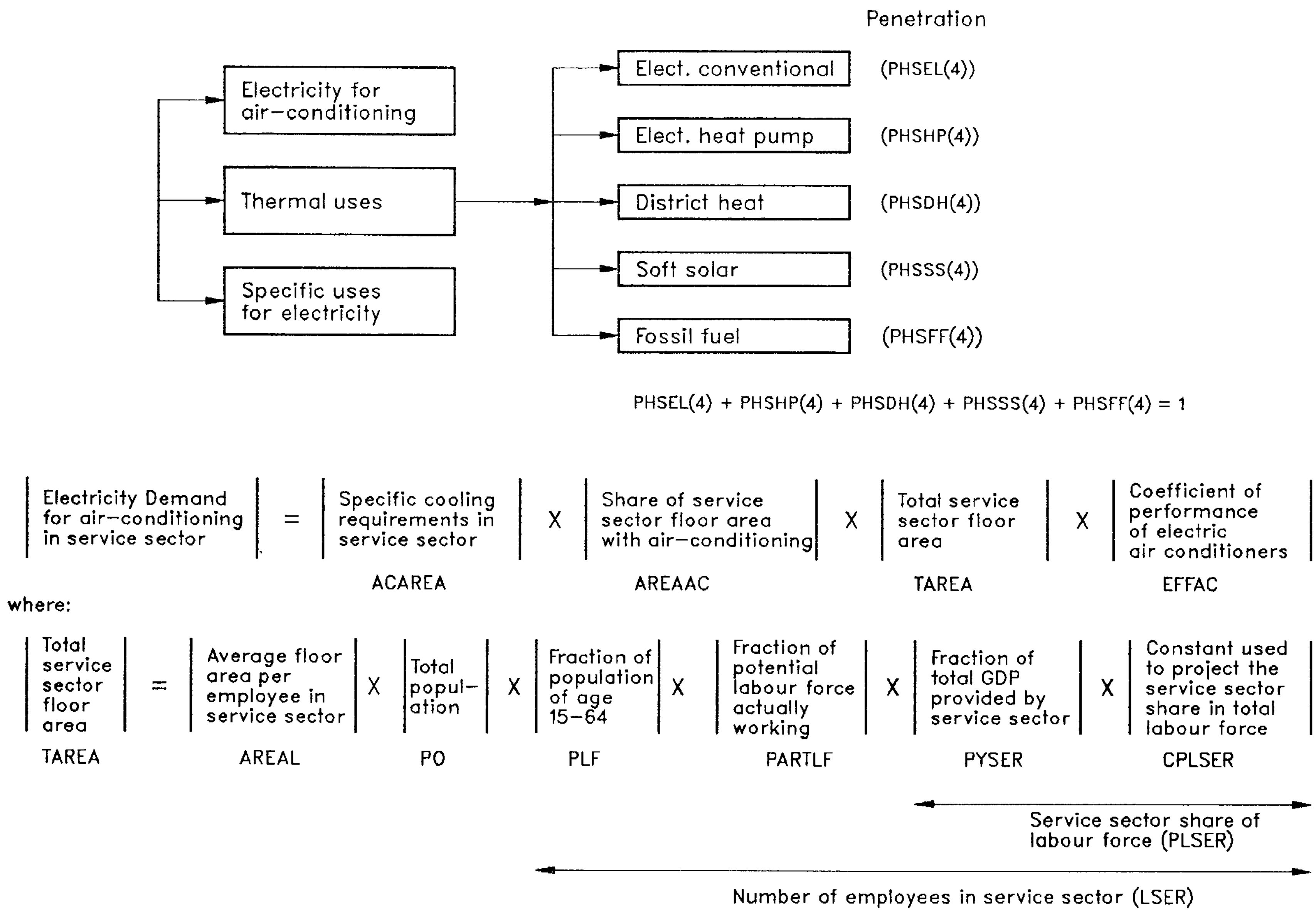


FIG.6.1.16. Energy demand in the service sector.

6.1.3.2 Module 2: Hourly electric power demand

The purpose of this module is to convert the total annual demand for electricity (in terms of energy, i.e. kW.h or GW.h) of each economic sector to the demand broken down on an hourly basis, i.e. to the power demand (i.e. kW or GW) imposed on the distribution grid by each sector.

This analysis is carried out using the various "modulation coefficients" describing variations in electricity consumption about a mean trend as illustrated in Figure 6.1.17. For each sector, the annual energy demand is converted to the power demand of the same sector at a particular hour on a particular day in a given week by taking into account:

(a) The trend in the average growth of electricity demand during the year;

(b) Seasonal variations in electricity consumption (measured in monthly or weekly terms, depending on the information available);

(c) The impact of the type of day in question (working day, week-end or public holiday); and

(d) Hourly variations in consumption during a given type of day (working day or holiday).

Each of these time sequences has its own modulation coefficient which, when multiplied, provides the correction to be applied to the mean hourly consumption rate.

When the modulation coefficients are known for each sector, the electricity demand over the 8760 hours of the year can be calculated as graphically illustrated in Table 6.1.7. When plotted as a graph, the result is known as the electric load curve, or the curve of the demand imposed on the grid by the sector in question. When the load curves in each sector are known, the annual load curve of the power grid can be plotted by summing the sectoral load curves.

The dimensions of the program allow the following variations.

Two electricity consumer sectors are considered grouping the various sectors treated in Module 1 as follows:

Sector 1:	Industry (including Agriculture, Construction, Mining and Manufacturing) plus Transportation
Sector 2:	Household/Service sectors

For <u>each sector</u>, the following information is required:

(1) Annual electricity demand of the sector and average annual growth rate of this demand (calculated by Module 1);

(2) Trend coefficients are always calculated by the program for each week of the year from the average growth rate of electricity demand in the year considered;

STEPS:	LOAD MODULATION COEFFICIENT
1) Calculation of energy consumption for one equivalent working day	Number of equivalent working days (N)
2) Calculation of energy consumption in a working day of a given week –i–	SEASONAL COEFFICIENTS: K(i)
3) Consideration of the average annual growth rate of the energy consumption	GROWTH TREND COEFFICIENTS: T(i)
4) Determination of energy consumption in other days (Saturday, Sunday, Monday) of week –i– from the consumption in the working day of same week	DAILY WEIGHT COEFFICIENTS: P(i,id)
5) Distribution of energy consumption among the different hours of each day	HOURLY COEFFICIENTS: HC(ic,i,id)

Note: Day types considered by MAED are:

Code 0–3: Working day, Saturday, Sunday and Monday of normal weeks

Code 4–7: Working day, Saturday, Sunday and and Monday of the so–called special holiday periods

MAED allows for variations of these coefficients by type of client –ic–, by day type –id– and between summer –S– and winter –W– periods. The data for each sector are the hourly load curves (LCOEFS, LCOEFW) of the clients and the share of each client (LCONTS, LCONTW) in the total electricity consumption of the sector.

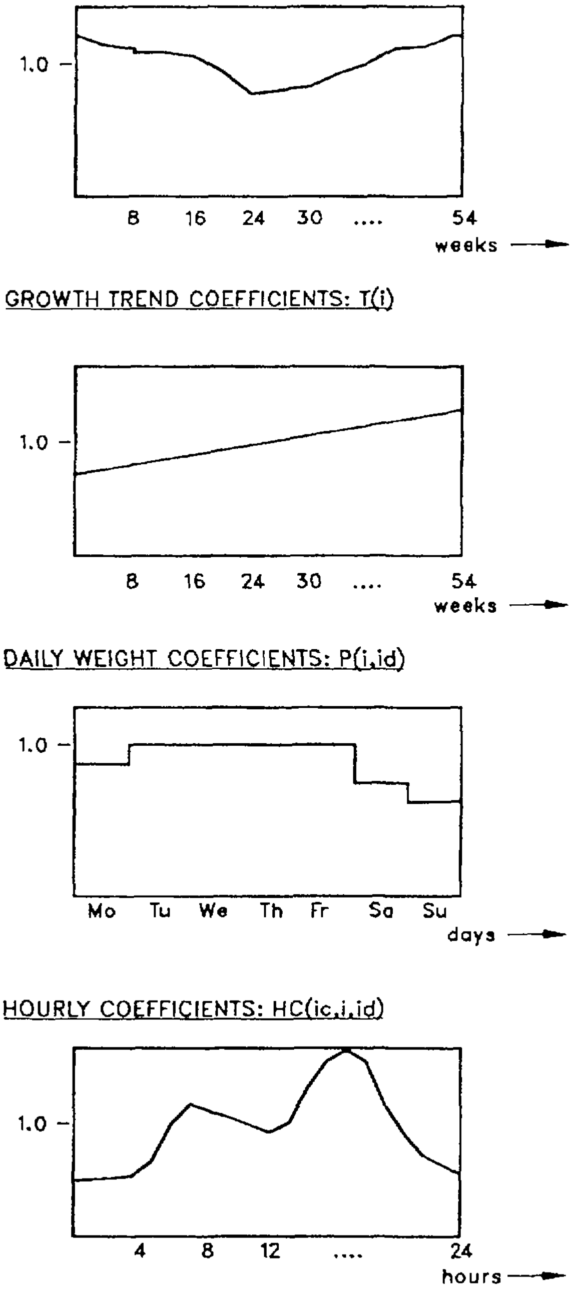


FIG.6.1.17. Simplified representation of the sector's load modulation coefficients.

TABLE 6.1.7. COMPUTATION OF POWER DEMAND OF EACH SECTOR BY MODULE 2 OF MAED

1. FROM GENERAL INFORMATION ABOUT THE YEAR: (Identification of each day –m–)

CALEND (m,1) = Date of day –m–
CALEND (m,2) = week number of day –m–
CALEND (m,3) = day type of day –m–

2. FOR EACH SECTOR: (Calculation of hourly power demand)

a) Reads: annual energy demand (ENERGY)
on load modulating coefficients (K, P, LCONTS, LCOEFS, LCONTW, LCOEFW)

b) Calculation of growth trend coefficients for each week –i– :

$$T_i = (1.0 + \mathrm{GROWTH}/100.0)^{(i-26)/52}$$

c) Calculation of hourly coefficients of the sector for each hour –h– and day type –id– :

$$\mathrm{LCSS}_{h,id} = \sum_{ic=1}^{ic=5} \mathrm{LCONTS}_{ic,id} * \mathrm{LCOEFS}_{ic,h,id}$$

$$\mathrm{LCSW}_{h,id} = \sum_{ic=1}^{ic=5} \mathrm{LCONTW}_{ic,id} * \mathrm{LCOEFW}_{ic,h,id}$$

d) Calculates number of equivalent working days (N):

$$N = \sum_{m=1}^{365} K_i * P_{i,id} * T_i$$

where: i = CALEND(m,2)
id = CALEND(m,3) + 1

e) Calculation of average consumption in equivalent working day (EWDS):

$$\mathrm{EWDS} = \mathrm{ENERGY} / N$$

f) Calculation of power demand in each hour –h– of a given day –m– :

$$\mathrm{PV}_{is,h,m} = \mathrm{EWDS}/24.00 * K_i * T_i * P_{i,id} * \mathrm{LOAD}_{h,m}$$

where: $\mathrm{LOAD}_{h,m} = \mathrm{LCSS}_{h,id}$ for summer days
$\mathrm{LOAD}_{h,m} = \mathrm{LCSW}_{h,id}$ for winter days

3. FOR TOTAL SYSTEM: (Calculation of hourly power demand)

$$\mathrm{PT}_{h,m} = \sum_{is=1}^{is=2} \mathrm{PV}_{is,h,m}$$

where: is=1 Industry+Transport
is=2 Households+Services

(3) The seasonal coefficients must be specified by the planner for each week;

(4) To account for the impact of the type of day considered, the following types of day can be differentiated in the program:

1	Working day
2	Saturday
3	Sunday
4	Monday
5 - 8	Correspond to the same days as 1 - 4 in the same sequence but for days belonging to special holiday period;

(5) The hourly variation of electricity consumption of the sector is reflected by calculating normalized daily load curves for the sector and for each type of day mentioned above. These calculations take into account the various types of subsectors with different pattern of electricity consumption during the day. Up to five subsectors can be specified for each sector considered in Module 2. Normalized load curves for each subsector for each day type must be specified, together with the contribution of each subsector in the total electricity demand of the sector. In addition, a differentiation is allowed to take into account the varying pattern of consumption between winter and summer periods (if applicable) of each subsector.

For a given MAED study the time variation of each of these coefficients will be highly dependent on data availability for the system under study.

It should be noted that the modulation coefficients for each sector can be determined only on the basis of statistical studies covering previous years. Various statistical studies have shown that the modulation coefficients for a given sector vary very little over the years (with the obvious exception of the trend coefficient). A country's load curve is much more a function of variations in the proportion of energy consumed in each economic sector than of variations in the various (seasonal, daily or hourly) modulation coefficients for each of these sectors.

6.1.3.3 Module 3: Load duration curve

This module is used to switch from a chronological representation of the demand imposed on the power grid to the format required for studying the optimization of the electricity generating capacity using the WASP model.

Module 3 of the MAED model takes the 8760 values for demand imposed on the grid (calculated by module 2) and arranges them in decreasing order. Module 3 carries out this operation somewhat differently by calculating the duration of each power level. Plotting the power against its duration gives what is known as the "annual load duration" curve for the grid. This curve is then normalized by dividing each power level by the maximum power for the year and dividing its duration by 8760. The normalized load duration curve for each year considered serve as input data for the WASP model.

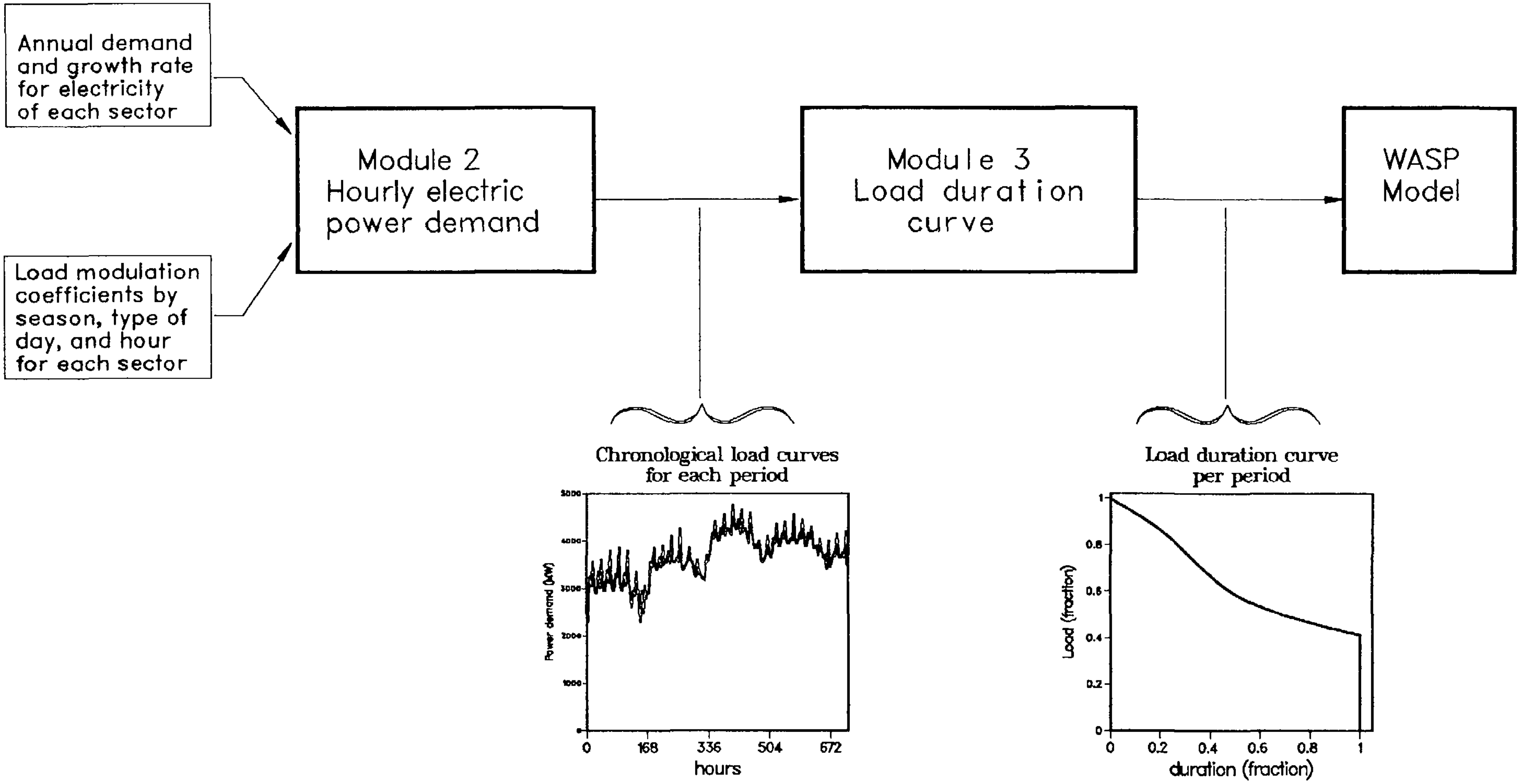


FIG.6.1.18. Schematic representation of the calculations performed by means of modules 2 and 3 of MAED.

Owing to the requirements of the WASP program, it may be desirable to subdivide the year into a certain number of equal periods. The analysis for each period is carried out separately by Module 3 which produces a load duration curve per period (normalized to the period's peak load and total number of hours).

Figure 6.1.18 shows graphically how MAED modules 2 and 3 operate, as well as: (1) the type of information produced as output and (2) the link with the WASP model.

6.1.3.4 Module 4: Load modulation coefficients

This module is considered an auxiliary tool for MAED. It may be used for determining the various load modulation coefficients (trend, seasonal, daily and hourly) characterizing the total system power demand in a given year or eventually the demand of a given sector, a type of client, a feeder, etc. For this analysis, module 4 uses the same methodology already explained for module 2 but applied in a reverse mode. Execution of this module for several years of past experience for the system under consideration may be very useful in the analysis of the power demand characteristics of the system and their variations with the years.

6.1.3.5 Execution of a MAED-1 study

It has been mentioned before that the MAED model, and more specifically its module 1, is based on the MEDEE methodology and particularly on the version MEDEE-2.

From the description given in preceding sections, it is clear that this type of model is mainly controlled by the planner by the construction of scenarios of development for the country or region under consideration and that the model simply provides a consistent framework for evaluating the resulting energy demand. Thus, the MAED/MEDEE models can be considered more as a convenient tool for exploration of the long-term energy demand and this characteristic makes them applicable to a wide range of uses.

For example the paper in Ref. [10] lists the following applications as principal categories of use of the MEDEE models so far:

a) in helping to elaborate national energy plans or energy policies with a direct link with the administration concerned

b) in carrying out prospective estimates at international or national level without any direct link with the process of decision-making and based on scenarios chosen as a function of important questions of the moment; e.g. oil shock, end of economic crisis, etc.; and

c) to help understanding the relationship between energy demand and economic growth within the framework of theoretical or practical reflections (for example, evaluation of energy savings)

Of special importance is the application of MAED (and MEDEE) as a planning tool in studies mentioned in a) above.

On the other hand, the reader is reminded that MAED is mainly intended for use by the IAEA in carrying out Energy and Nuclear Power Planning (ENPP) studies in co-operation with interested Member States (Appendix A describes this type of study). Consequently, whenever applicable, the following subsections emphasize the use of MAED in the context of an ENPP study.

Preparation of input data

The execution of a particular study by means of the MAED-1 model requires a large amount of information which is needed as input data for running the various modules. Table 6.1.8 depicts in a conceptual way the most important data linked to each MAED-1 module. These data are distributed in various input data files as shown in Figure 6.1.19. In addition, each module creates one or more output data files for later use by subsequent MAED modules or for internal calculations as shown in the same figure.

Two important phases can be differentiated in the preparation of information for a given case study, i.e. the reconstruction of the base year and the preparation of scenarios of development.

Reconstruction of the base year: This phase consists of reconstruction of the structure of the country's energy consumption for the so-called base year of study by means of the MAED model. This phase is very important because it allows to check the accuracy of the model's structure with the real situation of the country and also because the estimates of future energy requirements would be strongly influenced by this structure as described in previous Sections.

The selection of the base year of study should be made with great care. This year should be as close as possible to the year in which the study is conducted. Besides, sufficient statistical information on energy consumption by energy form, category of end-use and by sector should be available for this year, including data on the pattern of electricity consumption by sector and subsector and the hourly distribution of electricity consumption for the total power system. Further all above information should be consistent and highly reliable so as to permit calculating a consolidated energy balance for the country. Finally, it should be avoided to select as base year, one for which abrupt changes in the energy consumption or economic growth were experienced, unless they are thought of representing a definite and long-lasting trend.

Using all statistical information for the base year, it is necessary to run successively modules 1, 2 and 3 of MAED in order to reconstruct (as close as possible) first, the country's structure of final energy consumption (module 1) and then, the electric load curves (module 2) and load duration curves (module 3) of the power grid.

Reconstruction of the base year by means of MAED can be cumbersome owing to the generality of the model and to the fact that the statistical data for a country normally would include different breakdowns as in the model.

TABLE 6.1.8. LIST OF THE MOST IMPORTANT INPUT INFORMATION REQUIRED BY MAED-1

TYPE OF DATA / MODULE NUMBER:	1	2	3
GENERAL INFORMATION:			
Definition of base year	X	X	X
Total number of years	X	X	X
Total number of sectors	X	X	
Total number of peridos per year			X
No. of points of Load Duration Curves			X
SCENARIO PARAMETERS:			
Macroeconomy and demography			
– Gross domestic product and structure	X	X	X
– Population and its distribution in rural/urban areas	X	X	X
Parameters for the Industry Sector			
– Energy intensity by type of use	X	X	X
– Substitutable categories of energy use and alternative energy forms	X	X	
– Penetration of alternative energy forms in energy markets	X	X	
– Efficiencies of each energy form and of equipment used	X	X	
– Demand for coke and feedstock	X	X	
Parameters for the Transport Sector			
– Level of economic activity of productive sectors	X	X	
– Mobility of the individual in urban areas and intercity	X	X	
– Distribution of transport demand among various modes	X	X	
– Energy intensity and load factor of each mode of transport	X	X	
– Demand for international and miscellaneous transportation	X		
Parameters for the Household Sector			
– Household size	X	X	
– Distribution of dwellings by type of construction (old/new) and by type of dwelling (villa, flat..)	X	X	
– Specific consumption per dwelling by category of use	X	X	
– Electrification of households	X	X	
– Substitutable categories of energy use and alternative energy forms	X	X	
– Market penetration of alternative energy forms by type of use	X	X	
– Efficiencies of each energy form and of equipment used	X	X	
– Use of non–commercial fuels	X		
Parameters for the Service Sector			
– Total number of employees	X		
– Area per employee	X	X	
– Specific consumption for electricity, air conditioning and thermal uses	X	X	
– Substitutable categories of energy use, alternative energy forms, and market penetration of each form	X	X	
– Efficiencies of each energy form and of the equipment used	X	X	
Electricity Consumption per Sector			
– Degree of interconnection and factor of losses (of the grid)	X	X	X
– Annual electricity demand and growth rate	X	X	X
– Load Modulation coefficients:			
– Seasonal		X	X
– Daily		X	X
– Different types of clients and their share in demand of sector		X	X
– Hourly distribution of demand by client and day types		X	X

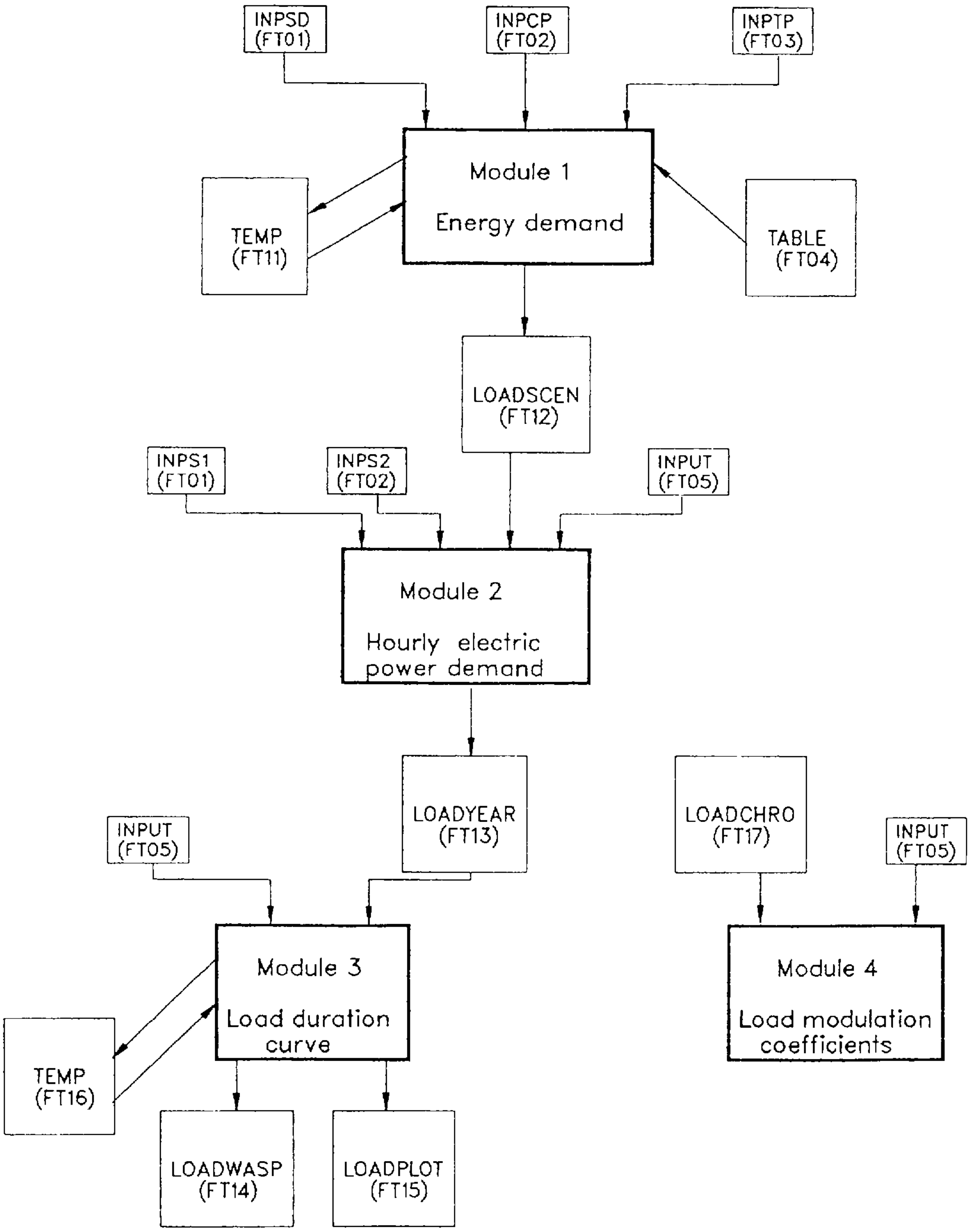


FIG. 6.1.19. Organization of the MAED computer program.

<u>Scenario Description</u>: The next phase in the data preparation of MAED consists of establishing development scenarios to be analyzed and selecting among the possible scenarios those to be retained for the study. Naturally, both aspects, creation and selection of scenarios, are highly dependent on the objectives of the particular MAED study and the responsible(s) for carrying it out. There are, however, certain rules to be emphasized here.

The first consideration to be kept in mind while <u>setting up</u> development scenarios for the country under study is that these scenarios should be internally consistent in terms of the assumptions made. For this purpose, it is necessary to recall the methodological approach for scenario writing that has been established for the MAED/MEDEE methodology which can be summarized as follows (see Ref.[7] for more details).

At the beginning of the scenario writing process, it is necessary to establish a list of the basic features of the scenario. This list should include aspects such as (not an exhaustive list):

International environment:
- Primary energy prices
- Trade patterns and external relations

Socioeconomic development:
- Economic growth
- Development type (emphasis on agriculture, type of industrialization, etc.)
- Population development and distribution
- Life-style standards

Government policy on energy:
- General energy policy
- Final energy price structure
- Specific policies
  - Transport and infrastructure
  - Conservation policies
  - Environmental aspects

Technological evolution:
- Technological changes
- Energy efficiencies
- Market penetration of energy forms

Combining all these aspects, it is possible to construct a development pattern for the country. For the scenario to be consistent, it is necessary that all assumptions be consistent (for example that the energy policies are consistent with the assumptions on economic growth).

In order to further ensure consistency of the scenario, the process continues by organizing the qualitative scenario elements in a hierarchical way in order of importance. Following this rule, at the top of this hierarchical list are the scenario descriptors that have a determining influence on the other descriptors but which cannot be significantly affected by them either, because of their strong inertia (for example, life-style and distribution of population) or because of external constraints (for example, imported energy prices).

The qualitative scenario description is then used to quantify the evolution of the scenario variables. As already indicated in Section 6.1.1.3.1, the scenario elements in MAED are organized in two subscenarios: socioeconomic subscenario (social and economic factors) and the technical development subscenario (see Figure 6.1.4).

From looking at the list of information that is required to describe a scenario (see Figure 6.1.4 and Table 6.1.8) it is obvious that if all variables were treated as scenario elements the consistent construction of the scenario would become rather complex. To avoid this inconvenient, it is required to discard from the list of scenario elements those factors that only slightly influence total energy demand.

These are considered exogenous determinants for which an intermediate evolution is postulated exogenously and assumed to be the same for all scenarios.

The scenario writing consists of formulating assumptions about the evolution of the scenario elements. The scenario is built up by choosing stepwise assumptions for each scenario element, from the top of the hierarchy to the bottom. The main advantage of this systematic scenario writing process is to force the scenario writer to account for the interdependence of the scenario elements and therefore to reduce the risks of inconsistency.

In order to facilitate understanding of the results of the study it is desirable to reduce the number of alternative assumptions (scenarios) to just a few. This requires that an analysis of the likely future evolution of each scenario element must be made before proceeding to actually construct the scenario. This analysis should make broad use of the findings of all long-range studies of the country being considered (e.g., on the evolution of the industrial infrastructure).

In the case of application of MAED for the conduction of ENPP studies, these general guidelines for scenario construction must be obviously extended owing to the objectives of the study and to the fact that the study is carried out by special request and with direct involvement of the national authorities for decision-making on energy matters. Appendix A describes in detail the procedure usually established for writing and selecting scenarios of development within the framework of an ENPP study.

Having established the scenarios of development, the next phase of the study consists of execution of the MAED modules to evaluate the impact of the assumptions made for each scenario of development and to proceed to verify these results. During this phase, sensitivity analyses are executed in order to determine how much the results are affected by variations of the scenario parameters, particularly of those parameters which are most likely to deviate from the original assumptions made in writing the scenarios or parameters for which no good knowledge about their future evolution is available. This step permits identifying which parameters might require further analysis or execution of surveys for their proper determination.

Verification of the results is the next phase of the MAED study. In the general case of application of MAED (or similar approaches) as a planning tool (in helping to elaborate national energy plans), the model is used to evaluate the final energy demand resulting from various development scenarios. In principle, the consistency of the several hypotheses on socioeconomic development and energy policies is inherent to the scenario formulation.

In order to guarantee successful adaptation of the methodology for the system under study, in a first step the results should be verified against hand calculations and, if possible, against the results obtained from the application of other projecting methodologies and from other studies. In addition, the results on energy demand should be verified for consistency at three different levels.

In a first place, the internal consistency of the results must be verified. At this level, it is necessary to verify that the evolution of the different variables described by the model are not impossible or unlikely (for example, if the results lead to utilization rates of some equipment greater than 1.0, or if the number of employees in the service sector is too high when compared to the total labour force), and that the evolutions remain well within a realistic prolongation of the historical evolution.

Furthermore, it is necessary to ensure the consistency of the results with the hypotheses behind the scenario. This includes mainly verifying that the values of certain ratios (i.e., total energy/GDP, energy consumption in households/revenue per household, etc.) are compatible with the logics of the scenario.

Finally, to complete the energy chain for the system under study, it would be necessary to quantify the requirements of primary energy and to determine the level of investments required by the energy sector plus the cost of eventual energy imports. At this level, it is necessary to ensure that these expenditures are compatible with the economic growth rates assumed in the scenario.

The above verifications of consistency of the results have the objective, either to refine or modify the original scenario if large inconsistencies are detected, or to identify and enlighten the risks of inconsistency of the exercise and their meaning with regard to the validity of the results. For instance, if the investments and costs imposed by the energy requirements mentioned above are considered too heavy for the economy, the scenario hypotheses should be revised accordingly, assuming, for example, a lower GDP growth or a less energy-intensive economy, or a combination of both.

In the more particular case of application of the MAED model for conducting ENPP studies, the analysis of eventual feedbacks is rather simplified since at the supply side only the electricity supply system is optimized by means of the WASP program (see Appendix A).

Sensitivity analysis: Apart from the sensitivity analysis conducted during the initial phase of scenario selection and after the final selection of scenarios to be retained for the study and the execution of the MAED runs for these scenarios have been made, it is necessary to conduct further sensitivity analysis for the most important parameters that were identified in the previous phase in order to analyze the effect on the results of the analysis.

Interpretation of Results: This is a very important phase of the execution of a MAED study. Reference is made to the literature on the MEDEE approach [7] [9], and to the paper in Ref. [10], from which the following ideas have been extracted.

The interpretation of the scenario results is needed owing to the non-deterministic and often relative characteristic of the results. It consists of describing the mechanisms that have led to the results on energy demand for a given scenario and to place them in the light of historical tendencies and in relation to other scenarios.

This means that for each scenario, it is necessary to complete the whole quantification of the results, by a qualitative analysis of the chain of events and of evolutions. This will involve describing the role played by the various hypotheses made, and the degree of reliability that can be accorded to the different results. This last point emphasizes the recommendation to conduct sensitivity analysis on the exogenous scenario variables for which data is less known or its development is more uncertain.

The comparative interpretation of the results from different scenarios is a very good learning process particularly with MAED and similar models where the gross results alone are difficult to interpret separately. Here, emphasis is given to the analysis of the consequences in energy terms of important changes in the condition of socioeconomic development and, if it is the case, in the definition of energy policies. It is not the absolute values of the results that need to be interpreted but the divergencies (absolute or relative) of the results between different scenarios. Thus the interpretation consists of linking these divergencies to the differences in the hypotheses behind the scenarios.

Report of the MAED Study: Once all major stages of the MAED analysis have been completed, it is necessary to produce a report summarizing the principal findings of the study.

The findings of the study should concentrate on analysis of the major results obtained by means of the scenarios. At this level, it is important to remember that the results of MAED do not have a meaning of their own but only in relation to the original scenario which they quantify. In other words, the MAED results presented alone will not have any proper meaning without mentioning the context of the corresponding scenario.

In addition to the above, it should be kept in mind that the results of MAED (or any other model based on the same approach) do not have a value of precision in the traditional sense of deterministic prevision. They are always conditional and do not have a meaning but in relation to the question:

"What would happen if .... ?"

Consequently, the major findings of the study should also be accompanied by the major hypotheses combined with the study. These hypotheses should cover not only those related to the construction of the scenarios of development but also approximations that were necessary to be made for the reconstruction of the country's energy structure for the base year of analysis, mentioning also their importance in terms of their influence on the results.

Combined with these hypotheses, the report should include proposals and recommendations for follow up studies and actions in the energy field, including needed actions to improve the knowledge of the energy consumption pattern of the country to the actual recommendations on energy policies.

In the case of ENPP studies conducted by the Agency, the actual contents of the report of a particular study will obviously be dependent on the main objectives of the study. One example of such reports is given in the IAEA publication in Refs. [11] and [12]. Similar reports are expected to be published in the future for the different countries for which ENPP studies are being conducted [13].

6.1.3.6 Program output

Apart from the output files created during execution, each MAED module produces a report with the results of the analysis carried out, as illustrated in Figure 6.1.19.

For Module 1, a standard report is produced as follows. This report is organized in a tabular manner aggregating the information into several tables and subtables containing either results of the analysis or a summary of input data in an aggregated form. Results on final energy demand are presented broken down by energy form and by economic sector and as absolute values (in the energy units specified to the program) or in relative terms (in %). Summary tables with major results, as well as results of intermediate calculations are also presented for quick checks. Finally, input information for each sector is also combined in some tables for completeness of the report. Table 6.1.9 shows one of the various output tables produced by the MAED program. This table corresponds to the results provided by the program for the case example developed to document the MAED-1 Users' Manual [9].

The output for each of the other three MAED modules vary according to the amount of information that is required from the run and is controlled by an output option that must be specified to the program. The so-called maximum output option is normally recommended for execution of the programs during the phase of reconstruction of the base year whereas minimum output option is used for the actual scenario runs.

For maximum output option, the report for module 2 contains detailed information on electrical load curves (hour-by-hour power demand) per sector and for the total power grid and for each year of analysis. Electrical load curves are not included in the report when minimum output option is specified owing to the long output that will be produced when many years of analysis are involved.

The report of module 3 will always contain the load duration curves of the power grid for each period and for each year of analysis. The maximum output option will add to the report information on the hour-by-hour power demands that are read as input for each month of each period.

The report of module 4 contains basically the load modulation coefficients resulting from the analysis. A detailed description and illustration of the above reports can be found in Ref. [5].

6.1.4 Description of the modified version MAED-2

The modified version MAED-2 is based on the same methodology as the one described for MAED-1. Modifications were made entirely to Module 1 where energy demand is calculated. Modules 2, 3 and 4 remain unchanged. Ref. [14] describes in more detail the characteristics of the MAED-2 model.

6.1.4.1 Structure of the MAED-2 model

The structure of the model is shown in Figure 6.1.20. The model consists of eight blocks. The first block is used for the purpose of defining, in quantitative terms, the evolution of the growth of each economic sector.

TABLE 6.1.9. ILLUSTRATION OF THE TABULAR OUTPUT OF MODULE 1 of MAED-1

```
DETAILED RESULTS OF MAED/TABLE 2 :                                                            CASENA   /SCENARIO-1
**********************************

FINAL ENERGY RESULTS (GWYR):                    1980        1985        1990        1995        2000        2015
----------------------------                 ----------  ----------  ----------  ----------  ----------  ----------

BY SECTOR:
----------
   AGR/CONSTR/MIN/MAN.(INCL.FEEDST.)             3.761       7.308      12.613      19.742      27.838      48.192
   TRANSPORTATION                                3.064       4.022       5.164       6.507       7.906      12.299
   HOUSEHOLD/SERVICE (EXCL.NON-COMM.)            2.975       5.485       7.251       9.897      13.261      25.031
   ----------------------------------         ----------  ----------  ----------  ----------  ----------  ----------
   TOTAL COMMERCIAL (INCL.FEEDST.)               9.800      16.816      25.028      36.145      49.005      85.522

BY ENERGY FORM:
---------------
   FOSSIL (SUBST.)                               4.215       7.630      10.084      14.012      18.079      31.784
   CENTRALIZED HEAT SUPPLY                       0.0         0.0         0.0         0.0         0.0         0.0
   SOFT SOLAR                                    0.0         0.002       0.026       0.099       0.297       1.100
   ELECTRICITY                                   0.687       1.272       2.358       3.361       4.825       9.376
   MOTOR FUEL                                    3.824       5.101       7.011       9.516      12.553      19.948
   COAL, SPEC.USES                               0.303       1.160       2.529       4.272       6.215      10.807
   FEEDSTOCKS                                    0.772       1.650       3.020       4.885       7.036      12.507
   ----------------------------------         ----------  ----------  ----------  ----------  ----------  ----------
   TOTAL COMMERCIAL (INCL.FEEDST.)               9.800      16.816      25.028      36.145      49.005      85.522
   NON-COMMERCIAL FUELS                          0.452       0.361       0.339       0.316       0.294       0.226
   ----------------------------------         ----------  ----------  ----------  ----------  ----------  ----------
   TOTAL (COMMERCIAL+NON-COMMERCIAL)            10.252      17.177      25.367      36.461      49.299      85.748

FINAL ENERGY RESULTS (%):
-------------------------

BY SECTOR:
----------
   AGR/CONSTR/MIN/MAN.(INCL.FEEDST.)            38.4        43.5        50.4        54.6        56.8        56.4
   TRANSPORTATION                               31.3        23.9        20.6        18.0        16.1        14.4
   HOUSEHOLD/SERVICE (EXCL.NON-COMM.)           30.4        32.6        29.0        27.4        27.1        29.3
   ----------------------------------         ----------  ----------  ----------  ----------  ----------  ----------
   TOTAL COMMERCIAL (INCL.FEEDST.)             100.0       100.0       100.0       100.0       100.0       100.0

BY ENERGY FORM:
---------------
   FOSSIL (SUBST.)                              43.0        45.4        40.3        38.8        36.9        37.2
   CENTRALIZED HEAT SUPPLY                       0.0         0.0         0.0         0.0         0.0         0.0
   SOFT SOLAR                                    0.0         0.0         0.1         0.3         0.6         1.3
   ELECTRICITY                                   7.0         7.6         9.4         9.3         9.8        11.0
   MOTOR FUEL                                   39.0        30.3        28.0        26.3        25.6        23.3
   COAL, SPEC.USES                               3.1         6.9        10.1        11.8        12.7        12.6
   FEEDSTOCKS                                    7.9         9.8        12.1        13.5        14.4        14.6
   ----------------------------------         ----------  ----------  ----------  ----------  ----------  ----------
   TOTAL COMMERCIAL (INCL.FEEDST.)             100.0       100.0       100.0       100.0       100.0       100.0
   NON-COMMERCIAL FUELS                          4.6         2.1         1.4         0.9         0.6         0.3
   ----------------------------------         ----------  ----------  ----------  ----------  ----------  ----------
   TOTAL (COMMERCIAL+NON-COMMERCIAL)           104.6       102.1       101.4       100.9       100.6       100.3
```

There are two options for such estimation. The evolution of economic growth for each sector could be defined either as a fraction of the total GDP or by econometric equations with macro-economic characteristics. The total GDP, its distribution by sector, or the coefficients of the macro-economic equations are determined exogenously by the scenario for every specified year.

The seven other blocks correspond to the seven consumer sectors considered: manufacturing, mining, agriculture, construction, transportation, services and household.

Each block or consumer sector also includes at least two sub-blocks or options. If a detailed estimation of energy demand is required for the case study and if proper information is available, the sub-blocks located on the right-hand side of Figure 6.1.20 could be used. These sub-blocks consider the sector with further breakdowns, either monetary units or physical units could be used to specify the value of the determinants of energy requirements.

If detailed information about the consumer sectors is not available for a given country one can use the sub-blocks located on the left-hand side of Figure 6.1.20. These sub-blocks consider the sector as a whole and, in this case, the economic activity expressed by the GDP contribution of the sector serves as a driving force.

A slightly different structure could be observed for two sectors, transportation and household. The transport sector is broken down from the beginning into the following four sub-blocks or subsectors: urban passenger, intercity passenger, international and freight transportation. In order to determine the energy demand by freight transportation it is also possible to do it either, from economic activity expressed in monetary units, or from the ton-kilometer of goods transported.

Taking into account the importance of the household sector for most developing countries, three options are included in the model for this sector:

- either, the sector is treated globally and its energy requirements are driven alternatively by the evolution of the average income per household or by the number of people living under a given level of energy consumption;

- or finally, the sector is subdivided into three subsectors, each one representing a type of human settlement with different type of specific energy requirements.

The selection of the specific options which will be used by the program is accomplished by means of user specified indices.

6.1.4.2 Macro-economic block

This block defines the GDP formation for the following sectors of the economy: manufacturing, mining, construction, agriculture, transportation, service and energy. Since the manufacturing sector is considered in the model to be composed of three subsectors, i.e., group of energy-intensive industries, group of consumer goods industries and

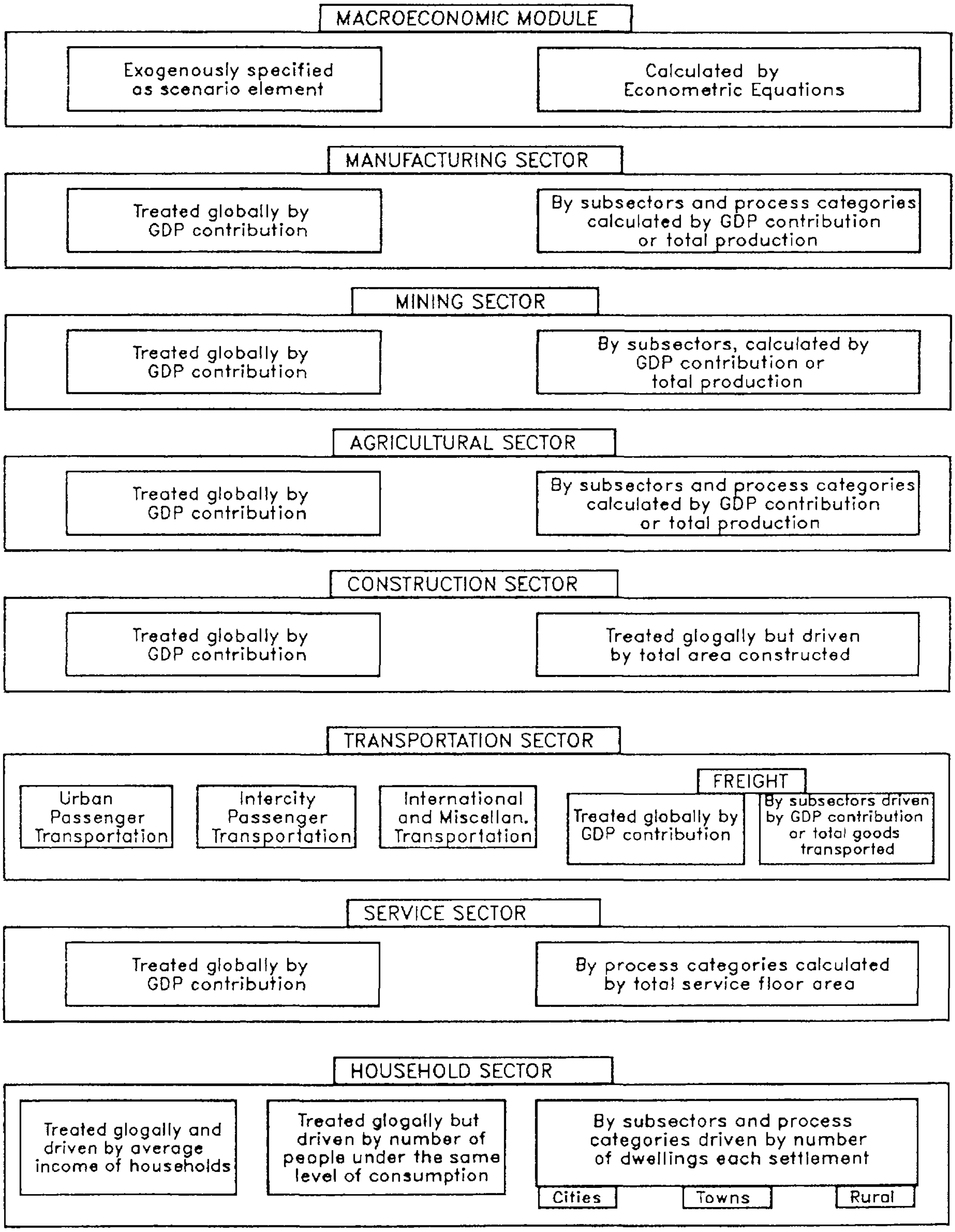


FIG.6.1.20. *General structure of the MAED-2 model.*

group of all other industries, the value added by each of these subsectors is also determined in the macro-economic block of the model. There are two options for determining GDP formations and value added: either as a portion of total GDP or by econometric equations using some coefficients specified in the scenario.

For the cases of more detailed estimation of energy demand for specific industries or processes, it is necessary to have, alternatively, either the total production of those industries or their contribution to value added. Figure 6.1.21 provides an example of the breakdown of the economic sectors considered in MAED-2. It should be noted that the definition of the actual sector and subsectors to be included in each sector is totally controlled by the user.

6.1.5 General features of the MAED modeL

The main features of the MAED model could be summarized as follows:

- It is designed to evaluate medium and long term energy demand for a country as a whole, broken down by sector and by energy forms;
- It is driven by the scenario which is defined by a certain number of economic, social and technical factors;
- It is oriented towards the case of developing countries;
- It allows to analyse the substitution of energy forms;
- It pays special attention to the evaluation of the electricity demand;
- It permits that the final results of the calculations could be presented in different units;
- It produces the output file which could be used directly for the supply model WASP;
- In addition, MAED-2 has options to consider different levels of detail of the structure of consumer sectors; as well as to consider different sets of determining factors as driving forces. This characteristic gives flexibility to select one or another option, depending on the data available.

6.1.6 Conclusion

Decision making at the national level is an increasingly difficult task. Links which may often be imperceptible or at least unapparent may transform the best of intentions in one area into catastrophe in another. One particularly sensitive area where any wise decision-maker must act with caution is energy, owing to its many links and interdependence with the various sectors of the economy.

MANUFACTURING SECTOR

ENERGY–INTENSIVE INDUSTRIES

For example:
1– Steel, fossil fuel furnaces
2– Steel, electrical furnaces
3– Non–ferrous metals
4– Cement and building materials
5– Chemical industries
6– Glass industries
7– Pulp and paper
8– Iron
9– Others

CONSUMER GOODS INDUSTRIES

For example:
10– Food
11– Textiles
12– Beverages
13– Others

OTHER INDUSTRIES

For example: 14– Other

MINING SECTOR

For example:
15– Drilling
16– Mining

AGRICULTURAL SECTOR

For example:
17– Grain
18– Meat
19– Other animal products
20–Milk and dairy products
21– Other agricultural prducts

CONSTRUCTION SECTOR

Household
Service
Industry

TRANSPORT SECTOR

Urban passenger
Intercity passenger
Freight
International and others

HOUSEHOLD SECTOR

Cities
Towns
Rural areas

SERVICE SECTOR

FIG. 6.1.21. Consumer sectors considered in the MAED-2 model.

The two models, MAED-1 and MAED-2, may assist the energy authorities to better grasp the energy problem and use a consistent methodology for energy and electricity forecasting. However, MAED-2 is more adaptable to the needs of developing countries owing to its greater flexibility for defining the driving parameters of each category of end-uses of energy. The data and information requirements for the two models impose a certain discipline in data gathering and may force several governmental bodies, particularly in developing countries to interact and exchange information which will undoubtedly increase the reliability and availability of data.

6.2 TUV: Technical University of Vienna model

The TUV model was designed to evaluate long term global energy demand scenarios and supply strategies. It is a simple model that can be applied to large geographical or aggregrated geopolitical regions. It is not particularly suitable for application to national energy studies, where a greater level of detail is normally required.

The TUV model was developed by Prof. P.J. Jansen and Mr. G. Rotter of the Energy Economics Institute of the Technical University of Vienna, under a research contract with the IAEA.

The model is a simplification and integration of three separate energy models developed by IIASA (International Institute for Applied Systems Analysis, Laxemburg, Austria) for a global energy study presented in the report Energy in a Finite World [8].

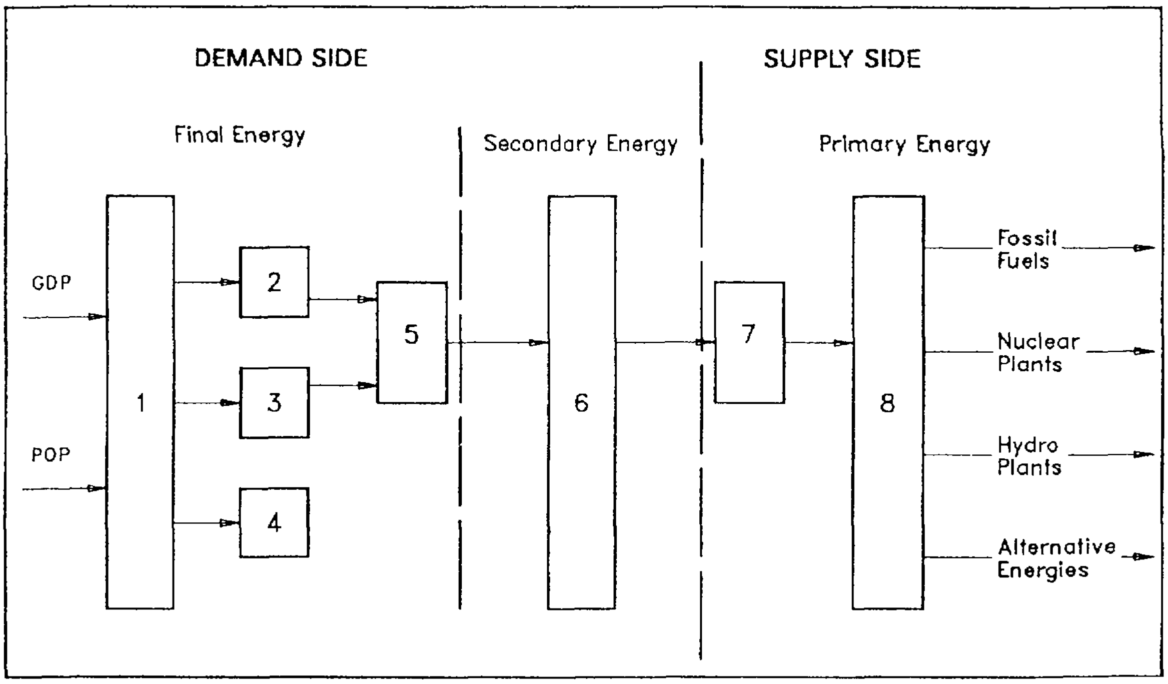
A brief presentation of the structure of the TUV model will follow. A detailed description of the model can be found in the User's Manual for the TUV Model [13].

Figure 6.2.1 presents the general structure of the TUV model, showing the demand and supply sides of the model.

Modules 1 to 5 on the demand side compute final energy demand. They are a simplification of the MAED model described in the previous section, but the methodology used is the same as that used in MAED (particularly by Module 1 of MAED) and other models of the MEDEE family (see references 5 and 6 and section 6.1.2 of this guidebook).

The most important simplification introduced in the demand side, compared to the MAED model, is that the TUV model requires only two sets of data to specify a scenario, one describing the base year and another describing the final year. The input parameters for the intermediate years are computed automatically by the model. This computation is a non-linear interpolation between the values of the base year and final year, guided by the historical and projected evolution of the GDP and population of each world regions. A historical series of these two parameters covering a period prior to the base year must be provided as well as projections for every future year (step) for which energy demand results are desired.

Still at the demand side, final energy demand is then converted into secondary energy demand in module 6 (fuel-mix and substitution). There is no optimization procedure in module 6. When there is possibility of interfuel substitution, the shares of each fuel must be specified by the user.



1. Macro-economic and socio-economic module
2. Agriculture and industry module
3. Service and household module
4. Transport module (intercity and urban passanger, freight)
5. Thermal module
6. Fuel-mix module
7. Electricity generation module
8. Supply module for secondary and primary energy

FIG.6.2.1. TUV model — general structure.

Finally, the supply side of the TUV model (modules 7 and 8) searches for an "optimum solution" to balance energy demand, i.e., the requirements for different forms of primary energy.

The supply side is a linear programming formulation of the energy supply problem. The "optimum solution" should be understood as the solution which maximizes or minimizes the value of a linear objective function chosen by the user, such as total cost or use of indigenous resources.

In addition to secondary energy demand, calculated by the demand side, the supply side requires as input data the costs of primary energy, such as oil, gas, coal and uranium, and costs related to energy transformation such as costs of installation and operation of power plants and costs of building refineries.

Bounds to restrict the evolution of the supply structure are specified by the user:

- limits for the build-up of energy supply technologies,
- limits for annual extraction of energy resources,
- limits for overall resource availability over the time horizon,
- limits for energy trade between world regions.

Characteristics of power plants and load duration curves must also be provided, so that module 7 (electricity generation module) can determine the capacity and type of plants to be used in the expansion of the electricity generation system.

To apply the model the user divides the world in reasonably homogeneous regions, builds a socio-economic scenario for each region and starts an iterative procedure trying to balance energy supply and demand.

The demand side of the TUV model evaluates a first approximation of world energy demand. Then the supply module verifies the plausibility of the demand levels obtained. If the growth of energy demand is too fast in one or more regions, causing unacceptable strain on energy supplies, or an unrealistic pattern of energy trade, the user must review the scenario assumptions.

This iterative procedure is not automatic, but is instead an open loop requiring analysis and judgement from the user.

The output of the model is a series of tables showing for each world region:

- the evolution of final and secondary energy demand per economic sector and per type of fuel,
- the structure of primary energy supply
- energy imports and exports
- installed electrical capacity per type of power plant,
- total annual expenditures for primary energy costs,
- capital and operational costs of energy transformation plants, such as oil refineries and electrical power plants.
- The TUV model has been used in a recent joint study by IAEA/OECD to evaluate the world energy demand up to the year 2025 [14] .

The TUV model gives a perspective view of the energy demand and supply problem looking at the world taken as a whole [16].

6.3 EDE / MONODIA model

Energy and electricity demand forecasting and electric load modelling are two steps in the electric and nuclear power planning process. The common process of electric power planning is illustrated in Fig. 6.3.1. EDE and MONODIA are models to cover these two steps within the planning process. Both models were developed by Messrs. K. Schippers and W. Strack of the Institute of Nuclear Energy of the University of Aachen, F.R. of Germany, under a research contract with the IAEA [17].

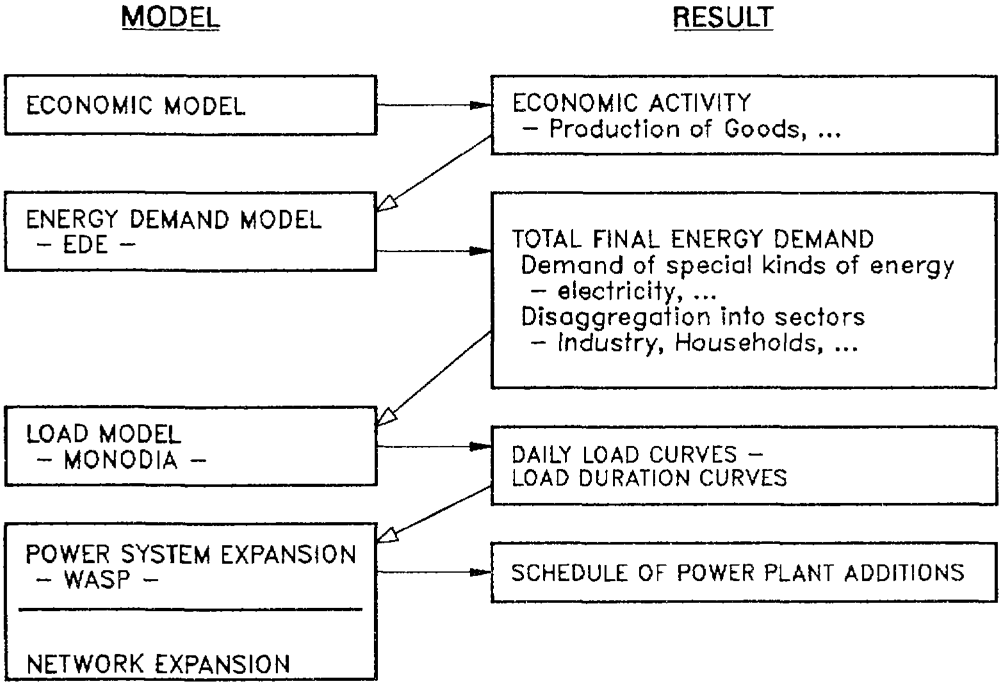


FIG. 6.3.1. Process of electric power planning.

The EDE (Energy Demand Evaluation) model was developed with special regard to the planning problems of developing countries. Some of these problems are:

- the big contrast in energy supply within the country between big cities and rural areas, which calls for regional disaggregation;
- an appreciable amount of non-commercial energy use, which cannot be neglected;
- a rather limited statistical data base on energy consumption, which calls for an appropriate corresponding model design.

EDE and MONODIA are both able to run as independent models as well as one model package, wherein some values calculated by EDE (electricity demand, losses) are prepared as input of MONODIA. Figure 6.3.2 shows the general structure of the models.

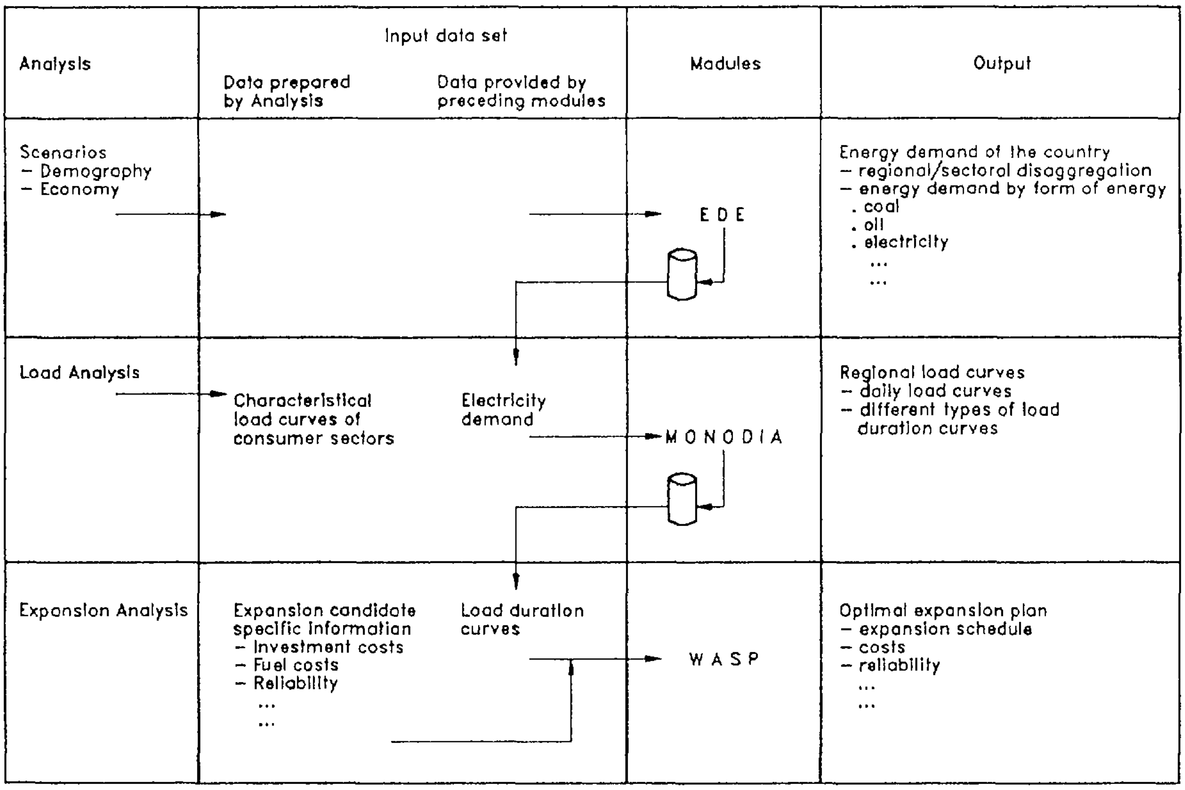


FIG. 6.3.2. The general structure of the EDE-MONODIA model.

6.3.1 The EDE model

6.3.1.1 General description

Similar to the MAED model, in EDE the demand of total energy, electricity and, optionally other nonsubstitutable energy sources are calculated as a function of socio-economic determinants (e.g. population, number of dwellings, GDP, activity of the different industrial sectors).

These determinants must be given as input data, which have to be defined and introduced exogenously by the user (see Fig. 6.3.2). Therefore, the EDE model is not an econometric model, though some checks of economic consistency are provided for.

The main differences between MAED and EDE can be summarized as follows:

a) In EDE the activity of the industrial sectors is preferred to be specified in terms of physical units instead of monetary units as it is the case in MAED.

b) The EDE model offers the opportunity to separate a country into different regions and to calculate the energy demand within each region on a different level of sectoral disaggregation (e.g. industry, household, agriculture). An exception is made for the transport sector, for which energy demand is calculated only for the total country. Depending on the importance of the different sectors (e.g. industry, manufacturing, ...) and the available data for the country considered, one sector, e.g. the chemical industry, can be subdivided in subsectors, e.g. the production of fertilizers, and beyond these, down to technical processes.

EDE includes a reference list of the most common sectors and subsectors considered, but new sectors can simply be inserted by the user.

c) In MAED, definition of a development scenario requires the complete specification of the values of the scenario parameters for each year of study, whereas in EDE the evolution of the scenario parameters over the study period can be specified in a more flexible way. In order to simulate different time developments the user can choose between different time functions:
   - constant
   - linear
   - logistic upward
   - logistic donward
   - direct input

   These functions are implemented into the computer code and can be applied either to any specific energy consumption data or to any time dependent determinant such as population or GDP. To use this feature, no external calculations are necessary. By specifying a certain number of points (year and value) the model tries to make a curve fitting through the given points and makes interpolations for the time intervals in between. Thus, it facilitates introduction of changes of time functions during the simulation process, or correction of time series if more accurate ones are available.

d) In EDE energy demand for all end uses is directly calculated in terms of final energy, whereas in MAED an evaluation in two steps (first useful then final) is performed (Section 6.1). The explanation for this choice in EDE is given in Section 6.3.1.3.

The EDE model was designed as a computerized tool which enables the user to easily understand and follow the mathematical functions and relationships. Thus avoiding the problem of following a high sophisticated model philosophy. The clarity of the computational scheme makes it possible to check the calculations or the impacts of changing input data easily.

The model is a tool for analysing the energy demand evolution over the planning period in relation to the evolution of the input data. The most interesting problem in this field is the investigation of the impacts of structural changes (changes among different sectors - changes of industrial processes) or the impacts of decrease in the specific energy consumption by introducing energy saving techniques.

Furthermore, the model is suitable to analyse the energy situation if the country reaches a certain economic or social level. This level could be defined by a global scenario for the whole country, e.g. screening the situation when the country develops to European or American standards, or could be defined by the saturation of a special sector, e.g. the private car ownership.

The application of EDE to developing countries requires to pay special attention to the input data base. In general, it is often impossible to get statistical data in the amount as data exist for industrialized countries. The reasons are manifold; often simply no statistical evaluation exists or data are treated as secret material. In order to avoid this inconvenience the energy demand analysis with the EDE approach requires only a few country specific data. For other data (e.g. specific energy consumption data) it is practicable to make use at the beginning of the available international data base. During continuous improvement of analyses, the data base can be enlarged and adapted to the special requirements of the country.

6.3.1.2 Main characteristics and basic equations

The main characteristics of EDE can be summarized as follows:

- disaggregation of the country into different regions (up to 20);
- within each region disaggregation into the important sectors household, industry, manufacturing, agriculture (6.3.1.4);
- within each sector an additional disaggregation into subsectors or special energy consuming processes if possible or required;
- disaggregation of the planning interval into up to ten periods (the single period length is defined by the user);
- calculation of energy demand at the end of each period;
- calculation of all energy demand values in terms of final energy to allow an easy comparison with international statistics.

Using the final energy concept, leads to the basic equation:

$$\text{ENERGY} = P \times \text{SEC} \qquad (6.3.1)$$

where P is the production in tons, and SEC the specific energy consumption in kW.h/t.

All energy which cannot be substituted by any other energy source, e.g. electricity for lighting or motive power, is calculated from:

$$\text{ENERGY}_{\text{specific}} = P \times \text{SEC} \times \text{SH} / 100 \qquad (6.3.2)$$

where SH is the share of energy which cannot be substituted (in percent).

These simple equations are used to derive all other calculations performed by the model in order to produce the results of the analysis. The results of the EDE model include:

- the total energy demand in terms of final energy at the end of each period defined;
- the demand of those types of energy which are specified as non-substitutable, e.g. electricity, motor fuel, etc.;
- the electricity demand for each defined sector, subsector or important process;
- disaggregation into regional and sectoral demand including different summaries; and
- the losses in the electrical network.

All results concerning electricity demand are prepared for later use by the MONODIA model which can be used to generate daily load curves and load duration curves (see Figure 6.3.2).

6.3.1.3 Remarks to the final energy approach in the EDE model

The energy demand required by the consumer for manifold purposes, e.g. lighting, mechanical power, etc., is useful energy. For this reason, energy demand for forecasting should be based on the useful energy demand. On the other hand, the energy made available to the consumer is final energy in all known types, e.g. gasoline, electricity, etc. The final energy demand can easily be measured and many statistical data about all types of energy consumption are available (except noncommercial energy). The data base on useful energy demand is, however, very limited. To obtain the useful energy required, the consumer has to transform the final energy, a process which involves always losses of energy depending on the efficiency ('η') of the equipment used.

In the EDE model, the 'specific energy consumption' (variable SEC) measures the final energy demand and includes the step of transformation of final energy to useful energy.

Three different cases of energy consumption are discussed in the following paragraphs in order to demonstrate that energy demand forecasting based on the final energy demand provides as appropriate results as energy demand forecasting based on useful energy demand:

- energy consumption with a fixed energy spectrum: For this special application one or more special types of energy are necessary which are not substitutable.

  Example: aluminium plant, in which the nonsubstitutable energy is electricity.

  Any change in efficiency, e.g. as a result of technical improvement, will be taken in account in the time function of the specific energy consumption.

- energy consumption with a variable energy spectrum: For this application several energy sources are possible and they are completely substitutable.

  Example: steam generation, with oil, gas, coal, etc.

  In this case the efficiencies of the different equipments installed are equal or differ only slightly. Any change in efficiency will be taken into account in the time function of the specific energy consumption.

- energy consumption for which two or more different technical processes exist: For this application several technical processes are used for the same purpose.

  Example: pig iron production with - blast furnace, or
  - direct reduction

  In this case the sector considered 'pig-iron-production' will be split into the two (or more) processes existing and each process will be considered separately as explained above. Thus, the problem of substitution of energy is transformed into the problem of substitution of technical processes.

For developing countries one special case must be taken into consideration additionally:

- countries with large resources of hydroelectric power: Probably in these countries the price of electricity will be lower than in other countries. Thus a part of the energy demand, classified as substitutable, will be covered by electricity. The share of electricity of the specific energy consumption for a special application will be higher than in the same application in other countries.

  In order to get the whole electricity demand for this case, the share of electricity must be increased by the user.

Having discussed these general aspects the different sectors considered in the EDE model are now explained in detail.

6.3.1.4 Modelling of the different sectors

All time-dependent variables presented in the following sections are calculated in fixed time steps (smallest = one year) depending on the total length of the planning horizon. The values are calculated for the base year and up to ten time intervals. All energy calculations are done with the unit kW.h.

Transport Sector

The energy demand of this sector is calculated for the whole country only (no region loop). The sector can be broken down into the important subsectors: railway, aviation, ship, truck, bus, pipeline.

The time dependent development of demand for transportation in the different subsectors is dependent on the exogeneously defined parameters: - GDP(t), - Population(t), and - the share of total transportation (t).

The energy demand of all subsectors except the subsector "private cars" is calculated as follows:

$$ENERGY(i,t) = GDP(t) \times CO(t) \times PA(i,t) \times SEC(i,t) \qquad (6.3.3)$$

where:

i	subsector
t	time
SEC(i,t)	specific energy consumption; (kWh/t-km or kWh/pa-km)
PA(i,t)	part of total transportation; (%) (freight or passenger)
CO(t)	coefficient: for freight transportation: t-km/unit of the transport intensive sectors; namely: agriculture, industry total, construction, sale + trade for (public) passenger transportation: pa-km/unit GDP total
GDP (t)	GDP(total) for passenger transport (currency units) GDP contribution of the transport intensive sectors for freight transport; (currency units).

Even in developing countries the energy consumption of private vehicles is generally the most important subsector. This subsector is calculated in a different manner:

$$ENERGY(i,t) = POPUL(t)/CO(t)/GDPC(t) \times SEC(t) \times RP(t) \times 100 \quad (6.3.4)$$

where:

i	subsector car - private
POPUL(t)	population
CO(t)	coefficient: inhabitants per car/GDP per capita
GDPC(t)	GDP per capita
SEC(t)	specific energy consumption of the car; (kWh/100 km)
RP(t)	average annual road performance of the car; (km/a)

Public Sector

This sector and the following ones are calculated for each region defined by the user.

The public sector is very heterogeneous including hospitals, schools, administration buildings, etc. Therefore, it is very difficult to get reliable data about the energy consumption of this sector. At best, only data about the number of employees and the total energy consumption are available, whereas detailed information, for instance about floor area and energy consumption of air-conditioning and heating, is missing. For this reason the energy consumption of the public sector is calculated as a function of the number of employees:

$$ENERGY(i,t) = NO(i,t) \times \sum_{j=1}^{3} SEC(i,j,t) \times PAI(j,t) \quad (6.3.5)$$

where:

i	public sector
NO(i,t)	number of employees
SEC(i,j,t)	j=1 specific energy consumption for heating; (kWh/(a . employee . degree day)) (only if necessary) j=2 specific energy consumption for air conditioning; (kWh/ (a . employee)) (only if necessary) j=3 specific energy consumption for electric appliances; (kWh/ (a . employee))
PAI(j,t)	percentage of employees supplied with air-conditioning (only for j=2)

Household Sector

The EDE model distinguishes between three different types of dwellings to represent different socio-economic structures.

- DWELLING-1: represents the poorest class of the population, e.g. people living in rural areas or typical slums of the big cities. This type of dwelling has no electricity supply and the main energy source is noncommercial energy. During periods of economic growth the number of people belonging to type 1 will decrease and change to type 2 if the household is connected to the grid.

- DWELLING-2: represents that social class which lives under "normal" conditions. "Normal" means that the dwelling has electrical power supply, and commercial energy is regularly used for the different energy needs. At least one member of the family has a regular income, therefore the family can afford to consume the energy. During periods of economic growth with rising income, the energy demand will have high growth rates, due to high growth rates of the equipment stock, e.g. refrigerators, TV's etc. This part of the population will consume the highest amount of energy in the household sector.

- DWELLING-3: represents the social class with a living standard similar to industrialized countries. The equipment stock and energy demand of this class is relatively high, but the total number of dwellings type 3 is rather small.

The defined assignment of the dwelling type to the different end uses is explained in Table 6.3.1. The figures in brackets (x) indicate that this application can be introduced for this dwelling type but should only be used if necessary, because normally this end use represents only a small part of energy consumed by this dwelling type. The application MISCELLANEOUS or MISCELLANEOUS-NONCOM should be used only if no detailed data are available or if no disaggregation is required.

TABLE 6.3.1. END-USE APPLICATIONS OF HOUSEHOLD SECTOR BY TYPE OF DWELLING

Application type	DWELLING-1	DWELLING-2	DWELLING-3
cooking	(x)	x	x
cooking-noncommercial	x	(x)	–
heating	(x)	x	x
heating-noncommercial	x	(x)	–
hot water supply	–	x	x
electrical appliances	–	x	x
air-conditioning	–	–	x
miscellaneous	(x)	x	x
miscellaneous-noncommercial	x	(x)	–

The increase in energy demand of the Household sector is directly related to the population growth, but substitution takes place by growing urbanization. In contrast the poorest cannot afford commercial fuels because of continuosly rising energy prices. That means noncommercial energy will be a very important energy source for the next years, especially for those countries with limited energy resources. Using noncommercial fuels the efficiency of cooking, or heating if required, is only low (10% - 20%). Having extremely different efficiencies, the demand of noncommercial energy is always separated and not incorporated into any balance concerning those applications dealing with commercial energy.

In order to simulate the socio-economic development, e.g. the decrease of the part of the population living in DWELLING-1 and the increase of the part of the population living in DWELLING-2 and-3, the EDE model uses the terms: PA1(nreg,t), PA2(nreg,t), and PA3(nreg,t) as the part of the population of the region living in dwelling 1, 2, 3, respectively. In addition, to simulate the decreasing family size during rising living standards, EDE uses the terms: NO(nreg,1,t), NO(nreg,2,t) and NO(nreg,3,t) for the number of persons living in each type of dwelling. These two variables enable the user to define the total dwelling mix which is one part of the scenario assumed.

Now the different equations are explained in detail for dwelling type-3. (The equations for DWELLING-2 and DWELLING-1 are analogous)

Dwelling type-3 has the following characteristics:

Energy demand for:
- cooking
- heating (if necessary, depending on climate)
- hot water (shower, bath)
- air conditioning (if necessary)
- electrical appliances (lighting, refrigerator,...)

Supply only with commercial energy.

The basic equations are:

$$\begin{aligned}\mathrm{ENDW3}(j,t) = {} & \mathrm{NOPR}(nreg,t) \times \mathrm{PDW3}(nreg,t) \,/\, \mathrm{NO}(nreg,3,t) \\ & \times \mathrm{SEC}(nreg,3,j,t) \times \mathrm{PAI}(nreg,t) \times \mathrm{NODD}(nreg)\end{aligned} \tag{6.3.6}$$

$$\mathrm{ENERGY}(i,t) = \sum_{j=1}^{3} \mathrm{ENDW3}(j,t)$$

where:

NOPR(nreg,t) : population of the region

PDW3(nreg,t) : part of population of the region living in dwelling type-3 (%)

NO(nreg,3,t) : number of persons living in dwelling type-3

SEC(nreg,3,j,t): j=1 specific energy consumption for cooking; (kWh/ (a . dwelling))

: j=2 specific energy consumption for heating; (kWh/ (a . dwelling . degree day))

: j=3 specific energy consumption for electric appliances; (kWh/ (a . dwelling))

: j=4 specific energy consumption for hot water supply; (kWh/ (a . dwelling))

: j=5 specific energy consumption for air conditioning (only electric air conditioned assumed); (kWh/ (a . dwelling))

PAI(nreg,t) : percentage of dwellings with air-conditioning (%) (only for j=5, otherwise set to 1.)

NODD(nreg) : no. of degree days (only for heating, otherwise set to 1.)

Industry Sector

Many developing countries have been exporters of raw materials up to the present. But in the future these countries will try to process their raw materials themselves, at least to intermediate goods. Therefore, varying from country to country, one or more subsectors of industry will sooner or later become very important energy consumers especially for that particular country.

The model covers the most important industry subsectors. Many are broken down into processes to ensure that a realistic approach is made if changes in technology take place which enforce either a reduction in energy consumption or a change in the fuel mix of the industrial processes. If necessary the user can insert additionally up to ten new subsectors [15].

If no disaggregation of a subsector into processes is required, the user should specify the subsectors in a global manner as "STEEL-TOTAL", "CEMENT-TOTAL", etc. In this case only these subsectors are considered because the program will handle only those data which appear in the input list; all other data are set to zero. The energy demand is then calculated as:

$$ENERGY(i,t) = PRO \times SEC(i,t) \qquad (6.3.7)$$

where:

i : subsector

PRO(i,t) : production; (t/a) or (currency unit/a)

SEC(i,t) : specific energy consumption; (kWh/t) or (kWh/currency unit)

If possible, physical units 't/a' (tons/annum) are used to measure the production of the different sectors and in this case, the specific energy consumption must be given in 'kWh/t'.

On the other hand, the activity of certain heterogeneous sectors like 'food' or 'construction', etc. can only be efficiently described (and data available) in terms of monetary units. For these sectors the production is measured in 'currency unit/a' and the specific consumption must be given in 'kWh/currency unit'.

The electricity demand of all subsectors of industry is split into demand of: -1-shift, -2-shift, -3-shift work to make a correct load curve synthesis within the MONODIA-model:

$$ELSHI(i,j,t) = ENINEL(i,t) \times SHIFT(i,j) / 100 \qquad (6.3.8)$$

where:

ELSHI(i,j,t): electricity demand of subsector i of the shift class j; (kWh)

ENINEL(i,t) : electricity demand of subsector i; (kWh)

SHIFT(i,j) : percentage of electricity demand in the shift class j; (kWh)

Thus EDE can transfer to the MONODIA model the electricity demand results related to the whole industry broken down into: INDUSTRY-1-SHIFT, INDUSTRY-2-SHIFT, and INDUSTRY-3-SHIFT.

Manufacturing sector

The manufacturing sector is treated in the same manner as the subsectors of industry. Manufacturing belongs to the class of heterogeneous sectors where production is measured in 'currency units/a' and the specific energy consumption in 'kWh/currency unit'.

Agriculture Sector

Agriculture is also a heterogeneous sector because it includes a variety of different consumption processes, e.g. motor fuel for tractors or farming equipment, heat for drying processes, energy for ventilation, energy for irrigation, etc. Energy demand of this sector is calculated as follows:

$$\text{ENERGY}(i,t) = \text{AR}(t) \times \text{SEC}(i,t) + \text{ENIRR}(t) \qquad (6.3.9)$$

where: i stands for sector agriculture, AR(t) is the arable land (km^2), and SEC(i,t) the specific energy consumption ($kW.h/(km^2.a)$).

The energy demand for irrigation -ENIRR(t)- can be treated separately and calculated from the number of irrigation pumps -NOP(t)- and the specific energy consumption for pumping -SECIRR(t), expressed in kW.h/(pump.a)-:

$$\text{ENIRR}(t) = \text{NOP}(t) \times \text{SECIRR}(t) \qquad (6.3.10)$$

Losses in the electrical network

The regional structure ot the model offers the opportunity to calculate the electrical losses in each individual region. After completion of the regional account the total regional electricity demand is calculated:

$$\text{ENEL}(nreg,t) = \sum_i \text{ENSEL}(i,t) \qquad (6.3.11)$$

where ENEL(nreg,t): eletricity demand of that particular region; (kW.h)
ENSEL(i,t) : eletricity demand of subsector i of that region; (kW.h)

Then the losses are calculated as:

$$\text{ELLOS}(nreg,t) : \text{ENEL}(nreg,t) \times \text{SHLOSS}(nreg,t) / 100 \qquad (6.3.12)$$

where ELLOS(nreg,t) : losses within the region; (kW.h)
SHLOSS(nreg,t): losses as percentage of total demand; (%)

Therefore, the losses are directly calculated by specifying them as a (time-dependent) percentage of total demand, which is given as input data. In order to determine the variable SHLOSS(nreg,t), two different approaches are possible.

If detailed knowledge about the network is available the losses can be specified directly as percentage of the energy consumption. In many cases, however, these data are not available. For this reason, the EDE model provides an approach to calculate the electrical losses as a function of the consumption per supplied area based on a curve fitted to the values obtained from several developing countries and from the development of the F.R. of Germany's network during 1953-1982. This curve is shown in Figure 6.3.3.

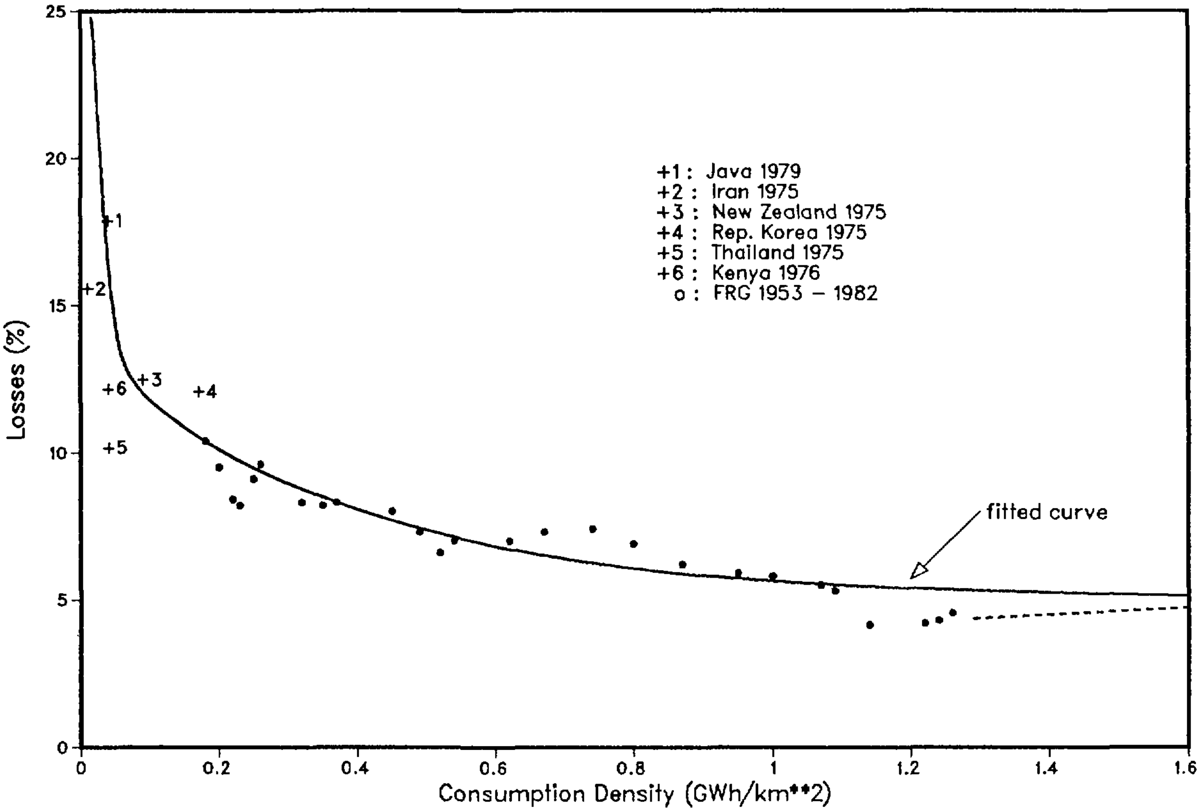


FIG.6.3.3. Losses of the electrical network as a function of the consumption per supplied area.

With increasing consumption density, losses are decreasing to the margin of 4% - 5%. This is the average of the total electricity transmission and distribution losses including all network levels from 380 kV transmission to 380/220 kV low voltage distribution (Detailed description of this curve fitting is given in [17]).

6.3.2 The electrical load curve synthesis model MONODIA

6.3.2.1 General description

After evaluating the total energy demand and separating the electricity demand, the next step, the electrical load curve synthesis, is realized by the program MONODIA (MONOtone DIAgrams). MONODIA is the linking model between the energy demand evaluation and the power station expansion planning models (Figure 6.3.1).

Naturally the electrical load curve of a given power system changes during the day, from workdays to weekends, during the seasons and from year to year.

The system daily load curve depends mainly on the following factors:

- the structure of the consumers in the given power system
- the consumers' behaviour on the different weekdays
- the influence of the season.

In practice, the daily load curve is additionally influenced by many other factors e.g. daily change of temperature, day light, socioeconomic effects, etc., but for long-term planning it is necessary to restrict the analysis to the main influencing factors mentioned above.

The main idea of the MONODIA approach is the application of normalized consumer load curves which result in connection with the matching energy demand into the daily load curve of the system. It must be pointed out that this procedure gives reliable results only then if the number of consumers is large enough. This condition is normally fulfilled at high voltage level. Thus the model is designed for:

- i typical days, e.g. i=3: workday, saturday, sunday and
- k typical seasons, e.g. k=3: winter, spring + autumn, summer.

The actual values of i and k are defined by the user and for each i and k specified, the user must provide normalized load curves for each consumer sector. The typical shape of each normalized load curve represents the consumers' behaviour on the different weekdays. Normalizing the hourly load values means that the maximum peak load of workday of each season is set to 100%. Nevertheless load values which exceed 100% are allowed, e.g. the Sunday peak. Figure 6.3.4 shows some examples of normalized load curves of various consumer sectors in the Federal Republic of Germany (winter season).

For the calculations by MONODIA all sectors of the EDE model must be considered. The present version includes the following ones:

- transport
- dwelling type 2
- dwelling type 3
- public
- industry -1- shift
- industry -2- shift
- industry -3- shift
- manufacturing
- agriculture

After having generated the daily load curves of the system and added the electrical losses, the load duration curves are calculated.

As the load duration curves are used for different power expansion planning models, two different methods of generating a load duration curve are introduced. The WASP [5] package is supported by a special routine of MONODIA which saves the necessary data for the WASP module LOADSY.

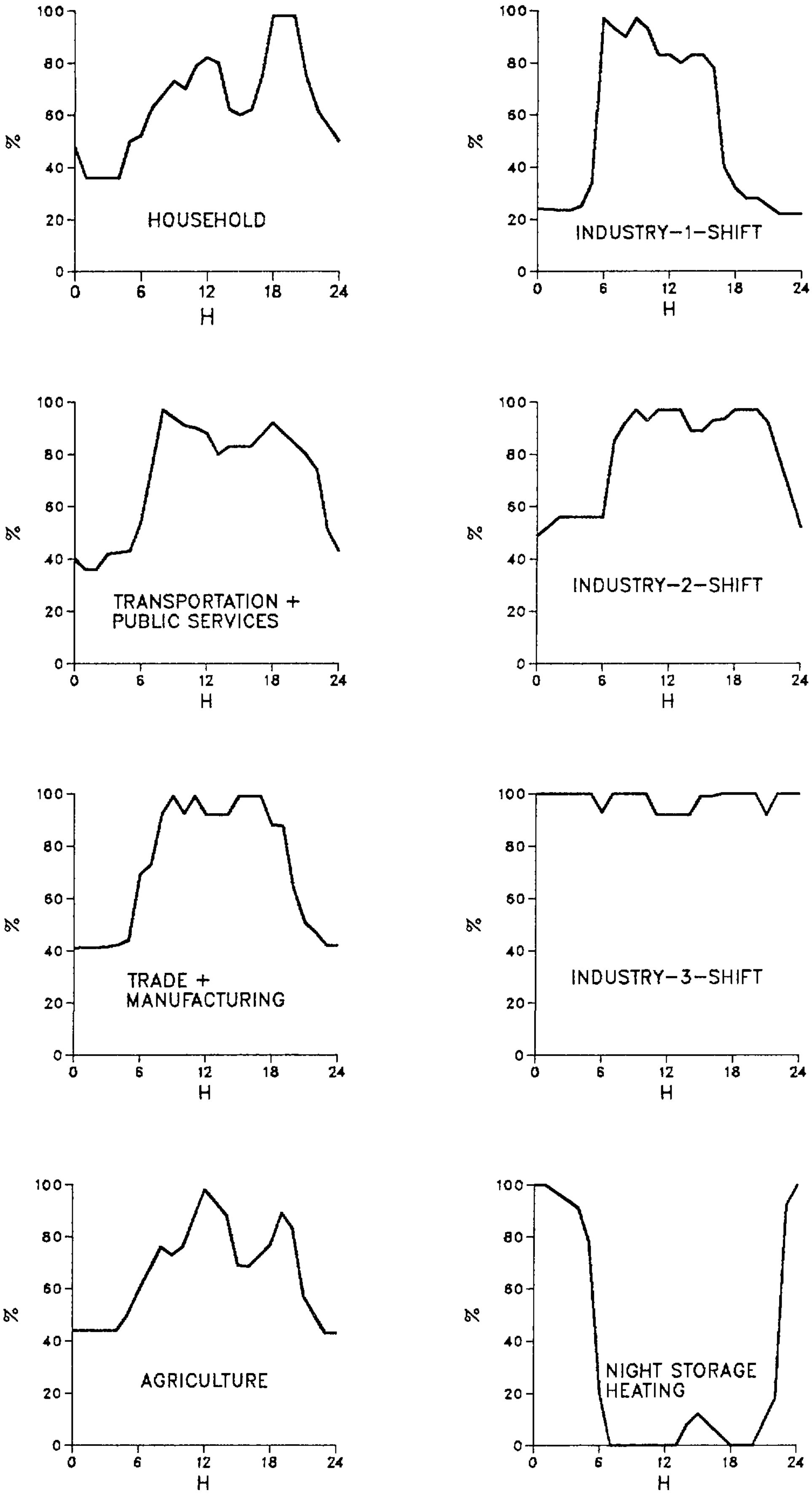


FIG.6.3.4. *Example of normalized load curves.*

6.3.2.2 Basic equations

Calculation of the daily load curves of the consumer sectors

In the first step the daily load curves of the different consumer sectors (sector j) during the different days (day i) and during the different seasons (season k) are generated.

All examples below are presented with three days in three seasons. The normalized daily load curves of the sectors are given by the values f(i,j,k,t). The area under the normalized load curves multiplied with the according number of days, represents the duration of the load in one season. This area is calculated as follows:

$$T(i,j,k) = \sum_{j=1}^{24} f(i,j,k,t) \times DNO(i,k) \qquad (6.3.13)$$

where:

i : daily index
i=1 workday
i=2 saturday
i=3 sunday

j : sector index
j=1 transport
j=2 dwelling 2
.
j=9 agriculture

k : season index
k=1 winter
k=2 spring+autumn
k=3 summer

T(i,j,k) : duration of the load for day type i and sector j in season k; (h)
f(i,j,k,t): hourly normalized load values for type of day i and sector j in season k;
DNO(i,k) : number of days for that day type i occurs in season k;

The duration of the load for one sector j in season k is:

$$TGES\ (j,k) = \sum_{i=1}^{3} T(i,j,k,) \qquad (6.3.14)$$

The demand of electricity has been previously calculated by the energy demand model. This however is the demand for the actual year (ENER(j)) and must be devided into the seasonal demand:

$$ENERGY(j,k) = ENER(j) \times ENDIS(j,k) \qquad (6.3.15)$$

where:
ENERGY(j,k): seasonal energy demand, sector j; (kW.h)
ENER(j) : energy demand for the actual year of sector j; (kW.h)
ENDIS(j,k) : energy share of season k; (-) [this factor must be defined by the user as input data for MONODIA].

On the other hand, ENERGY(j,k) is equal to:

$$ENERGY(j,k) = TGES(j,k) \times PNORM(j,k) \qquad (6.3.16)$$

where PNORM (j,k) stands for the real load value (GW) of the workday of sector j in season k, equivalent to 100% of the normalized load curve.

Therefore PNORM (j,k) can be calculated as:

$$PNORM(j,k) = ENERGY(j,k)/ TGES(j,k) \quad (6.3.17)$$

Now the actual daily load curve LC of each sector can be generated by multiplying the normalized load variables by PNORM:

$$LC(i,j,k,t) = PNORM(j,k) \times f(i,j,k,t) \quad (6.3.18)$$

where LC(i,j,k,t) represents the real hourly values (GW) of the daily load curve for day i, sector j, season k.

For all sectors the real daily load curve LC (i,j,k,t) is calculated in this manner. Then the daily load curve of the total system, which is the superposition of all real daily load curves of all sectors, is calculated:

$$DLC(i,k,t) = \sum_{j} LC(i,j,k,t) \quad (6.3.19)$$

where DLC(i,k,t) is the daily load curve (GW) of the system considered for day i, and season k.

Calculation of the daily load curves with losses

Finally the losses must be inserted into the calculated daily load curves. Losses occuring during transmission and distribution in a system have two effects:

- reducing the available power, power-losses
- reducing the available energy, energy-losses

Both power and energy losses have two components: a load dependent part and a load independent part

The load dependent losses are proportional to I^2 (I: electric current) and are caused by the resistance of wires, transformers, etc. The load independent part is caused by dielectric losses, magnetic losses of transformers, corona losses, etc.; they are proportional to V^2 (V: voltage). For the purpose of long-term planning it is impossible to consider all these effects in detail. Thus the following method was developed:

For each time step (t_i) of the daily load curve DLC(i,k,t) the corresponding load independent losses PADC and the load dependent losses PADD are calculated. The load independent part is calculated assuming constant voltage level:

$$PADC(i,k,t) = X \times ELOSS/8760 \quad (6.3.20)$$

where X: share of load independent losses;
(For the FRG in the 1980's: X=0.40)

The load dependent part PADD is calculated proportional to the square of the load:

$$\mathrm{PADD}\ (i,k,t) = \frac{\mathrm{ELOSS} \times (1-X)}{\mathrm{DELTAT}} \ X\ \frac{\mathrm{DLC}\ (i,k,t)^{2}}{\sum\limits_{i}\sum\limits_{k} \mathrm{DNO}(i,k) \quad \sum\limits_{t} \mathrm{DLC}(i,k,t)^{2}} \qquad (6.3.21)$$

where:

1-X : share of load dependent losses; (-)

ELOSS : total annual losses; (kWh)

DELTAT : period of each load value; (h)

DLC(i,k,t): load value (time step t) of the daily load curve in day i of season k; (GW)

DNO(i,k) : no. of days i in season k; (-)

Thus the daily load curve including losses is calculated as:

$$\mathrm{DLCL}(i,k,t) = \mathrm{DLC}(i,k,t) + \mathrm{PADD}(i,k,t) + \mathrm{PADC}(i,k,t) \qquad (6.3.22)$$

and this load curve appears DNO(i,k)-times within one year.

Simulation of network connections

The MONODIA model provides a simulation process for analysing the interconnection of single regions during the planning periods. In the starting year several single regions may exist which are not connected to a central power grid. However, during development of the country the different regional distribution systems may be connected to one or more networks and finally to a national interconnected system.

In order to simulate this development, the user can define those regions which shall be connected in each year of analysis (the periods defined). At least two regions define the new NETWORK No. i., e.g. if EDE defines 20 regions in the starting year, 10 different networks at most are possible. During further development the user can define a 'Network-matrix' which contains the information about the regions or networks which shall be connected at each period [15]. Thus the development of the load curves from a regional level to the total interconnected system can be analysed.

6.3.2.3 Computing load duration curves

Load duration curves classified according to size

As mentioned above MONODIA is the linking model between energy demand and expansion planning. Thus, different load duration curves must be provided. One type is the load duration curve classified according to size which is then passed to the WASP module LOADSY. Figure 6.3.5 illustrates this normalization procedure. Normalization means any point of the ordinate becomes the fraction of the maximum peak and any point of the abscissa becomes the fraction of time. The generated information is saved for later use by LOADSY.

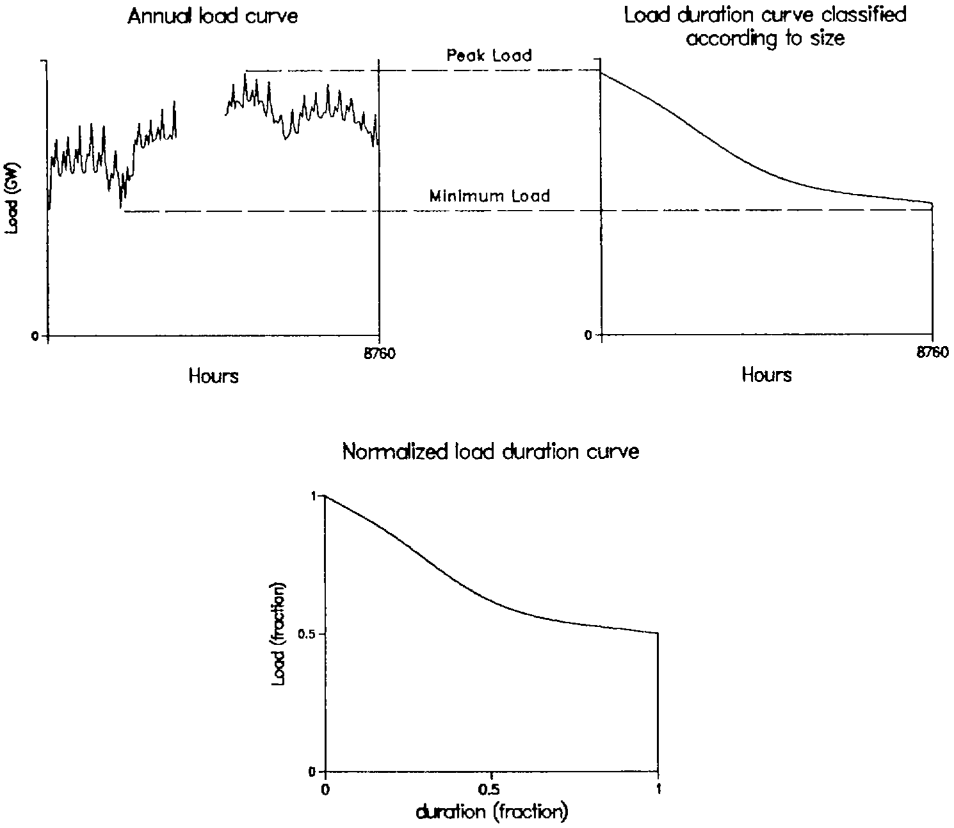


FIG. 6.3.5. Construction of the load duration curve according to WASP.

Load duration curves classified according to time of continuous load

The procedure of arranging the load values according to their size has the disadvantage that the amount of peak load and intermediate load is underestimated in most cases because the real criterion of a peak load is not the absolute value but the duration of the peak. Especially, those peak load values which are smaller than the maximum peak, but their duration is for example less than two hours, are arranged next to load values which belong to the basic or intermediate load. So the real demand for peak load is underestimated. This effect increases if daily load curves of different seasons are considered. Figure 6.3.6 shows the load curves of June and December 1981 of the F.R. of Germany. It is obvious that the amount of peak load in summer is nearly equal to the amount of basic load in winter. Therefore, the classification according to size does not calculate the right amount of peak, intermediate and basic load, particularly when generating annual load duration curves.

To avoid this disadvantage, another method of load duration curve analysis has been implemented within the MONODIA algorithm.

The decision criterion in this method is the duration of continuous load within the daily load curves. Figure 6.3.7 illustrates the procedure. Peak load is defined as loads having continuous duration less or equal a given number of hours, e.g. 4 hours. Then all energy e3 (see Figure 6.3.7) is taken as peak load energy in spite of the fact that the absolute size of the second peak is less than the first peak. If the

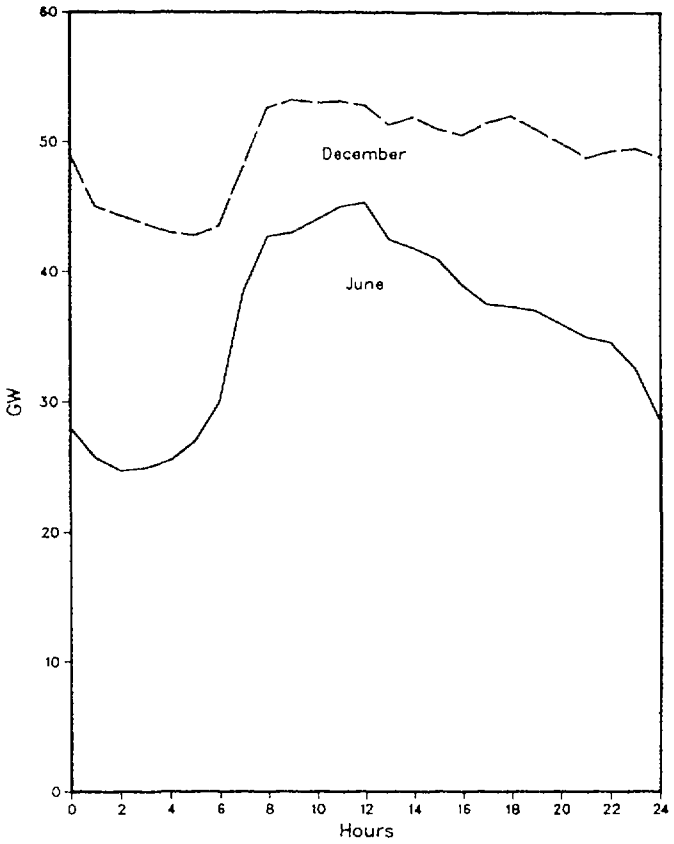
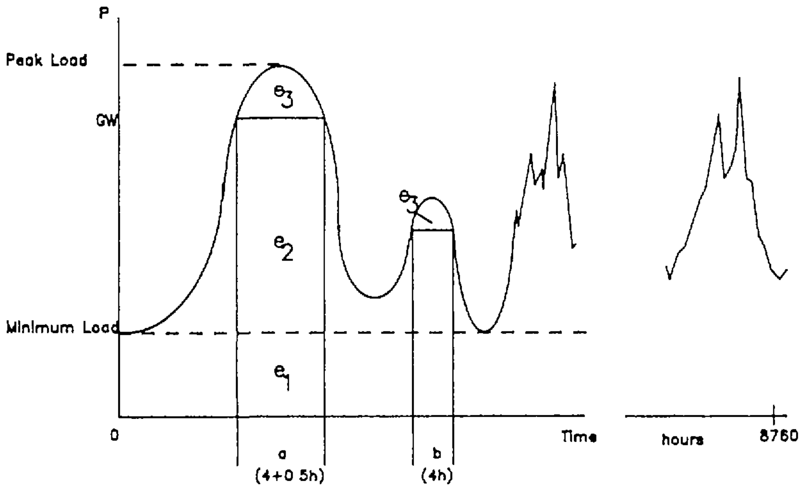


FIG.6.3.6 Load curves summer/winter 1981, Fed Rep of Germany.



chronological daily load curve

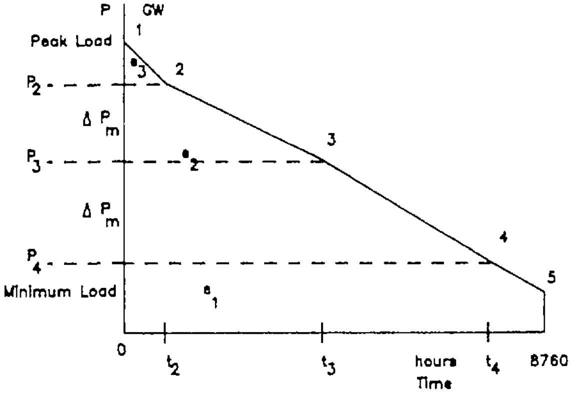


FIG.6.3 7. Construction of the load duration curve according to time of continuous load.

duration of the peak load (DUR(1)) was defined as 4 hours, this duration is extended to DUR(1) + 0.5 hrs for the maximum peak of the day. This extension considers the fact that the system has to provide the biggest amount of peak-energy at the maximum peak of the day.

In the same way the base load is defined by the continuous duration which exceeds 22 hours (energy e1). Analogously the energy e2 is defined through a continuous duration which exceeds 4 hours but is less than 22 hours.

All the previously calculated daily load curves are classified according to the criterion of time of continuous load, and the respective energies determined. The energies e1, e2, e3 of each day are multiplied by the respective number of days and summarized.

Then the load duration curve is constructed considering the following:

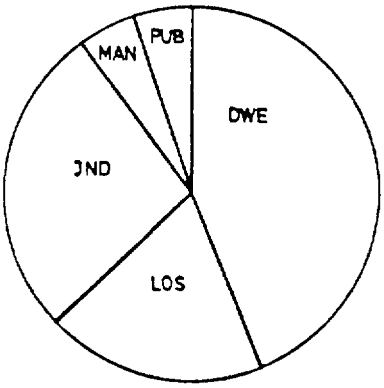
- transfer minimum load (t = 8760 h, P5 = PMINV)
- transfer maximum load (t = 0 h, P1 = PMAXV)
- the duration t2 and t4 must be defined exogeneously by the user corresponding to the daily load curves, e.g.:
  t2 = 4 h x 365
  t4 = 22 h x 365
- calculate P4 from energy e1
- calculate P2 from energy e3
- calculate P3 from PM = 2ΔPM and energy e2

Using this procedure means that the demand of peak load energy, intermediate load energy, and basic load energy are calculated in the correct amount. But the typical shape of the load duration curve, produced with the first method which represents the real steps of the load, is lost because this alternative duration curve is fitted by straight lines. A comparison of the results of the two methods is explained in [15].

6.3.2.4 Illustrative example of the MONODIA model

With the following small example the capability of MONODIA shall be demonstrated. The situation in the base year shall be defined as follows:

TRANSPORT		0,0 %
DWELLING		43,4 %
DWE-2-	15,8 %	
DWE-3-	27,6 %	
PUBLIC		5,3 %
INDUSTRY		27,3 %
IND-1-SH	1,8 %	
IND-2-SH	4,4 %	
IND-3-SH	21,4 %	
MANUFACTURING		5,3 %
AGRICULTURE		0,0 %
LOSSES		18,6 %



TOTAL ENERGY = 7,975 E09 KWH

DEFINITION REFERENCE CASE : BASE YEAR 1982

Figure 6.3.8 presents the corresponding load curve. This could be the load curve of a developing country today. The predominant influence of lighting is obvious.

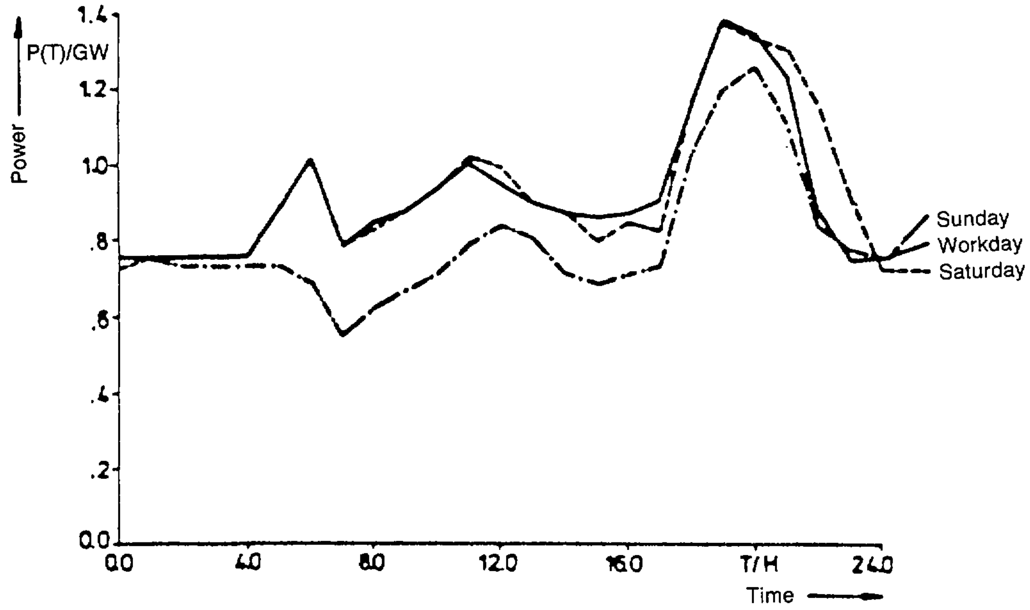
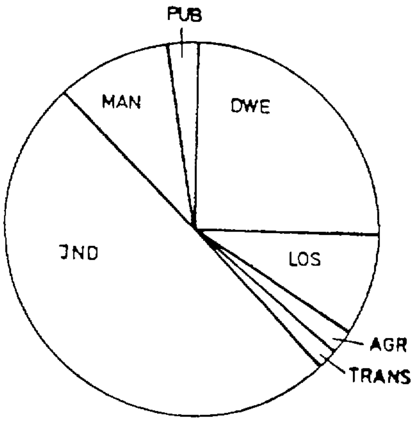


FIG. 6.3.8. Daily load curve of the total country — Season 1: Workday — Saturday — Sunday 1982.

Now a scenario is postulated which influences the total demand and the energy distribution among the different sectors. For this short example it is reduced to the following: increasing growth rate of total energy to 15%/a and a new energy distribution set to:

TRANSPORT		1,0 %
DWELLING		25,0 %
DWE-2-	15,0 %	
DWE-3-	10,0 %	
PUBLIC		3,0 %
INDUSTRY		50,0 %
IND-1-SH	10,0 %	
IND-2-SH	10,0 %	
IND-3-SH	30,0 %	
MANUFACTURING		10,0 %
AGRICULTURE		1,0 %
LOSSES		10,0 %

TOTAL ENERGY = 32.269 E09 KWH



NEW SITUATION IN 1992

Figure 6.3.9 shows this assumed situation. The main effects are now the changing from a typical "lighting curve" to a curve which is dominated during the day by economic activities. The peak at the beginning of dawn is now less important. Only on Sunday it is the dominating factor.

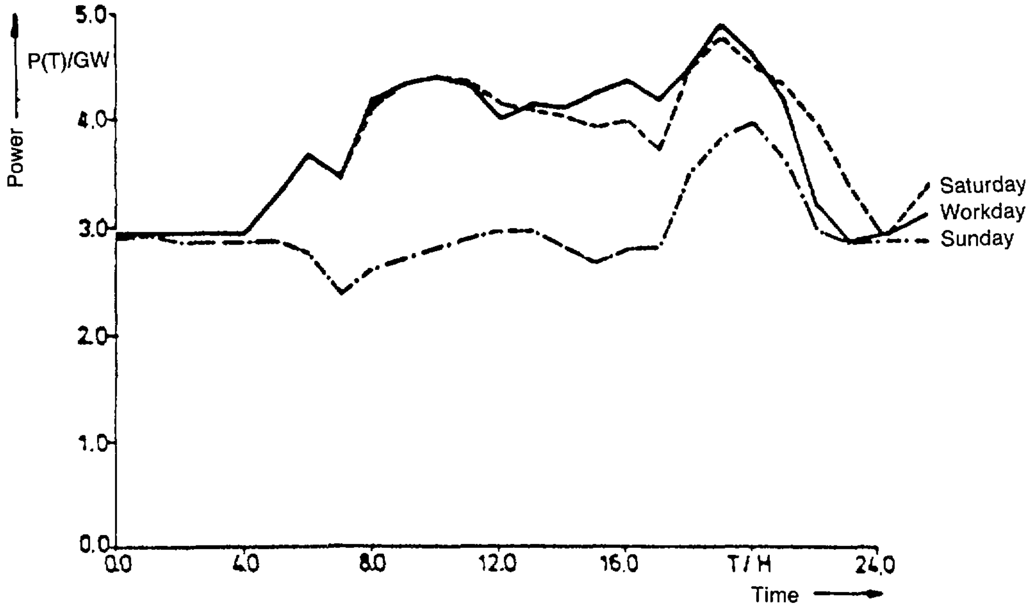


FIG.6.3.9. Daily load curve of the total country — Season 1: Workday — Saturday — Sunday 1992.

6.4 Projections with saturative function (logistic curve)

The nuclear capacity over the next decade is largely fixed already. Due to the long implementation times needed to bring a nuclear power plant into commercial operation, power stations not yet ordered or under construction will not contribute significantly to the electricity generation in the next ten years. Therefore, for the short term, the IAEA relies on factual information about plants in operation, plants under construction, the average construction time for a nuclear plant in a given country, new orders and bids for new plants. As the forecast horizon is extended this "pipe line analysis approach" reaches its practical limit and other forecasting methodologies must be employed.

Instead of projecting directly the long-term nuclear power capacity of a region, the IAEA projects the nuclear share of total electricity generation. On a second step the nuclear electricity generation is obtained from projections of total electricity generation.

A logistic curve is used to project the evolution of the share of electricity provided by nuclear power, based on the concept that nuclear energy is a commodity competing with other energy sources on the energy market.

The logistic is an S-shaped function often used to model growth processes because of its simplicity and the possibility of interpreting its parameters.

The logistic function can be derived from the assumption that the growth rate of the market's share of a new product or technology is a function of time and both the actual share of the market already achieved and the potential market still available, i.e., the share of market still occupied by its competitors. This assumption can be written as a differential equation:

$$ds/dt = s.(L-s).B \qquad (6.4.1)$$

where: s is the share of the market gained by the new technology at time t; L is an asymptotic limit to s representing the maximum share of the market that the new technology can achieve, within the forecasting horizon; (L-s) the share of the market still occupied by its competitors at time t; and B a factor of proportionality.

Rearranging the terms and integrating equation 6.4.1 the logistic growth curve is obtained:

$$s = L / [1 + \exp (-L (A+Bt))] \qquad (6.4.2)$$

where A is an integration constant.

Figure 6.4.1 shows an example of a logistic curve. Because the growth rate is proportional to both the actual share achieved and the remaining share of the market, the growth rate starts slowly due to the initial small share attaining its maximum when the new technology reaches 50% of the market. From then on the growth rate is constrained by the diminishing space available for further penetration of the new technology.

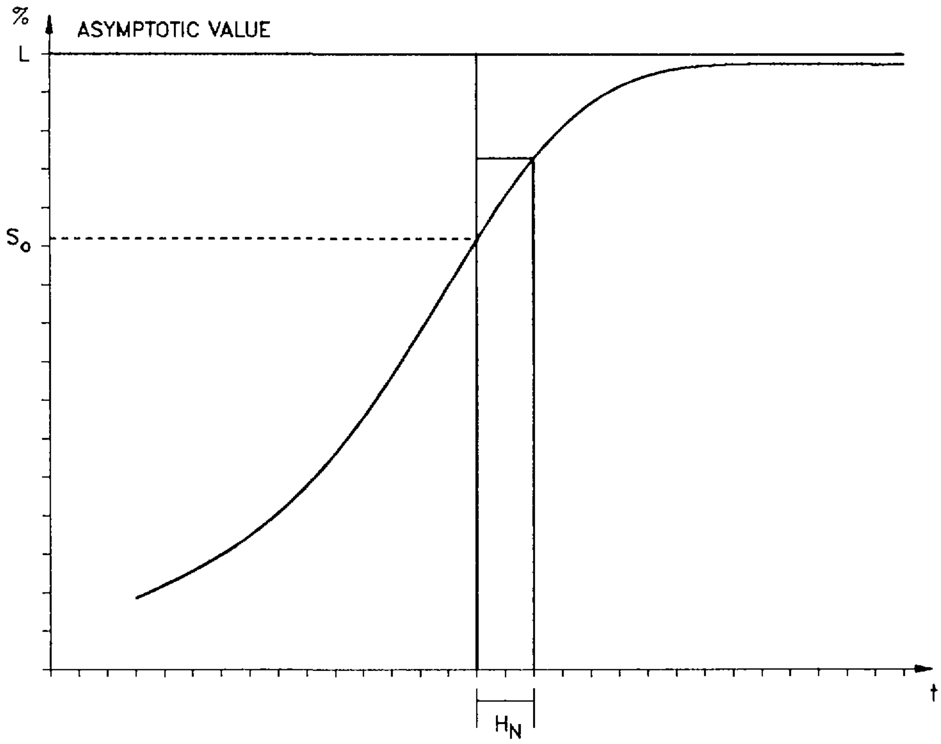


FIG.6.4.1. Example of logistic S-curve.

To project the share of electricity provided by nuclear power a logistic curve is defined by one point, namely the nuclear initial share in the year where the projection starts (So), and two parameters - the asymptomic limit to the nuclear share (L) and a halving time (Hn). The halving time is the period elapsed to reach the mid point between the initial share and the asymptomic share.

To adopt this approach equation 6.4.2 is re-written as:

$$St = L / [1 + \exp(-a+bT)] \qquad (6.4.3)$$

where: St is the nuclear share of total electricity generation in year t.
So is the nuclear share in the base year (start of long range projection).
L is an estimated asymptote to which the nuclear share of total electricity generation tends.
T is the time in years from the base year

$$a = \ln [So / (L-So)]$$

$$b = (1/Hn) \ln [(So+L) / So]$$

Hn is the halving time, i.e., the time taken, counted from the base year, for the nuclear share to reach a value half way between the value at the base year and the asymptotic limit.

"Short-term" forecasts of nuclear power are available for the next ten years, so that the "initial" nuclear share - So - of a country or region is obtained from these short-term forecasts. The base year, considered as starting point of the projections with the logistic curve, is usually ten or more years ahead in the future.

To define completely the curve it is necessary to choose a combination of asymptote (L) and halving time Hn). No analytical procedure is used to determine these parameters, they are evaluated on a trial and error basis so that the curve reflects market penetration rates considered technically feasible and in reasonable agreement with targets set by national governments.

Table 6.4.1 shows asymptotic nuclear shares and halving times chosen in a recent study carried out jointly by IAEA and OECD for different world regions.

The asymptotic limit of 70% adopted for OECD Europe and Pacific represents the view that eventually nuclear power could supply the entire base load curve after taking hydro power into account.

The lower asymptote, on the other hand, represents an extrapolation of present trends. The halving time of 20 years corresponds to a penetration rate compatible with a feasible development of the nuclear power industry in this region.

The extrapolated nuclear shares of total electricity generation are then used to estimate nuclear electricity generation levels from total electricity demand projections.

Finally, nuclear generation figures are converted to installed capacities by assuming a constant 70% load factor.

TABLE 6.4.1. NUCLEAR SHARES AND HALVING TIMES

	Asymptotic Nuclear Share %	Halving Time Years
OECD Europe and Pacific	40	20
	70	20
OECD America	30	20
	40	20
Developing Countries	25	30
	50	30
Centrally Planned Economies	30	20
	50	20

Note: Top and bottom figures are high and low estimates respectively.

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Appendix A

EXPERIENCE WITH CASE STUDIES CARRIED OUT BY THE IAEA

A.1 Energy and Nuclear Power Planning (ENPP) Studies for IAEA Member States

Any country intending to launch a nuclear power programme must take early decisions. Such decisions need to be based on careful assessment of future energy supply and demand, economic and financial implications, and requirements for infrastructure and technology transfer. Consequently, when consideration is given to the possible introduction of nuclear power in the electricity generating system, the first task to be performed is a nuclear power planning study.

Before continuing, it is necessary to make it clear that the Agency concerns itself only with the situation of developing countries, at least in this sphere. Furthermore, the IAEA works only with those countries which explicitly request it. Those who approach the IAEA are therefore countries which, from the start, have the more or less firm intention of taking an interest in nuclear power as a new source of energy.

The standard procedure adopted by the Agency for providing technical assistance to its Member States in the nuclear power planning field entails three principal stages: the first stage, and the one that really interests us in this Chapter, is to analyse the economic realism of an overall nuclear power development programme in the country under consideration over a fairly long period, i.e., 20 to 30 years.

The second stage consists in providing the country with information on the financial, industrial and human consequences of choosing such a power development programme. The Agency may assist the country in gauging the financial impact of such a decision on its foreign payments balance and in assessing the role which its own industry could play in the construction of the plants; or, on the other hand, it may encourage the country to develop or improve certain sectors so that they can later play a more effective role. Finally, stress is also laid on an appropriate training programme designed to provide the personnel that will eventually be required for the introduction of nuclear power.

The third and final stage of assistance consists in helping the country to carry out feasibility studies bearing on preparatory and organizational work needed before the construction of its first nuclear power station.

For the purposes of this Guidebook, all that is likely to interest us is the procedure followed by the IAEA during the first stage, i.e., the analysis of the economic viability of a nuclear power programme in a developing country.

Experience has shown that such a study should be carried out taking into consideration the overall energy requirements of the country and the share that may be accorded to each alternative form of energy (particularly electricity) in satisfying these needs. Thus, the study becomes in fact an Energy and Nuclear Power Planning (ENPP) study.

Energy and Nuclear Power Planning (ENPP) studies can be executed by the IAEA in close co-operation with its developing Member States following a standard procedure. [1].

A.1.1 Purpose and scope of an ENPP study

The global objective of this co-operation effort is to assist the Member State in detailed economic analysis and planning studies to determine the need for and appropriate role of nuclear energy within its national energy plan. This assessment of the role of nuclear energy is done essentially on economic basis but within the global energy and social framework of the country. For these purposes, two Agency-developed models are used in the study: MAED (Model for Analysis of Energy Demand) and WASP (Wien Automatic System Planning Package); the MAED model is described in detail in Chapter 6. Both models are released to the country as part of the co-operation effort.

Thus, the ENPP study has two specific objectives:

a) working with the requesting Member State to quantify the future energy requirements and the expected share of electrical energy within the overall energy needs. The study then outlines an economically optimum electrical system expansion plan, including an assessment of the need for and role of nuclear power.

b) in conducting the study, on-the-job training to a local team of engineers and economists is provided. The country receives the two computer models, MAED and WASP, in order that future energy planning studies can be carried out by its national experts.

Ideally, in meeting the objetive of the study indicated in (a) above, the following tasks should be accomplished:

a.1 Analysis of overall energy requirements and electricity supply projections as required to reach national development goals and possibilities covering a long-term period (20-30 years).

a.2 An assessment of available energy resources.

a.3 An assessment of relevant, economic, financial, technical and policy factors which may influence the structures of future electricity demand and supply.

a.4 An assessment of the available infrastructures and their development requirements, constraints and possibilities (electric supply structures, manpower availability, industrial, organizational and regulatory structure).

a.5 The analysis of the need for and possibility of nuclear power and the determination of the extent and schedule for the introduction of nuclear power plants.

In practice, an ENPP study concentrates in a detailed analysis of items (a.1), conducted by means of the MAED model, and (a.5), conducted by means of the WASP model, whereas the other items are treated in a preliminary way in order to detect if any of these aspects may act as a constraint to the electricity generation expansion programme.

Owing to the non-deterministic nature of the model used (i.e. the MAED model) to evaluate the energy and electricity requirements considered in the study, the overall results can only be accepted as indicative of the type of electricity generation development that appears to be more attractive for the country in the light of certain socio-economic and technical development pattern. These indications, however, could serve as the basis for some decisions.

If, for example, the results of the ENPP study indicate a clear economic advantage for undertaking a nuclear power programme and naturally, if the political will of the country leans in this direction, more detailed studies should be undertaken such as the ones normally conducted during the execution of feasibility studies.

They would normally include detailed analysis of the consequences of undertaking the generation expansion programme and would involve other factors and considerations, such as: technical impact of introducing nuclear power plants in the power generating system (stability of the grid, system reserve requirements); manpower and infrastructure requirements; financial requirements and viability of the programme; assurances of the energy supply; influence on the country's overall economic, technical, social and industrial developments; effects on the society and the environment; disposal of spent fuel and radioactive waste; sources and assurance of supply for nuclear power plants, nuclear fuel and fuel cycle services; etc.

In fact, although the above problems are not considered in detail during the execution of an ENPP study, they are all pre-examined and identified as part of the conclusions of the report of the study.

A.1.2 Organization for conducting ENPP studies

As such studies are carried out in close co-operation with the requesting country, a joint team of specialists in energy planning is established. Each joint team includes two or three IAEA staff members and a group of specialists from the Member State integrated by representatives of the principal institutions involved in the process of decision-making on energy and economic matters (i.e. the Ministry of Economy and Finance, Ministry of Energy and/or Industry, the Ministry of Planning or the planning body, the electricity generating utilities, large mining companies, etc.).

Participation in the study by the organizations above mentioned is a very important condition in order to make certain that the study has the support of these institutions, and that no major problems would be encountered in gathering the information required. Moreover, to ensure that the political will is properly taken into consideration in the study, the local team is further subdivided into two levels (see Figure A.1.1):

A "steering group" integrated by senior government officials who are responsible for providing general guidance for construction of the future scenarios of development in order to ensure that the assumptions made about socioeconomic and technical development do in fact reflect the macro-economic objectives of the country. Further, this steering group would be responsible, at a first stage, for identifying and assessing the major issues that would have an impact on the development of nuclear power in the Country and, at a later stage, to avail the results of the study and, consequently, to carry out some supplementary studies that will be needed before a decision whether to embark on a nuclear power programme can be made by the Country.

A "working team" integrated by five to six engineers and economists who should be well acquainted with the energy and electricity situation in their country. The task of this working group is to carry out the bulk of the work as described below, and in particular to transform all information provided by the steering group into the appropriate format required by the computer models. In the final phase of the study, this group will be responsible for preparing the first draft of the report. The draft is then submitted for the approval and criticism of the steering group and the IAEA. Among these specialists is a senior officer, designated as the Co-ordinator who will be responsible for co-ordinating the various activities within the Country, including the preparation of the report of the study. In addition to the above, the team leader will be the official Country contact with Agency experts on matters related to the study.

Both groups include one or more representatives of the various institutions participating in the study. The organization for the conduction of an ENPP study is illustrated in Figure A.1.1.

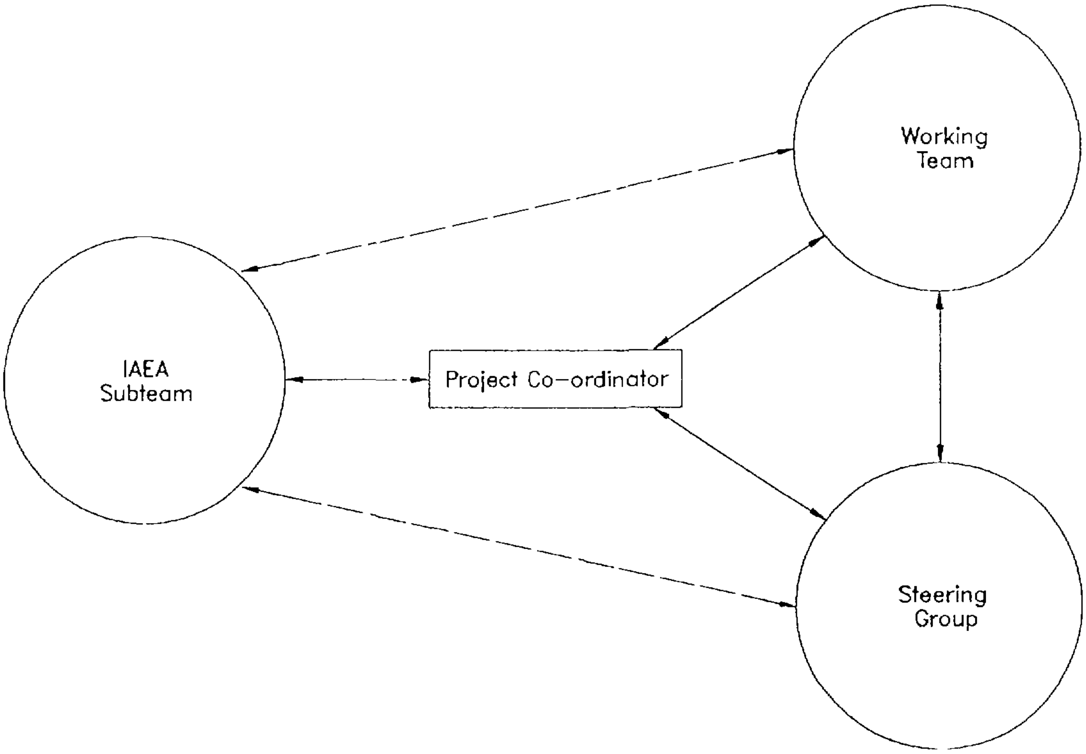

FIG.A.1.1. Organization of Joint Team for an ENPP study.

There is a clear division of responsibilities between the members of the joint team for the study. The Country team carries the major responsibilities for execution of the study, including: gathering of all information needed, carrying out the computer runs and interpreting the results, and finally, drafting of the study report. The Agency team is responsible for providing guidance and overall co-ordination during the execution of the study, as well as providing training in the use of the MAED/WASP models to the local specialists and assisting them in the implementation of the models on the country's computer installations.

It is always emphasized to the Country authorities that the main burden and responsibility for the execution of the study will remain with the Country team, with support and guidance from the Agency experts. These two aspects of the approach proposed, i.e., participation of various Country organizations and execution of the study by the national team, are considered necessary in order to guarantee: a) credibility and acceptance of the results of the study in the Country, and b) effective transfer of technology in the planning field to the Country.

A.1.3 Steps involved in the execution of an ENPP study

When a request for assistance in the nuclear "planning" sphere is sent to the Agency by one of its developing Member States, the first task is to determine the stage of "planning" to be dealt with. In response to requests associated with the initial phase indicated above, the IAEA proceeds in the following manner.

A small team of Agency experts is sent to the requesting country for an on-site reconnaissance mission. The mission has a threefold purpose:

(a) To make a rapid assessment of the country's energy status and economic situation and to determine whether the nuclear option could be valid for that country over the next 15 to 20 years;

(b) To make sure that the political and technical will, needed to handle the nuclear option, is actually present within the national bodies involved in energy decisions and that there is a general consensus in favour of the nuclear option; and

(c) Finally, to explain and formulate the study programme that will have to be undertaken, emphasizing quite clearly the respective roles of different national bodies in the event that the programme is ultimately adopted.

If the reconnaissance mission comes to positive conclusions, the next phases are as follows:

- The <u>first</u> consists in making up a national team of specialists capable of conducting such a study successfully (Section A.1.3.1)

- The <u>second</u> phase involves providing the members of the national team with training in the planning techniques to be used during the study (Section A.1.3.2)

- The <u>third</u> phase, which is linked entirely with the study, itself breaks down into two stages:
  - First, an overall energy demand study is carried out. The purposes of this is to gauge the respective shares of the market likely to be taken by various final energy forms, in particular electricity, in satisfying the country's economic development objectives as efficiently as possible.

- Second, an economic optimization study is carried out with the aim of evaluating the future electric power development programme which will lead to the desired goal at lowest cost.

- The fourth phase, finally, consists in preparing an understandable report on the subject.

Given inevitable delays in the training of local specialists and in the accumulation of essential information, the whole process usually requires about two years of team work. Table A.1.1 summarizes the principal activities to be carried out by the national team. Co-ordination is provided by IAEA experts by means of joint meetings, lasting approximately two weeks on average, which take place either in the country being studied or at the Agency's Headquarters in Vienna. Usually, six such meetings (three in the country and three in Vienna) are required to complete the analysis successfully.

TABLE A.1.1. SUMMARY OF THE PRINCIPAL ACTIVITIES OF THE COUNTRY TEAM IN THE EXECUTION OF THE ENPP STUDY

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1. Careful review and analysis of all previous studies that have been carried out for the Country on energy, social, economic and technological matters in order to avoid duplication of work.

2. From the information available, to decide upon which year is to be selected as the reference year (base year) for the analysis.

3. Collection of the remaining required data that are not readily available from other studies, and reconstruction of the energy requirements of the country by sector and energy form for the base year, using the MAED methodology.

4. Preparation of the scenarios of socioeconomic and technological development of the Country, that should be analysed with special attention to the time horizon of the study. In the execution of this phase, appropriate co-ordination should be maintained with other studies on energy planning being executed or under preparation in the Country.

5. From among the many conceivable scenarios of development, selection of those which could represent the bounding conditions for analysing the possibilities of electricity expansion.

TABLE A.1.1. (cont.)

6. Execution of all computer runs of the MAED and WASP programs in order to analyse the energy and electricity requirements of the Country over the next twenty to thirty years (MAED) and to assess the role of nuclear energy in satisfying the electricity needs (WASP) under the criterion of minimum economic cost.

7. To analyse the results of the computer runs and, if necessary, to modify the input data and execute new runs of the programs.

8. To review and assess the principal issues that may have an impact on the development of nuclear energy in the Country and to identify the additional studies that should be undertaken by the Country authorities before making a decision for implementing a nuclear power programme. The principal issues and supplementary studies will include aspects such as:

   - careful review of energy resources, reserves and production;
   - present situation and future trends of the various costs (investment, fuel and O&M costs) for generating electricity with due account for the local conditions;
   - financial requirements arising from a nuclear power programme;
   - manpower development needed to support the programme;
   - possible participation of the local industry;
   - nuclear fuel requirements imposed by a nuclear power programme and related aspects, such as the assurance of supply in light of existing sources for nuclear fuels and services and contracts that have been signed by other countries;
   - development of a legal and organizational framework;
   - implementation of a public acceptance programme;
   - decisions related to some studies needed to be executed on: - site selection, - quality assurance survey, - electrical network development, - industrial survey, etc.

9. To prepare the report of the study including its major findings, as well as the recommendations to the decision-makers for actions to be taken in the energy field.

The total manpower effort required from the Country team during the execution of the ENPP study is estimated to be about eight man-years. This total takes into consideration the following time estimates for the various Country specialists:

a. 30% - 50% of full-time for the team leader;

b. 5% - 10% of full-time for members of the steering group;

c. 20% - 30% of full-time for members of the working group.

It should be pointed out that the above estimated percentages of full-time dedication represent averages during the total period of the study. Time dedication from each participant for executing any intermediate task will vary according to the needs.

The manpower requirements from Agency experts are estimated to total about 10-12 man-months with half of this total expended in missions to the Country and the other half expended at Agency Headquarters.

A.1.3.1 Integration of the national team

This process is completely accomplished within the country and usually takes about 15 to 30 days after the IAEA reconnaissance mission has taken place and its outcome has been positive. This time is usually required in order to designate the various officials that would integrate the two national subteams.

A.1.3.2 Training of the national team

Training of the working group's members in the various planning techniques also takes place in two stages (at least for some members of the group).

During the first stage the Agency sends them to one or more of its three interregional training courses organized each year on the subject of energy planning.

The first of these courses - Energy Planning in Developing Countries with Special Attention to Nuclear Energy - is designed to show participants the various aspects of energy planning. None of these aspects is actually treated in detail, but all are passed in review systematically; questions relating to technology, economics, finances, human and organizational problems and also modelling.

The other two training courses available through the Agency are highly specialized, one in the analysis of energy demand -Electricity Demand Forecasting for Nuclear Power Planning- and the other in economic optimization of investment in electricity generation -Electric System Expansion Planning-. These two courses are designed to show trainees how the two models developed by the Agency (MAED and WASP) can be used; they are described in more detail in the introduction of this Guidebook.

The training of the local specialists is complemented in a second phase with on-the-job training provided throughout the execution of the study.

A.1.3.3 Execution of the analysis

Analysis of future energy requirements

When the members of the working group have received the minimum training required, the co-operative work with the IAEA experts begins. The first task is to obtain a better understanding of the country's overall future final energy needs, for each economic sector and each energy form. This analysis is carried out by means of the MAED model (see Chapter 6).

In summary, it may said that the philosophy of the MAED model is based on the observation that energy demand is induced by three major sets of factors linked to:

- the economic activities of the country (such as steel production, freight transportation, etc.);
- the satisfaction of social needs (such as cooking, heating, mobility of persons, etc.);
- the technology used to transform final energy (coal, oil, electricity) into useful energy (process heat, lighting, motive power, etc.) or, in other words, to transform final energy vectors into various forms of "services" obtained with energy.

The MAED model provides a flexible framework for exploring the influence of these various social, economic and technical factors on the long-term evolution of energy demand.

Furthermore, the MAED model makes it possible to combine information on macro- and micro-economic changes, technology improvements and substitution possibilities in a consistent manner and to perform various simulations of possible situations. The main difficulty at this stage is to limit the number of simulations so as to retain only those associated with plausible development scenarios. This is precisely where the steering group referred to above comes in. Composed as it is of senior officials from the various government offices of the country, the steering group's responsibilities then lie in finding a consensus on a very limited number of scenarios (generally between two and five) which will make it possible to obtain an understandable view of the future evolution of energy demand in the country.

A final step of the process is to execute some sensitivity analysis so as to determine how much the results are affected by variations of the scenario parameters, particularly of those parameters which are most likely to deviate from the original assumptions made in writing the scenarios or those for which no good knowledge about their future evolution is available. This step permits identifying which parameters might require further analysis or execution of surveys for their proper determination.

This phase of analysis of the country's future energy demand ends with the generation of a few scenarios for future needs broken down by economic sector and by final energy form. Since the Agency's purpose is to analyse the possible role of nuclear energy for electric power generation (so far at least: district heating by nuclear power plants is still a very limited technology, especially in the developing countries), analysis of electric requirements is treated in a particularly detailed way.

Analysis of electrical load curves

The energy demand study described above indicates future annual electricity requirements, but this information is still inadequate for an investment study designed to show how the electricity can be produced most efficiently. What is needed to know in fact is how and when electricity is required, hour by hour, over the year. In other words we need to know the "electric load curve" of the country, as the electric power experts call it. Only a knowledge of the annual load curve enables the electricity producers to forecast the required structure of their power station park (base-load plants, peaking plants and so on) and to run it at minimum cost. Thus, at this stage of the study the working team is simply trying - within the framework of an existing tariff structure - to find out what is the behaviour of various consumers as a function of season (summer, winter, etc.), the type of day (weekday or weekend) and hour (midday, midnight, 3 o'clock, 6 o'clock, etc.).

The objective pursued in this analysis is to break down the annual electricity demand obtained in the overall final energy analysis into an hourly electricity demand over the 8760 hours of the year. This hourly demand or "load curve" constitutes the basic information needed for the electricity producer to forecast and run his future power station park.

In principle, only an analysis performed by sector of activity would enable the planner to predict the behaviour of consumers correctly. Unfortunately, such statistical information does not exist in most developing countries. One has then to proceed on the basis of surveys, retaining only the data corresponding to certain consumers who are typical or representative of their sector of activity. This type of analysis is normally problematic and rarely gives complete satisfaction. It does enable the planners, however, to draw the attention of the responsible authorities in the electricity generation sector to the importance of this type of information and provides an opportunity to launch a systematic research and analysis programme on their sectoral load curves. Programmes like this require research and measurements of various kinds stretching over two or three years. In the first instance, therefore, the study limits itself to the results of a few probes. On the other hand, the attention of national electricity producers is drawn to the value of these studies; they see that they have an interest in carrying them out without delay, because from them they will obtain a solid foundation not only for their planning studies but also for tariff structure analyses and studies of electricity demand management.

Analysis of electric power generating system expansion

After having concluded the energy demand evaluation, including the analysis of the electrical load curves, the next task is to execute the analysis of the economic optimization for the expansion of the electric power generating system by means of the WASP model. [2] [3]

Although the WASP model is rather complex in structure, the approach underlying this model can be summed up as follows. One introduces as input data the annual electrical load curves as well as the set of characteristics both technical (power, availability, etc.) and economic (investment, fuel and operating costs) for various types of power stations (hydroelectric power, conventional thermal power plants burning oil or coal, nuclear plants, etc.) which are selected as possible candidates for the future. Technical and economic characteristics of the existing, under construction and committed plants must also be defined as input data. Allowing for the various technical constraints which are also introduced as input data (availability of water power in the country, reliability level of the system, etc.), the model initially simulates all possible combinations which could be realised with the candidate plants to satisfy the annual load curves. Then, at a second stage, the model selects the most economic combination.

Of course, before the effective utilization of the WASP model, certain complementary studies have to be carried out to ascertain whether the technical and economic assumptions made are in fact realistic. As examples, one could mention an inventory of the country's energy resources and an analysis of grid reliability.

The selection of power generating plants introduced as potential candidates in the model cannot be made arbitrarily. The type of plant - hydro, coal, oil, gas or nuclear - depends to a large degree on the national energy resources available to the country. Obviously, the possibility of importing fuels cannot be dismissed, but it may be taken into account only after a thorough knowledge of local resources, including information on volume, availability and price, has been obtained. Similarly, the composition of the existing power plant mix as well as the structure of the electric power grid (transport and distribution) can impose limitations on the size of future power plants. Electric power specialists are familiar with this extremely complex problem. On this subject, it is customary to recall that the largest size of a new plant to be installed should not exceed 10 - 15% of the aggregate power of all plants already installed (in order of magnitude): otherwise there is a risk of grid instability in both frequency and voltage.

It would be possible to mention many other difficulties in the formulation of technical input data, lying, for example, in plant availability factors, water power conditions and so on. Economic input data are also often hard to specify precisely.

Without going into the question of discount rate - which would merit a chapter all by itself - we may say that obtaining as accurate a grasp as possible of likely investment costs for different power plant types, as well as of fuel and operating costs, represents an extremely complex information and documentation effort. Numerous sensitivity analyses have to be carried out to offset the uncertainties that may exist in these data. Normally, these analyses relate to:

- The discount rate;
- The investment costs for power plants of various plant types;
- The time required for construction of these plants (this plays an important role in evaluating interest during construction [IDC]); and
- Fuel costs, for fuel obtained domestically and for imported fuel.

Important additional factors to be taken into account when defining the size and timing of the nuclear plants to be installed are:

- Compatibility with the electric system (size and stability);

- Lead times necessary for project implementation and for infrastructure development;

- Commercial availability of nuclear power plants.

Additional considerations

Owing to the non-deterministic nature of the MAED model, an important consideration to be retained throughout the execution of the ENPP study is the need for consistency of the development scenarios considered in the study. This is to be verified by the planner as follows:

In principle, the consistency of the several hypotheses on socioeconomic development and energy policies is inherent to the scenario formulation. The results on energy demand must be verified at various levels.

In the first place, it is necessary to verify the internal consistency of the results. At this level, it is necessary to verify that the evolution described by the model for the different variables are not impossible or unlikely and that the evolutions remain well within a realistic prolongation of the historical evolution. It is convenient to verify the results also against hand calculations and if possible, against the results obtained from other studies carried out for the country.

Furthermore, it is necessary to ensure the consistency of the results with the hypotheses behind the scenario. This consists mainly of verifying that the values of certain ratios (i.e. energy/GDP, energy in household/income per household, etc.) are compatible with the logics of the scenario.

Finally, it is required to verify that the evolution of the energy demand reflected by the model will not imply evolutions of the total energy system that will cause questioning the validity of some of the socioeconomic hypotheses of the scenario. In other words, that the level of expenditures that would be needed to satisfy the energy requirements reflected by the scenario are compatible with the macroeconomic hypothesis of the scenario.

As mentioned in Chapter 6, these verifications of consistency of the results have the objective, either to refine or modify the original scenario if large inconsistencies are detected or to identify and enlighten the risks of inconsistency of the study and their meaning with regard to the validity of the results.

In the case of ENPP studies, the analysis of eventual feedbacks is rather simplified since at the supply side only electricity supply system is optimized by means of the WASP program. Figure A.1.2 illustrates the process and shows the different levels at which consistency checks must be exercised, as well as the possible feedbacks (in discontinued lines) that may arise from the various checks. Dashed lines encircle the part of the energy supply system not normally treated in ENPP studies.

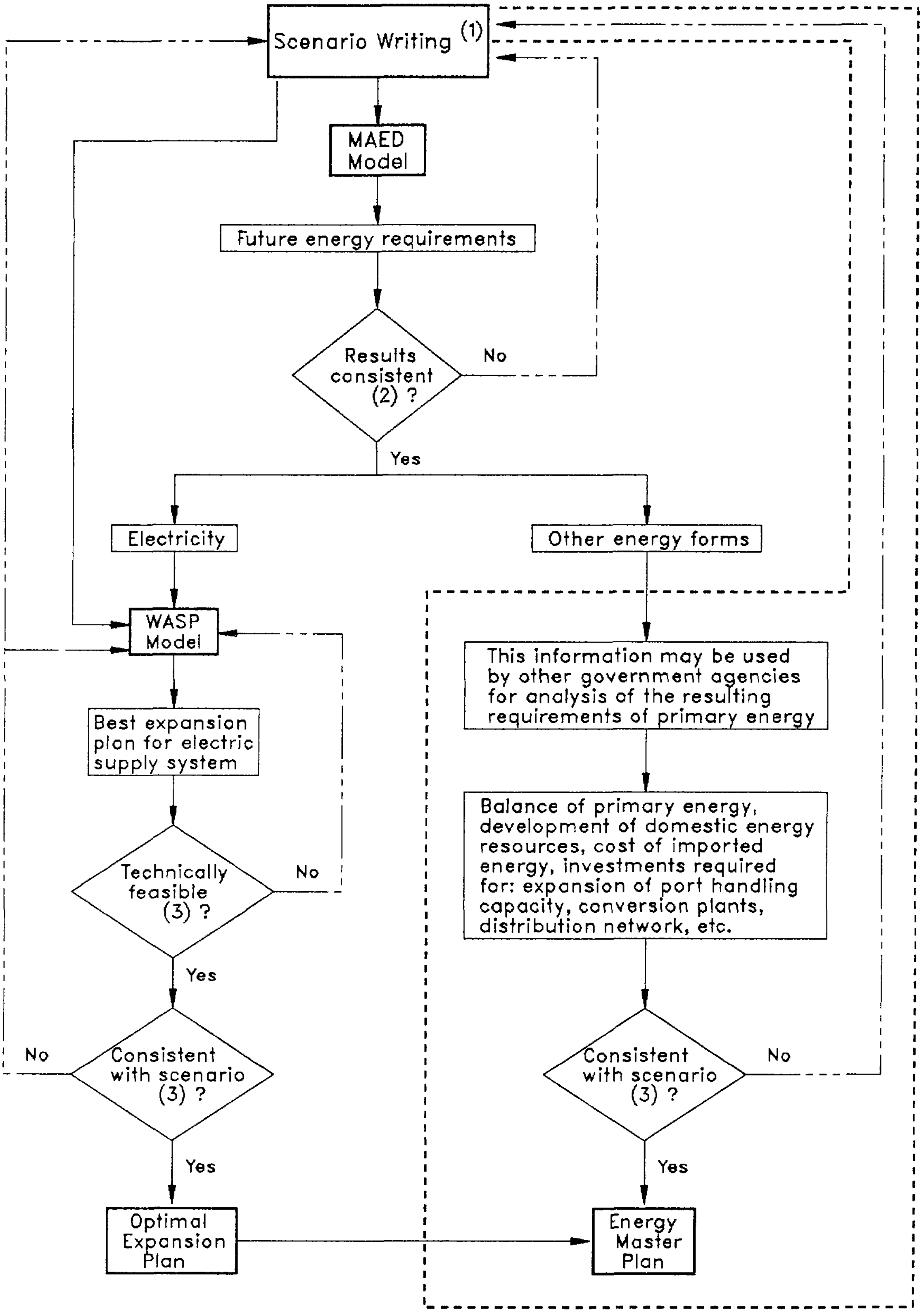

FIG.A.1.2. Consistency checks required in ENPP studies.

A.1.3.4 Report of the study

The final task imposed to the local specialists consists in preparing a report for the study summarizing its major findings in terms of the results obtained and the principal assumptions made, as well as providing the decision-makers in the country with information about the impact and consequences of the development scenarios and the interlaced socioeconomic policies and expected trends in the energy demand level and standard of living of the population. Emphasis should be made also on the resulting electricity generation expansion programme(s) and the consequences in terms of required investments to support the programme.

The final report which concludes these studies thus has two main sections, one analysing the future final energy demand of the country, the other attempting to define the methods which will enable the country to satisfy future electricity demand at the lowest possible cost.

In addition, the major findings of the study should also be accompanied by the major hypotheses combined with the study. These hypotheses should cover not only those related to the construction of the scenarios of development but also approximations that were necessary to be made for the reconstruction of the country's energy structure for the base year of analysis, mentioning also their importance in terms of their influence on the results.

Within the framework of an ENPP study, inclusion of the above information in the report of the study is considered very important in order to permit a complete reproduction of the study by other specialists in the country. This is particularly important in many developing countries owing to the greater mobility of specialists among government bodies and also the private sector.

Combined with these hypotheses, the report should include proposals and recommendations for follow up studies and actions in the energy field. These should go from the mere proposal of actions to improve the knowledge of the energy consumption pattern of the country to the actual recommendations on energy policies.

Proposals on actions to improve the knowledge of the pattern of energy consumption of the country should include a detailed listing of the type of surveys and/or studies that should be carried out before other planning studies are executed, with the view of establishing a comprehensive and coherent data base for the use of MAED or other models. Empahsis should be given to those scenario parameters for which greater uncertainty is recognized, as well as those having a greater impact on energy demand.

A final point concerning the recommendations on energy policies to be made in the report of the study should be emphasized. Obviously, such recommendations can only be prepared with the participation of senior government officials such as those integrating the Steering Committee for an ENPP study.

If in the light of these first studies the nuclear option seems likely to play a useful part in the country's future energy production system over the next 15 or 20 years, and if the country makes an appropriate request, the Agency may continue the co-operation and endeavour to determine the impact of choosing nuclear power in three spheres:

(a) The financial sphere. In collaboration with investment banks, the Agency is elaborating a model called FINPLAN [4] the purpose of which is to analyse, on the assumption of possible loans, the financial impact of nuclear programmes on the management of electricity utilities;

(b) The personnel training sphere. The Agency has already published a guidebook [5] which describes the main elements of a personnel training programme. Obviously, this has to be supplemented by more detailed studies related to the specific situation of each country; and

(c) The industrial sphere. Here the aim is to evaluate the role which local industry might play in a nuclear investment programme and at the same time to assess the stimulating impact which such a programme might have, in return, on the development of national industry in various sectors.

Examples of reports for studies conducted for some Member States are Algeria [6] and Jordan [7]. Other countries for which ENPP studies are being carried out, or have been carried out, are listed in Ref. [8]. Many other countries have also formulated requestes for co-operation with the Agency in this field.

When these pre-feasibility studies have been terminated - that is, when a possible long-term nuclear development programme has been identified and its consequences evaluated - then the specific feasibility studies required for the installation of the country's first nuclear power station can begin.

A.1.4 Concluding remarks

The development of an energy planning activity is a long-range undertaking requiring constant review, additions and improvements.

The evaluation of the economic benefits from nuclear energy needs a broad-based and in-depth analysis of the total effects of a nuclear power programme on the overall economic development of the country.

Three main points must be emphasized:

- Nuclear energy development cannot be evaluated in an isolated way. Nuclear technology is only one among many means to supply secondary energy (such as electricity and heat), and nuclear power planning should be carried out within the context of all supply options. Nuclear power planning involves evaluation of the various types and forms of energy requirements, and it should consider the general energy and economic development planning of a country.

- Energy, electricity or nuclear planning can be done reasonably and rationally only by national energy specialists. The Agency can provide advice and some methodologies but it cannot be a

TABLE A.1.2. LIST OF MAJOR ISSUES CONNECTED TO THE INTRODUCTION OF NUCLEAR POWER IN THE COUNTRY

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1. Careful review of present energy resources, reserves and production in the country.

2. Information on capital investment costs, fuel costs and operation and maintenance costs for the various alternatives for electricity generation that can be considered (i.e. hydro, coal, gas and nuclear). This information should take into account latest experience of costs in the country and current estimates for power plants being planned or under construction, as well as the development of international market conditions with regard to technologies not already developed in the Country (e.g. nuclear) and trying to adjust these interational market prices to the Country conditions.

3. Nuclear fuel requirements imposed by a nuclear power programme. An important issue that needs to be addressed in this respect is the question of assurance of supply in the light of existing sources for fuel and services and contracts that have been signed in various countries. The problem of nuclear waste management should also be investigated. Considerations about the choice of and participation in the nuclear fuel cycle.

4. Manpower requirements for a nuclear power programme (for this purpose, the technical Report Series No. 200 published by the IAEA will be the principal reference, with adjustment as needed to reflect the practices and conditions of the country).

5. Possible participation of the national industry in the implementation of a nuclear power programme.

6. Financial requirements that would be imposed by a nuclear power programme with due consideration as to the possible sources for loans; standard or reference conditions; etc. as well as the implications for the balance of payments of the Country.

7. Development of legal and organizational framework such as implementation of a nuclear regulatory body and a nuclear law in the Country.

8. Initiate various studies on:

    - Site selection for nuclear plants
    - Quality assurance survey
    - Electrical network development
    - Industrial survey
    - Other infrastructures

9. Public information programme that would be necessary to deal with problems of public receptance of nuclear energy in the Country.

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substitute for the Government experts who must take the final responsibility for planning the development of energy supplies in their country.

- Finally, it must be emphasized that economic studies such as those mentioned are only a first step in the long process of nuclear power planning. Many additional studies and analyses should follow, to determine whther nuclear power is a practical option, and what the national implications of a decision to undertake a nuclear power programme would be. Complex problems, such as impact on the balance of payment, financing constraints, manpower requirements, and local industry participation, will be involved. These are additional factors that should be kept in mind when a country is evaluating the possibility to utilize nuclear energy.

A non-exhaustive list of issues to be addressed and the supplementary studies that need to be carried out before embarking on a nuclear power programme are given in Table A.1.2. From this list, it is obvious that not all supplementary studies will have to be completed by the end of the ENPP study, but most of them will have to be initiated as soon as possible in order to be completely and clearly identified in the ENPP study.

Technical assistance may be provided by the Agency for dealing with the issues referred to above. In a first step, the Agency can provide the Country team with all the necessary technical reports and information on those matters that are at its disposal. At a later stage, upon official request, the Agency could provide the Country with technical assistance consisting of sending experts to the Country or granting fellowships that could permit Country experts to obtain the necessary information and expertise abroad.

A.2 Energy and Nuclear Power Planning Study for Algeria [6]

A.2.1 Introduction

In response to a request from the Algerian Government, a co-operation agreement was reached in 1980 between the IAEA and Algerian representatives to investigate the possible role of nuclear energy in supplying part of electricity that Algeria will require in the next decades.

It was agreed that such a study should be carried out by a joint team integrated by IAEA and Algerian experts. Two IAEA experts were assigned to this task. The Algerian team consisted of five experts, all staff of the Société Nationale d'Electricité et du Gaz (SONELGAZ); the company which was assigned full responsibility for the study by the Algerian authorities. Close co-operation between both teams was maintained and several missions of IAEA experts to Algeria and SONELGAZ experts to Vienna were undertaken during the execution of the study.

The total duration of the study was two years. During this time the total manpower requirement accumulated to 6-8 man-years without taking into account the contribution from many staff in several Algerian organizations who supplied useful information and data for the study and the development of the computer codes which was carried out in the Agency.

At the outset of the study, it was recognized that the role of nuclear power in the electricity supply of a developing country, such as Algeria, could not be effectively studied in an isolated manner, but within the context of the overall energy requirements of the country that are consistent with the goals for economic, social and technological development for the country. Taking into account the relatively long lead times required for implementation of a nuclear power programme, it was deemed necessary to consider the long term period covering about 30 years.

It should be borne in mind that the purpose of the study was in no way to solve the energy problems of Algeria (i.e. to produce a national energy and electricity plan for the country) but to propose methods of analysis which may allow the energy authorities of the country to gain a better idea of the impact and the social and economic repurcussions of some decisions.

A.2.2 Purposes and scope of the Algerian study

The main purpose of this study was to initiate thinking on the role that nuclear energy could play in meeting the energy requirements of Algeria. With that in view, two successive analyses were performed:

The first analysis consisted in evaluating the final energy requirements which will result in the medium and long-term (by 2015) from the implementation of the economic development policies contained in the Five-year Plan (up to 1984) and in the proposals for the next decade (up to 1990) being studied by the Algerian Ministry of Planning.

This first analysis was carried out by examining as closely as possible the structure and factors which give rise to energy demands from the various final consumers in each economic sector: industry, transport, services and domestic users, in order to determine not only the amount of final energy required but also the form that this energy should take: steam, hot water, various heat applications, fuels, electricity, etc. When one form of energy can be substituted for another, scenarios are constructed to examine the economic consequence of a particular choice. Since the ultimate goal of the study was to examine the role of nuclear energy in the electricity supply only three constrasting scenarios were used to reflect the varying degrees by which electricity might penetrate the Algerian energy system.

The three scenarios were selected in collaboration with various energy experts in Algeria and were considered sufficient to allow, as a first step, clarification of the role that electricity might play in Algeria's global energy structure. This study was conducted by means of the MAED Model (MAED-1 version, see Chapter 6).

The second study is concerned only with the results regarding future electricity requirements, which are used as input data in order to study the optimization of Algeria's future electricity generating system. Various methods of generation (e.g. gas- or oil-fired, hydroelectric and nuclear power plants) were analysed and included in an econometric model in order to make a sequential determination of the most economic pattern of expansion for the power generating system. The starting dates and sizes of the nuclear power plants which would be economically justified were derived from this analysis. It is clear from the aforesaid that only the economic aspects has been considered in this analysis of the possible future programme for the development of nuclear energy in Algeria. This study is therefore only the first stage in the decision-making process and would have to be followed by more specific studies and analyses. This analysis was performed by means of the WASP Model.

An additional objective of the study was to enhance the country's capabilities for conducting energy and electricity planning studies. This was fully accomplished since all computer programs used for the analyses were transferred to Algeria and implemented in its facilities, and the Algerian experts were adequately trained in the use of these methodologies.

A.2.3 Conduction of the Algerian study

There was a division of responsibilities between the IAEA and the national teams in carrying out the various tasks involved in the study. The national team was responsible for gathering and analysis of the information to be used, the preparation of scenarios of development, analysis of results and preparation of the draft report. The IAEA team was to provide assistance and guidance in the conduction of the study and execution of the various computer runs needed, training the Algerian counterparts in the use of the computer models, and the implementation of these models on the Algerian computer facilities.

Concerning the activity of gathering of input information, a great effort by the national team, working in co-operation with experts from the various Algerian organizations concerned, was necessary in order to ensure consistency of this information.

A similar co-operative effort between the national team and experts from various Algerian organizations was required for selecting the different scenarios of development for the study, so as to ensure that these scenarios adequately reflected all presently scheduled and foreseeable development plans for the various sectors considered, allowing for technological improvements in installed equipment and the introduction of new technologies.

The preparation of the scenarios of development was a very important phase of the study whose execution required:

- The definition of a consistent socio-economic framework, which in the case of a developing country, amounts to selecting a form of development, i.e. to defining options and priorities and predicting structural changes in the economy while ensuring overall consistency. This framework was defined in accordance with the national five-year and longer term development plans for the Algerian economy.

- An identification of the factors determining energy consumption, and particularly electricity consumption, calls for an in-depth analysis of past trends which can be made only on the basis of detailed and reliable statistical data which are not always available in developing countries. In view of the time limitations and information available, an iterative approach was adopted for the study alternating between MAED runs, additional analysis and gathering of data and meetings with various Algerian experts concerned.

Given the purpose of the study, the variables selected to differentiate one scenario from another corresponded to those parameters which have a direct or indirect influence on the demand for electrical energy. Therefore, the scenarios chosen were based on a more or less equivalent (or at least not too contrasting) levels of final energy demand and strongly contrasting electricity demand levels.

Three scenarios were selected for the development of the electricity sector and were ranked as Low, Medium and High according to their levels of electricity consumption. The scenarios were then discussed and refined at informal meetings with representatives of the national organizations concerned with the view to determine a single, consistent socio-economic framework for the three scenarios.

Features common to all three scenarios

- In demographic terms: A strong growth of population leading to approximately 35 million in 2000 and 54 million in 2015, and a continuing trend toward urbanization (Table A.2.1).

- In economic terms: GDP growing over the study period but slightly decreasing rates over the study period. This GDP growth is also accompanied by significant changes in the GDP formation. (Table A.2.1).

- In social terms: Major housing programmes aimed, in a first step, at maintaining the present rate of occupancy and then improving it slightly; greater individual mobility with an improvement in public transport in order to limit the use of private cars; and a substantial

TABLE A.2.1. PAST AND FUTURE TRENDS IN POPULATION AND GDP

	1969	1979	2000	2015
Population total (10^3 inhabit.)	13549	18525	35213	54410
- of which, fraction living in urban areas (%)	12.67	14.40	28.30	36.70
Total population growth rate (%)	-	3.18	3.13	3.07
Total GDP (10^9 DA 1979)	62.2	124.8	440.2	685.4
Total GDP growth rate (%)	-	7.21	6.52	5.36
GDP per capita (DA 1979)	4591	6737	12501	12597
GDP structure (%)				
Agriculture	10.06	6.10	3.7	3.5
Construction	11.48	12.30	18.8	20.5
Mining	30.78	23.20	12.5	3.6
Manufacturing	8.51	12.50	19.6	22.3
Energy	0.50	3.60	7.1	8.9
Services, including transport	38.67	42.30	38.3	41.2

improvement in domestic equipment (increase in the number of appliances per dwelling) without reaching the levels comparable to the currently enjoyed in industrialized countries.

- *In energy terms:* Energy conservation through improvement of equipment efficiency. Identical values for variables determining demand for final energy, apart from those with a direct bearing on electricity demand. Recourse on small scale to solar energy for low temperature heat applications in households and services sectors; a common hypothesis for all three scenarios which was constructed only to show how the model can be used in this field, since additional analyses will be needed in order to study the role of solar energy in meeting the future energy requirements of the country.

Principal Differences among the Three Scenarios

As already mentioned the scenarios selected are ranked as Low, Medium and High according to the level of electricity consumption. The variables related to electricity demand and integrating the scenario concern this demand either directly (e.g., technical or technological factors, electricity consumption per unit value added in a given economic sector, use of electricity in non-specific applications such as space heating in households or furnace/direct heat in manufacturing industry); or indirectly for reasons of consistency.

The principal differences in the variables integrating each scenario are:

- specific electricity consumption per unit value added of the various sectors,
- use of electricity in industrial heat applications, specially in steel-making,
- railway electrification,
- specific consumption level (kW.h/m^2/a) in services sector,
- specific consumption level (kW.h/dwelling/a) in the domestic sector,
- use of electricity for heat applications in domestic and services sectors,
- use of solar in manufacturing industries (which for reasons of consistency was higher when the market penetration of electricity was relatively low).

Optimization of the investments in the electricity sector

The optimal pattern of development for the electricity generating system was studied over the period 1986-2015 on the basis of the three scenarios of electricity consumption selected and carrying out a separate optimization analysis for each scenario.

As for the analysis of energy demand, certain features were common to all three scenarios, in particular:

- the composition of the so-called fixed system including all existing and firmly committed additions and retirements of generating units,
- for expansion of the generation system only nuclear and gas-fired plants were considered as candidates and the sizes

used were selected on the basis of system development and permitting effective competition between alternatives,

- the technical and economic characteristics of the power plants used were taken from the most recent information available with due consideration to future developments and local conditions,
- the fuel prices, set on the basis of international prices but reflecting also the market conditions for export of natural gas from Algeria, and
- the constraints to the expansion problem, which were set with due consideration to present practices in the country and expected development and also interconnections with neighbouring countries.

A.2.4 Summary of results

A.2.4.1 Long-range energy forecasts

The main results of the three scenarios considered in the study are presented in Table A.2.2.

The demand for final energy is almost equivalent in all three scenarios ranging from 81 to 87 GW.a in 2015, (Fig. A.2.1), and the participation of electricity in this total for each scenario is considerably higher than in 1979.

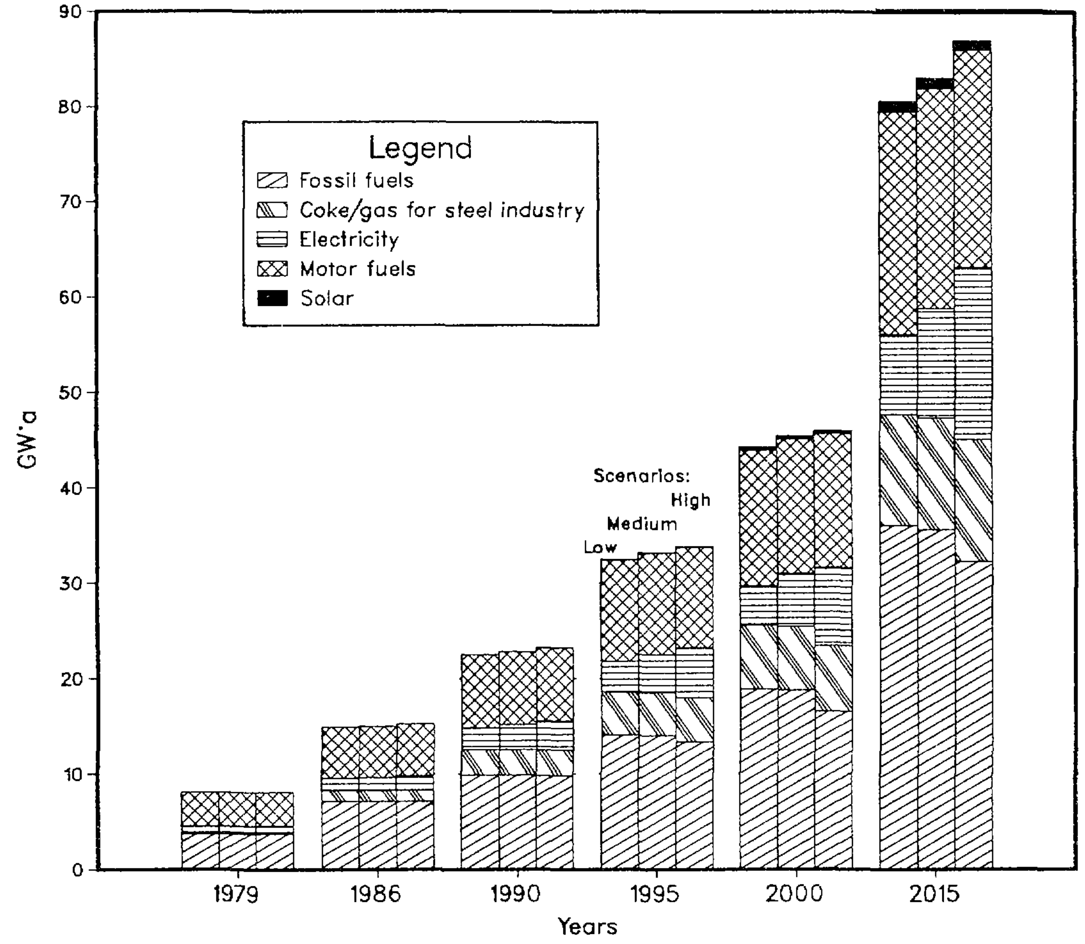

FIG. A.2.1. Energy and Nuclear Power Planning Study for Algeria — Breakdown of total demand for final energy by energy form.

TABLE A.2.2. ENERGY DEMAND FORECASTS ACCORDING TO THE VARIOUS SCENARIOS

Year:	1979	1985	1990	1995	2000	2015
LOW SCENARIO						
Final energy, GW.a	8.1	14.9	22.5	32.5	44.2	80.6
Growth rate*, %/a	–	10.6	9.7	9.0	8.4	6.6
Electricity, GW.a	0.6	1.3	2.3	3.0	4.1	8.4
Growth rate*, %/a	–	2.4	12.4	10.7	9.3	7.4
Electricity, % of total	7.8	8.6	10.4	10.0	9.4	10.4
Peak load (MW)	905	2101	3410	4713	6258	14249
MEDIUM SCENARIO						
Final energy, GW.a	8.1	15.0	22.8	33.2	45.4	83.0
Growth rate*, %/a	–	10.8	9.7	9.2	8.5	6.7
Electricity, GW.a	0.6	1.4	2.6	4.0	5.5	11.5
Growth rate*, %/a	–	13.7	13.8	12.2	10.8	8.4
Electricity, % of total	7.8	9.2	11.6	12.1	9.4	13.9
Peak load (MW)	905	2300	3862	6342	8808	19119
HIGH SCENARIO						
Final energy, GW.a	8.1	15.2	23.2	33.8	45.9	86.9
Growth rate*, %/a	–	11.0	10.0	9.3	8.6	6.8
Electricity, GW.a	0.6	1.6	3.1	5.3	8.2	18.1
Growth rate*, %/a	–	16.4	15.5	14.1	12.9	9.7
Electricity, % of total	7.8	10.4	13.4	15.6	17.9	20.8
Peak load (MW)	905	2648	4897	8205	12879	29366

*All the growth rates are calculated from the base year 1979.

The breakdown of energy demand by economic sector shows a familiar pattern of development for all three scenario (Fig. A.2.2): for the first year of study (1979) the participation of each sector is about one third of the total, and at the horizon (2015) a predominancy of the industry sector is noticed since its share is almost 50% of the total consumption, in agreement with the industrial development objectives of Algeria and particularly for the steel, cement and petrochemical industries.

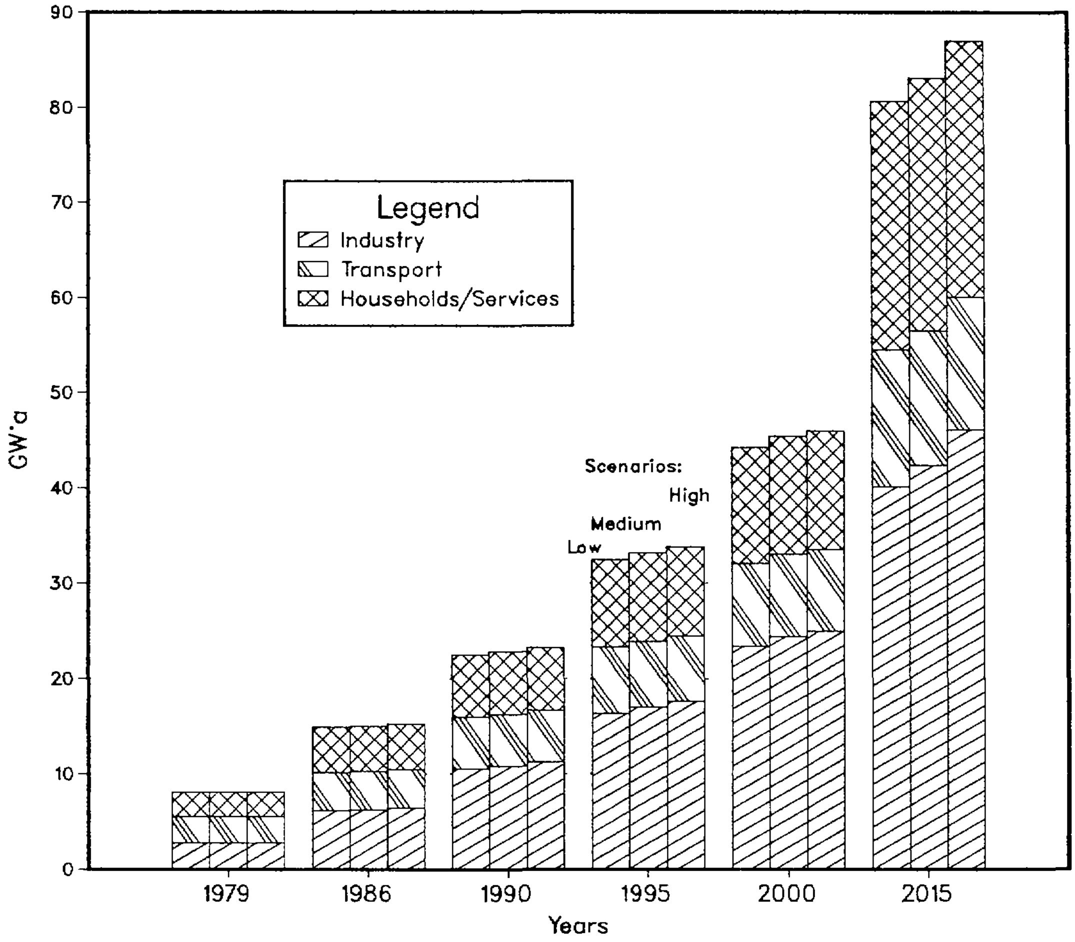

FIG.A.2.2. Energy and Nuclear Power Planning Study for Algeria — Breakdown of total demand for final energy by economic sector.

In comparing the results of the three scenarios, the methodology adopted at the outset of the study should not be forgotten: contrasting trends in electricity demand were to be viewed against a given pattern of development of the total demand for final energy. This is illustrated in Figure A.2.3 which shows the results on electricity demand both as total and per capita.

The electric power demand to be satisfied in each scenario were determined directly from the MAED results leading to peak demands (in MW) as shown in Table A.2.2.

A.2.4.2 Results concerning the development of electricity generating capacity and the role of nuclear power

The principal results are summarized in Table A.2.3. In terms of capacity additions, up to year 2000, the expansion of the generation system may be covered by gas-fired units with a higher participation of steam thermal units. From that year up to 2015, the capacity mix is strongly influenced by the scenario hypothesis: In the Low and Medium scenarios the expansion can still be covered by gas-fired units. Nuclear power appears only in the optimum expansion programme for the High scenario since 2003.

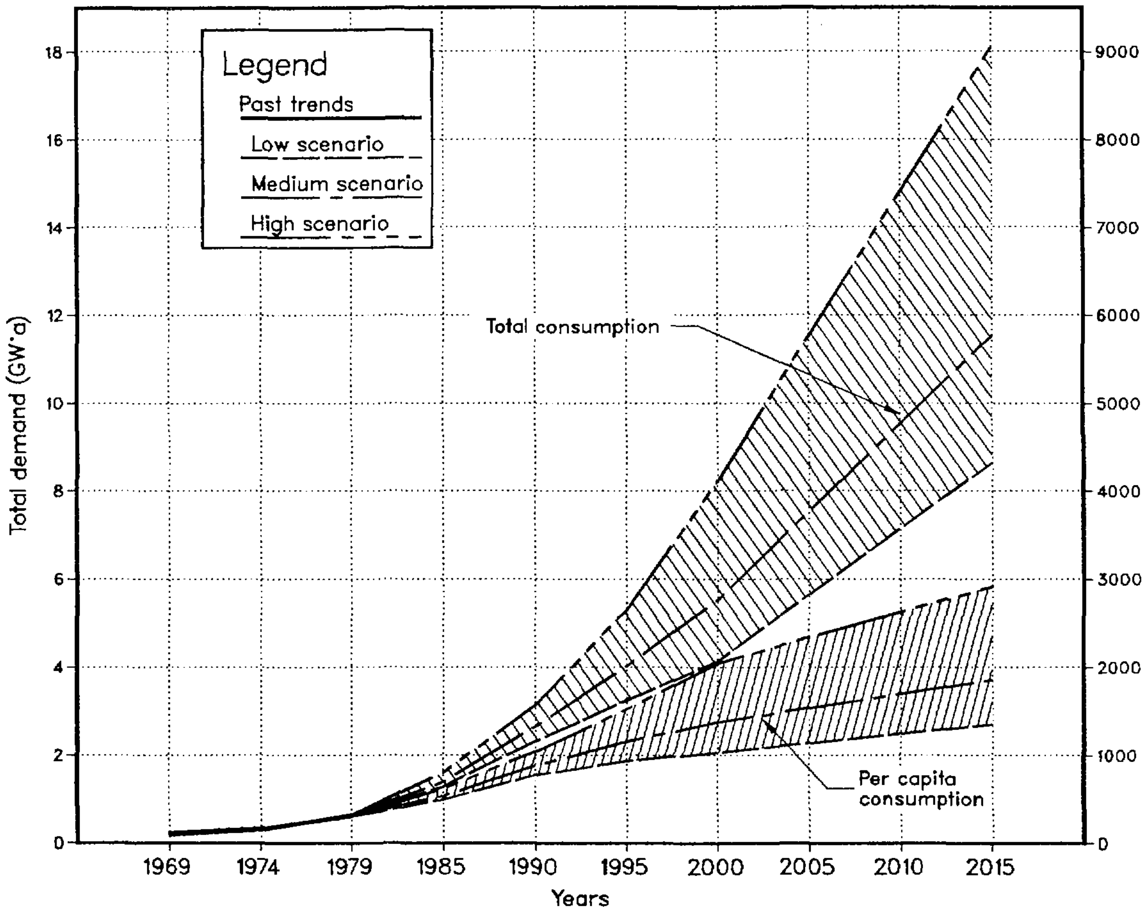

FIG.A.2.3. Energy and Nuclear Power Planning Study for Algeria — Trends in total and per capita demand for electricity according to the various scenarios.

Two important aspects related to the optimum solution for each scenario were considered of prime interest due to their repercussions on Algeria's economy: the capital investments and the requirements for natural gas (a principal source of revenues for the country) imposed by these solutions, which are shown in Table A.2.3.

Sensitivity analyses were conducted using only the results provided for the medium scenario to analyse the variations of the solution to changes in some basic parameters in order to provide the background for a decision to introduce nuclear power. Although conducted only for the medium scenario, the results can be easily extrapolated to the other two scenarios taking into account that there is time span of about 6 plus or minus years between each of them and the Medium scenario.

The sensitivity studies included: price of natural gas; investment cost of conventional (gas-fired) units at various escalation rates; cost of energy not supplied; discount rates for investment and operating costs; and modification of the refence solution trying to define more realistic programmes of capacity expansion based on engineering practices and taking advantage of the economies of scale.

TABLE A.2.3. DEVELOPMENT OF ELECTRICITY GENERATING CAPACITY AND ROLE OF NUCLEAR POWER BY SCENARIO*

Low Scenario	Medium Scenario	High Scenario
a. 16 575 MWe installed between 1986 and 2015 including(**): - 11 100 MW-GS 5 475 MW-GT	a. 23 550 MWe installed between 1986 and 2015 including(**): - 17 100 MW-GS 6 450 MW-GT	a. 38 025 MW installed between 1986 and 2015 including(**): 14 400 MW-PWR 13 800 MW-GS 9 825 MW-GT
b. Maximum annual capital investment (in 2010): 4 354 x 10^6 DA (1979) i.e. 0.7% GDP	b. Maximum annual capital investment (in 2009): 4 024 x 10^6 DA (1979) i.e. 0.8% GDP	b. Maximum annual capital investment in (2009): 9 979 x 10^6 DA (1979) i.e. 1.7% GDP
c. Cumulative capital investment 61.5 x 10^9 DA (1979)	c. Cumulative capital investment 85.5 x 10^9 DA (1979)	c. Cumulative capital investment 188 x 10^9 DA (1979)
d. Annual requirements of natural gas in 2015 18.2 x 10^9 m^3	d. Annual requirements of natural gas in 2015 24.6 x 10^9 m^3	d. Annual requirements of natural gas in 2015 19.2 x 10^9 m^3
e. Cumulative requirements of natural gas 279 x 10^9 m^3	e. Cumulative requirements of natural gas 379 x 10^9 m^3	e. Cumulative requirements of natural gas 416 x 10^9 m^3

* Including only capacity additions made by the expansion programme, i.e. firmly committed additions are not considered.

** Types of units: PWR: Pressurized light water reactor
GS: Gas-fired steam unit
GT: Gas-turbine

A.2.5 Conclusions of the study

In general, the study not only met its objective but also proved very instructive from the methodological point of view.

Some effort to improve the analytical methodologies may arise from the experience gained with the Algerian experts trying to improve certain modelling techniques for a better representation of the Algerian energy system. Internally, the IAEA has also adopted a programme of work aimed at improving some weaknesses of the models identified during the study (a new version, MAED-2, has been prepared as described in Chapter 6).

A.2.5.1 Energy forecasts

In qualitative terms, the study is not confined to providing figures on electricity consumption but places these figures in a global energy context, identifying the factors which determine them. Despite all the difficulties encountered in assembling the data and some limitations of the present version of the MAED model, the advantages of the methodology and its overall consistency remained the decisive considerations.

In quantitative terms, the three scenarios largely covered the spectrum of possible trends in the electricity sector. It would be illusory to seek to give preference to one of the three suggested paths without referring to the national energy policy which would define the role of electricity in meeting the future energy needs of Algeria, a task beyond the scope of this study. It may, nevertheless, be stated that final energy demand and, more specifically, electricity demand will continue to show a marked increase over the next 20-30 years under the combined effects of a determined development policy, strong population growth and an increase in energy demand as a result of higher living standards.

A.2.5.2 Expansion of the generating capacity and the opportunity of introducing nuclear power

The study was made using the WASP model; a methodology which has become traditional as a result of its widespread application and distribution by the IAEA. This procedure refrains from providing final answers which would soon become obsolete owing to the changing technical and economic conditions, but seeks rather to identify in a dynamic way all the factors to be considered in the decision-making process.

Since the main objective of the study was to determine the role that nuclear power may play in meeting the demand for energy in Algeria, all alternative studies were chosen with a view to help clarify the debate on this important subject and assist the decision-making process. The results show that nuclear power could meet part of the overall demand for electricity from the beginning of the next century, if the appropriate decisions are made.

The key factors influencing these decisions are: the role of electricity in satisfying the energy needs of the country, the price of gas (at present the main fuel used for electricity generation), the availability of other forms of energy to generate electricity and the capacity of the country to cope with a high rate of investments.

If it is decided to install nuclear generating capacity in Algeria, it must be remembered that this is a complex technology whose introduction requires most careful preparations and close co-ordination between all the sectors concerned. Among the most important issues to be addressed are: setting-up of an institutional framework tailored to fit the specific requirements of this technology; training of personnel in order to guarantee that sufficient qualified staff is available to participate in all the phases of a nuclear power programme; availability of funds to support the programme; appropriate development of the national industry to secure its participation in the construction of nuclear power plants; the search for suitable locations; the structure of the electric power network, etc.

A.2.5.3 Recommendations for follow-up studies

The results of the study were presented to the various Algerian authorities involved in the decision-making process in the energy sector. Following this presentation, it seems that a whole process of co-ordination and consultation will be implemented among the principal national organizations for adequate decisions on the development of nuclear energy.

Further analysis and studies will be probably suggested and some kind of technical assistance may be requested from the IAEA in the near future. In this respect, additional sensitivity studies should be carried out in order to analyse the effect on the proposed solutions to major changes in the hypothesis chosen, specifically with respect to: the price of natural gas, the investment costs of nuclear and conventional plants and the adequate level of the national discount rate. These studies can be performed by the national team, which is now well acquainted with and in possession of all analytical tools.

In addition, some other studies should be conducted in order to analyse the impact of introducing nuclear energy in the country, particularly on:

- the impact of a nuclear power programme on primary energy requirements;
- the impact of financing a nuclear power programme on macroeconomic development plans of the country;
- the balance of payment conditions;
- the selection of suitable types and sizes of nuclear reactors;
- the choice of and national participation in the nuclear fuel cycle;
- etc.

A.3 Energy and Electricity Planning study for Jordan up to year 2010

A.3.1 Introduction

Following a request of the World Bank which was undertaking a global advisory study on energy management and planning for Jordan, a co-operation agreement was reached in 1983 between the International Atomic Energy Agency (IAEA) and the Jordan Government to undertake an Energy and Electricity Planning (EPP) study for analyzing the future energy and electricity needs of Jordan over the next 20 to 30 years using planning methodologies developed by the IAEA [7].

It was recognized by the IAEA that launching such a co-operative project would provide an appropriate framework for enhancing the country's capabilities for undertaking similar planning studies. Moreover, it was recognized that in order to guarantee full transfer of technology, the study should be carried out by a joint team consisting of some experts from the IAEA and several Jordanian experts.

A joint team was created for the conduction of the study, including some experts from the IAEA and from the country. The Jordan team were all staff from the Jordan Electricity Authority (JEA), the company which was assigned full responsibility for the study by the Jordan authorities.

The actual work for the EEP study started in September 1983 when the computer programs to be used in the study were implemented in JEA's computer and the data collection phase was launched. The study lasted for about 21 months and included several missions by IAEA experts to Jordan and JEA experts to Vienna.

It should be emphasized here that the principal activities and the major responsibility for execution of the study were on the side of the JEA team which gathered all information required, prepared the input data to the various computer models, analyzed all computer printouts and introduced the required changes, and finally produced the draft report of the study. The IAEA team was responsible for overall coordination of the study and to provide guidance and advice during its execution, as well as to train the local experts in the use of the planning methodologies involved and to implement the computer models in Jordan's computer facilities.

A.3.2 Objectives of the study

The main objectives of the EEP study were:

1- to provide planning methodologies for the long-term energy and electricity demand forecasts, as well as generation expansion schemes for the electrical system.

2- to establish a nucleous for the energy statistical data base.

3- to provide a training procedure on the use of computer programs in planning for the local staff.

4- to provide forecast results for energy and electricity demands and electric power generating system expansion plans by the use of the above methodologies.

At the outset of the study, it was recognized that the future electricity requirements of a developing country, such as Jordan, could not be effectively studied in an isolated manner; they must be examined in the context of the overall energy requirements of the country consistent with the goals for national economic, social and technological development and the possibilities to achieve these objectives. This made it necessary to examine the energy demand in all its forms before undertaking a more detailed analysis of the electricity requirements, including an assessment of the optimal pattern of expanding the electric power generating system in order to meet the above needs.

A.3.3 Results of the study

Long-term energy demand forecast

Estimates of the future requirements for all forms of energy (including electricity) have been produced by means of a global methodology (see Chapter 6) which apart from evaluating energy demand of a country permits also to identify the factors influencing this demand.

On the other hand, these estimates cover the period 1985 to 2010 recognizing that the impact of changing values of these factors (due to changes in policy, life-style, etc) on the structure of energy consumption can only be observed over the long-term period.

TABLE A.3.1. ENERGY DEMAND RESULTS OF THE EEP STUDY

LOW SCENARIO

	1985	1990	1995	2000	2010
Total final energy* (10^3toe)	2191	2819	3531	4305	5620
Average annual growth rate (%)	6.7	5.2	4.6	4.0	2.7
Total final electricity demand (GW.h)	2131	3189	4279	5417	7529
Average annual growth rate (%)	20.0	8.4	6.1	4.8	3.4
Ratio of electricity/total energy (%)	8.4	9.7	10.4	10.8	11.5
Peak demand of I.S.** (MW)	407	600	814	1038	1491

MEDIUM SCENARIO

	1985	1990	1995	2000	2010
Total final energy* (10^3toe)	2377	3330	4517	5714	8273
Average annual growth rate (%)	8.9	7.0	6.3	4.8	3.8
Total final electricity demand (GW.h)	2328	3896	5452	7529	12060
Average annual growth rate (%)	22.7	10.9	7.0	6.7	4.8
Ratio of electricity/total energy (%)	8.4	10.1	10.4	11.3	12.5
Peak demand of I.S.** (MW)	448	733	1067	1502	2449

HIGH SCENARIO

	1985	1990	1995	2000	2010
Total final energy (10^3 toe)	2537	3691	5060	6444	9534
Average annual growth rate (%)	10.7	7.8	6.5	5.0	4.0
Total final electricity demand (GW.h)	2556	4621	6905	9653	15511
Average annual growth rate (%)	25.6	12.6	8.4	6.9	4.9
Ratio of electricity/total energy (%)	8.7	10.8	11.7	12.9	14.0
Peak demand of I.S.** (MW)	491	873	1355	1939	3272

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* Final energy (does not include refinery consumption, losses and electricity generation fuel, but includes the energy equivalent of electricity).

** Interconnected system.

These estimates have been produced taking into account the present policies contained in the current national and sectoral development plans as well as foreseeable developments for the trends observed in the past.

From all possible patterns of future development of the country, three were retained for the analysis of energy demand and they are categorized as Low, Medium and High Scenarios according to the expectations of achieving all development plans that have already been envisaged for the country, with the medium (basic) scenario representing the most probable continuation of the current trends and the low (pessimistic) and high (optimistic) scenarios representing extreme deviations with respect to the basic scenario.

The results for these three scenarios are shown in Table A.3.1. Figures A.3.1 and A.3.2 show the breakdown of the total energy demands by energy form and consumer sector respectively.

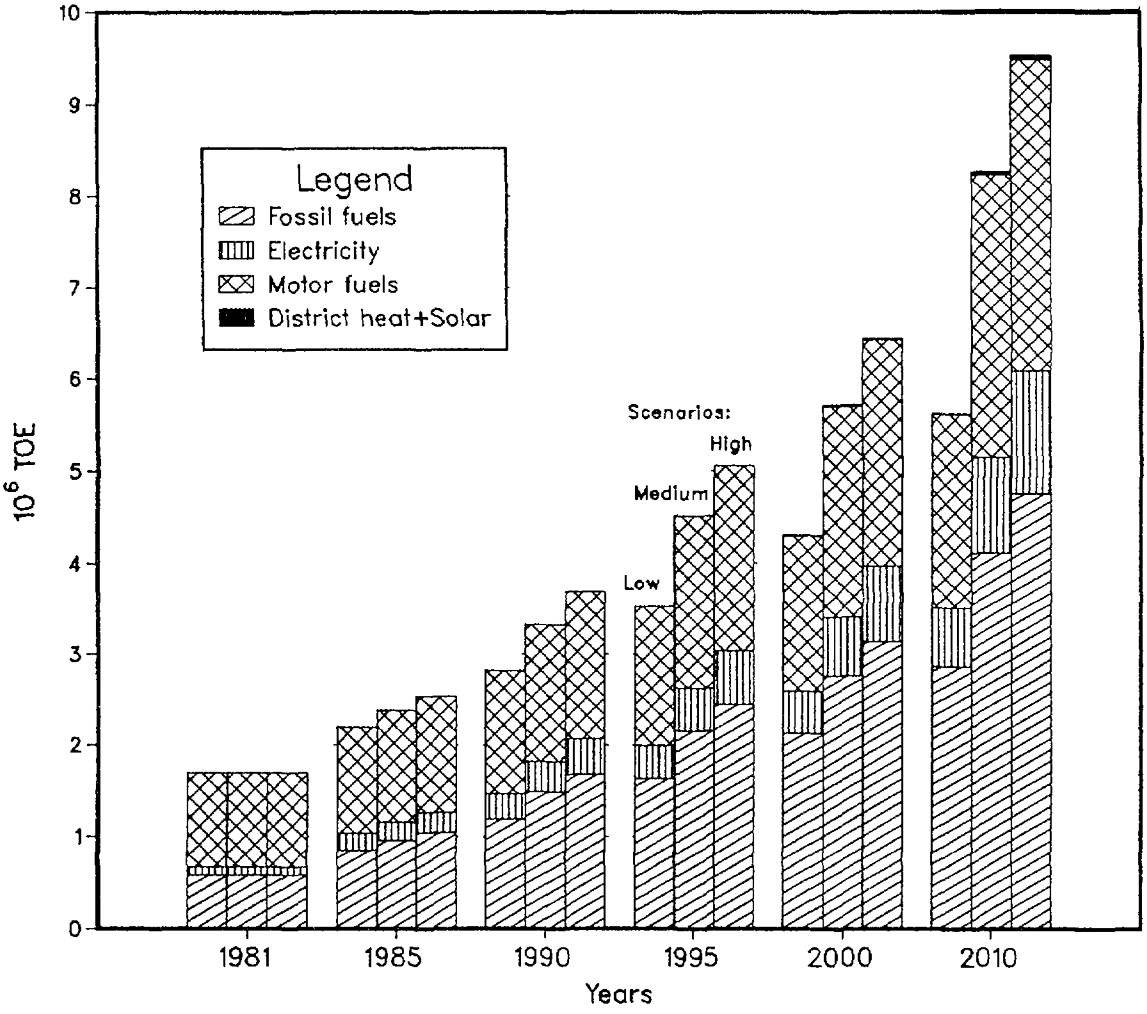

FIG A.3.1. Energy and Electricity Planning Study for Jordan — Breakdown of total demand for final energy by energy form.

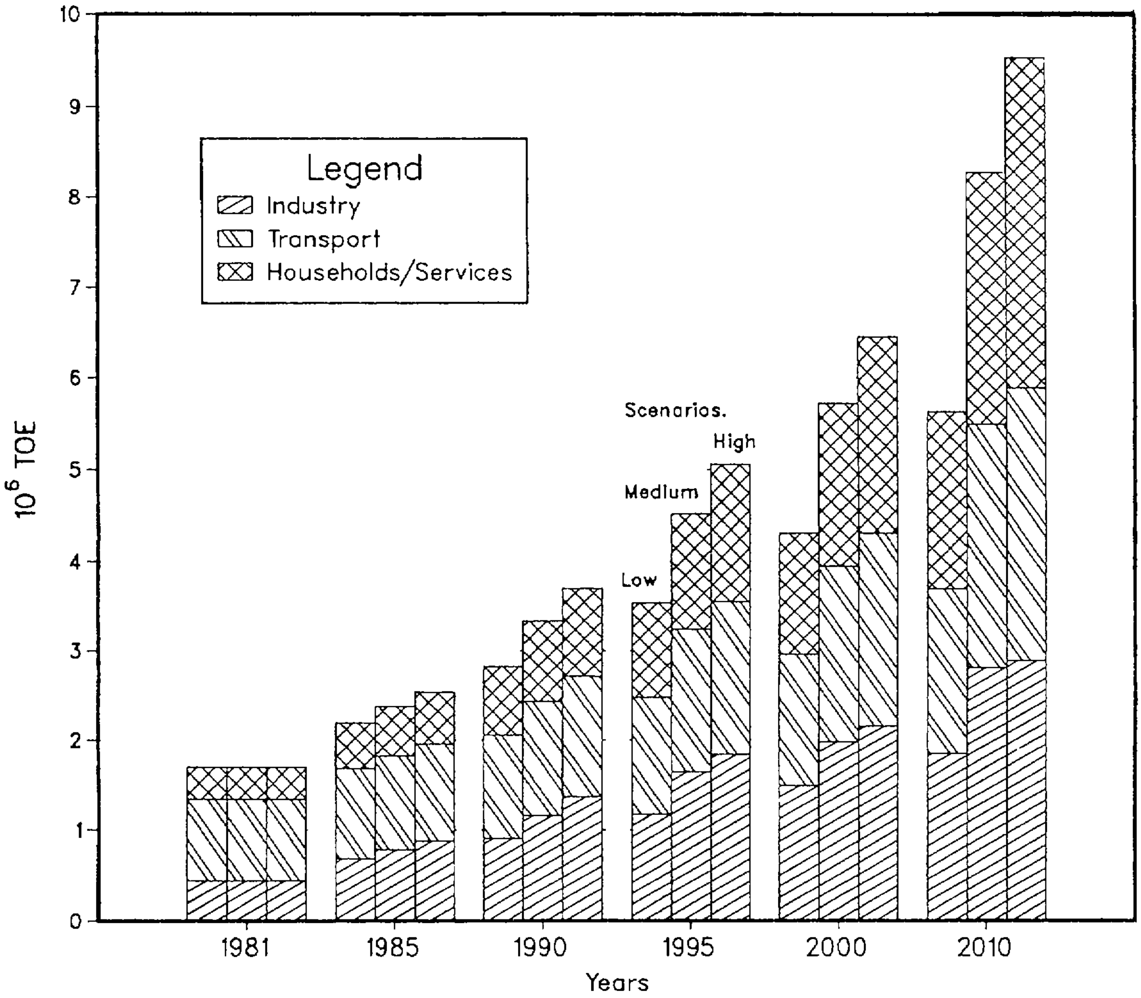

FIG.A.3.2. Energy and Electricity Planning Study for Jordan — Breakdown of total demand for final energy by sector.

Future development of the electric power generating system

The expansion of the electric generating system in Jordan was analyzed over the period 1989-2000 on the basis of the results on energy and electricity requirements above mentioned. The selection of a shorter period for this analysis lies on the fact that investment decisions in the electricity sector to satisfy the expansion needs up to 1997 should be made over the next few years, owing to lead times normally associated for constructing large power plants.

Figure A.3.3 represents the resulting trends for total and per capita demand for electricity (on terms of final energy) according to the scenarios of development considered.

By means of an econometric model (WASP-III) all future possible alternatives of power generation were examined within the overall optimization of the expansion of the power generating system of the

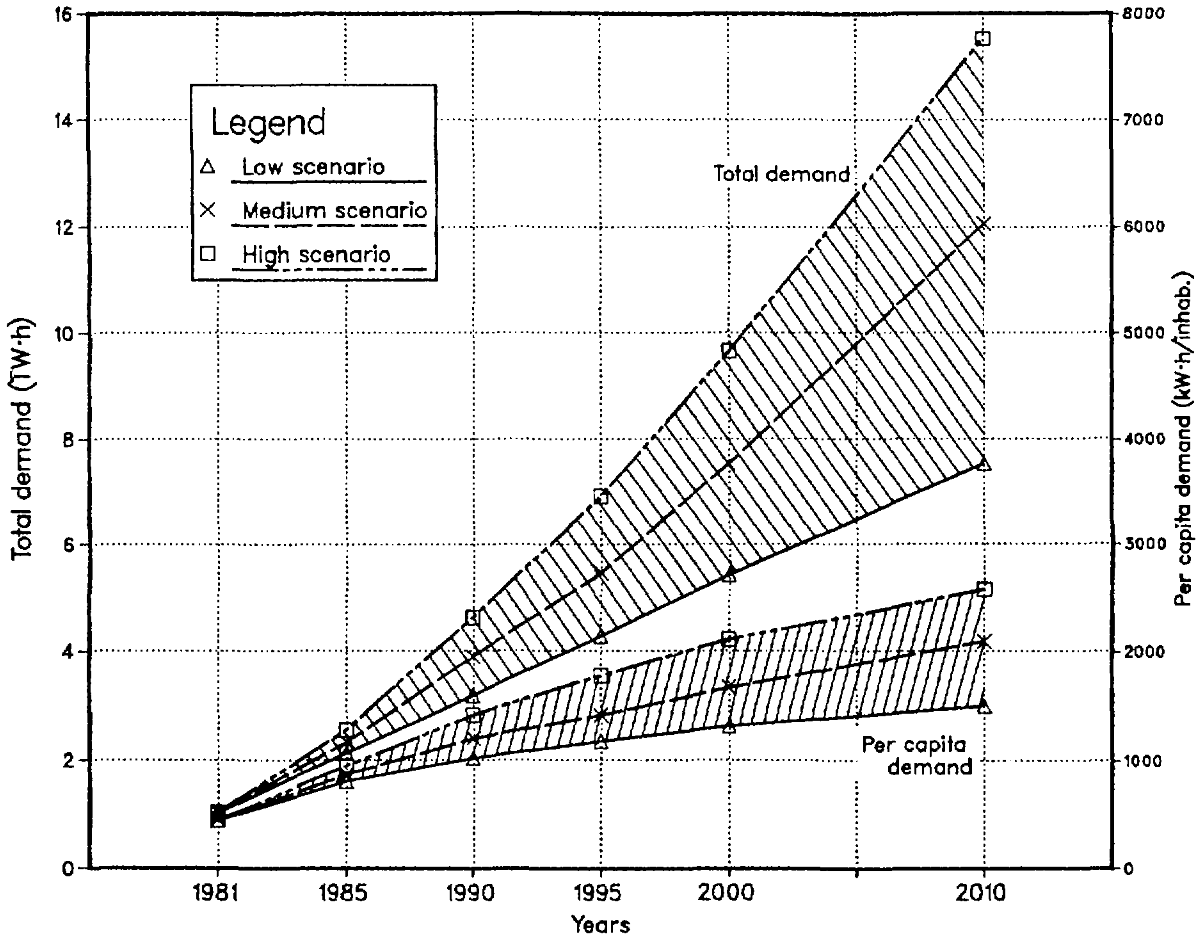

FIG.A.3.3. Energy and Electricity Planning Study for Jordan — Trends in total and per capita demand for electricity according to the various scenarios.

country. The optimal pattern of power plant additions in order to meet the future electricity requirements was found only for the medium scenario above described, considering that the results for the other scenarios can be extrapolated by simply anticipating (for high scenario) or delaying (for low scenario) the optimal schedule determined for the medium scenario. The main results of this analysis are summarized in Table A.3.2.

Within the framework of this strictly economic study for the expansion of the generating means of Jordan, it appears that steam coal-fired operating in base will play a very important role in satisfying the electricity requirements of the country accompanied by combustion turbines to satisfy the peak requirements. Oil will be still used in existing and committed power plants and which will supply the intermediate loads but the role of oil-fired plants in the generating system will decline over the years.

TABLE A.3.2. OPTIMAL DEVELOPMENT PLAN OF THE ELECTRIC POWER GENERATING SYSTEM (MEDIUM SCENARIO)

Year	Existing/ committed capacity (MW)	Schedule of additions	Total (MW)	Cumulative capital investments (10^6 US$)	Total annual coal consumption (10^3 ton)
1990	827	1 x 130 MW coal	957	407	268
1991	818	1 x 30 MW G.T.	978	512	271
1992	812	1 x 200 MW coal	1172	628	632
1993	788	1 x 30 MW G.T.	1178	722	645
1994	767	1 x 200 MW coal	1357	809	943
1995	764	1 x 30 MW G.T.	1384	858	982
1996	746	1 x 200 MW coal	1566	923	1252
1997	743	1 x 30 MW G.T.	1593	1003	1311
1998	725	3 x 30 MW G.T.	1665	1019	1344
1999	722	1 x 130 MW coal	1792	1045	1551
2000	719	3 x 30 MW G.T.	1879	1045	1607

G.T.: Gas turbine

A.3.4 Conclusions

The study has been successfully accomplished since all its main objectives have been fulfilled.

In spite of the difficulties encountered in gathering of the data and preparing these data in the way required by the planning methodologies used, the results of the analysis are very encouraging.

As a result of conducting the EEP study, JEA has obtained long-term energy and electricity demand forecasting and generation expansion planning methodologies. In the process JEA has established the basis for what could develop into a detailed energy statistical data base. Furthermore, the local team which conducted the study has gained a valuable experience in using the methodology as well as in computer use in general.

Due to the insufficient information regarding sectoral energy consumption, statistical data for many sectors, as well as the pattern of electricity consumption by the different consumers, it is recommended to conduct follow-up studies and surveys to cover for this insufficiency for future planning studies. Furthermore, several sensitivity studies need to be conducted in order to verify the results of the generation expansion plans, taking into consideration other aspects outside the strictly economic analysis performed by the EEP study.

If the proposed methodology for energy and electricity planning were to be adopted by the Jordan authorities for conducting future EEP studies, it is recommended that such studies concentrate more efforts in the analysis of the requirements of primary energy in all its forms, an aspect not directly treated by the MAED model in its present version. Furthermore, the analysis of the expansion of the electrical generating systems to be carried out by means of the WASP model should be extended to cover all possible scenarios of development determined for the analysis of the energy demand.

The reader of this Appendix is reminded that the objective of the Jordan study was in no way to solve the energy problems of Jordan (i.e. to produce a national energy and electricity plan for the country) but to propose methods of analysis which might allow the energy authorities of Jordan to gain a better idea of the impact and the social and economic repercussions of some decisions and thus improve the decision-making process on energy matters.

Moreover, being the first comprehensive study using the proposed methodology, it would be too ambitious to propose to adopt its results as a national energy policy. They, however, can be used by decision makers in the country as a reference for proposing courses of action in energy matters. The advantages of the methodological approach used in the study should be apparent to the reader.

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Appendix B

REFERENCE TECHNICAL DATA

For a country-specific planning activity it is absolutely necessary to collect data about the country's own features. In a second step these values can be checked against those specified, for example, in this reference data set.

The information presented below was collected from a variety of published sources and is meant to provide an overview of typical values to the user concerned with energy/electricity forecasting.

B.1. System of units, dimensions, energy conversion matrix

The traditional systems of units differ among themselves in the choice of the number and magnitude of the original units and in the choice of the physical nature of the units. The traditional units are either weight or volume based, i.e. barrel or ton for crude oil, cubic meter for natural gas, short or long ton for coal, kg ore for uranium, bundels for fuelwood, etc.

The modern tendency is to commonly use the Systeme International (SI) unit system which is based on 7 fundamental units (see Table B.1.1).

Derived units were introduced since the dimensions of the fundamental units are often not convenient for specific practical applications. Some basic derived units are listed in Table B.1.1.

TABLE B.1.1. UNITS OF THE SI SYSTEM

	unit	dimension
Fundamental:		
length	meter [m]	
mass	kilogram [kg]	
time	second [s]	
substance amount	molecule [mol]	
temperature	kelvin [k]	
electric current	Ampere [A]	
light intensity	Candela [cd]	
Derived:		
force	Newton [N]	1 [N] = 1 [kg m/s^2]
pressure	Pascal [Pa]	1 [Pa] = 1 [N/m^2]
	bar	1 [bar]= 10^5 [N/m^2]
energy	Joule [J]	1 [J] = 1 [N m]
power	Watt [W]	1 [W] = 1 [J/s]

Owing to the fact that the fundamental as well as derived units are either too small or too large to express the quantities involved in a particular measumerement, the SI sets out a series of Multiplier Prefixes for use with all units of measurement:

TABLE B.1.2. MULTIPLIER PREFIXES

10^{-3}	Milli	10^{3}	Kilo
10^{-6}	Micro	10^{6}	Mega
10^{-9}	Nano	10^{9}	Giga
10^{-12}	Pico	10^{12}	Tera
10^{-15}	Femto	10^{15}	Peta
10^{-18}	Atto	10^{18}	Exa

There are other unit systems (i.e. CGS - centimeter, gramme, second; engineering metric system - meter, second, force: kilo-weight; English engineering system - foot, second, force: pound-weight, which all use different fundamental and derived units. In order to convert units from one sytem to another, one utilizes Conversion Tables like the one shown in Table B.1.3.

B.2. Technical characteristics of fuels

Significant technical characteristics of primary and intermediary fuels are their content of non-combustible substances (e.g. moisture, ash), the composition of the clean fuel, and the resulting calorific values, net and gross. These characteristics, as well as the convenience of use and the release of harmful substances from combustion are decisive for their end use applicability.

The gross calorific value includes the condensation energy of steam in the flue gas. However, it is generally uneconomic to use this latent condensation energy since the condensate is highly corrosive, particularly if the flue gas contains SO_x. The net calorific value excludes this condensation energy and should be used in practice.

The amount of energy that can be released from uranium depends on the type of reactor and its fuel cycle parameters; it is about:

600 to 620 TJ/t U Nat	for natural uranium reactors,
460 to 500 TJ/t U Nat	for enriched uranium reactors with once through fuel cycle.
650 to 750 TJ/t U Nat	for enriched uranium reactors with re-cycling of uranium and plutonium [1, 2].

The fossil fuel equivalent of nuclear and hydroelectricity can be recorded by dividing the generated electricity by the average thermal efficiency of the thermal power stations in the country concerned.

TABLE B.1.3. ENERGY CONVERSION TABLE

Since many units commonly used in the field of energy are not standard SI units, the following conversion factors may be helpful to the reader

	J	Btu	Quad	kcal	mtce	10^6 mtce	boe	10^6 boe
1 J	- 1	$947\ 9 \times 10^{-6}$	$947\ 9 \times 10^{21}$	239×10^{6}	$34\ 14 \times 10^{12}$	$34\ 14 \times 10^{18}$	$163\ 4 \times 10^{12}$	$163\ 4 \times 10^{-18}$
1 Btu	= 1055	1	1×10^{15}	0 2522	$36\ 02 \times 10^{-9}$	$36\ 02 \times 10^{15}$	$172\ 4 \times 10^{15}$	$172\ 4 \times 10^{-21}$
1 Quad	$= 1055 \times 10^{15}$	1×10^{15}	1	252×10^{12}	$36\ 02 \times 10^{6}$	36 02	$172\ 4 \times 10^{6}$	172 4
1 kcal	= 4184	3 966	3966×10^{-15}	1	$142\ 9 \times 10^{9}$	$142\ 9 \times 10^{-15}$	$683\ 8 \times 10^{9}$	$683\ 8 \times 10^{15}$
1 mtce	$= 29\ 29 \times 10^{9}$	$27\ 76 \times 10^{6}$	$27\ 76 \times 10^{9}$	7×10^{6}	1	1×10^{-6}	4 786	$4\ 786 \times 10^{6}$
10^6 mtce	$= 29\ 29 \times 10^{15}$	$27\ 76 \times 10^{12}$	$27\ 76 \times 10^{3}$	7×10^{12}	1×10^{6}	1	$4\ 786 \times 10^{6}$	4 786
1 boe	$= 6119 \times 10^{6}$	$5\ 8 \times 10^{6}$	$5\ 8 \times 10^{9}$	1462×10^{3}	0 2089	$208\ 9 \times 10^{9}$	1	1×10^{6}
10^6 boe	$= 6119 \times 10^{12}$	$5\ 8 \times 10^{12}$	$5\ 8 \times 10^{3}$	1462×10^{9}	$208\ 9 \times 10^{3}$	0 2089	1×10^{6}	1
1 mtoe	$- 44\ 76 \times 10^{9}$	$42\ 43 \times 10^{6}$	$42\ 43 \times 10^{9}$	$10\ 7 \times 10^{6}$	1 528	1528×10^{9}	7 315	7315×10^{9}
10^6 mtoe	$= 44\ 76 \times 10^{15}$	$42\ 43 \times 10^{12}$	$42\ 43 \times 10^{3}$	$10\ 7 \times 10^{12}$	1528×10^{3}	1 528	7315×10^{3}	7 315
1 m^3 gas	$= 37\ 26 \times 10^{6}$	$35\ 31 \times 10^{3}$	$35\ 31 \times 10^{12}$	8905	1272×10^{6}	1272×10^{12}	6089×10^{6}	6089×10^{12}
1 ft^3 gas	$= 1055 \times 10^{3}$	1000	1×10^{12}	252 2	36×10^{6}	36×10^{12}	$172\ 4 \times 10^{6}$	$172\ 4 \times 10^{12}$
1 kW a	$= 31\ 54 \times 10^{9}$	$29\ 89 \times 10^{6}$	$29\ 89 \times 10^{9}$	7537×10^{3}	1 076	1076×10^{9}	5 154	5154×10^{9}
1 GW a	$= 31\ 54 \times 10^{15}$	$29\ 89 \times 10^{12}$	$29\ 89 \times 10^{3}$	7537×10^{9}	1076×10^{3}	1 076	5154×10^{3}	5 154
1 TW a	$= 31\ 54 \times 10^{18}$	$29\ 89 \times 10^{15}$	29 89	7537×10^{12}	1076×10^{6}	1076	5154×10^{6}	5154

	mtoe	10^6 mtoe	m^3 gas	ft^3 gas	kW a	GW a	TW a
1 J	$= 22\ 34 \times 10^{-12}$	$22\ 34 \times 10^{-18}$	$26\ 84 \times 10^{-9}$	948×10^{9}	$31\ 71 \times 10^{12}$	$31\ 71 \times 10^{18}$	$31\ 71 \times 10^{21}$
1 Bru	$= 23\ 57 \times 10^{-9}$	$23\ 57 \times 10^{-15}$	$28\ 32 \times 10^{-6}$	0 001	$33\ 45 \times 10^{9}$	$33\ 45 \times 10^{15}$	$33\ 45 \times 10^{18}$
1 Quad	$= 23\ 57 \times 10^{6}$	23 57	$28\ 32 \times 10^{9}$	1×10^{12}	$33\ 45 \times 10^{6}$	33 45	$33\ 45 \times 10^{3}$
1 kcal	$= 93\ 47 \times 10^{9}$	$93\ 47 \times 10^{15}$	$112\ 3 \times 10^{-6}$	3966×10^{-6}	$132\ 7 \times 10^{9}$	$132\ 7 \times 10^{-15}$	$132\ 7 \times 10^{18}$
1 mtce	= 0 6543	$654\ 3 \times 10^{9}$	786 1	$27\ 76 \times 10^{3}$	0 9287	$928\ 7 \times 10^{6}$	$928\ 7 \times 10^{12}$
10^6 mtce	$= 654\ 3 \times 10^{3}$	0 6543	$786\ 1 \times 10^{6}$	$27\ 76 \times 10^{9}$	$928\ 7 \times 10^{3}$	0 9287	$928\ 7 \times 10^{6}$
1 boe	= 0 1367	$136\ 7 \times 10^{9}$	164 2	5800	0 194	194×10^{9}	194×10^{12}
10^6 boe	$= 136\ 7 \times 10^{3}$	0 1367	$164\ 2 \times 10^{6}$	$5\ 8 \times 10^{9}$	194×10^{3}	0 194	194×10^{6}
1 mtoe	= 1	1×10^{6}	1201	$42\ 43 \times 10^{3}$	1 419	1419×10^{9}	1419×10^{12}
10^6 mtoe	$= 1 \times 10^{6}$	1	1201×10^{6}	$42\ 43 \times 10^{9}$	1419×10^{3}	1 419	1419×10^{6}
1 m^3 gas	$= 823\ 2 \times 10^{6}$	$832\ 3 \times 10^{12}$	1	35 31	1181×10^{6}	1181×10^{12}	1181×10^{15}
1 ft^3 gas	$= 23\ 57 \times 10^{6}$	$23\ 57 \times 10^{-12}$	$28\ 32 \times 10^{3}$	1	$33\ 45 \times 10^{6}$	$33\ 45 \times 10^{12}$	$33\ 45 \times 10^{15}$
1 kW a	= 0 7045	$704\ 5 \times 10^{9}$	846 4	$29\ 89 \times 10^{3}$	1	1×10^{6}	1×10^{9}
1 GW a	$= 704\ 5 \times 10^{3}$	0 7045	$846\ 4 \times 10^{6}$	$29\ 89 \times 10^{9}$	1×10^{6}	1	1×10^{3}
1 TW a	$= 704\ 5 \times 10^{6}$	704 5	$846\ 4 \times 10^{9}$	$29\ 89 \times 10^{12}$	1×10^{9}	1000	1

k kilo = 0^3 G giga = 10^9 P peta = 10^{15} M mega = 10^6 T tera = 10^{12} E exa = 10^{18}

1 mtce = 1 tonne of coal equivalent

1 boe = 1 barrel of oil equivalent

Examples of frequent conversions

	PJ	TW h
1×10^6 tce	29 308	8 1388
1×10^6 toe	41 868	11 63
1×10^9 m^3 natural gas	35 169	9 7692

7 barrel crude oil (159 L per b) ≈ 1 t

1×10^6 b/d (barrel per day) ≈ 50×10^6 t/a

Unless otherwise specified, throughout the book dollars are US dollars, tons are metric, billion is 10^9

TABLE B.2.1. TECHNICAL CHARACTERISTICS OF COMMERCIAL SOLID FUELS [1, 2, 3, 4, 5, 6]

Fuel	Calorific Value (GJ/t)		Ingredients		
	Gross	Net	% Ash mean	% Water mean	% Sulfur mean
Hard Coal					
UN Standard		29.3			
Examples of traded coal:					
Australia	29.0	28.1	9.5	4.5	0.9
China	29.2	28.3	0.5	0.5	1.5
Germany, FR	32.0	31.0	6.0	4.5	0.9
South Africa	28.2	27.2	13.8	2.2	
USSR	27.6	26.5	17.1	5.0	3.5
USA, East	25.9	24.3	9.5	13.7	3.4
Lignite					
UN Standard		11.3			
Germany, FR	9.8	7.9	2.7	60.0	0.5
India		9.7			
Others					
Peat (UN standard)		9.5			
Steam coal	27.2	29.3	6.0	5.0	
Gas coal	29.3	31.0	6.0	5.0	
Anthracite	31.0	31.8	6.0	3.0	
Coke	30.1				
Petroleum coke	34.8				

TABLE B.2.2. TECHNICAL CHARACTERISTICS OF SELECTED LIQUID FUELS [3, 4, 5, 6, 7]

Fuel	Calorific Value (GJ/t)	
	Gross	Net
Crude Oil API 34		42.6
Liquified Petroleum Gas	49.4	45.2
Propane C_3H_8	50.3	45.8
Butane C_4H_{10}	49.5	45.7
Gasoline	47.7	43.9
Naphtas	47.3	43.9
White spirit	47.7	44.4
Jet fuel	47.3	43.5
Kerosene	47.3	43.1
Distillate fuel oil	46.4	42.7
Residual fuel oil	44.4	40.2
Lubes	44.4	41.4
Liquified Natural Gas	57.7	52.7
Ethyl alcohol C_2H_5OH	29.9	26.8
Methyl alcohol CH_3OH	22.3	19.6
Tar (from hard coal)	39.0	37.7

Note: Calorific values are at 0° Celsius, 1.0132 bar. Net calorific values will apply to all standard combustion processes.

TABLE B.2.3. TECHNICAL CHARACTERISTICS OF SELECTED GASEOUS FUELS [3, 4, 5, 6, 7]

Fuel		Calorific Value (MJ/m^3)	
		Gross	Net
Natural Gas (1)			39.0
Refinery Gas (2)		50.2	46.0
Methane	CH4	39.8	35.9
Ethane	C2H6	70.3	64.4
Propane	C3H8	101.6	93.2
Butane	C4H10	133.9	123.6
Pentane	C5H12	145.2	133.9
Coke Oven Gas		19.2	17.6
Blast Furnace Gas			3.8
Biogas (60% CH4)			21.5
Hydrogen Sulfide H2S			23.4

(1) UN standard
(2) varying, maximum value given

Note: see Table B.2.2

TABLE B.2.4. TECHNICAL CHARACTERISTICS OF SELECTED NON-COMMERCIAL FUELS AND WASTES [4]

Fuel	Net Calorific Value (GJ/t)
Bagasse (UN standard)	14.6
Bark	11.3
Coffee grounds	13.4
Corncobs	19.2
Dung cakes	8.8
Fuelwood, green	5.4 - 16.5
Fuelwwod, dried	10.8 - 21.3
Garbage	19.7
Nut hulls	18.0
Oil shale (UN standard)	9.2
Paddy husk (rice hulls)	13.4
Paper	17.6
Rags	18.0
Sawdust and shavings	11.3
Spent lubes	14.2

B.3. Energy conversion efficiencies from primary to secondary (intermediate) energy

Primary energy is sometimes used in its original form and at the location of occurrence, but usually it is transported, processed, and/or converted for end use. The portion of energy which is converted to convenient and clean intermediate energy, in particular to electric energy, is increasing in practically all countries. Since a fraction of the energy is consumed or rejected in each transportation and conversion step, the extent and performance of conversion processes is essential for the primary energy demand. Efficiencies of relevant conversion processes are summarized in Tables B.3.1 and B.3.2.

TABLE B.3.1. ENERGY CONVERSION EFFICIENCIES [8, 9, 10]

Technology	Net Efficiency (%)
Refinery	88 - 94 (1)
Power Plants:	
Diesel motor	40
Gas turbine	30
Gas-fired steam power plant	40
Oil-fired steam power plant	40
Combined cycle plant	45
Coal-fired power plant	36 - 40 (2)
Nuclear power plant: - LWR	32 - 34
- HWR	28 - 32
Photovoltaic cell	10
Solar tower plant	27

(1) depends on extent of cracking and coking
(2) depends on coal quality and extent of flue gas desulphurization

TABLE B.3.2. EFFICIENCIES OF CHEMICAL ENERGY CONVERSION PROCESSES [9, 10]

Process	Efficiency (%)
Coal gasification	59
Coal conversion into coke and coke oven gas	90
Cracking (refinery)	88
Methanol production (from natural gas)	65
Biomass conversion	
Gasification, LHC gas, raw	81
Gasification, MHC gas	76
Combustion, steam	70
Gasification, LHC gas clean	69
Combustion, steam + power	68
Liquifaction	63
Gasification, SNG	61
Gasification, methanol	57
Fermentation, corn	57
Digestion, MHC gas, (menure)	48
Digestion, SNG (kelp)	46
Gasification + conversion (gasoline)	45 (1)

(1) By-products with fuel value produced in addition to intermediate energy form but not included in efficiency calculation.

B.4 Efficiencies at the final/useful energy level

Continuing down in the energy chain, it is important to distinguish among the different energy consumptions by type of energy carrier and different sectors. Table B.4.1 gives approximate efficiencies relevant to the various sectors and Table B.4.2 illustrates the efficiencies of some selected appliances/equipment. As can be seen in this table, the end use efficiency of electricity is usually high, in some cases up to 1.00.

TABLE B.4.1. APPROXIMATE EFFICIENCIES OF FINAL ENERGY UTILIZATION BY COMMODITY AND SECTOR [4]

	Airplanes, Highway, Agriculture	Rail-ways	Inland Water-ways	Industry	Domestic Sector
Coal	-	0.05	0.15	0.60	0.50
Lignite	-	0.04	0.10	0.60	0.50
Coal briquettes	-	0.05	0.15	0.60	0.50
Lignite briquettes	-	0.05	0.15	0.60	0.50
Coke	-	0.05	-	0.70	0.50
Coke breeze	-	-	-	0.60	-
Crude oil	-	-	-	0.70	-
LPG/LRG	0.20	-	-	0.80	0.70
Aviation gasoline	0.20	-	-	-	-
Motor gasoline	0.20	0.20	0.20	0.20	-
Jet fuel	0.20	-	-	0.20	-
Kerosene	0.20	0.15	-	0.15	0.30
Distillate fuel oil	0.25	0.30	0.30	0.30	0.60
Residual fuel oil	0.50	0.06	0.20	0.70	0.60
Refinery fuel	-	-	-	0.70	-
Petroleum coke	-	-	-	0.70	-
Refinery gas	-	-	-	0.80	-
Natural and manufactured gas	0.25	-	-	0.80	0.70
Non-commercial fuel	-	0.03	-	0.40	0.20

TABLE B.4.2. AVERAGE EFFICIENCIES OF APPLIANCES [3]

Appliances	Efficiency (%)
Cement kilns (medium-dry, semi-wet process)	30 - 40
Glasswork radiation furnace	40
Blast furnace	70 - 77
Petrol engine	20
Diesel engine	35
Turbo-prop, aircraft jet	25
Gas engine	22
Coal-fired industrial furnaces and boilers	60
Coal-fired cooker	25
Coal-fired domestic heating boiler and coal-fired stove	55 - 65
Oil-fired industrial furnaces and boilers	68 - 73
Oil-fired domestic heating boilers	68 - 73
District heating boilers fired with residual fuel oil	66 - 73
Paraffin burners	55
Gas-fired industrial furnaces and boilers	70 - 75
Gas cooker	37
Gas-fired water heater	62
Gas-fired domestic heating boiler	67 - 80
LPG cooker	37
Space heating with LPG	69 - 73
Electric motors	95
Electric furnances	95
Electrolysis	30
Electric rail haulage	90
Electric cooker	75
Electric water-heater	90
Electric storage heating	95
Direct electric heating	100

B.5. Energy end-use characteristics

Energy is used in all sectors of a national economy. The development of activities in industry, transport, agriculture, households and commerce and in particular the deployment and specific energy consumption of the energy-intensive technologies govern the development of energy demand.

B.5.1 Industry

Table B.5.1 lists the specific useful energy consumption per unit of product for some important processes in selected types of industry.

TABLE B.5.1. USEFUL ENERGY CONSUMPTION PER UNIT OF PRODUCT IN THE INDUSTRY SECTOR [3, 9, 10, 11, 12]

Industry	Total Energy (GJ/t)	Electricity (kWh/t)
Aluminium (> 400° C)		
production	55	11,000 - 18,000
recycling	10 - 12	< 1,000
finishing	9 - 30	1,300 - 2,300
Bayerprocess and		
electrolysis	10	1,260
Cement production (> 400° C)		
wet process	5 - 7	92 - 136
dry process	3 - 6	87 - 154
Glass production (> 400° C)	8	
Paper & Pulp	17	1,075
Steel		
production (> 400° C)	17 - 23	75
rolling	4 - 7	190 - 360
arc-furnace	2	550
direct-reduction	11	160
Textiles		
Chemical processes		
carbide (arc furnace)	11	3,000
chlorine (HCL)		
electrolysis)	6	1,800
chlorine (Diaphragma)	12	3,300
Water desalination (100-400° C)		
multi-stage flash	0.35	
reverse osmosis		7 - 8

B.5.2 Transportation

The importance of the transportation sector in economic terms and thus within the structure of the energy consumption in the country varies according to the characteristics of the country and to the modes of transportation used and the respective efficiencies of each mode. Table B.5.2 gives specific energy consumptions of the most important transport modes for freight and passengers. The ranges of these consumptions are graphically shown in Figures B.5.1 and B.5.2.

TABLE B.5.2. SPECIFIC ENERGY CONSUMPTION FOR PASSENGER AND FREIGHT TRANSPORTATION BY MODE OF TRANSPORT [13, 14, 15]

Type and Mode of Transport	Efficiency
Passenger:	kWh/100 pkm
automobiles	25 - 44
train (diesel)	13 - 22
train (electric)	8
airplane	58 - 84
bus	9 - 14
Freight:	kWh/100 tkm
truck	19 - 23
train (diesel)	10
train (electric)	5 - 6
airplane	340 - 513
ships	4 - 5
pipeline	4 - 15

pkm stands for passenger-kilometers and tkm for ton-kilometers

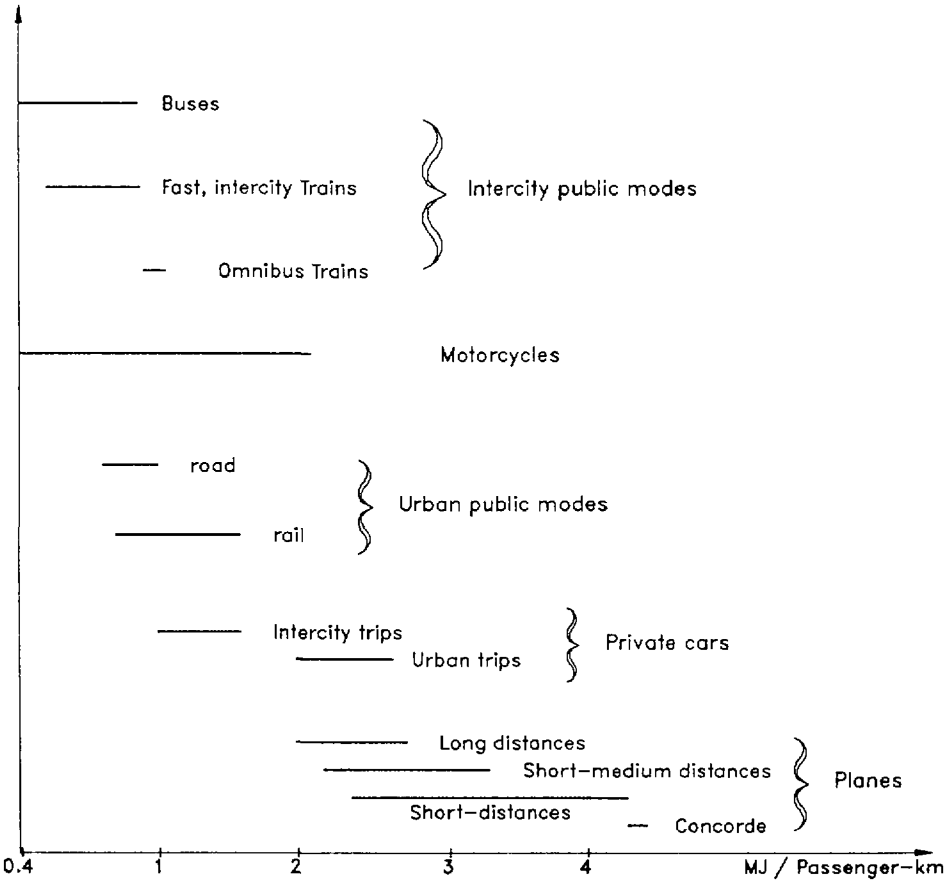

FIG.B.5.1. Range of specific energy consumption of passenger transport modes [5].

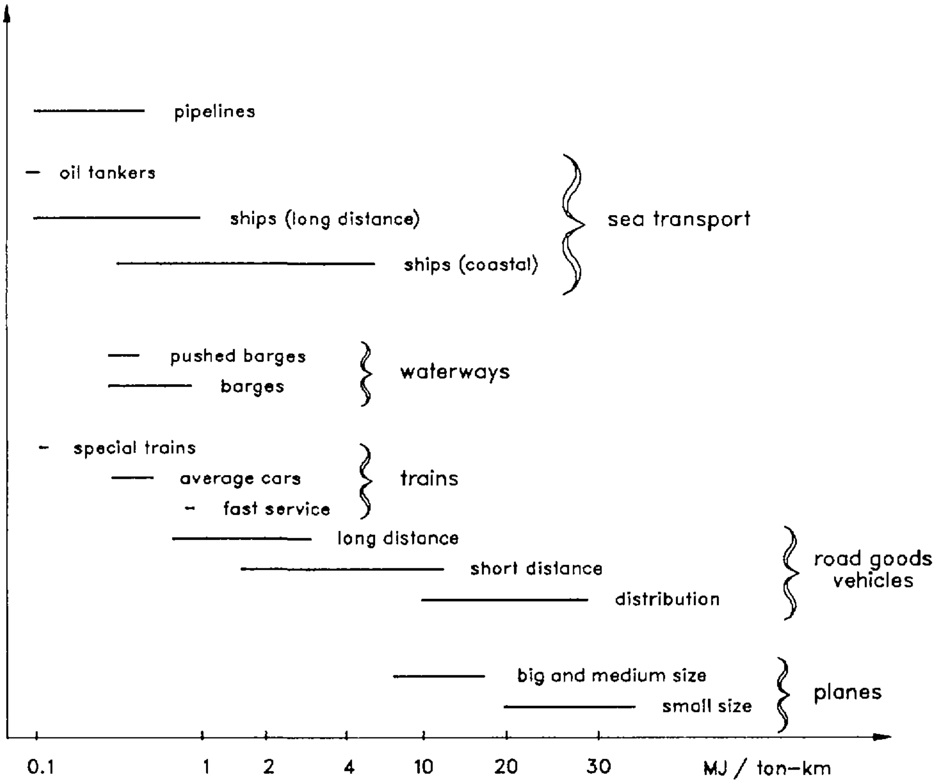

FIG.B.5.2. Range of specific fuel consumption of freight transport modes [5].

B.5.3 Agriculture

In many developing countries, agriculture remains one of the most important sectors of the economy and thus requires special consideration when preparing socio-economic development plans. Of particular importance is the energy consumption of this sector, since the activities related to it may impose increasing specific energy requirements as long as more mechanization is used to replace activities which were executed by human and animal power or by using solar power for drying products. Figure B.5.3 illustrates the chain for production of food and its interaction with other economic sectors in terms of inputs (e.g., feedstocks from industry) or outputs (e.g., needs for freight transportation, the actual food products). For illustrative purposes, Table B.5.4 provides the energy consumption in different areas of crop production in the USA in 1974 and Table B.5.3 shows the ranges of energy requirements per ton of food produced and the distribution by type of energy form used. Finally, Table B.5.4 gives typical inputs per hour for tractor use in the UK in 1968.

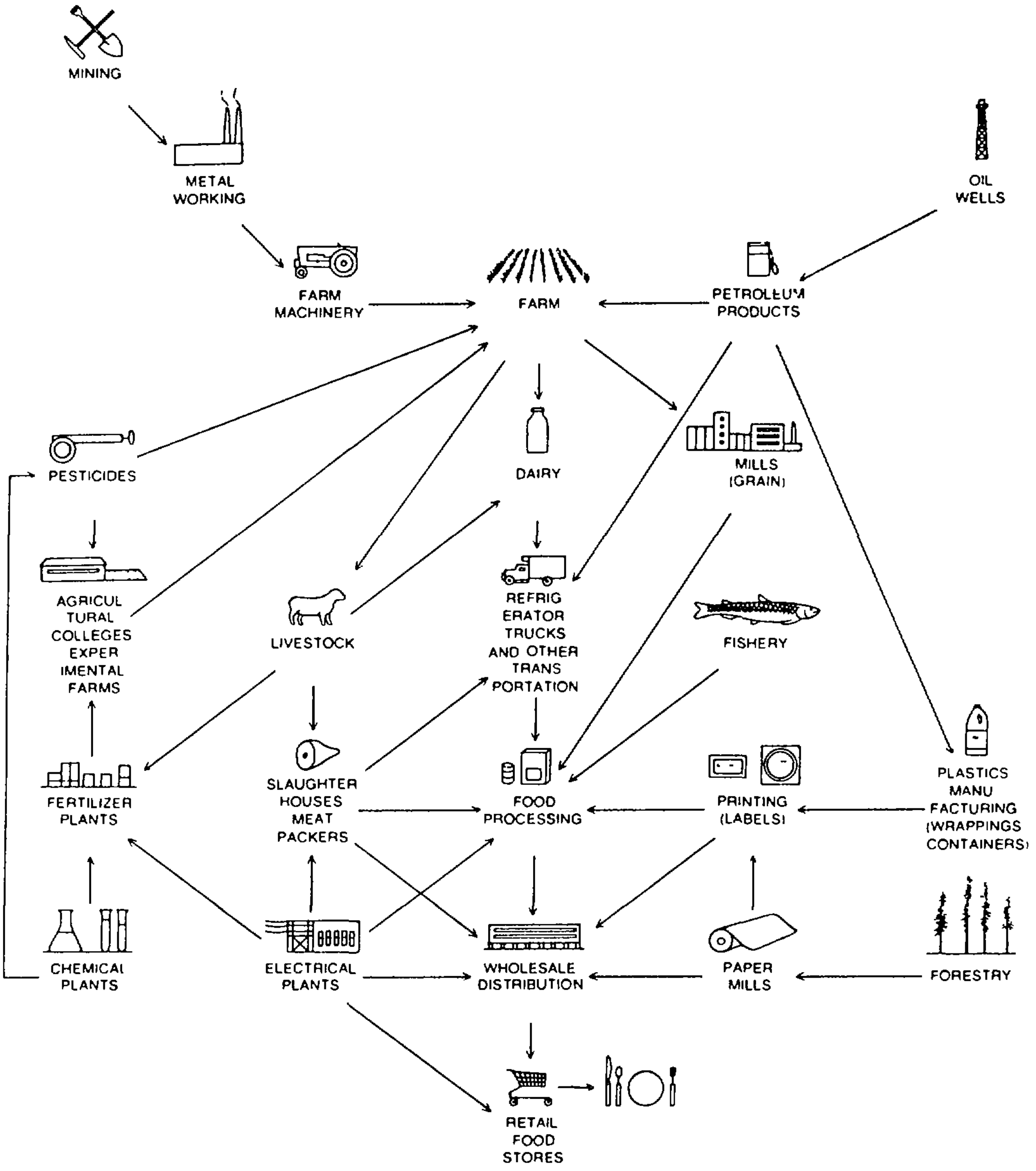

FIG.B.5.3. Food chain and its interaction with other economic sectors [17].

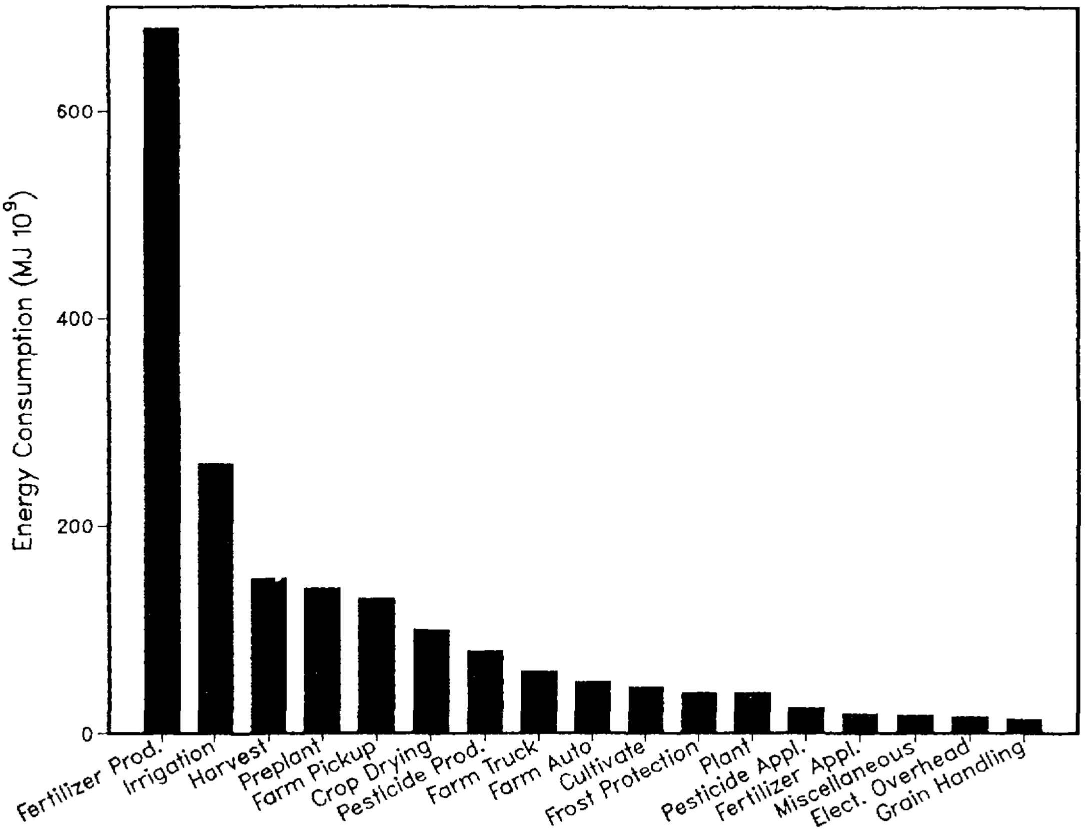

FIG.B.5.4. Energy consumption in different areas of crop production, USA, 1974 [18].

TABLE B.5.3. ENERGY REQUIREMENTS PER TON OF PROCESSED FOOD [18]

Product	Average % of Energy Used				Energy Range in MJ/ton of production
	Solid Fuel	Fuel Oil	Gas	Electricity	
Milling	2.4	74.0	3.3	20.3	453 - 6206
Sugar	56.3	2.5	40.6	0.6	3757 - 6278
Fruit and Vegetables	10.7	67.5	7.6	14.3	1756 - 19831
Oil and Fats	0	4.1	86.5	9.4	2789
Brewing (Vinegar)	21.7	51.2	14.4	12.7	235 - 2123
Fish Freezing and storing					600 - 1000

TABLE B.5.4. ENERGY INPUTS FOR A TYPICAL HOUR OF TRACTOR USE, UNITED KINGDOM 1968 [18]

Tractor Specification	Energy MJ/h
50 horsepower (37.3 kW) 6000 h life, 900 h/yr	137.7
65 horsepower (48.5 kW) 7000 h life, 900 h/yr	167.2
90 horsepower (67.2 kW) 7500 h life, 900 h/yr	291.7

B.5.4 Residential, rural communities

The energy consumption of the population at the household side is highly dependent on the per capita income level. This, together with population habits, climate, etc., determines standards of living. This, in turn, influences the requirements of the individual, and the type of equipment and energy carrier to be used for satisfying these needs. Usually, in developing countries, the energy used by residential consumers is higher than that of the rural population. Table B.5.5 shows specific consumption of certain appliances in selected industrialized countries.

TABLE B.5.5. SPECIFIC CONSUMPTION OF HOUSEHOLD ELECTRICAL APPLIANCES [11]

(kWh/yr/dwelling)

	U.K. 1978	France 1976	U.S.A. 1970	Denmark 1975	F.R.G. 1975
Refigerator	350	290	1300	515	405
Freezer	1000	800	1380	775	700
Washing-machine	200	450	360	630	370
Dishwasher	500	1000	360	660	645
Television	365	180	410	200	
Lighting	330	260	750	750	

The use of non-commercial energy is widespread in all developing countries. Fuelwood and charcoal are prefered but dung and crop residues are also used remarkably. Table B.5.6 gives a summary about the results concerning different villages' non-commercial energy consumption level.

TABLE B.5.6. NON-COMMERCIAL ENERGY USE IN SELECTED COUNTRIES

Country, Year, Village	GJ/person and year
Bangladesh, 1978/79, Dhanishwor Village	5.5
Bangladesh, 1979, Ulipur	7.5
Bolivia, 1975, Quebrada Household	30.0
Botswana, 1979, Matsheng Village	16.5
Cameroon, 1979, Ngaoundere	18.0
Chad, 1977, N'Djamera	44.0
China, 1975, Peipan Village	21.0
Congo People's Rep., 1978, Brazzaville	13.5
India, 1975, Mangoan Village	4.1
India, 1980, Ungra Village	9.0
Tanzania, 1975, Kilombero Village	22.5
Mexico, 1975, Arango Village	13.0
Nigeria, 1975, Batagawara Village	16.0
South Africa, 1979, Jozanna' Nek	5.3
South Africa, 1979, Mashunka Kwazulu	17.0

B.5.5 Commercial/institutional

Specific energy consumptions of the commercial and institutional sector are also very country-related. Table B.5.7 gives an example of these specific consumptions for some selected types of service sub-sectors in Japan in 1980.

TABLE B.5.7. SPECIFIC ENERGY CONSUMPTION IN SELECTED SERVICE SECTORS, JAPAN 1980 [19]

(Mcal/square-meter and year)

	Electricity	Gas	Oil	Total
Communications	117	34	42	193
Wholesale/retail	89	25	43	157
Restaurants	631	583	114	1,328
Finance/insurance	117	34	42	193
Real estate	117	34	42	193
Entertainment	150	33	55	238
Medical service/ health care	80	37	205	322
Schools	16	14	31	61
Museums	70	12	66	148
Social welfare facilities	81	31	131	243
Public services	177	15	108	300

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Appendix C

REFERENCE ECONOMIC DATA

C.1 Gross Domestic Product and its Composition (illustrative examples)

TABLE C.1.1. BRAZIL: GROSS DOMESTIC PRODUCT BY ECONOMIC ACTIVITY, 1972–1982, IN CURRENT PRICES (thousand million Brazilian Cruzeiros) [1]

	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Agriculture, hunting, forestry	20	53	79	107	198	348	469	789	1649	3119	5321	...
Mining and quarrying	1	2	4	6	10	15	22	39	77	168	366	...
Manufacturing	47	121	185	263	409	605	920	1561	3413	6362	12396	...
Electricity, gas and water	3	7	11	17	23	36	51	72	176	328	814	...
Construction	10	26	41	62	89	134	194	294	628	1210	2488	...
Wholesale and retail trade, restaurant, hotels	30	76	114	161	264	409	595	995	2129	4082	7687	...
Transport, storage communication	8	19	28	40	70	107	165	274	575	1273	2658	...
Finance, insurance, real estate and business service	24	55	75	124	190	290	573	1008	1868	4013	8483	...
Community, social and personal services	13	38	59	90	146	229	348	586	1282	2581	5192	...
Total industries	156	397	596	870	1399	2173	3337	5618	11777	23136	45405	...
Producers of Government Service	16	36	48	75	117	164	250	417	813	1583	3224	...
Other Producers	...	...	...	...	...	...	...	...	...	...	...	...
Subtotal	172	433	644	945	1516	2337	3587	6035	12590	24719	28629	...
Imputed bank services	−7	−19	−30	−52	−85	−146	−240	−336	−681	−1599	−2915	...
Import duties	...	...	...	...	...	...	...	...	...	...	...	...
Value added tax	...	...	...	...	...	...	...	...	...	...	...	...
Other adjustments	32	69	94	118	195	296	416	814	1234	2512	5101	...
Gross Domestic Product	197	483	708	1011	1626	2487	3763	6313	13163	25632	50815	121055

TABLE C.1.2. BRAZIL: GROSS DOMESTIC PRODUCT BY ECONOMIC ACTIVITY, 1972–1983, RELATIVE TO 1970, IN CONSTANT PRICES OF 1970 [1]

	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Agriculture, hunting, forestry	100.0	120.0	129.8	136.0	139.9	156.4	152.4	160.0	170.0	180.8	176.3	180.2
Mining and quarrying	100.0	116.3	143.3	147.6	149.1	141.8	151.2	166.3	187.3	187.7	200.2	229.2
Manufacturing	100.0	149.6	161.5	168.2	190.0	195.6	209.3	223.2	240.2	224.7	225.1	211.0
Electricity, gas and water	100.0	144.1	161.6	178.4	203.9	230.0	256.2	288.5	318.8	329.6	350.4	377.7
Construction	100.0	140.6	157.6	178.5	197.8	210.9	225.7	233.6	251.9	241.2	241.6	205.4
Wholesale and retail trade, restaurant, hotels	100.0	142.3	156.2	160.4	172.1	180.2	187.7	197.9	211.4	205.5	207.5	200.2
Transport, storage communication	100.0	151.2	177.7	202.0	231.2	253.1	277.3	316.0	348.1	348.9	368.4	368.6
Finance, insurance, real estate and business service	...	...	...	...	...	...	...	...	...	...	...	...
Community, social and personal services	...	...	...	...	...	...	...	...	...	...	...	...
Total Industries	...	...	...	...	...	...	...	...	...	...	...	...
Producers of Government Service	...	...	...	...	...	...	...	...	...	...	...	...
Other Producers	...	...	...	...	...	...	...	...	...	...	...	...
Subtotal	...	...	...	...	...	...	...	...	...	...	...	...
Imputed bank services	...	...	...	...	...	...	...	...	...	...	...	...
Import duties	...	...	...	...	...	...	...	...	...	...	...	...
Value added tax	...	...	...	...	...	...	...	...	...	...	...	...
Other adjustments	...	...	...	...	...	...	...	...	...	...	...	...
Gross Domestic Product	100.0	141.4	155.1	163.5	179.4	189.7	199.2	211.9	227.2	223.6	225.7	216.6

TABLE C.1.3. REPUBLIC OF KOREA: INDUSTRIAL OUTPUT AND VALUE ADDED [2]

Industry	Output in producers' prices a/ (billion Won)				Value Added in producers' prices a/ (billion Won)			
	1979	1980	1981	1982	1979	1980	1981	1982
Coal mining	240	349	520	564	198	246	366	447
Petroleum and gas	...	...	...	...	...	...	...	...
Metal ore mining	50	71	84	86	31	48	57	38
Other mining	98	118	161	172	60	82	106	116
mining quarring	397	538	785	802	298	376	529	601
Food products	2226	3135	3948	4547	650	927	1063	1280
Beverages	694	901	993	1127	308	347	474	534
Tobacco	799	1043	1224	1546	564	694	876	1060
Textiles	3314	4555	5801	5679	1268	1609	2021	2005
spinning,weaving	2708	3681	4556	4587	1025	1274	1633	1613
Wearing apparel	1140	1458	1974	1973	402	550	792	803
Leather and prod.	272	302	447	507	77	84	148	141
Footwear	142	190	249	340	59	68	91	135
Wood products	736	713	812	820	165	145	162	242
Furniture, fixtures	126	171	158	217	52	61	69	87
Paper and products	640	937	1211	1264	192	259	332	358
pulp,paper etc.	381	596	690	755	107	156	183	197
Printing and publishing	364	465	595	744	207	267	309	398
Industrial chemicals	1323	2430	3022	3137	392	606	767	785
basic excl. fertilizers	375	848	1112	1051	118	221	294	257
sythetic resins	492	915	1183	1390	140	215	292	378
Other chemical products	959	1251	1444	1786	442	617	681	849
drugs and medicines	434	586	657	804	226	320	370	452
Petroleum refineries	2000	4143	5542	5831	162	460	765	776
Petroleum,coal products	375	501	686	740	91	128	162	172
Rubber products	730	1048	1107	1150	308	399	417	420
Plastic products n.e.c.	622	695	861	910	211	218	286	301
Pottery,china etc.	63	86	114	118	40	54	70	68
Glass and products	176	241	296	297	94	120	129	143
Non–metal products n.e.c.	962	1275	1380	1579	396	509	568	535
Iron and steal	2000	2833	3800	4161	639	763	1107	1310
Non–ferrous metals	346	554	704	772	92	161	189	174
Metal products	843	965	1430	1708	347	386	559	702
Machinery n.e.c.	1026	913	1234	1502	414	408	517	602
office,computing etc.	40	50	48	42	14	11	15	13
Electrical maschinery	2415	2720	3732	4113	819	964	1319	1521
radio,television etc	1594	1880	2542	2713	520	654	893	1005
Transport equipment	1775	2048	3057	3911	551	700	1070	1402
shipbuilding, repair	423	702	1417	1959	135	343	556	894
motor vehicles	1236	1139	1405	1703	380	278	445	613
Professional goods	246	315	364	383	94	130	135	152
Other industries	373	501	761	789	169	223	314	351
manufacturing	26692	36279	46716	51651	9205	11857	15412	17306

a/ Establishments with 5 or more persons engaged

C.2 Bulk and retail prices of selected energy commodities

Note to the following tables: The prices are in current US$ of the indicated years. Source of information is reference [3].

TABLE C.2.1. US DOLLAR EXCHANGE RATES IN NATIONAL CURRENCIES

	1978	1980	1982	1983	1984	1985	1986	Q187	Q287	Q387
Australia	0.87	0.88	0.99	1.11	1.14	1.43	1.50	1.50	1.40	1.48
Austria	14.52	12.94	17.06	17.97	20.01	20.69	15.27	12.93	12.69	12.93
Belgium	31.49	29.24	45.69	51.13	57.76	59.43	44.69	38.13	37.43	38.16
Canada	1.14	1.17	1.23	1.23	1.29	1.37	1.39	1.34	1.33	1.32
Denmark	5.51	5.64	8.33	9.14	10.36	10.59	8.09	6.95	6.80	7.04
Finland	4.12	3.73	4.82	5.56	6.00	6.20	5.07	4.56	4.39	4.43
France	4.51	4.23	6.57	7.62	8.74	8.98	6.93	6.13	6.03	6.13
Germany	2.01	1.82	2.43	2.55	2.85	2.94	2.17	1.84	1.80	1.84
Greece	36.75	42.62	66.80	87.90	112.66	138.05	139.48	134.10	133.82	139.17
Ireland	0.52	0.49	0.70	0.80	0.92	0.95	0.75	0.69	0.67	0.68
Italy	848.66	856.45	1352.51	1518.94	1756.73	1909.42	1491.00	1308.00	1300.00	1331.00
Japan	210.44	226.74	249.05	237.48	237.55	238.62	168.50	153.20	142.60	145.20
Luxembourg	31.49	29.24	45.69	51.13	57.76	59.43	44.69	38.13	37.43	38.16
Netherlands	2.16	1.99	2.67	2.85	3.21	3.32	2.45	2.08	2.03	2.07
NZ	0.96	1.03	1.33	1.50	1.77	2.03	1.92	1.83	1.72	1.55
Norway	5.24	4.94	6.45	7.30	8.16	8.59	7.39	7.03	6.71	6.73
Portugal	43.94	50.06	79.47	110.79	146.38	169.93	148.17	141.39	140.09	144.03
Spain	76.67	71.70	109.86	143.52	160.80	170.06	139.97	128.66	126.06	124.67
Sweden	4.52	4.23	6.28	7.67	8.27	8.60	7.12	6.51	6.30	6.43
Switzerland	1.79	1.68	2.03	2.10	2.35	2.46	1.80	1.55	1.49	1.52
UK	0.52	0.43	0.57	0.66	0.75	0.78	0.68	0.65	0.61	0.62
USA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE C.2.2. HEAVY FUEL OIL PRICES FOR INDUSTRY IN US DOLLARS/METRIC TON

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	91.81	198.40	240.67	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Austria	102.39	179.75	196.78	178.64	187.48	160.12	n.a.	n.a.	n.a.
Belgium	90.46	184.40	178.55	188.77	169.63	91.43	109.60	131.82	136.03
Canada	71.19	97.50	141.14	166.15	161.63	100.84	87.97	101.28	114.08
Denmark	95.75	201.08	198.08	192.56	170.66	112.25	154.72	139.01	134.27
Finland	97.64	202.94	207.24	186.24	206.21	143.19	144.86	n.a.	n.a.
France	93.04	182.46	190.42	197.95	185.66	132.52	134.67	151.51	163.00
Germany	103.69	186.45	189.42	191.66	181.61	108.55	120.17	123.27	136.00
Greece	80.83	152.93	170.28	162.29	173.84	189.75	180.01	180.38	173.45
Ireland	138.45	244.86	224.91	198.20	214.70	148.80	178.21	180.19	183.88
Italy	86.96	181.54	177.59	191.96	179.60	89.37	103.75	124.85	140.26
Japan	113.15	268.33	253.18	234.41	230.71	200.53	147.73	177.16	181.23
Luxembourg	n.a.	n.a.	178.08	190.49	181.77	101.63	118.59	134.92	157.00
Netherlands	99.13	186.74	198.29	197.79	179.00	109.06	149.61	155.09	164.46
NZ	130.65	235.71	287.78	227.50	232.41	189.62	188.86	233.18	258.69
Norway	n.a.	198.36	203.32	201.98	197.38	127.25	164.04	176.63	187.94
Portugal	75.10	139.83	179.31	157.38	176.55	164.82	130.98	145.41	141.43
Spain	88.04	157.95	199.58	132.83	191.11	149.75	111.03	113.32	114.58
Sweden	110.66	234.89	251.57	276.53	268.71	206.06	265.67	258.25	264.88
Switzerland	112.56	209.63	198.79	199.55	187.71	127.11	140.23	135.48	141.27
UK	102.65	213.36	205.36	205.06	199.01	119.40	140.12	142.04	165.28
USA	77.92	146.28	170.90	184.32	165.41	85.09	107.13	117.19	124.74

TABLE C.2 3. HEAVY FUEL OIL PRICES FOR ELECTRICITY GENERATION IN US DOLLARS/ METRIC TON

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	91.81	198.40	240.67	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Austria	94.89	164.63	175.45	150.95	158.57	n.a.	n.a.	n.a.	n.a.
Belgium	90.46	184.40	178.55	188.77	169.63	91.43	109.60	131.82	136.03
Canada	70.09	79.85	128.13	139.36	n.a.	n.a.	n.a.	n.a.	n.a.
Denmark	n.a.	162.93	187.46	176.53	170.66	n.a.	n.a.	n.a.	n.a.
Finland	97.64	202.94	207.24	186.24	206.21	143.19	144.86	n.a.	n.a.
France	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Germany	103.80	197.50	191.21	192.50	180.79	103.11	122.72	128.08	137.76
Greece	68.12	136.26	154.18	150.37	n.a.	n.a.	n.a.	n.a.	n.a.
Ireland	n.a.	n.a.	n.a.	n.a.	169.66	95.41	111.92	122.81	118.69
Italy	85.70	181.11	181.20	186.88	172.55	102.27	101.15	112.63	n.a.
Japan	109.48	250.25	267.04	235.78	223.74	171.51	n.a.	n.a.	n.a.
Luxembourg	n.a.	181.73	185.26	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Netherlands	91.12	192.43	193.12	200.67	182.86	n.a.	n.a.	n.a.	n.a.
NZ	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Portugal	66.00	129.84	179.31	127.24	111.81	124.98	130.98	145.41	141.43
Spain	88.04	168.41	204.13	185.94	199.93	149.75	111.03	113.32	114.58
Sweden	92.01	199.01	183.60	187.11	163.50	95.84	118.62	122.54	119.01
Switzerland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
UK	95.34	199.23	191.14	201.24	213.72	144.53	n.a.	n.a.	n.a.
USA	88.65	178.01	200.75	201.46	177.13	100.61	122.62	127.03	135.14

TABLE C.2.4. LIGHT FUEL OIL PRICES FOR INDUSTRY IN US DOLLARS/1000 LITRES

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	129.91	259.44	313.65	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Austria	149.91	276.30	298.88	252.03	252.94	274.19	n.a.	n.a.	n.a.
Belgium	148.66	301.60	274.04	227.07	235.58	162.77	165.64	171.71	180.53
Canada	90.70	136.95	207.40	214.98	224.85	189.94	165.40	171.79	161.12
Denmark	137.20	293.17	297.14	244.03	244.28	196.56	222.08	201.68	212.42
Finland	142.08	304.68	295.22	268.09	263.99	210.28	221.04	n.a.	n.a.
France	179.21	349.74	345.07	299.50	321.32	278.91	312.44	302.69	304.97
Germany	136.02	301.19	286.96	235.00	236.45	172.92	170.57	177.01	191.41
Greece	n.a.	323.48	280.36	233.50	239.94	275.13	263.81	264.36	254.20
Ireland	157.85	324.93	325.28	258.09	284.02	240.95	281.41	269.44	283.42
Italy	152.23	311.58	306.16	300.77	297.81	302.17	364.53	361.65	386.55
Japan	154.35	298.47	354.83	346.71	326.94	340.89	281.21	344.25	n.a.
Luxembourg	n.a.	n.a.	274.44	237.80	238.91	190.37	196.70	187.82	202.70
Netherlands	142.02	296.32	289.94	233.20	227.96	n.a.	n.a.	n.a.	n.a.
NZ	170.41	312.86	403.76	355.82	352.00	251.06	188.54	231.44	256.76
Norway	140.46	285.76	309.40	261.47	250.57	201.13	224.16	220.15	229.24
Portugal	170.69	327.09	377.49	379.16	388.40	435.44	449.51	481.18	468.01
Spain	84.78	252.78	286.73	254.97	264.62	264.73	235.95	240.81	243.50
Sweden	138.41	314.59	346.06	299.52	303.85	245.23	284.88	270.48	285.87
Switzerland	138.02	291.13	276.56	224.85	228.38	176.38	171.26	168.40	182.88
UK	126.77	298.49	281.92	229.61	241.05	178.81	175.72	172.23	n.a.
USA	100.15	212.73	252.07	227.49	224.78	139.73	151.11	153.22	157.44

TABLE C 2 5 LIGHT FUEL OIL PRICES FOR HOUSEHOLDS IN US DOLLARS/1000 LITRES

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	150 44	294 51	366 76	n a	n a	n a	n a	n a	n a
Austria	n a	n a	381 02	339 96	335 99	342 17	332 56	338 85	332 56
Belgium	157 50	331 09	320 63	265 66	275 63	190 42	193 81	200 91	211 22
Canada	109 09	140 53	232 75	262 29	273 11	229 30	201 05	216 05	214 07
Denmark	180 61	422 74	415 22	340 13	340 75	443 81	595 85	578 11	579 71
Finland	142 08	304 68	295 22	268 09	263 99	210 28	221 04	n a	n a
France	187 95	365 59	360 54	312 92	334 54	290 49	317 34	305 34	326 00
Germany	153 03	340 38	324 24	267 90	269 55	197 12	194 45	201 79	218 21
Greece	n a	315 91	271 54	229 49	239 94	275 13	279 64	280 23	269 45
Ireland	157 85	324 93	327 56	278 84	309 09	263 68	315 19	307 64	325 58
Italy	172 80	355 20	346 83	345 89	351 42	356 42	430 14	426 74	456 14
Japan	167 64	338 47	377 80	323 69	315 33	350 81	292 28	327 49	316 12
Luxembourg	n a	313 23	288 18	252 06	253 21	201 79	208 50	199 09	214 86
Netherlands	175 36	355 15	352 54	293 40	290 64	241 91	301 73	298 38	307 10
NZ	174 71	327 20	410 15	362 39	359 48	326 76	342 25	400 23	447 23
Norway	177 87	346 17	377 65	321 95	308 27	241 42	268 94	264 42	275 44
Portugal	170 69	327 09	377 49	379 16	388 40	452 18	466 79	499 68	486 01
Spain	84 78	252 78	286 73	254 97	264 62	296 49	264 26	269 71	272 72
Sweden	137 44	319 37	338 85	301 80	310 39	250 60	290 41	286 67	291 15
Switzerland	149 57	303 88	288 53	239 51	240 35	192 34	188 71	187 04	200 42
UK	161 50	343 13	351 35	271 94	276 89	200 70	217 90	194 47	220 87
USA	132 32	261 98	317 67	289 76	284 70	217 97	224 80	222 00	224 60

TABLE C 2 6 GASOLINE PRICES IN US DOLLARS/LITRE

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	0 211	0 347	0 394	0 416	0 367	0 348	0 372	0 388	0 351
Austria	0 482	0 671	0 662	0 570	0 575	0 624	0 704	0 741	0 727
Belgium	0 504	0 791	0 653	0 551	0 569	0 572	0 635	0 682	0 662
Canada	0 185	0 223	0 361	0 392	0 384	0 347	0 345	0 370	0 387
Denmark	0 500	0 805	0 712	0 578	0 579	0 794	0 960	0 981	0 955
Finland	0 484	0 774	0 721	0 632	0 616	0 624	0 708	n a	n a
France	0 564	0 800	0 673	0 590	0 622	0 681	0 780	0 800	0 808
Germany	0 462	0 641	0 574	0 492	0 490	0 496	0 553	0 602	0 585
Greece	0 558	0 795	0 653	0 490	0 484	0 557	0 574	0 575	0 553
Ireland	0 384	0 658	0 728	0 675	0 702	0 794	0 863	0 892	0 853
Italy	0 589	0 817	0 762	0 734	0 692	0 858	0 979	0 985	0 962
Japan	0 470	0 648	0 659	0 610	0 587	0 730	0 764	0 870	0 840
Luxembourg	n a	0 610	0 547	0 463	0 459	0 469	0 519	0 553	0 542
Netherlands	0 498	0 722	0 652	0 563	0 554	0 608	0 751	0 791	0 787
NZ	0 317	0 479	0 514	0 452	0 460	0 432	0 456	0 534	0 592
Norway	0 499	0 751	0 711	0 638	0 608	0 642	0 732	0 759	0 768
Portugal	0 592	0 869	0 758	0 647	0 641	0 761	0 792	0 821	0 798
Spain	0 483	0 753	0 646	0 578	0 547	0 586	0 606	0 619	0 626
Sweden	0 412	0 697	0 631	0 510	0 542	0 582	0 631	0 652	0 665
Switzerland	0 513	0 689	0 621	0 515	0 513	0 563	0 634	0 671	0 656
UK	0 320	0 658	0 638	0 540	0 553	0 548	0 592	0 622	0 615
USA	0 177	0 328	0 342	0 321	0 316	0 245	0 239	0 249	0 263

TABLE C 2 7 AUTOMOTIVE DIESEL OIL PRICES IN US DOLLARS/LITRE

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	0 197	0 332	0 380	0 409	0 339	0 309	0 329	0 350	0 331
Austria	0 389	0 612	0 517	0 435	0 433	0 479	0 528	0 545	0 535
Belgium	0 253	0 433	0 392	0 341	0 341	0 322	0 348	0 358	0 363
Canada	n a	n a	0 336	0 344	0 348	0 332	0 333	0 345	0 357
Denmark	0 166	0 326	0 322	0 255	0 266	0 227	0 257	0 241	0 250
Finland	0 302	0 525	0 505	0 450	0 445	0 434	0 491	n a	n a
France	0 342	0 557	0 496	0 430	0 441	0 447	0 506	0 496	0 507
Germany	0 391	0 554	0 478	0 403	0 400	0 399	0 443	0 455	0 452
Greece	0 163	0 342	0 293	0 240	0 228	0 275	0 280	0 280	0 269
Ireland	0 247	0 471	0 528	0 487	0 478	0 562	0 606	0 609	0 594
Italy	0 170	0 321	0 316	0 316	0 318	0 347	0 408	0 416	0 415
Japan	0 271	0 450	0 474	0 438	0 419	0 499	0 477	0 519	0 496
Luxembourg	n a	0 395	0 370	0 341	0 319	0 302	0 328	0 320	0 332
Netherlands	0 243	0 412	0 378	0 318	0 311	0 295	0 362	0 361	0 366
NZ	0 171	0 343	0 403	0 359	0 357	0 327	0 342	0 400	0 433
Norway	0 168	0 323	0 339	0 286	0 275	0 234	0 257	0 255	0 264
Portugal	0 171	0 327	0 377	0 379	0 388	0 435	0 450	0 481	0 468
Spain	0 218	0 373	0 391	0 361	0 365	0 383	0 402	0 411	0 415
Sweden	0 164	0 346	0 373	0 350	0 357	0 327	0 390	0 402	0 404
Switzerland	n a	0 719	0 631	0 547	0 543	0 574	0 653	0 664	0 663
UK	0 328	0 576	0 542	0 444	0 468	0 455	0 468	0 496	0 485
USA	0 143	0 270	0 305	0 319	0 322	0 248	0 249	0 256	0 257

TABLE C 2 8 ELECTRICITY PRICES FOR INDUSTRY IN US DOLLARS/Kwh

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	0 027	0 032	0 041	0 038	0 031	0 033	0 033	0 036	n a
Austria	0 040	0 051	0 047	0 040	0 039	0 054	n a	n a	n a
Belgium	0 045	0 058	0 047	0 043	0 043	0 052	n a	n a	n a
Canada	0 017	0 021	0 022	0 023	0 023	0 022	n a	n a	n a
Denmark	n a	0 050	0 051	0 039	0 046	0 045	0 043	0 040	0 038
Finland	0 047	0 055	0 052	0 041	0 041	0 050	0 060	0 063	0 062
France	0 035	0 051	0 042	0 037	0 037	0 046	n a	n a	n a
Germany	0 047	0 058	0 053	0 047	0 047	0 066	0 079	0 080	0 083
Greece	0 028	0 045	0 053	0 048	0 048	0 058	n a	n a	n a
Ireland	0 039	0 072	0 075	0 062	0 061	0 073	n a	n a	n a
Italy	0 042	0 064	0 059	0 057	0 059	0 066	0 073	0 070	n a
Japan	0 062	0 086	0 090	0 095	0 095	0 127	n a	n a	n a
Luxembourg	0 035	0 047	0 043	0 039	0 044	0 056	n a	n a	n a
Netherlands	0 031	0 059	0 056	0 043	0 040	n a	n a	n a	n a
NZ	n a	0 024	0 023	0 020	0 022	n a	n a	n a	n a
Norway	0 012	0 015	0 015	0 014	0 014	0 018	n a	n a	n a
Portugal	0 027	0 045	0 056	0 052	0 056	0 074	0 083	0 086	0 083
Spain	n a	0 044	0 049	0 046	0 046	0 062	n a	n a	n a
Sweden	0 029	0 040	0 029	0 030	0 029	n a	n a	n a	n a
Switzerland	0 051	0 056	0 050	0 048	0 047	0 067	0 078	0 081	0 079
UK	0 038	0 063	0 060	0 046	0 046	0 053	0 058	0 053	n a
USA	0 028	0 037	0 049	0 050	0 052	0 051	0 048	0 048	0 051

TABLE C.2.9. ELECTRICITY PRICES FOR HOUSEHOLDS IN US DOLLARS/Kwh

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	0.039	0.045	0.058	0.060	0.052	0.052	0.053	n.a.	n.a.
Austria	0.080	0.101	0.096	0.085	0.085	0.117	n.a.	n.a.	n.a.
Belgium	0.115	0.141	0.112	0.102	0.101	0.129	n.a.	n.a.	n.a.
Canada	0.025	0.029	0.033	0.037	0.036	0.035	n.a.	n.a.	n.a.
Denmark	n.a.	0.102	0.100	0.078	0.086	0.110	0.124	0.120	0.115
Finland	0.058	0.070	0.067	0.052	0.052	0.067	0.080	0.083	0.081
France	0.081	0.115	0.098	0.086	0.087	0.119	n.a.	n.a.	n.a.
Germany	0.085	0.100	0.093	0.083	0.082	0.114	0.137	0.140	0.145
Greece	0.063	0.075	0.085	0.064	0.061	0.077	n.a.	n.a.	n.a.
Ireland	0.059	0.101	0.102	0.088	0.089	0.114	n.a.	n.a.	n.a.
Italy	0.046	0.071	0.070	0.078	0.077	0.093	0.105	0.106	n.a.
Japan	0.093	0.117	0.118	0.126	0.126	0.170	n.a.	n.a.	n.a.
Luxembourg	0.074	0.090	0.071	0.067	0.071	0.093	n.a.	n.a.	n.a.
Netherlands	0.082	0.115	0.105	0.088	0.087	0.094	n.a.	n.a.	n.a.
NZ	0.024	0.034	0.031	0.027	0.029	n.a.	n.a.	n.a.	n.a.
Norway	n.a.	0.035	0.038	0.038	0.039	0.049	0.055	0.057	0.057
Portugal	0.046	0.071	0.075	0.069	0.075	0.099	0.113	0.115	0.112
Spain	n.a.	0.080	0.097	0.083	0.086	0.111	n.a.	n.a.	n.a.
Sweden	0.046	0.059	0.045	0.039	0.040	n.a.	n.a.	n.a.	n.a.
Switzerland	0.066	0.073	0.064	0.059	0.059	0.082	0.096	0.099	0.097
UK	0.053	0.089	0.089	0.069	0.067	0.078	0.078	0.083	n.a.
USA	0.043	0.054	0.069	0.075	0.078	0.078	0.073	0.078	0.082

TABLE C.2.10. NATURAL GAS PRICES FOR INDUSTRY IN US DOLLARS/10*7* kcal (GCV)

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	44.09	32.07	65.18	89.94	75.81	77.95	81.89	90.87	n.a.
Austria	107.43	172.98	226.80	183.89	191.06	201.11	n.a.	n.a.	n.a.
Belgium	92.32	151.58	186.91	176.71	175.96	154.98	122.11	132.11	121.33
Canada	55.67	65.42	103.75	108.11	103.60	97.70	98.98	91.73	89.24
Denmark	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Finland	96.00	193.37	196.16	169.69	158.81	140.05	106.20	114.00	113.64
France	98.45	176.13	187.36	167.11	179.13	157.15	n.a.	n.a.	n.a.
Germany	107.04	156.95	207.03	180.64	185.02	196.66	n.a.	n.a.	n.a.
Greece	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ireland	n.a.	n.a.	615.95	262.12	268.45	333.53	289.24	294.81	290.51
Italy	83.44	173.38	175.90	180.77	n.a.	n.a.	n.a.	n.a.	n.a.
Japan	388.90	448.65	442.25	479.55	460.14	557.69	n.a.	n.a.	n.a.
Luxembourg	n.a.	173.55	258.25	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Netherlands	87.77	146.22	172.60	163.85	156.84	n.a.	n.a.	n.a.	n.a.
NZ	103.69	133.92	115.69	95.25	95.62	116.29	142.79	151.74	168.34
Norway	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Portugal	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Spain	131.58	237.51	317.52	244.56	250.99	258.70	n.a.	n.a.	n.a.
Sweden	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Switzerland	279.64	341.80	424.08	321.66	318.26	354.15	308.37	265.16	259.42
UK	87.13	162.03	159.28	137.63	145.91	150.88	n.a.	n.a.	n.a.
USA	59.55	98.22	143.85	162.58	152.18	118.28	111.89	99.20	95.74

TABLE C.2.11. NATURAL GAS PRICES FOR ELECTRICITY GENERATION IN US DOLLARS/10*7* kcal (GCV)

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Austria	95.51	211.86	211.50	186.84	193.81	n.a.	n.a.	n.a.	n.a.
Belgium	84.15	158.33	177.06	166.16	140.19	124.03	84.21	103.02	99.76
Canada	44.26	42.29	76.91	90.95	n.a.	n.a.	n.a.	n.a.	n.a.
Denmark	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Finland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
France	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Germany	78.04	126.70	158.41	146.17	147.57	162.18	n.a.	n.a.	n.a.
Greece	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ireland	n.a.	n.a.	n.a.	n.a.	100.45	125.84	114.83	117.04	115.33
Italy	81.60	172.87	169.91	173.95	150.67	72.49	95.17	112.83	n.a.
Japan	93.99	195.50	226.26	202.52	193.19	148.96	n.a.	n.a.	n.a.
Luxembourg	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Netherlands	79.07	163.16	176.25	158.86	157.85	n.a.	n.a.	n.a.	n.a.
NZ	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Portugal	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Spain	80.40	179.55	252.89	208.79	216.13	231.15	n.a.	n.a.	n.a.
Sweden	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Switzerland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
UK	68.02	119.78	173.03	133.48	152.10	156.22	n.a.	n.a.	n.a.
USA	56.43	87.26	134.02	142.55	138.97	92.99	92.78	87.50	88.18

TABLE C.2.12. NATURAL GAS PRICES FOR HOUSEHOLDS IN US DOLLARS/10*7* kcal (GCV)

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	154.30	173.41	190.57	209.50	175.25	177.23	183.07	n.a.	n.a.
Austria	n.a.	548.23	572.53	518.53	506.60	633.60	n.a.	n.a.	n.a.
Belgium	235.20	321.28	354.36	328.90	331.98	365.72	350.72	358.40	339.31
Canada	96.87	103.69	147.32	166.80	160.93	149.62	144.80	156.42	182.66
Denmark	n.a.	n.a.	n.a.	362.14	372.84	492.77	684.37	636.95	640.81
Finland	96.00	193.37	196.16	169.69	158.81	146.29	123.19	132.24	131.82
France	288.96	414.10	407.51	355.59	373.69	455.19	n.a.	n.a.	n.a.
Germany	248.58	335.39	355.79	301.14	299.99	373.58	n.a.	n.a.	n.a.
Greece	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ireland	n.a.	n.a.	688.33	408.76	428.03	553.76	558.82	569.59	561.27
Italy	169.03	210.23	289.31	314.60	n.a.	n.a.	n.a.	n.a.	n.a.
Japan	489.19	617.08	613.14	637.83	631.75	832.28	n.a.	n.a.	n.a.
Luxembourg	n.a.	211.16	271.17	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Netherlands	164.64	227.05	255.41	240.92	244.85	327.51	277.66	283.26	278.33
NZ	190.79	232.78	207.05	131.87	115.63	143.18	178.89	190.09	210.89
Norway	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Portugal	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Spain	224.87	509.41	430.02	389.54	414.29	541.09	n.a.	n.a.	n.a.
Sweden	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Switzerland	791.25	887.09	837.81	723.92	692.20	946.05	1100.26	1140.85	1116.14
UK	144.15	219.73	247.69	208.45	207.98	234.27	n.a.	n.a.	n.a.
USA	99.02	142.34	199.98	235.79	235.79	241.85	206.09	228.39	263.76

TABLE C 2 13 STEAM COAL PRICES FOR INDUSTRY IN US DOLLARS/METRIC TON

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	n a	n a	38 51	30 60	25 68	25 45	n a	n a	n a
Austria	88 83	117 92	96 02	64 58	64 59	86 51	n a	n a	n a
Belgium	23 51	33 98	44 00	28 95	43 02	44 04	46 00	32 86	n a
Canada	44 78	43 52	51 79	53 18	51 00	49 33	54 42	54 79	55 16
Denmark	n a	95 42	101 53	67 24	81 88	90 74	92 83	88 26	85 25
Finland	44 93	64 68	75 82	50 89	59 55	63 07	58 95	55 08	56 14
France	54 84	95 24	85 59	69 46	73 57	87 81	96 31	97 91	96 17
Germany	91 11	120 28	111 58	101 18	98 18	133 06	157 15	160 11	160 41
Greece	n a	n a	n a	n a	n a	n a	n a	n a	n a
Ireland	n a	n a	79 83	n a	n a	n a	n a	n a	n a
Italy	61 63	50 02	66 24	43 70	49 72	46 01	39 59	40 72	n a
Japan	56 69	59 67	66 98	59 48	52 51	58 64	58 13	60 31	59 23
Luxembourg	n a	n a	n a	n a	n a	n a	n a	n a	n a
Netherlands	57 79	62 92	71 95	60 50	60 35	n a	n a	n a	n a
NZ	35 26	40 66	45 79	36 43	n a	n a	n a	n a	n a
Norway	n a	59 73	52 68	36 15	43 78	n a	n a	n a	31 20
Portugal	n a	n a	n a	n a	n a	n a	n a	n a	n a
Spain	n a	n a	n a	n a	n a	n a	n a	n a	n a
Sweden	70 93	85 53	78 79	55 45	64 05	74 73	80 98	75 24	n a
Switzerland	n a	82 06	74 62	57 45	60 23	53 53	45 28	53 66	59 06
UK	44 58	81 80	83 64	66 13	65 42	72 79	72 74	78 03	n a
USA	33 57	38 72	45 22	43 27	41 05	39 50	37 37	37 97	n a

TABLE C 2 14 STEAM COAL PRICES FOR ELECTRICITY GENERATION IN US DOLLARS/METRIC TON

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	10 20	13 63	21 33	21 72	18 01	19 36	n a	n a	n a
Austria	163 62	167 03	83 83	56 43	71 69	n a	n a	n a	n a
Belgium	40 49	47 65	57 16	53 47	49 88	47 62	47 86	42 69	n a
Canada	32 98	42 32	49 02	50 83	n a	n a	n a	n a	n a
Denmark	n a	46 53	61 01	36 60	47 38	42 90	n a	n a	n a
Finland	n a	n a	n a	n a	n a	n a	n a	n a	n a
France	n a	52 02	55 31	42 23	41 66	45 42	44 76	44 19	n a
Germany	82 96	98 82	95 11	80 63	81 43	104 47	117 10	119 09	n a
Greece	n a	n a	n a	n a	n a	n a	n a	n a	n a
Ireland	n a	n a	n a	n a	75 14	57 90	53 34	53 78	50 66
Italy	36 56	50 78	69 63	47 24	50 81	50 66	47 66	45 22	n a
Japan	72 09	71 80	72 92	56 85	62 36	77 57	83 09	87 24	86 23
Luxembourg	n a	n a	n a	n a	n a	n a	n a	n a	n a
Netherlands	40 97	64 00	85 22	64 03	65 73	n a	n a	n a	n a
NZ	n a	n a	n a	n a	n a	n a	n a	n a	n a
Norway	n a	n a	n a	n a	n a	n a	n a	n a	n a
Portugal	27 22	38 61	48 13	[illegible] 20	56 92	54 16	37 78	60 90	63 93
Spain	33 48	54 81	46 64	38 61	39 93	n a	n a	n a	n a
Sweden	47 58	87 48	77 04	47 32	48 01	53 48	49 48	53 02	n a
Switzerland	n a	n a	n a	n a	n a	n a	n a	n a	n a
UK	42 13	73 99	70 25	56 98	58 62	67 79	n a	n a	n a
USA	26 11	31 69	38 47	38 72	38 07	36 70	35 37	36 08	34 41

TABLE C.2 15 METALLURGICAL COAL PRICES IN US DOLLARS/METRIC TON

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	28 83	28 72	36 33	27 84	24 16	23 56	n a	n a	n a
Austria	n a	n a	n a	n a	123 28	n a	n a	n a	n a
Belgium	63 69	66 50	71 69	58 57	60 38	58 49	56 33	52 15	47 01
Canada	64 17	66 35	70 90	60 15	55 28	54 04	58 09	58 36	58 28
Denmark	n a	n a	n a	n a	n a	n a	n a	n a	n a
Finland	n a	n a	n a	n a	n a	n a	n a	n a	n a
France	53 96	60 81	65 16	52 41	52 37	51 32	53 54	n a	n a
Germany	62 47	71 24	80 07	65 73	62 95	59 12	n a	n a	n a
Greece	n a	n a	n a	n a	n a	n a	n a	n a	n a
Ireland	n a	n a	n a	n a	n a	n a	n a	n a	n a
Italy	66 25	79 62	81 27	70 15	64 71	66 62	73 84	66 21	n a
Japan	67 90	68 71	75 73	65 46	62 11	61 60	60 57	n a	n a
Luxembourg	n a	204 90	n a	n a	n a	n a	n a	n a	n a
Netherlands	102 54	128 08	121 26	96 12	95 13	n a	n a	n a	n a
NZ	n a	n a	n a	n a	n a	n a	n a	n a	n a
Norway	n a	111 35	n a	57 90	69 53	n a	n a	n a	n a
Portugal	175 69	242 40	88 22	70 32	68 38	60 69	50 75	56 76	60 95
Spain	70 26	105 95	73 47	63 00	64 95	n a	n a	n a	n a
Sweden	58 98	67 03	79 23	63 52	59 52	57 83	49 48	52 86	n a
Switzerland	n a	131 29	133 97	99 69	105 80	135 57	148 77	147 55	131 23
UK	n a	n a	n a	n a	n a	n a	n a	n a	n a
USA	49 57	61 99	71 39	62 62	59 86	55 96	51 37	50 97	n a

TABLE C 2 16 COAL PRICES FOR HOUSEHOLDS IN US DOLLARS/METRIC TON

	1978	1980	1982	1984	1985	1986	Q187	Q287	Q387
Australia	n a	n a	n a	n a	n a	n a	n a	n a	n a
Austria	165 61	226 54	209 21	n a	n a	n a	319 41	325 45	368 21
Belgium	127 11	177 18	155 74	134 66	139 79	199 66	231 71	239 25	n a
Canada	n a	n a	n a	n a	n a	n a	n a	n a	n a
Denmark	n a	177 03	178 37	148 26	157 80	247 25	296 49	303 03	292 70
Finland	n a	n a	n a	n a	n a	n a	n a	n a	n a
France	161 24	288 05	263 68	247 06	262 35	360 18	421 54	n a	n a
Germany	194 86	289 38	257 77	230 82	230 59	299 49	367 05	367 31	n a
Greece	n a	n a	n a	n a	n a	n a	n a	n a	n a
Ireland	95 19	141 75	144 03	129 74	146 36	174 94	186 53	190 12	187 34
Italy	167 97	209 61	180 89	n a	n a	n a	n a	n a	n a
Japan	n a	n a	n a	n a	n a	n a	n a	n a	n a
Luxembourg	n a	161 27	103 22	n a	n a	n a	n a	n a	n a
Netherlands	191 79	257 89	232 12	217 09	223 32	313 38	369 84	377 29	370 73
NZ	n a	n a	99 45	79 85	n a	n a	n a	n a	n a
Norway	n a	208 94	176 07	141 45	150 78	n a	n a	n a	n a
Portugal	n a	n a	n a	n a	n a	n a	n a	n a	n a
Spain	n a	n a	n a	n a	n a	n a	n a	n a	n a
Sweden	120 73	163 79	148 55	141 30	152 29	192 59	203 75	n a	n a
Switzerland	203 52	237 87	234 66	232 39	236 29	333 47	393 98	403 62	397 57
UK	83 46	150 59	139 50	120 69	121 79	141 69	152 00	151 03	154 32
USA	n a	n a	n a	n a	n a	n a	n a	n a	n a

TABLE C.2.17. AVERAGE RETAIL PRICES AND TAXES FOR GASOLINE AND KEROSENE IN 1984 (US$/barrel) [4]

	Gasoline		Kerosene	
	Price	Tax	Price	Tax
Argentina	74.56	12.94	31.91	5.54
Brazil	82.44	na	40.81	na
Canada	62.04	12.63	44.45	na
Dominican Republic	96.60	11.34	50.61	6.17
Ecuador	19.13	2.98	3.24	0.74
France	93.04	52.57	na	na
Germany, F.R.	80.67	38.48	na	na
India	78.50	36.01	23.04	5.33
Indonesia	62.82	10.47	22.19	3.70
Iran (1)	64.45	7.16	4.77	1.36
Iraq (1)	30.65	8.44	6.30	0.34
Italy	114.52	75.98	60.74	17.87
Japan	100.19	37.61	54.36	18.99
Kenya	85.97	na	46.16	na
Korea	153.00	77.16	57.45	4.67
Kuwait	24.43	na	10.48	na
Mexico	41.52	19.67	30.34	1.66
Morocco	91.35	4.06	51.26	3.06
Nigeria	44.72	7.07	20.59	4.58
Norway	100.22	44.09	55.39	9.23
Portugal	103.48	43.57	61.68	1.99
Qatar	25.12	na	17.47	na
Saudi Arabia	12.36	na	6.23	na
Spain	91.19	36.06	47.25	2.01
Sweden	80.32	49.16	na	na
Switzerland	84.70	40.52	na	na
Thailand	76.02	32.25	41.36	6.26
Tunisia	63.60	37.9	20.08	4.40
United Arab Emirates	44.78	na	39.06	na
United Kingdom	101.00	49.22	57.66	0.61
United States	51.96	12.91	42.99	0.13
Venezuela	20.84	6.52	8.98	0.02

(1) 1983 values

C.3 Investment costs of power plants

The very substantial investments which are often required for the expansion and/or restructuring of energy systems and of the supporting infrastructure must be properly accounted for in demand forecasting and energy supply planning. Investment cost ranges of some energy conversion plants are summarized in Table C.3.1. Further information can be found in Refs. [5] and [6].

TABLE C.3.1. INVESTMENT COSTS OF ENERGY CONVERSION PLANTS [5]

Plant type	Capacity PJ/a	Investment cost US$/GJ/a (1980)
Oil refinery	1)	1 - 2.4
Coal gasification		
Low/medium calorific value gas	2)	12 - 20
SNG (high calorific value gas)	3)	18 - 29
Ethanol from biomass	2.8	30
Biogas from manure	0.0023	42

1) Designs for 70 to 290 PJ/a are available
2) Designs for 15 to 85 PJ/a are available
3) Designs for 60 to 100 PJ/a are available

Fore cost ranges (in US$ 1986) of commercially available power plants (first units at a site) are summarized in Table C.3.2. Extension units will cost about 20% less than first units at a given site.

These cost ranges include all direct and indirect expenditures incurred in the design, licensing, construction, manufacture, erection and commissioning of the plants, also the owner's costs and contingencies. Excluded are:

- financial charges (escalation and interest during construction)
- costs of infrastructure improvement
- costs of technology transfer.

The investment costs of hydroelectric plants depend strongly on the location, site conditions, and type (e.g. run-of-river, storage, multi-purpose). Depending on the plant capacity, they could be as low as 500 US$/kW(e) or as high as 3000 US$/kW(e) [5].

TABLE C.3.2. FORE COST RANGES OF POWER PLANTS [5, 6, 7, 8, 9]

Plant type	Fuel	Unit capacity MW(e)	Fore costs US$/kW(e) net (1986)
Combustion turbine	Oil, gas	100	250 - 300
Combined cycle plant	Oil, gas	400	370 - 450
Steam-electric plants			
	Gas	600	550 - 680
	Oil	600	550 - 680
	Oil 1)	600	650 - 780
	Coal	600	700 - 850
	Coal 1)	600	800 -1000
Nuclear plants		1000	1300 -1700
Hydroelectric plants		see explanation in text	

1) with flue gas desulphurisation (FGD)

The cost ranges in Table C.3.2 indicate only orders of magnitude. Actual costs could also be above or below the indicated ranges; this will depend strongly on:

- the regulatory environment
- previous relevant experience of the owner (utility)
- plant standardization
- site conditions
- fuel quality (in particular for coal-fired plants).

Realistic fore cost estimates must be evaluated for every specific case. Financial charges and expenditures for infrastructure improvement and technology transfer, if applicable, must be included to assess the impact of these investments on the owner's balance sheets and on the national economy. The procedures described in Refs. [6] and [10] treat this subject in detail.

Illustrative examples for the investment cost experience with a nuclear and a coal-fired power plant in Korea are given in Table C.3.3.

TABLE C.3.3. KOREA: INVESTMENT COSTS OF NUCLEAR AND COAL-FIRED PLANTS (in US$ of Dec. 1986) [11]

Plant type		PWR	Coal w/o FGD
Plant capacity	MW(e) net	2 x 938	2 x 510
Direct cost	10**6 US$	1330	543
Indirect cost	"	490	20
Owner's cost and contingencies	"	65	11
SUBTOTAL (fore cost)	"	1885	547
Interest during construction	"	535	101
TOTAL capital investment cost	"	2420	675
Total capital cost per capacity	$/kW(e) net	1290	662

The investment costs for an energy system, including the fuel production and transportation infrastructure, can under certain circumstances be of the same order of magnitude for nuclear and coal-based power systems (see Table C.3.4, [12]).

TABLE C.3.4. INDIA: INVESTMENT COSTS OF NUCLEAR AND COAL-FIRED PLANTS 1983 (Rupees/kW installed)

	Nuclear		Coal-fired	
Capacity factor	75%	62.8%	75%	62.8%
Exploration and mining	670	560	3430	2840
Coal transportation (800 km)	not applicable		4160	3440
Fuel fabrication plant	250	210	not applicable	
Heavy water plant	3300	3300	not applicable	
Power plant	11300	11300	9520	9520
TOTAL	15520	15370	17110	15800

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GLOSSARY

Anergy	is evacuated heat during a transformation of a heat carrier and impossible to recover for further work
Annual Equivalent Cost Analysis	is the process of converting all cash flows to an equivalent annual annuity.
Annual Revenue Requirement	denotes the sum of the annual fixed and variable costs associated with all plants in the utility system.
Annuity	(1) An amount of money payable to the beneficiary at regular intervals for a prescribed period of time out of a fund reserved for that purpose. (2) A series of equal payments occuring at equal periods of time.
Average Load	The hypothetical constant load in an electric system over a specified time period that would produce the same energy as the actual load would produce for the same period.
Benefit-to-Cost Ratio	calculates present worth values of revenues over present worth values of costs.
Book Value	defines the asset in any year of an equipment and is equal to the initial investment minus accrued depreciation.
Capacity	The electric power for which a generating unit or station is rated under the specific conditions defined by the manufacturer (in MW(e)).
Capacity Factor (CF) (%)	The capacity factor for a unit or station for a given period of time is the ratio of the energy that it produced during the period considered to the energy that it could have produced at maximum capacity under continuous operation during the whole period. CF = E * 100/(Pn * H) where: E is the net energy produced (MW.h(e)), Pn the maximum net capacity (MW(e)), H the number of hours in the reference period.

Capital Cost, direct	Cost of all material, equipment and labour involved in the fabrication, installation and erection of facilities.
Capital Cost, indirect	Costs asociated with construction but not directly related to fabrication, installation and erection of facilities. Can be broken down into field costs (temporary structure, field supervision) and office costs (engineering, drafting, purchasing and office overhead expenses).
Carnot Factor	defines the thermodynamic degree of efficiency of a process.
cif	border price for imported goods (cost, insurance, freight).
Constant Monetary Accounts	express the purchasing power of an economy in monetary values in comparison to the purchasing power of a base year, thus excluding the effects of inflation.
Current Monetary Accounts	express the purchasing power of an economy in actual prices of the running year, thus including the effects of inflation.
Deflation	A situation in which prices and money incomes are falling, accompanied by an increase in the value of the monetary unit.
Depreciation	describes the diminution in the original value of an asset due to use and/or obsolence. In terms of cost accounting, the fundamental concept of depreciation is that the capital invested in an energy facility must be recovered in some systematic fashion from the revenues it generates during its operating life. Depreciation does not account for the replacement value of an asset which, due to real escalation and inflation, may increase substantially over time with respect to its original purchase price.
Depreciation Period	The time during which an asset is depreciated. The depreciation period is equal or shorter than the economic life of the asset.
Discount Rate	The rate of interest reflecting the time value of money that is used to convert benefits and costs occurring at different times to equivalent values at a common time. Theoretically, it reflects the

	opportunity cost of money to a particular investor (or, in broad terms, in a particular country).
Ecosphere	That portion of the Earth which includes the biosphere and all the ecological factors which operate on the living organisms it contains.
Ecosystem	A natural complex of plant and animal populations and the particular sets of physical conditions under which they exist; the organisms of a locality together with the functionally related aspects of environment considered as a single entity.
Effluent	A fluid (liquid or gas) which is discharged into the environment.
Elasticity of Demand, Income (ei)	Its computation is done according to: $ei = \frac{\text{Percentage change in quantity demanded}}{\text{Percentage change in income}}$
Elasticity of Demand, Price (ep)	The price elasticity of demand is measured by: $ep = \frac{\text{Percentage change in quantity demanded}}{\text{Percentage change in price}}$
Endogenous Variable	defines the parameters determined by and used in the mathematical system.
Energy	Energy is the ability of a system to invoke external effects (Max Planck).
Energy Consumption	The fuel and electricity used by the consumers.
Energy Conversion Chain	identifies the different energy forms passed during the conversion of primary energy, through secondary or intermediate energy, to final and useful energy and the energy services provided to fulfill a social need.
Energy Conversion Losses	are releases of energy during a conversion process mostly in the form of heat.

Energy Cost Components	- fixed component: independant of the amount of energy processed in the year of reference and which represents thefixed annual costs: depreciation (amortization) of the invested capital and the related interest charges, - variable component: dependant on the amount of energy processed, for instance the fuel costs of a thermal power station, and - category of costs of mixed character, i.e. depending both on the size of the installation as well as on the amount of energy processed.
Energy Demand	is the request for an energy amount in the (commercial) market.
Energy Intensity	is the ratio relating the energy required to the economic value created (or socio-economic activities). It is an efficiency measure of energy use for economic and socio-economic activities.
Energy Module	homogeneous group of energy users.
Energy Requirement	is the amount of energy required to satisfy a socio-economic (or basic) need.
Energy Service	refers to the served needs of the consumer resulting from the utilization of useful energy and other services and goods.
Escalation, Apparent	denotes the total annual rate of increase in a cost; it includes the effect of both inflation and real escalation.
Escalation, Real	denotes the escalation in prices caused by factors such as resource depletion and new regulations; it is independent and exclusive of inflation. The relation between inflation f, real escalation e' and apparent escalation e, is: $(1+e) = (1+e')*(1+f)$.
Exergy	is defined as the maximum mechanical work that could be obtained from a heat carrier in a transformation from a certain physical status down to the ambient temperature.
Exogenous Variable	is determined outside a mathematical system and fed into the system when required.

FGD	flue gas desulphurisation; encompasses all processes and components needed to remove SO_2 from the flue gas of a thermal power plant.
Final Energy	refers to energy delivered to consumers. It excludes losses in conversion, distribution and transmission, the energy sector's own consumption and the non-energetic use of energy.
fob	border price for exported goods (free on board).
Fore Cost	The overnight construction costs of power generation facility, including all direct and indirect costs, owner's costs and commissioning expenses, spare parts and contingencies. These costs exclude escalation and interest charges.
Gross Calorific Value (GCV)	measures the total amount of heat that will be produced by combustion. Part of that heat will be locked up in the latent heat of evaporation (or condensation, depending whether one considers the energy initially absorbed or the energy later given up) of any water present in the fuel before combustion together with water produced by the combustion process.
Gross Domestic Product (GDP) (at market prices)	The GDP describes the value of goods and services produced within the nation, charged at ruling prices. Prices include all taxes on expenditure, subsidies being regarded as negative taxes.
Gross Domestic Product (GDP) (at factor costs)	GDP at factor costs is equal to GDP at market prices minus indirect taxes plus subsidies.
Gross National Product (GNP) (at market prices)	GNP at market prices equals the GDP at market prices plus net incomes from abroad. The GNP can be defined in a - flow-of-product approach: GNP = Personal Consumption + Gross Domestic Investment + Government Purchases of Goods and Services + Net Export of Goods and Services - flow-of-cost and earnings approach: GNP = Wages and other Employee Supplements + Net Interest + Rent Income of Persons + Income of Incorporated Enterprises + Corporation Profits +/- Inventory Valuation Adjustment + Indirect Business Taxes and Adjustments + Depreciation

	- GNP = Sum of the Value Added of the Economic Sectors +/- Net Contribution of Earnings and Property from Abroad
Heat	is energy which is transmitted between systems solely because of its difference in temperature.
Inflation	change over time in the average prices of goods and services in the general economy. Inflation causes the purchasing power of currency to decline over time.
Interest Rate	is applied whenever monetary amounts are moved forward in time. It is defined as the ratio between interest chargeable (or payable) at the end of a period of time to the money owned (or invested) at the beginning of the period.
Internal Rate of Return	of an investment is defined as the rate of discount at which the present worth of costs equals the present worth of revenues, i.e. net present worth of the operation becomes zero.
J (Joule)	Unit of work or energy, being the amount of work done by one newton acting through a distance of one meter, or electric energy of 1 Watt-second (Ws): $1 \text{ joule} = 1 \text{ newton.meter} = \frac{1 \text{ kg} * \text{m}^2}{\text{s}^2} = 1 \text{ Ws}$
Laws of Thermodynamics	First Law: In a closed system in which any process whatever (mechanical, thermal, electrical, chemical, etc.) takes place, the total energy remains unchanged. (In a closed system energy can be neither added nor removed). Energy can only be converted from one energy form into another. Second Law: The entropy of a closed system can only increase. In a closed system, the entropy of the final state is always larger than the entropy of the initial state.
Levelized Cost	are fictitous costs in order to levelize year-to-year variations in fixed and variable costs. For electricity generation, for example, it is representative of the generating characteristics of the plant or system under consideration and the time-varying costs actually incurred.

Life	(1) Economic: the period of time after which a machine or facility should be discarded or replaced because of its excessive costs or reduced profitability; the impairment may be absolute or relative. (2) Physical: the period of time after which a machine or facility can no longer be repaired in order to perform its design function properly. (3) Service: the period of time that a machine or facility will satisfactorily perform its function without major overhauls.
Life-Cycle Costing	applies present worth analysis techniques to convert all monetary amounts to a present value or annual equivalent cost.
Load	The amount of power needed to be delivered at a given point on an electric system.
Load Curve	A curve showing loads, plotted against chronological time of occurrence and illustrating the varying magnitude of the load during the period covered.
Load Duration Curve	A curve that portrays the percentage of time during which particular load levels occur or are exceeded.
Load Factor	The ratio of the average load during a designated period to the peak or maximum load occuring in that period.
Load Management	Any means or application of measures by which load curves may be made flatter in shape, i.e. increasing the system load factor.
Marginal Costs	are the additional costs of producing each successive increment of output. Marginal costs are subdivided into: - Short-run Marginal Costs which are marginal costs occuring for unchanged production facilities, and - Long-run Marginal Costs are additional costs for which corresponding investments in the appropriate facilities can be made at the right time.
Net Benefits or Savings	criteria determines the discounted profits, i.e. the difference between present value of revenues and present value of costs over the lifetime of the project.

Net Calorific Value (NCV)	excludes the latent heat during the combustion process and is readily available from the combustion process for capture and use.
Nominal Monetary Accounts	see Current Monetary Accounts.
Opportunity Cost	The real cost of satisfying a requirement or desire, expressed in terms of the cost of the sacrifice of the alternative activities. For example, if capital funds could earn 7 cent elsewhere, then that is their cost in present use.
Payback or Capital Recovery	criteria describes the process by which the original investment is recovered over its economic life.
Present Worth Analysis	is the mathematical process by which different monetary amounts are moved either forward or backward from one or more points in time to a single point in time, taking account of the time value of money during interim periods.
Price Elasticity	see 'Elasticity of demand, Price'.
Primary Energy	refers to energy in the form of its natural occurance which has not yet been transformed into other forms of energy (crude oil, natural gas, uranium, coal, etc.).
r^2	Proportion of total variation of a series explained by the set of explanatory variables used.
Radiant Energy	is transmitted electro-magnetically between systems.
Real Monetary Accounts	see Constant Monetary Accounts.
Salvage Value	defines the net sum to be realized from the disposal of an asset at thetime of its replacement, resale, or at the end of the study period.
Secondary or Intermediate Energy	refers to energy resulting from a conversion process (refining, gasification, liquifaction, electricity generation, etc.) of primary energy forms into respective derivatives, i.e. motor gasoline, fuel oil, LPG, electricity, charcoal, etc.

Shadow Prices	are used in situations when the market prices do not reflect properly the social costs (or benefits). The shadow price is the price -a management or planning price- which reflects at the margin the social value of goods or services; as such it may substantially differ from the actual prices paid on the market.
Simulation Analysis	A general method of studying the behaviour of a real system or phenomenon. The method usually involves devising a model representing the essential features of the system and carrying out the solution of the mathematical and logical relations of the model. The simulation can be either deterministic or stochastic depending on the model selected.
SNG	synthesized natural gas.
Social Costs	are costs which do not appear in the accounts of a company, e.g. the costs to the public caused by air pollution, or similar events. They are costs engendered at the level of the economy as a whole by any action generating physical or economic impacts outside its own sphere.
SSE	Sum of squared errors between predicted and observed values.
Stochastic Analysis	Decomposition of a time series into deterministic and probabilistic components.
Subsidized Prices	are prices on commercial markets which are fixed below the prices under normal economic conditions to support lower income consumers.
t-statistics	A test for the significance of a particular variable in explaining the variation of the series.
Thermal efficiency (eff)	As applied to a heat engine, the proportion of the heat taken up that is converted into useful work, i.e., $\text{eff} = \dfrac{\text{Heat converted into useful work}}{\text{Heat taken up}}$ In electric power generation, the useful work done (or heat converted into useful work) is taken to be the electrical energy generated in a certain time;

the thermal efficiency is then defined by:

$$\text{eff} = \frac{\text{Electrical energy generated}}{\text{Heat content of fuel consumed}}$$

where electrical energy and heat produced are expressed in the same energy units (e.g. kWh, J, etc.). The heat produced is based on the net calorific value of the fuel consumed for the period over which the energy is generated. In an electric power generation plant, a distinction is made between the gross and net thermal efficiencies. The gross efficiency is based on the total electrical energy (or power) generated. The net efficiency is based on the energy (or power) available for transmission. The difference represents the power required to operate the plant and associated equipment.

Total Capital Investment Cost	The total costs incurred throughout the project schedule including escalation and interest charges up to commercial operation of the plant.
Useful Energy	is energy used for the service to satisfy a need.
Work	is energy which results from the transference of a point of application along a defined path.

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