Technical co-operation

An assessment of nuclear energy in developing countries: how the Agency can help

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In meeting its objective to assist its developing Member States in the peaceful uses of nuclear energy, the IAEA conducts an extensive 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. These assessments involve three major types of interdependent and closely related activities: the development of appropriate methodologies specifically adapted to developing countries; the conduct of training courses on energy and nuclear power planning techniques, including use of methodologies developed by the Agency; and the carrying out of energy and nuclear power planning studies in co-operation with requesting Member States.

Estimating future electrical energy needs

One of the most important determinants of the need for nuclear power is the projected future demand for electrical energy. Experience showed that the electricity demand information supplied by developing countries often was not developed in a systematic procedure which would ensure internal consistency with their main economic and industrial development objectives and possibilities. Thus, the electricity demand projections 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 the estimates of future electrical energy needs, the IAEA developed a computer model called MAED**, working in collaboration with the Institute for Economic and Legal Aspects of Energy (IEJE, Grenoble, France) and the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria). It is based on experience with an existing model called MEDEE*. Development was begun in 1980 and completed during 1981. MAED is now used by the Agency to develop coherent projections of future energy and electricity needs.

The MAED model, outlined in Figure 1, provides a flexible simulation framework for exploring the influence of social, economic, technological, and policy changes on the long-term evolution of energy demand. To facilitate its application with the more limited data base which is typical of developing countries, it is somewhat simpler than MEDEE.

In order to analyse the energy demand of a given country, the economy is subdivided into the major economic sectors (household, transport, industry, services), and the energy needs of each sector are subdivided into various elementary needs of useful and final energy (needs for space heating, cooking, furnaces, inter-city transport, and so forth).

The useful and final energy requirements are described by two types of parameters: one linked to the technical considerations (such as the efficiency of different appliances) and the other linked to life-style considerations (e.g. average distance travelled by car during a year, size of dwelling, etc.).

Special emphasis is given to the forecast of electricity demand, not only in terms of total annual requirements as for other forms of energy but also in terms of the hour-by-hour distribution of power demand during the year.

The MAED approach involves the following steps:

- A systematic analysis of the social, economic and technological system in order to identify the major factors determining the long-term energy demand evolution;

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** Model for Analysis of Energy Demand.

* Modèle d'Evolution de la DEmande d'Energie.

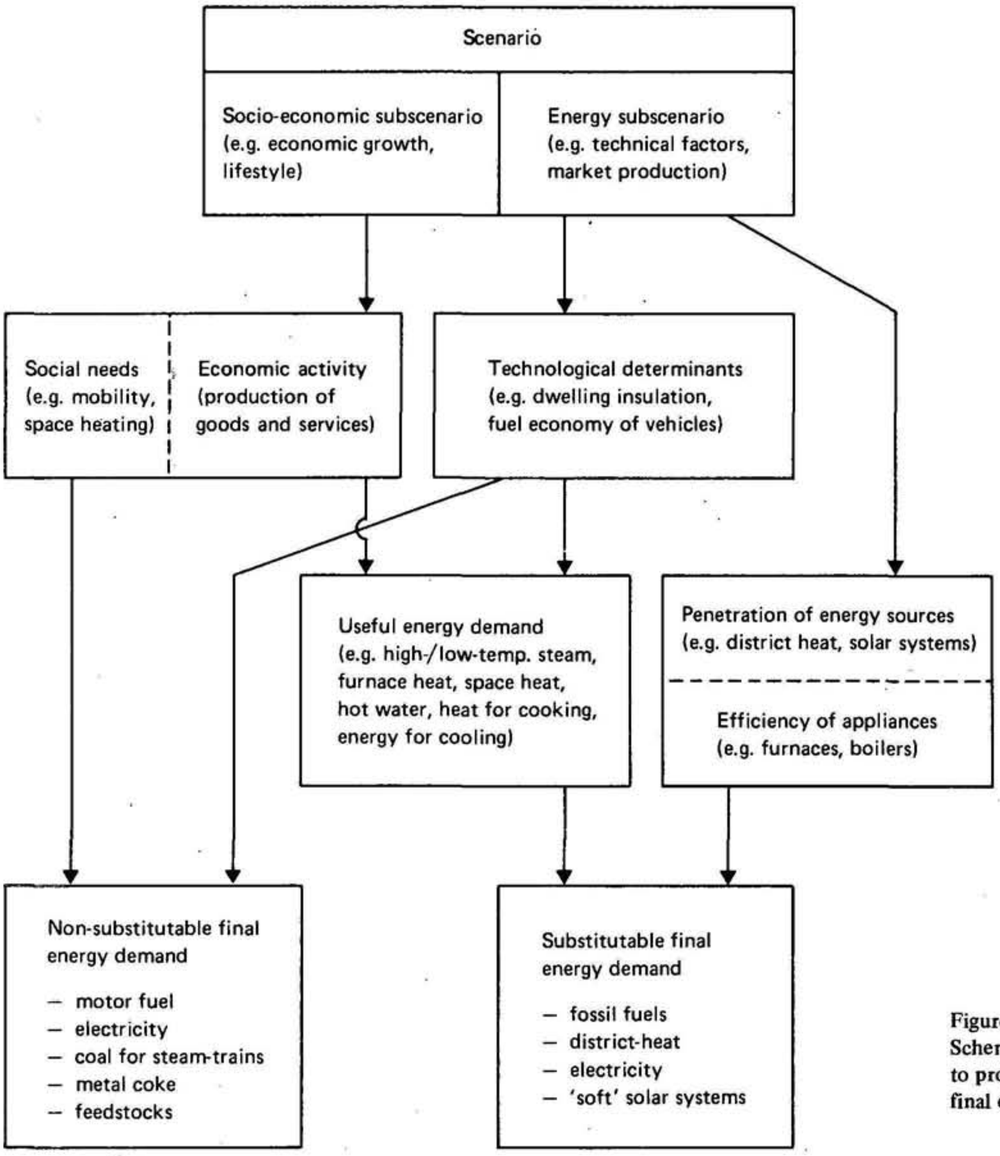

Figure 1. Scheme used in MAED to project useful and final energy demand.

- Disaggregation of the total energy demand into numerous end-use categories. The selection of the categories to be considered depends upon the objectives of the analyst and on the availability of data;

- Organization of all determinants into a multi-level structure, from the macro to the micro level, showing how the 'macro-determinants' affect each end-use category;

- Construction of a simulation model by simplifying the system structure and grouping the determinants into exogenous determinants and scenario elements. The *exogenous determinants* encompass those factors for which the evolution is difficult to model (e.g. population growth, number of persons per household), but for which long-term evolution can be adjusted suitably from past trends or from other studies such as demographic studies. The determinants chosen as *scenario elements* are those for which the evolution cannot be extrapolated from past trends because of possible structural changes in the energy demand growth pattern. Policy factors are an example.

Analysing the economics of system expansion

The WASP* model is a system of computer programs using dynamic programming techniques for economic optimization in electric system expansion planning (ESEP). It may be taken as an example of a supply model, whereas MAED is a demand model. The WASP model was developed for the Agency by the US Tennessee Valley Authority (TVA) and was first used during the 'Market Survey for Nuclear Power in Developing Countries' (1972–1973). With further assistance from the TVA and the US Oak Ridge National Laboratory, it was improved in 1976 to the WASP-II version which has been widely used by the

* Wien (Vienna) Automatic System Planning.

Agency and Member States. A joint effort of the United Nations Economic Commission for Latin America (ECLA) and the IAEA developed the WASP-III version which was completed in 1980. This latest version of the WASP model was designed to meet the needs of the ECLA to study the interconnection of the electrical grids of six Central American countries where large potential hydroelectric resources exist; it fulfilled the 1979 recommendations of an IAEA advisory group on electrical system expansion planning.

The WASP model is structured in a flexible, modular system which can treat the following interconnected parameters in an evaluation: load forecast characteristics (electric energy forecast, power generation system development); power plant operating and fuel costs; power plant capital costs; power plant technical parameters; power supply reliability criteria; and power generation system operation practices.

The electric energy forecast is obtained through use of MAED as described previously. In addition to the total annual demand for electricity, MAED provides WASP with some essential details about the estimated time distribution of the demand, that is, a 'load duration curve', as indicated in Figure 2.

The WASP model is composed of six principal programs. One of these programs can be used to describe the seasonal characteristics of the electrical loads for each year of study. With a second program, it is possible to describe the existing power system and all plants which have been scheduled for commissioning and decommissioning. A third program is available to describe the alternative plants which could be used to expand the power system (plant 'candidates'). With a fourth program one can generate alternative expansion configurations. A configuration is a set of power plants which meets the electrical capacity requirements of the utility or Member State. A fifth program determines whether system operation with a particular configuration has been simulated. If not, the program simulates that new configuration. Using a probabilistic simulation model, expected energy generation by each plant and the corresponding operation cost can then be calculated. The reliability of the generating system and the probable amount of unsatisfied demand are also estimated. A sixth program can be selected in order to calculate the lowest-cost expansion schedule for adding new units to the system over the period of interest, using the data files created by the other modules together with economic inputs and reliability criteria. The objective function of this dynamic programming optimization is the present-worth discounted value of operating costs (including fuel) plus capital investment costs, plus a penalty cost for energy not served, minus a salvage-value credit for plant economic life remaining at the planning horizon.

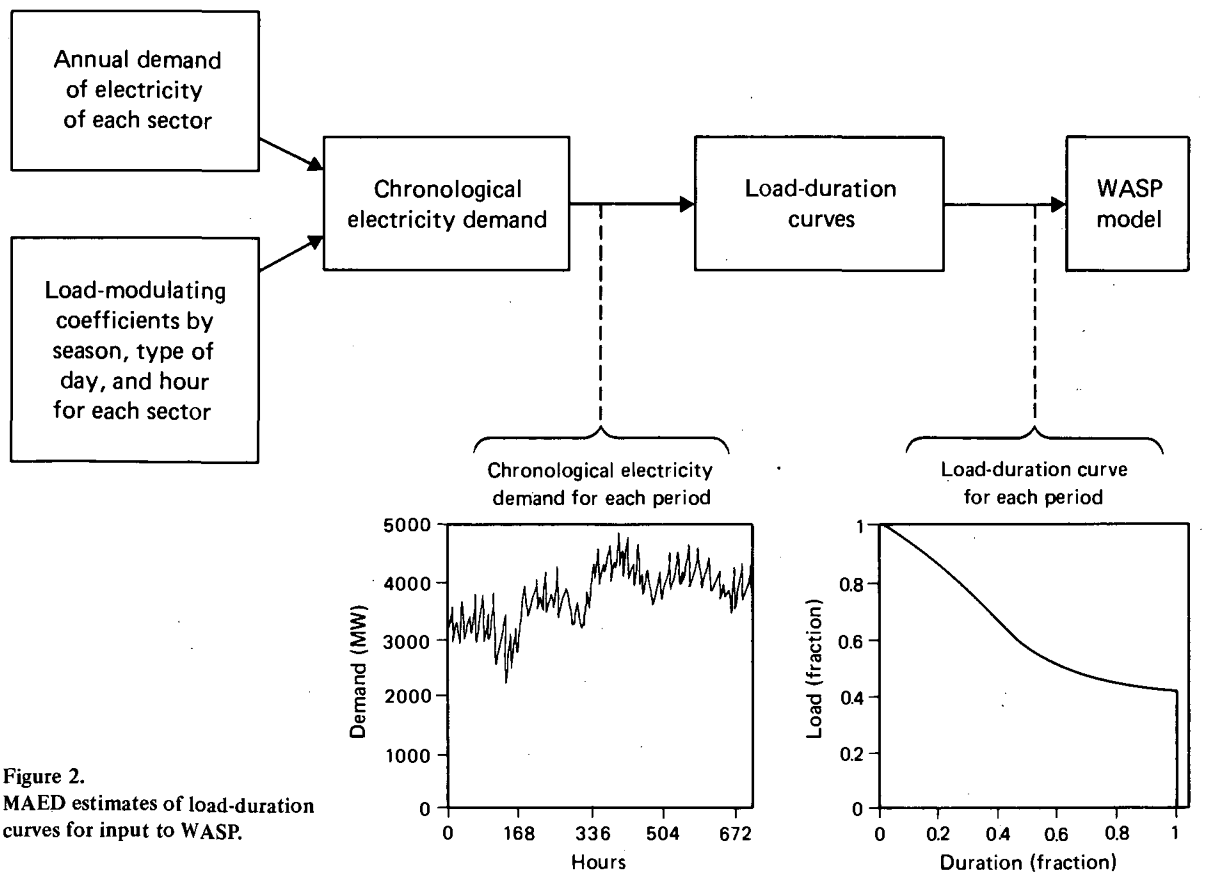

Figure 2.
MAED estimates of load-duration curves for input to WASP.

By mid-1982, the Agency had transferred the WASP package to 45 requesting countries and to five international organizations interested in planning for electrical system expansions. To date, the 45 countries report having used WASP in about 60 ESEP studies, with plans for an additional 30 or more studies.

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

Training for energy planning

The major objective of the training course *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. The course 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 this simplistic point of 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.

Initiated in 1978 by the National Institute of Nuclear Science and Technology (INSTN) at Saclay, France, this course has been given three times in French (1978, 1979, and 1980 at Saclay, France), once in Spanish (1981 at Madrid, Spain) and once in English (1982 at Jakarta, Indonesia). The first four courses *(Role of nuclear energy within a national energy plan)* each had a duration of seven weeks.

Based on those courses, a training manual was written and sent to participants of the 1982 course for advance study, so that the course duration could be shortened to three weeks.

During the first week of the current energy planning course, participants focus on the technical analysis of different energy chains (nuclear, coal, oil, gas, hydro, solar, etc.) and examine all the steps from the production of primary energy to the utilization of final energy. A systematic description of the benefits and disadvantages of each energy chain is presented in a manner designed to increase the participants' awareness of the complementary aspects of the various energy sources.

The second week is devoted to the economic and financial analysis that should be carried out as part of energy planning. Energy models are presented, but it is emphasized that they are only useful tools which cannot replace the comprehensive analysis and intelligent judgement of the energy planners themselves.

Finally, the third week is devoted to the analysis of case studies, about half of which are based on results of extended studies carried out previously 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. The conditions which must exist as a pre-requisite to using nuclear power in a developing country are emphasized, including: a national legal framework and a workable organizational infra-structure; adequate human resources; engineering capabilities enabling decision-making and technology transfer; an adequate level of national industrial development; and proper size and structure of the electrical transmission system to assure the grid stability under both normal operation and transient conditions.

From 1978 through 1982, 136 senior-level engineer-economists from 49 different countries were trained in energy planning. This course has been very successful, largely due to the fact that Member States have always nominated highly-qualified participants, but also due to the strong support of the contributing countries and organizations, i.e. Argentina, France, the Federal Republic of Germany, Indonesia, Spain, the USA, the UN 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).

Training on electric system expansion planning

In the period from 1975 to 1981, 139 senior engineers and power system planners from 43 countries and three international organizations were trained by the IAEA in the use of the various versions of WASP. During 1975 to 1977, training on the use of WASP was carried out by the Agency at its Headquarters in Vienna. During 1978 to 1981, an IAEA training course, *Electric system expansion planning* (ESEP) – sponsored by the United States Department of Energy – was given four times at the US Argonne National Laboratory (ANL), with participation by about 90 engineers and electric-system planners from 34 countries. The next course is planned for 18 April to 17 June 1983 at ANL, and will use a new IAEA *Guidebook on electric system expansion planning* which is now in preparation.

This ESEP course has the objective to train specialists in planning the expansion of an electric generation system; it emphasizes use of the WASP model. After completion of the course, the 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 include technical and economic characteristics of electric power plants; principles of generation expansion planning; electric grid considerations; characteristics of the WASP model and its auxiliary programs; evaluation and presentation of input data for WASP; analysis of optimum solutions; and preparation of a study report.

Every year, the training course is open to 24 candidates from developing countries of all geographical regions. Candidates are asked to apply in national teams of two or more persons who have experience in power system planning; this facilitates an ESEP study by each national team that is based on national data.

Carrying out studies for energy and nuclear power planning

An *Energy and nuclear power planning* (ENPP) study is initiated only upon official request by an IAEA Member State 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 and appropriate role for nuclear energy within its national energy plan. This requires assessment in terms of economic plans, and economic comparison with alternative energy sources. The analysis methodologies described previously (MAED and WASP) are used during the studies – with improvements or changes as necessary – and are released to the country at the end of the study.

Thus, the ENPP study has two specific objectives. One of these is to work with the requesting Member State to quantify the future energy requirements consistently 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 and role of nuclear power. Secondly, conducting the study provides on-the-job training to a local team of engineers and economists. The country receives the two computer models MAED and WASP, in order that further energy planning studies can be carried out by its 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. Each joint team includes two or three IAEA staff members familiar with all questions related to energy planning and different models which could be used. It also includes a team of specialists from the Member State, in particular, at least five or six engineers and economists well acquainted with the electricity and energy situation in their country. (It is recommended that most of them should have attended the two training courses previously described.) Among the national specialists is a senior co-ordinator who can contribute effectively to the work required, and who is responsible for making contacts with different organizations within his country in order to obtain the information and data needed for the study.

An ENPP study requires about two years of teamwork. Although members of the joint team need not dedicate full time to this activity, the time-period normally cannot be shortened, due to the time needed for data and information gathering.

Steps in an ENPP study

Although the exact content, scope and schedule for an ENPP study will vary depending on the Member States, conducting a study involves a well-established procedure.

After receipt of the request from the Member State, the Agency sends two to three Agency specialists to that country for a period of about two weeks to establish contacts, become familiar with the energy and economic situation of the country, set up the various organizational procedures (organization of the local team, agenda of work, etc.) and gather a first set of information and data.

Following this first mission, the Agency provides the Member State with a general report describing the programme of work for a possible ENPP study; the division of responsibilities; and the requirements in terms of manpower, data, etc.

After careful review of this report by both the Member State and the Agency, a decision is made whether to carry out the study.

In case of a positive decision by both parties, the Agency team initiates a first analysis of future energy demand, based on the data gathered during the first mission. The national team gathers additional information, including any missing data, and sends everything to the Agency. This period of testing and research for basic information requires approximately six months.

After sufficient progress has been made, the national team comes to the Agency for approximately one week in order to familiarize itself with the methodology used; review and comment on the first results obtained from the energy demand analysis, and introduce necessary modifications.

A period of about three months' work on both sides follows, during which the Agency team improves the energy/electricity demand study, and the national team finalizes the data collection on the demand side and starts to collect data for the ESEP (WASP) study.

After this period, a new meeting generally is needed in order to critically analyse the demand results, and decide on the major scenarios to be kept for the final report. This meeting should be at the Agency Headquarters in order to continue familiarizing the national team with the methodologies.

Again another period of three months is required for in-depth analysis of the various scenarios and to start with the ESEP (WASP) study. During this period, the national team should discuss the preliminary results with various decision-makers in their own country in order to get their reactions and, if necessary, to re-orient the study.

The Agency introduces any such changes into the study and supplies an advance set of results. At this stage, an Agency mission to the country by two or three staff members for about one week is advisable in order to implement the MAED and WASP models on the local computer facilities, proceed jointly, if necessary, to modify the advance set of results, and draft the structure of the final report.

Then begins approximately six months of intensive work, mainly for the national team, when these specialists should gain experience with the use of the models and repeat or modify the analyses already made by the Agency team, both on demand and supply aspects. Also during this time-period, both teams start with the preparation of the final report.

After this six-months' period, the national team should come to the Agency to finalize and adopt the final analysis; discuss and proceed to some final sensitivity analysis; and discuss the different parts of the draft report prepared separately by the two teams.

Following this meeting, the teams work together to prepare a mutually acceptable final report. This activity requires approximately four months of work. At a last meeting, either in Vienna or in the Member State, the exact content and structure of the final report are determined.

The printing of the report requires two to three months. Therefore, the official presentation of the final report to the national authorities can be made approximately two years after the first Agency mission to the Member State.

A need for long-range national planning

The Agency has a demonstrated capability to assist its developing Member States in the economic aspects of planning their future electric power system. However, the development of an energy planning activity is a long-range undertaking requiring constant review, additions and improvement.

The evaluation of the economic benefits from nuclear energy in a developing country 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 in a given country 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 is a problem which can be reasonably and rationally studied only by national energy specialists. The Agency can provide advice and some methodologies but it cannot be a substitute for the Government experts who must take the final responsibility for planning the development of energy supplies in their country. If needed, training to help develop local expertise can be obtained through the Agency 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. Through this approach, a trained national team will be in a better position to understand the situation in its own country, and will be able to follow up on the studies initiated in co-operation with the Agency.

- Finally, it must be emphasized that economic studies such as those mentioned in this article are only a first step in the long process of nuclear power planning. Many additional studies and analyses should follow, to determine whether 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 can be involved. These are additional factors that should be kept in mind when a country is evaluating the possibility to utilize nuclear energy.