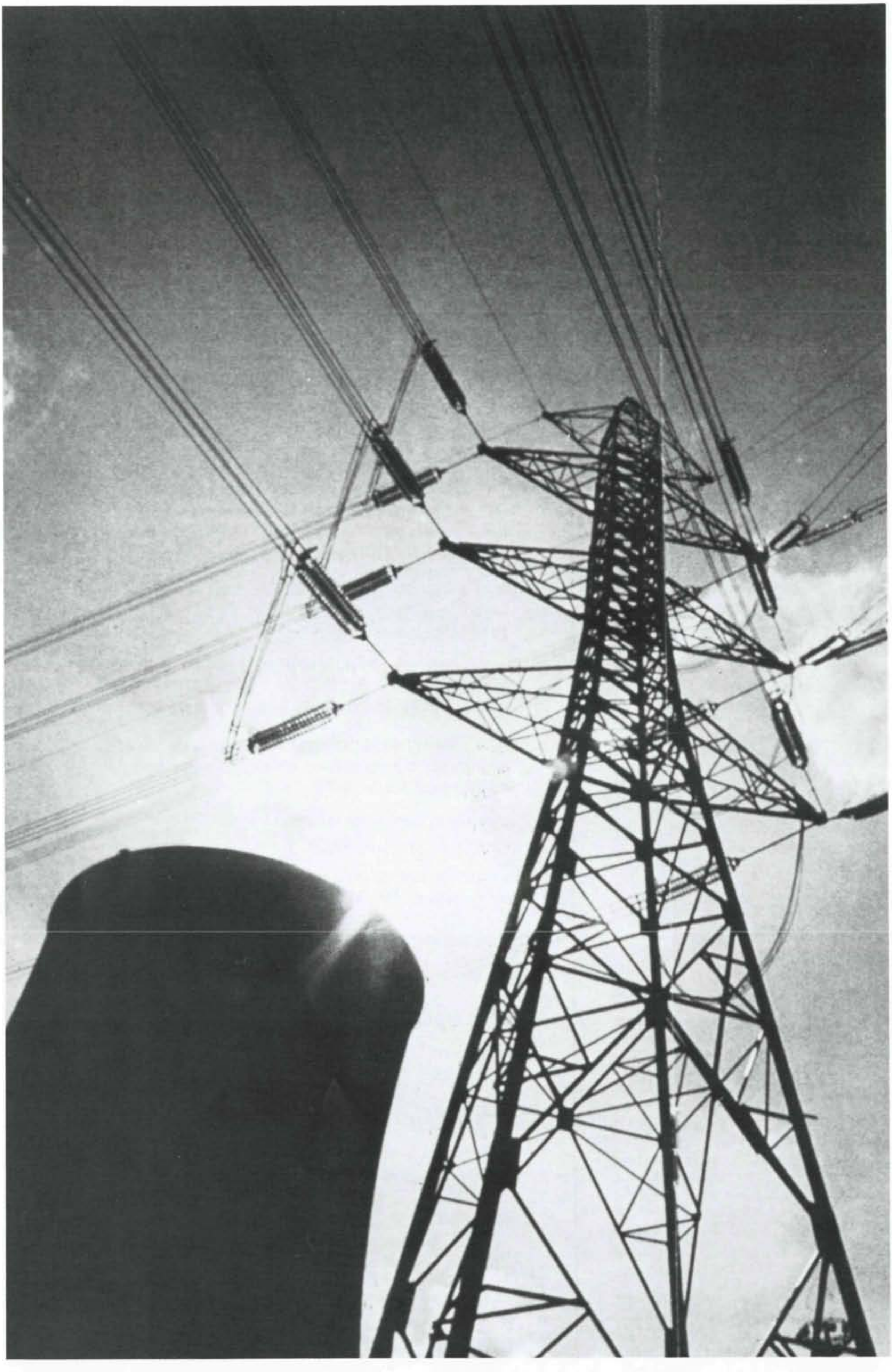

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Energy and nuclear power planning studies

A review of studies done in Algeria, Jordan, and Thailand, and the lessons learned

by L.L. Bennett, P.E. Molina, and T. Mueller

Any country seriously intending to launch a nuclear power programme must take early decisions based on careful assessment of future energy demand, supply options, economic and financial implications, and requirements for infrastructure and technology transfer. The IAEA is in a position to help interested Member States in conducting such studies, following a well-established procedure that entails three main stages.

- The *first stage* is to analyse the economic viability of a national nuclear power development programme over a fairly long time period, normally 20–30 years.
- The *second stage* is to provide the country with information on the financial and infrastructural implications of choosing such a power development programme. The IAEA can assist the country in gauging the financial impact of such a decision on its balance of payments and in assessing the role that domestic industries could play in plant construction. Finally, emphasis is given to appropriate training programmes designed for personnel that will eventually be required for the introduction of nuclear power.
- The *third stage* assists the country with feasibility studies directed at preparatory and organizational requirements before the construction of its first nuclear power station.

This article focuses on the procedure established by the IAEA for providing assistance during the first stage, namely the analysis of the economic viability of a nuclear power programme. Experience shows that such a study should take into consideration the country's overall energy requirements and the share that may be accorded to each alternative form of energy (particularly electricity) in satisfying these needs. Thus, the study in fact becomes an energy and nuclear power planning (ENPP) study.

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The organization of an ENPP study normally includes integration of a multidisciplinary team of national specialists who are responsible for the conduct of the study and a group of two to three IAEA experts.* ENPP studies have been concluded for Algeria, Jordan, Thailand, Egypt, Indonesia, Malaysia, Tunisia, Turkey, Venezuela, and Yugoslavia.** Studies for Egypt, Jordan, Turkey, and Yugoslavia were carried out in co-ordination and co-operation with the World Bank.

This article specifically reviews ENPP studies in Algeria, Jordan, and Thailand. It highlights major accomplishments in the context of study objectives and organization, and the principal lessons learned in the process.

ENPP for Algeria

This study's objective was to investigate the possible role of nuclear energy in supplying part of the electricity that Algeria will require in the next decades.

The study was carried out by a joint team integrated by two IAEA experts and five Algerian staff from the Societé Nationale d'Electricité et du Gaz. Although no formal multidisciplinary national team was created for the study, participation from other national agencies and organizations was secured through direct contacts established by the Algerian staff experts. Such participation proved to be crucial for gathering information. In particular, it facilitated selection of different development scenarios to ensure that they adequately reflected all scheduled and foreseeable development plans for various sectors, allowing for technical improvements in

* For more details on the steps taken during an ENPP study, see *IAEA Bulletin*, Vol. 24, No. 3.

** More information about the first three studies are in *Energy and Nuclear Power Planning Study for Algeria*, IAEA (1984); *Energy and Electricity Planning Study for Jordan up to year 2015*, IAEA-TECDOC-439 (1987); and *Energy and Nuclear Power Planning Study for Thailand*, IAEA-TECDOC-518 (1989). Technical reports on ENPP studies in the other countries are not yet available.

installed equipment and the introduction of new technologies.

The study was initiated in 1980 and effectively concluded in 1983. Its length was influenced by the parallel development of the Model for Analysis of Energy Demand (MAED), one of the economic analysis tools used for ENPP studies.* A study period of 1979 to 2015 was selected to reflect long-term trends and to evaluate the impact of energy policies, and to examine long-term trends for the expansion of the electricity generating system.

Given the study's purpose, the selection of socio-economic and technical development scenarios was based on a more or less equivalent level of final energy demand and strongly contrasting electricity demand levels. Three such scenarios (low, medium, and high) were selected.

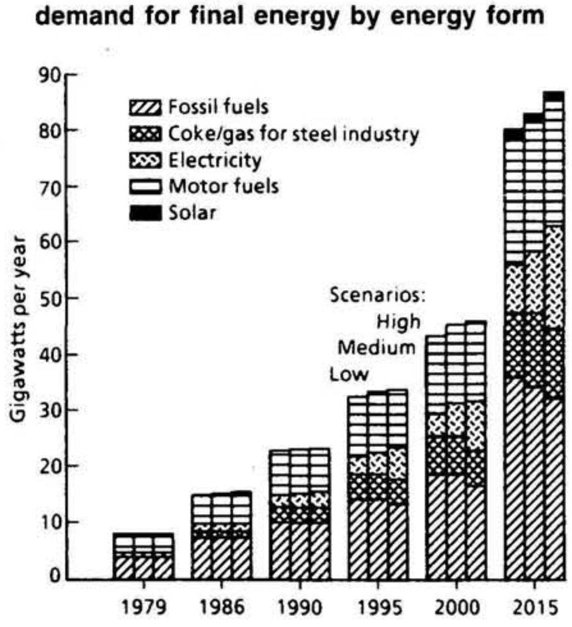
Features common to the three scenarios were population growth, evolution of gross domestic product (GDP), socio-economic development, and energy policies (including energy conservation). The features were all taken from the country's 5-year development plan (1980–1984) with some extrapolations for the long-term. The differences among the scenarios corresponded to the specific consumption of electricity for the various end-uses of energy by sector, market penetration of electricity in the various sectors and, accordingly, the market penetration of new energy forms (particularly solar).

For the analysis of the expansion of the generating system, the plants used as candidates included various sizes of gas-fired plants (steam turbines and gas combustion turbines) and nuclear power plants.

The results on final energy demand (MAED) are consistent with the scenarios' hypotheses, namely that final energy demand is very similar at the horizon (about 81–87 gigawatts per year) and that the contribution of electricity for each scenario is considerably higher than in the base year (1979), reaching 10.4% to 20.8% of the total demand, according to the scenarios. *(See accompanying figure.)*

The scenarios were also subjected to the analysis of electricity generation expansion by means of another economic model, the Wien Automatic System Planning Package (WASP).* It indicated that for all scenarios, the expansion of the generating system could be covered basically by gas-fired units (with higher component for steam thermal power plants). Nuclear power plants (1200-megawatts in size) appear only in the high scenario where the electricity requirements are higher. *(See accompanying table.)*

ENPP for Algeria: Breakdown of total demand for final energy by energy form



Development of electricity generating capacity in Algeria and role of nuclear power by scenario

Low scenario	Medium scenario	High scenario
16 575 MWe installed between 1986 and 2015 including:	23 550 MWe installed between 1986 and 2015 including:	38 025 MWe installed between 1986 and 2015 including:
—	—	14 400 MW PWR
11 100 MW GS	17 100 MW GS	13 800 MW GS
5 475 MW GT	6 450 MW GT	9 825 MW GT
Maximum annual capital investment in 2010: 4354×10^6 DA[a] (1979) (i.e. 0.7% GDP)	Maximum annual capital investment in 2009: 4024×10^6 DA (1979) (i.e. 0.8% GDP)	Maximum annual capital investment in 2009: 9979×10^6 DA (1979) (i.e. 1.7% GDP)
Cumulative capital investment: 61.5×10^9 DA (1979)	Cumulative capital investment: 85.5×10^9 DA (1979)	Cumulative capital investment: 188×10^9 DA (1979)
Annual requirements of natural gas in 2015: 18.2×10^9 m^3	Annual requirements of natural gas in 2015: 24.6×10^9 m^3	Annual requirements of natural gas in 2015: 19.2×10^9 m^3
Cumulative requirements of natural gas: 279×10^9 m^3	Cumulative requirements of natural gas: 379×10^9 m^3	Cumulative requirements of natural gas: 416×10^9 m^3

Notes: The table includes only capacity additions made by the expansion programme, i.e. firmly committed additions are not considered. DA = Algerian dinar. PWR = Pressurized light-water reactor. GS = Gas-fired steam unit. GT = Gas turbine.

* See *Model for Analysis of Energy Demand (MAED): Users' Manual*, IAEA-TECDOC-386 (1986), and *Expansion Planning for Electrical Generating Systems: A Guidebook*, IAEA Technical Reports Series 241 (1984).

* Summary information about WASP is contained in *Expansion Planning for Electrical Generating Systems: A Guidebook*, IAEA Technical Reports Series 241 (1984).

Two important aspects related to the optimal 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 revenue for the country) imposed by these solutions.

Various sensitivity analyses were conducted confirming the economic advantage of nuclear power in cases where:

- the price of natural gas (local fuel) has been increased to about 10% above the reference price;
- investment costs of gas-fired steam power units have increased 0.5% per year above the reference value;
- the discount rate for present-worth calculation of costs has been reduced to 7.5% per year from the reference value of 10% per year.

Study for Jordan

This study was initiated following a request of the World Bank which was undertaking a global advisory study on energy management and planning for Jordan.

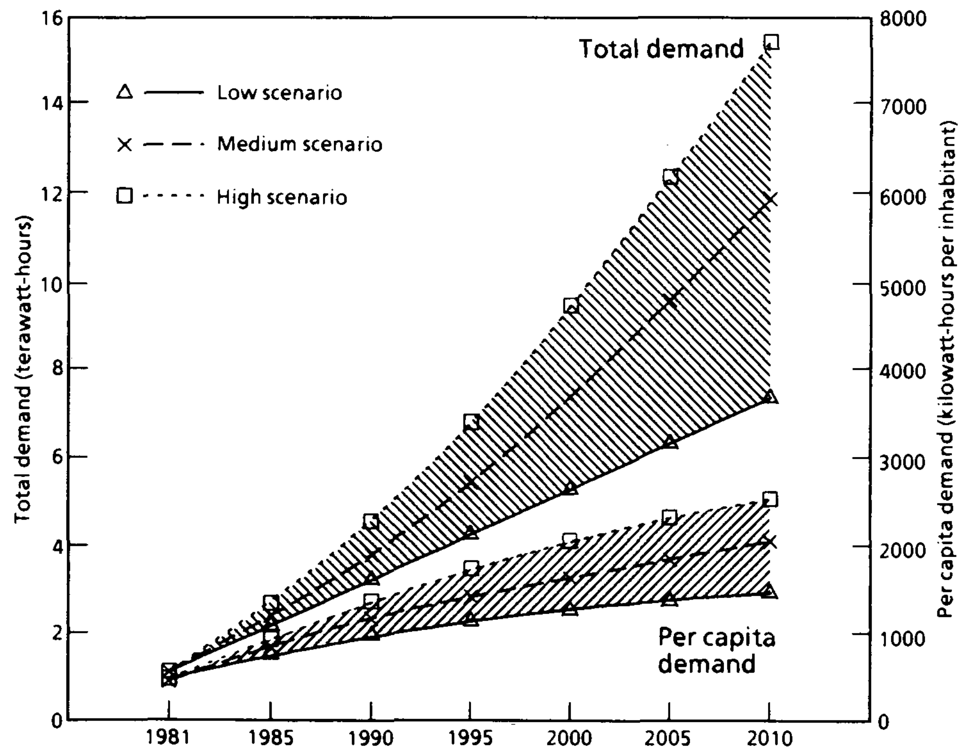
In this particular case, it was recognized from the study's outset that the nuclear option could not be envisaged for the country in the next 20 years owing to the expected size of the electrical grid and the size of commercially available power reactors. Consequently, it was decided to undertake an Energy and Electricity Planning Study (EEP) for analysing the future energy and electricity needs of Jordan over the next 20 to 30 years using the IAEA planning methodologies (MAED and WASP), in co-operation with the IAEA and Jordanian authorities.

The main objectives of the EEP study were to provide planning methodologies for long-term energy and electricity demand forecasts, as well as for generation expansion schemes for the electricity generating system; to establish a nucleus for the energy statistical database; to provide a training procedure on the use of computer programs in planning for the local staff; and to provide forecast results for energy and electricity demands and electric power generating system expansion plans by the use of the above methodologies.

The study was carried out by a joint team consisting of several IAEA experts and national experts from the Jordan Electricity Authority (JEA). The actual work for the EEP study started in September 1983 when the computer programs to be used were implemented in JEA's computer and the data collection was launched. The study lasted for about 21 months.

Estimates of the future energy requirements for all forms of energy (including electricity) were produced by means of the MAED model covering the period 1981-2010. These estimates were produced taking into account the policies contained in the current national and sectoral development plans at the time the study was carried out, as well as foreseeable developments for the trends observed in the past.

EEP for Jordan: Trends in total and *per capita* demand for electricity according to the various scenarios



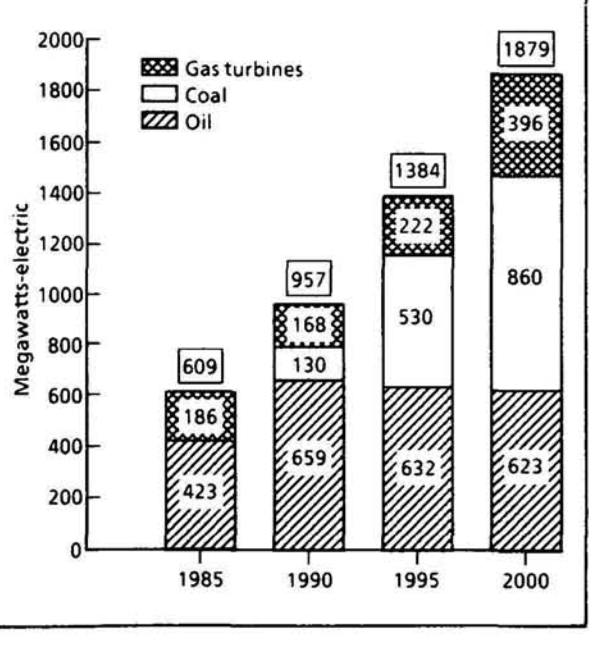
From all possible patterns of future development of the country, three were retained for the analysis of energy demand. They were categorized as low, medium, and high scenarios according to the expectations of achieving all development plans that had already been envisaged for the country. The medium scenario represented the most probable continuation of the current trends and the low (pessimistic) and high (optimistic) scenarios represented extreme deviations with respect to the medium trends.

The results of these three scenarios indicate that an important increase in the total demand for final energy is up to the horizon (three to five times over the period 1981-2010). The increase is less pronounced when observing the development of this total demand on a *per capita* basis. *(See accompanying figure.)* Under these results, in the year 2010 peak demand would reach 1491 megawatts (low scenario), 2449 megawatts (medium scenario) and 3272 megawatts (high scenario).

The future development of the electricity generating system was analysed by means of the WASP model over the period 1989–2000. A shorter period for this analysis was used, accounting for the fact that investment decisions in the electricity sector needed to be made over the next few years to satisfy the expansion needs up to 1997, owing to lead times normally associated for constructing large power plants.

The optimal schedule of plant additions for meeting future electricity requirements was found only for the medium scenario. This was done since the results for the other scenarios could be extrapolated by simply advancing (for the high scenario) or delaying (for the low scenario) the optimal schedule determined for the medium scenario.

EEP for Jordan: Schedule of total installed capacity for optimal expansion plan based on the medium scenario



Within the framework of this strictly economic study for the expansion of the electricity generating system of Jordan, it appeared that coal-fired steam units operating in baseload could play a very important role in satisfying the country's electricity requirements, accompanied by combustion (gas) turbines to satisfy peak requirements. Oil would still be used in existing and committed power plants to supply the intermediate loads, but the role of oil-fired plants in the generating system would decline over the years. *(See accompanying figure.)*

ENPP for Thailand

The study for Thailand had three main objectives: to adopt systematic planning procedures to assess the role that nuclear power could play within an optimized national power development plan for different socio-economic and technical development scenarios; to train and guide a team of Thai experts in energy and electricity planning methodologies and the relevant computer tools; and to develop the national capabilities for conducting future ENPP studies.

The study's results, combined with those of others at this prefeasibility level, were expected to serve as a more sound basis for making decisions about the viability of nuclear power in the country.

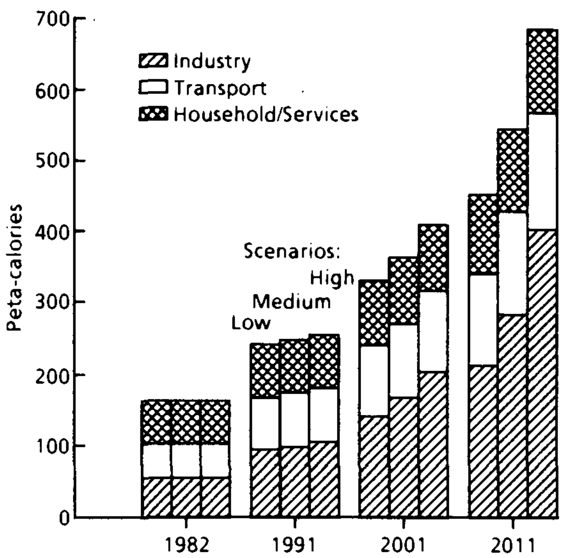
A Thai team of experts was assigned to work with IAEA experts and carry out various tasks to meet objectives. It was set up as a sub-committee, a functioning arm of the Thai Atomic Energy for Peace, comprising experts from the Office of Atomic Energy for Peace, National Energy Administration, National Economic and Social Development Board, and Electricity Generating Authority of Thailand.

The year 1982 was selected as the study's base year since it was the most recent year for which complete and consistent statistics on energy consumption were available at the National Energy Administration when the study began in 1984. In addition, 1982 was the starting year of the country's fifth 5-year National Economic and Social Development Plan.

In developing scenarios for the MAED study, special attention was paid to identifying the most important factors affecting energy demand. Consequently, it was decided to analyse the impact of four major driving forces on the final energy demand — population, economy (GDP), energy intensity, and electricity penetration into the various markets for end-uses of energy. Three scenarios (low, basic, and high) were defined to reflect possible evolutions of the above factors in accordance with Government policies and the principal assumptions. Each scenario covered a study period of 30 years, 1982–2011.

According to the assumptions, Thailand's total energy demand is expected to increase with similar trends for all three scenarios, each reaching different magnitudes. *(See accompanying figure.)* The industry sector (including manufacturing, construction, mining,

ENPP for Thailand: Evolution of final energy demand by sectors



Notes: The "Industry" category includes agriculture, construction, mining, and manufacturing. The term "final energy" includes non-commercial energy.

and agriculture) would have the largest share of the total energy demand by the year 2011, with most of this increase in the manufacturing sector. Therefore, the results are consistent with the Government's policy on industrial development and the expected contribution of industry to the total GDP.

The results of the WASP analysis of the electricity generation system expansion plans indicated that all candidate power plants using indigenous resources (hydro, lignite, and natural gas) are selected as part of the optimal solutions. In addition, according to these results, the indigenous resources would be fully utilized to satisfy the requirements of the existing plants and those selected by the expansion plans up to the year 2000. Thermal power plants using coal and nuclear would be dominant beyond the year 2000.

Sensitivity analyses were carried out with respect to the pure construction cost (that is, without including interest during construction) of nuclear power plants and the discount rate. The pure construction cost analysis of the nuclear power plant (900 megawatt) basically concluded that the optimal solution remained unchanged for variations of plus or minus 20% around the reference cost. On the other hand, as expected, variation of the discount rate to 10% per annum, instead of the 12% per annum used for the reference solution, favours the nuclear power plant.

Lessons learned

From the IAEA's viewpoint, important lessons — basically referring to organization and methodologies — have been learned from ENPP studies.

Study scope. The scope, which involves the analysis of overall energy and electricity needs for the next 20 to 30 years and optimization of the power generating system to meet this demand, is seen as very adequate for an economic appraisal of the nuclear power option at the prefeasibility level.

Future ENPP studies will have to be more explicit on the environmental impact of the proposed evolution of energy consumption, and the means of generating electricity, in view of the growing importance of environmental concerns.

If the study's results 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 can be undertaken.

Composition of the national team. Participation by specialists from different organizations dealing with energy planning at the national level has been very important. In many cases, the ENPP study represented the first time that the particular national organizations have effectively participated in a joint international co-operative endeavour. Some practical problems can arise, particularly since an ENPP lasts for 2 years and participating national specialists assigned to joint study teams have to be freed from their normal duties for considerable periods of time. However, there are important benefits from using the joint team approach. The approach fosters credibility and acceptance of the study's results within the country, and it encourages the effective transfer of planning methodologies to the country.

Training of national teams. National teams are trained on the study's planning methodologies through an approach that combines on-the-job training with attendance at regular IAEA training courses on appropriate subjects. Practical problems arise in scheduling national team participants for the training courses, since they are held on an annual basis and do not always coincide with the ENPP study's timeframe. This problem can be alleviated when countries which are interested in an ENPP study send some national specialists to training sessions even before the study is requested.

Methodologies. Both the MAED and WASP models are adequate tools for approaching energy strategies at the national level. In all ENPP studies, MAED and WASP proved their usefulness in this context. Despite their recognized advantages, both models also have some bottlenecks.

The MAED model. This methodology is rather simple in structure, but very data-intensive. The definition of the development scenarios involves specification of the evolution of major factors recognized to have an impact on energy demand (population, industrial output, transportation needs, etc.). In addition, the fact that electricity requirements are treated in a very detailed way increases the amount of information needed to describe the pattern of consumption of electricity by major types of consumers.

Considering the amount of data needed by the MAED model, this phase of the ENPP study has been the most time consuming in all studies reviewed here. Even so, all national teams have recognized that this phase is very rewarding as it enables planners to look at a country's complete energy picture, including the country's energy consumption and possible future developments resulting from changes to socio-conomic and technical factors influencing energy demand. Above all, it makes them appreciate the influence that policy making can have on this development.

A common problem observed in most country studies has been the insufficiency of detailed and reliable statistical data on energy and electricity consumption. Consequently, in view of the time limitations connected with the study's execution, a pragmatic approach has usually been followed to define scenario data. Initial data is tried with the model, and gradually refined, based on the model results and consultations with national experts participating in the study.

The same problem has occurred during detailed analyses of electricity demand requirements, as knowledge of the consuming behaviour of different sectors is not available in most developing countries. Thus, the usual approach has been to proceed on the basis of surveys, retaining only the data corresponding to certain consumers who are considered typical or representative of their sector of activity. Even with some shortcomings, this approach enables a better understanding of consumer behaviour. In addition, it allows planners to draw the importance of this type of information to the attention of authorities in the electricity supply sector. It further provides an opportunity to launch a systematic research and analysis programme on consumer behaviour that will provide a solid foundation not only for planning studies, but also for management of tariff structure and electricity demand. Programmes like this, which require research stretching over 2–3 years, have been recommended by most of the ENPP studies. In the case of Tunisia, an actual programme was implemented.

The WASP methodology. Although rather sophisticated in terms of programming techniques, WASP requires information and data that is normally available at national electric utilities. Basic problems, as observed in the studies, involve the definition of some technical and economic parameters, such as the discount rate and the level of reliability for future configurations of the power system. These have always been treated using the WASP capabilities for conducting sensitivity studies, in which reference values are adopted from current national practices or from indications by national experts and financing organizations (such as the World Bank and the Asian Development Bank).

The IAEA can help in providing guidelines for the selection of technical and economic parameters in the WASP analysis, particularly for nuclear power plants. Such values, however, ultimately must be decided by the country in the light of past experience (the preferred solution when information is available) or information for similar plants in neighbouring countries at a similar stage of development.

The IAEA further maintains a programme for reviewing and updating both the MAED and WASP models with the view of adapting them to changing needs of energy and electricity planning conditions. Particular attention is given to conditions existing in most developing countries.

Integrated assistance

To improve the effectiveness of its assistance, the IAEA has developed an Integrated Package of Assistance (IPA) for developing countries interested in nuclear power programme planning. The approach unifies IAEA's present individual activities on nuclear power planning and implementation with the needs of developing countries to develop their infrastructures and particularly their manpower base.*

The main objective of IPA is to provide a clearly defined sequential approach to nuclear power programme planning activities. It moves from the very beginning of the process up to the approval by national authorities to implement the first nuclear power project.

The IPA is closely connected to the newly instituted Nuclear Planning Advisory Team (NUPAT) missions to interested countries. The first NUPAT mission took place in June 1990 (Morocco) and plans call for another mission (Malaysia) in the second half of 1990.

These activities, together with ENPP and related studies, are providing important services to developing countries for sound energy planning and development.

* "Energy, electricity and nuclear power planning in developing countries", by K.F. Schenk et al., *IAEA Bulletin*, Vol. 30, No. 2 (1988).