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Energy and nuclear power planning using the IAEA's ENPEP computer package

Proceedings of a workshop held in Warsaw, Poland, 4–8 September 1995

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FOREWORD

The Regional (Europe) Technical Co-operation Project on the Study of Energy Options Using the IAEA Planning Methodologies was first implemented by the IAEA in 1995. The project aims at improving national capabilities for energy, electricity and nuclear power planning and promoting regional co-operation among participating countries in the European region.

Several participating countries, especially those in eastern Europe, are going through a transition process and reorganization of institutions in the process of transition from centrally planned economies to market oriented ones. In this situation, it was perceived that these countries will require assistance in overall energy and electricity planning and would need to have access to planning methodologies which are better adapted to the conditions of market economics. For this reason, the IAEA planning models for energy, electricity and nuclear power planning were selected as the basis of the assistance to be provided within the project.

The IAEA catalogue of computer methodologies for energy and nuclear power planning includes several models that have been accepted worldwide as very useful tools for analysing the future development of the energy and electricity systems, including the role that nuclear power can play in satisfying the future needs of a society. Among these models, the Model for Analysis of the Energy Demand (MAED) and Wien Automatic System Planning (WASP) can be considered the leading tools for determining the future energy and electricity demands and the economically optimal expansion strategies of the electricity generating system, respectively. Both models, MAED and WASP, are also included as part of a larger computer package called ENPEP (Energy and Power Evaluation Program). ENPEP is a microcomputer based package that was originally designed to allow integrated energy and electricity planning including all aspects from the determination of consistent projections of energy and electricity consumption based on the interrelationship between macroeconomic growth and the demand for energy and electricity, the balance of the energy demand and the supply of primary energy, taking into account the structure of the national energy network, the determination of the optimum schedule of additions of electricity generation plants, up to the evaluation of the resource requirements (land, manpower, finance, etc.) and the environmental impacts (emissions) of the resulting energy and/or electricity systems. ENPEP was originally developed by the Argonne National Laboratory (ANL), United States of America, with funding provided by the United States Department of Energy (USDOE). The complete package was transferred to the IAEA by USDOE for further release to IAEA Member States and international organizations.

Experience in the use of the IAEA models, and particularly of the ENPEP package, has been gathered in some of the participating countries through their attendance of the training courses on Integrated Energy and Electricity Planning for Nuclear Power Development with Emphasis on the ENPEP Package that have been organized at the interregional level at ANL in 1991 and 1992 and at the regional level for the European region in Paks, Hungary in 1994. Further experience has been accumulated through the application of the ENPEP package in the conduct of national projects that have been carried out under the Technical Co-operation programme of the IAEA. The above mentioned regional project is designed to utilize this experience as much as possible with the view of further promoting regional co-operation.

The project includes the organization of workshops, training activities at the regional and national levels, scientific visits, etc. The proceedings of a workshop held in Warsaw, Poland, from 4 to 8 September 1995 are contained herein. The workshop had as a basic objective the analysis of the specific problems encountered by the represented countries during application of the IAEA's ENPEP package in the conduct of national studies and to provide a forum for further co-operation among participating countries. A second objective of the workshop was to make proposals for future activities to be organized within the project.

This publication is intended to serve as reference for the users of the IAEA's ENPEP package, as well as for energy and electricity planners in general.

CONTENTS

INTRODUCTION

The IAEA maintains a comprehensive programme of activities in the area of nuclear power programme planning and implementation, aimed at helping developing Member States in making sound decisions in undertaking the timely actions for effective implementation of a nuclear power programme. In the specific field of nuclear power planning, the programme aims at assisting Member States in the assessment of nuclear power and its viability for satisfying future energy and electricity requirements. This assessment includes not only the economic comparison of nuclear power and alternative technologies for electricity generation, but also consideration of the impacts of each candidate technology in terms of resource requirements (land, manpower, financing, etc.) and environmental consequences (emissions).

Assistance by the IAEA in the area of nuclear power programme planning comprises several interrelated types of activities including: the development of computer models for energy, electricity and nuclear power planning, each model being designed for the conduct of the different analyses and studies required to support decisions on nuclear power programmes; dissemination of these models to interested Member States; and further support in their use through organization of training courses national planning studies using these models. Because of the large amount of resources required, most of the activities are organized through the Technical Co-operation (TC) programme of the IAEA.

In recent years, the TC programme has been reoriented to focus on end user needs and thus to adapt the assistance to each country's requirements in the light of their status in nuclear technology. At the same time, a new concept has been introduced in the TC approach by creating 'model projects' which basically address problems that are common to a group of countries within a region.

The Regional (Europe) TC Project on Study of Energy Options Using the IAEA Planning Methodologies was implemented in 1995-1996 with the objective of improving the national capabilities for energy, electricity and nuclear power planning and to promote regional co-operation among the participating countries. Although the recipients of this assistance are developing Member States in the Europe region, the project would involve participation by all Member States of the region in order to promote regional co-operation.

The activities within the project for 1995 aimed at two groups of developing countries, those with experience and training on the IAEA planning tools for which the present Workshop was organized, and countries with no experience in these models and for which field missions are being organized with a view to establishing contacts with the local organizations involved in energy and electricity planning and determining the most urgent needs of the country with regard to the IAEA models.

The workshop on Practical Issues Related to the Use of IAEA Planning Models with Emphasis on the ENPEP Package was held in Warsaw, Poland, from 4 to 8 September 1995. It was hosted by the Government of Poland and locally organized by the Energy Information Center (CIE) in collaboration with the Polish Atomic Energy Commission. The main objective of the workshop was to discuss the future activities to be organized within the project and to make suggestions and recommendations in this regard.

Closely related workshops on the use of the IAEA's planning methodologies among Member States in Europe, the Middle East and North Africa were organized by the IAEA in Nicosia, Cyprus (1989) and Budapest, Hungary (1994). The present workshop had the objective of updating the information gathered in the above two workshops but with emphasis on the ENPEP model.

The selection of the ENPEP package as the main focus for the workshop was based on the following. ENPEP is a microcomputer based tool for integrated energy and electricity planning originally developed by the Argonne National Laboratory (USA) under a project funded by the United States Department of Energy (USDOE). ENPEP consists of several models, each one with a specific purpose. Depending on the needs of a particular planning study, the modules can be executed independently or integrated into a sequential chain. The package was donated to the IAEA for further release to interested Member States and international organizations. Several European Member States have already received a copy of the package as part of their participation in training courses on this subject or through the conduct of planning studies as national TC projects. During this process numerous queries have been raised by the users relating to specific problems being faced in trying to adapt the locally available data to the modeling approach of ENPEP. Because of the specific needs in each country, national experts of the region have developed very ingenious approaches to solve some of these problems. Consequently, it was felt that the workshop would provide an opportunity to exchange the accumulated experience already gathered among participating countries.

The workshop consisted of a series of presentations made by each of the national participants. These were combined with technical sessions in order to achieve consensus on the best approach to solve a particular problem and to give advice on desirable improvements to the ENPEP package and on the future activities to be organized under the regional TC project.

The workshop was very useful in providing a forum for exchange of experience in the use of the IAEA's ENPEP package and the different approaches for solving specific problems according to the conditions of each country.

Several recommendations were made regarding the organization of future activities to be sponsored by the regional TC project, including the organization of similar regional workshops on the subject matter at regular intervals in order to update the exchange of experience in the IAEA planning models.

Other recommendations pertained to the desirable enhancements of the ENPEP package Of particular importance is the need for improved treatment of co-generation within the ENPEP package because of the special needs of many participating countries However, participants recognized that considerable time and effort would be required to develop a new algorithm and computer code, so that in the meantime a more practical solution was adopted For this purpose, it is intended to prepare a document to describe the different approaches to modelling the co-generation process with the BALANCE module that have been used by countries in the region, and to disseminate this report among all ENPEP users

It can be concluded that the high quality of the presentations made at the workshop and the variety of approaches that have been implemented to solve the problems faced by planners in the region, as discussed during the workshop, indicate intensive use of the ENPEP package and other IAEA planning models by the participating countries The large representation from the countries in the region is also a demonstration of the high interest in the IAEA planning models and their future developments This interest and the experience available in some of the countries represented in the meeting would be very valuable in the continuation of the regional TC project

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THE REGIONAL (EUROPE) PROJECT ON STUDY OF ENERGY OPTIONS USING THE IAEA PLANNING METHODOLOGIES

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Abstract

As a means to assist developing IAEA Member States in the Europe region in the broad area of energy, electricity and nuclear power planning, a new project has been implemented as part of the IAEA Technical Cooperation Programme. This paper describes the major objectives of this regional TC project and the activities to be organized in order to provide the required assistance. Focus is made on the present workshop and the current activities sponsored by the IAEA for further development of the IAEA planning tools for energy, electricity and nuclear power planning with emphasis on the Energy and Power Evaluation Program (ENPEP) and the Wien Automatic System Planning (WASP) packages.

I. HISTORY OF THE PROJECT

The Regional (Europe) Technical Co-operation Project on *Study of Energy Options Using the IAEA Planning Methodologies* (RER/0/012) has been implemented by the IAEA starting in 1995 and with a duration of four years. The principal aim of this project is to improve national capabilities for energy, electricity and nuclear power planning and to promote regional co-operation in the exchange of experience in the use of the IAEA planning methodologies among the participating countries.

For the purposes of IAEA Technical Co-operation, Member States of the Agency are grouped into geographical regions. The regional project was originally designed in 1993 as a so-called TC model project that was intended to cover all countries of the former Europe and Middle East region of the IAEA. By the time the project was finally approved, in 1994, a new regional TC coverage had been decided for these countries, which were split into two newly created TC regions, namely:

- *Europe,* and
- *West Asia*

Consequently, the original budget was split into two separate regional projects with the same title, one for each of the regions listed above.

Over a four-year period, different countries in the Europe region will host regional and national training courses and regional workshops to be organized with Agency assistance. In organizing these events, the expertise already accumulated by some of the countries in the region will be utilized as much as possible.

Countries in Europe that are recipients of Agency technical assistance will participate in the project. Similarly, developed Member States in the region, having experience in the IAEA planning methodologies, will also be invited to provide inputs to the various activities in order to further promote regional co-operation.

The main idea behind the design of this regional project was to provide a framework to attend current needs for assistance in improving energy and electricity planning procedures and methodological approach.

Many East European and former USSR States that are also included in the Europe region of the IAEA are going through a transition period from centrally planned to market oriented economies which requires a new approach to energy planning. To assist Member States in the region to build up their capabilities for decision making on future developments in national energy and electricity systems, the Agency would like to introduce its energy planning methodologies. These methodologies, such as MAED, WASP, ENPEP and DECADES, have been developed for energy, electricity and nuclear power planning, and permit the analyses necessary for making sound decisions on the future evolution of the different energy options. These methodologies which are adapted mainly to planning analyses under market driven conditions, include the following.

MAED (Model for Analysis of Energy Demand) is a simulation model for medium and long term evaluation of energy and electricity demand;

WASP (Wien Automatic System Planning) is a system of computer programs to determine economically optimal long term expansion of an electricity generation system;

ENPEP (ENergy and Power Evaluation Program) is a set of PC-based tools for conducting integrated energy and electricity planning with due consideration to the impacts of alternative development strategies of the energy and electricity systems in terms of their resource requirements and environmental impacts;

DECADES (Data bases and methodologies for comparative assessment of different energy sources) provides information on electricity generation chains and permits their comparison for expanding electric power systems.

II. PLANNED ACTIVITIES

In order to meet the project objectives, several activities will be organized throughout the next four years, including:

- Short training workshops or seminars aiming at providing the participating countries with first hand-on experience in the use of some of the IAEA models, in particular MAED and WASP;
- The training is to be complemented with national training seminars to be carried out by the trainees that participated in the regional training course. These national training seminars would need relatively small input from the Agency;
- Field missions would also be organized with the objective to follow up on the effectiveness of the course and the impact on the country's planning procedures;

- Finally, to the extent possible, some ad-hoc missions to the participating countries that cannot be supported by the on-going national TC projects, would be accommodated as part of the regional project.

Special emphasis will be made in trying to use as much as possible the expertise available within the region. In addition and whenever applicable, coordination will be maintained with similar activities to be organized under the regional TC project for West Asia. Asia.

The specific activities under the Regional project for Europe during 1995 aim at two groups of Member States:

a) Countries with experience and training on the IAEA planning tools, i.e.: *Belarus, Bulgaria, Croatia, Cyprus, Hungary, Greece, Poland, Portugal, Romania, Russia, Slovenia, Turkey, Ukraine.*

   The present workshop is being organized for the above countries.

b) Countries with very limited experience in the IAEA planning models and for which it is necessary to establish contacts with the local organizations involved in energy and electricity planning for the country, i.e.: *Albania, Armenia, Czech Republic, Estonia, Georgia, Latvia* [1], *Lithuania, Moldova* [1], *Slovak Republic, Macedonia.*

   For these countries, field missions are being organized.

III. WORKSHOP OBJECTIVES

The workshop on "Practical issues related to the use of IAEA planning methodologies with emphasis on the ENPEP package" has been organized with the following objectives:

(a) To discuss particular problems encountered by countries in the region while applying the IAEA's ENPEP package in the conduct of national studies.

(b) To discuss the future activities to be organized within the project and to make suggestions and/or recommendations in this regard.

In order to meet objective (a) above, during the workshop, accepted participants will present a paper describing the problem. All papers will be discussed thoroughly during the Workshop with the aim of finding practical solutions to the problems.

Owing to the variety of proposals of presentations made by the participants, it has been decided to group them into topical sessions in order to concentrate the discussions on a given topic. Three topical sessions have been defined:

1) *Energy and electricity demand planning and problems related to the organizational structure in the country.*

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[1] These countries are not Member States of the Agency and must be supported by extrabudgetary funds.

2) *Primary energy allocation with due account to environmental considerations and resource requirements.*

3) *Electricity and nuclear power planning.*

It is intended to publish the Proceedings of the Workshop as an IAEA report for future reference by ENPEP users.

Regarding objective (b), participants are requested to make suggestions and proposals for the type of activities to be organized in the future under the present TC project, including not only the type of activities for which the project was originally designed, but also recommendations concerning further enhancements to the ENPEP methodology.

Regarding organization of training events, participants are requested to provide suggestions not only for the possible topics to be covered, but also to make specific proposals for hosting some of the activities.

In giving the recommendations, participants are requested to keep in mind the relatively limited resources available for the project so that the countries are welcomed to contribute to the project in the form of providing cost-free experts for participation in field missions or training activities in other countries, hosting some of the workshops, etc.

In relation to the recommendations for model enhancements and in order to avoid suggestions for improvements that are already being implemented, a lecture by Argonne National Laboratory (ANL) will be presented to describe current enhancements being introduced in ENPEP at ANL. For the same reason, it is necessary to describe the current efforts of the IAEA for further development of the WASP model (ELECTRIC Module of ENPEP). These are discussed in the next section.

IV. THE WASP-IV MODEL

A new version of the WASP program, called WASP-IV, is being developed with the help of two Member States and institutions:

Greece: *Public Power Corporation & National Technical University of Athens*

Hungary: *Hungarian Power Companies Ltd. & Computer and Automation Research Institute (Academy of Sciences)*

Under this co-operative effort, the national teams are responsible for development of separate algorithms and computer coding, while the IAEA provides overall coordination of the project.

The principal enhancements introduced in the WASP-IV model with respect to the earlier version (known as WASP-III Plus) are as follows:

- Treatment of group limitations that may apply to the electricity production by one or several power plants (e.g., limits on fuel, ceilings for amount of energy generated, constraints on emissions, etc.) Up to five different types of limitations can be applied in the program, whereas WASP-III Plus only allows the treatment of fuel limitations for a group of plants.

- Modeling of pumped storage as a separate power plant which will take the place of one of the composite hydro plants for simulation purposes. The WASP-III Plus version does not consider explicitly such type of plant and its representation can only be approximated by external manipulation of the input data, which requires large efforts by the planner.

- Control by the user of the maintenance schedule of thermal power plants. In previous versions of the WASP model the maintenance schedule is determined by the program.

- Increase of the dimensions of several variables:

    - Number of thermal plants (98 against 58 in WASP-III Plus).

    - Maximum number of configurations accepted in a single run (500 per year and 5000 for the study, against 300 and 3000 in WASP-III Plus)

- Overall program update.

DEVELOPMENT SCHEDULE FOR THE WASP-MODEL

Currently the individual developments of the algorithms and computer coding by the Greek and Hungary teams are being finalized and some documentation of the new algorithms have already been prepared.

The next phase will be the integration of both developments into a single package. This will require considerable efforts not only to combine different portions of the code, but also in developing a wide variety of case studies to verify the functionality of the code. A new User's Manual should also be developed.

Conclusion of these activities is foreseen for November 1995 when the final product would be presented to the consideration of the participants in a WASP Advisory Group Meeting in Vienna. Their recommendations would be used as a basis for the final development. Conclusion of all development activities, including the program documentation and User's Manual is foreseen for 1996.

V. CONCLUSIONS

The Regional TC project for Europe on the IAEA methodologies is expected to make a valuable contribution in building up national capabilities for energy, electricity and nuclear power planning in the participating countries.

The exchange of experience in the use of these methodologies and computer models will be very useful in avoiding duplication of efforts to solve a particular problem being faced in the application of the models to local conditions. This exchange of experience will increase as more countries in the region become users of the models and new approaches to address certain problems are found.

The overall success of the project will be highly dependent on the effective participation by the interested countries and the support to be provided for the continuation of the project. The large number of participants in the present workshop is a good indication of such interest and support and thus anticipates, an excellent start for the project.

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ENPEP MODEL ENHANCEMENTS AT ANL

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Abstract

Argonne National Laboratory (ANL) has been involved in energy and electricity planning analyses for almost 20 years. Their activities include the development of analytical tools and methodologies along with their application to a wide variety of national energy planning studies. The methodologies cover all aspects of energy planning. In response to a request by the US Department of Energy (USDOE) to integrate existing tools into a package that could be distributed to developing countries for their own use, the ENergy and Power Evaluation Program (ENPEP) was developed. The USDOE wanted an all purpose tool that would allow the user to do a complete energy analysis, from demand forecast through primary energy resources allocation to electricity generation system expansion plan and environmental analysis. Since its original development, the ENPEP modules have been improved and enhanced to incorporate advancements in computer hardware and software technology, as well as to correct bugs that were identified in the programs. In cooperation with other organizations (e.g. The World Bank - IBRD - and the International Atomic Energy Agency - IAEA -), the ENPEP package has been used at national, regional and inter-regional training courses, as well as in the conduct of national energy/electricity planning studies. This paper reviews the development of the ENPEP package and the proposed enhancements to the package.

INTRODUCTION

The development of the ENPEP system began in 1985 at ANL. Prior to that time, most energy planning activities were carried out on large mainframe computers. These computers often belonged to the financial division of an organization and had little time available to run energy planning tools. The arrival of desk top PCs provided an opportunity to transfer the existing tools to a platform that the energy planners could control at a cost that was reasonable. ENPEP was planned as a modular tool that could be integrated. Each module can be used as a stand alone package or as in conjunction with other modules of the ENPEP system, depending on data availability and the scope of analyses to be conducted in each case. The different modules of the ENPEP package and alternative paths to use the system are illustrated in Figure 1.

Considering the limitations of the early PCs, e.g. memory and disk space, the program developers worked diligently to respect the constraints of the available technology. Because of these limitations special emphasis was given to the design of a flexible system that could be easily adapted to different working environments.

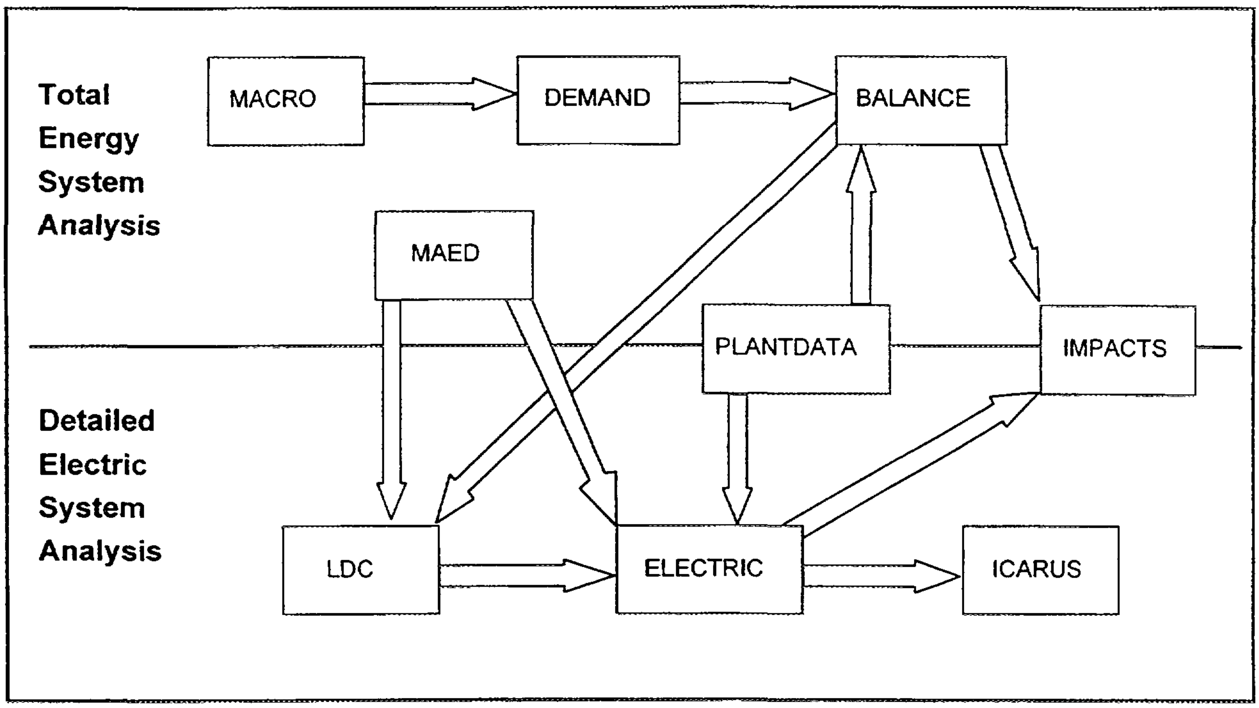

Fig. 1 Overview of the ENPEP System and the Various Chains for using the Modules

Upon completion, the ENPEP package was transferred by the USDOE to the IAEA for release to interested Member States and international organizations. Before initiating overall distribution of the program, the IAEA, in cooperation with some Member States and with support provided by the USDOE and ANL, conducted several field tests to validate the program and its application to national conditions. The first field test was executed in 1987 in co-operation with Indonesia followed by a second field test with Malaysia in 1988.

At the end of 1988, The World Bank initiated a regional project on energy planning for Europe and the Arab States, funded by the United Nations Development Programme (UNDP). Under this project several countries carried out energy planning analyses using different planning tools, including various modules of the ENPEP package and other planning tools supported by the IAEA (e.g. MAED, VALORAGUA). In support of these studies, training courses were required for users of the ENPEP modules. Table 1 shows that 42 persons participated in the World Bank/UNDP sponsored ENPEP training courses at ANL in 1988 and 1989.

The IAEA also recognized the need to provide formal training on the ENPEP package. As such, they organized the first Interregional Training Course on Integrated Energy and Electricity Planning for Nuclear Power Planning with emphasis on the ENPEP package in 1991. This was followed by a second IAEA sponsored ENPEP training course in 1992. A regional ENPEP course was held in Hungary in 1994. See Table 1 for the number of participants and countries represented in each course.

Since the development of the ENPEP package, it has been distributed to more than 35 countries and 5 international organizations which are using it for integrated energy and electricity planning. Independent modules of the system (e.g. MAED, ELECTRIC/WASP, LDC and ICARUS) have been released to additional countries who are using one or more of the modules for planning of their electricity system.

Enhancements to the ENPEP Package

Since the ENPEP package was first developed, several enhancements have been introduced in cooperation and with support from the IAEA. Additional funding from the United States government has also been provided for these enhancements.

These enhancements have been necessary to adapt the program to changing commercial software and to introduce improvements as required by the users. This has led to updated ENPEP versions that respond better to the needs of the planner while making use of limited commercial software packages.

Most Recent Enhancements

The latest version of the ENPEP package was distributed at the end of the 1994 regional training course in Paks, Hungary. Since then several enhancements have been made, including:

- increased the dimensions of the BALANCE module to accommodate networks with up to 1000 links and 100 demand growth projections. This was in response to requests of BALANCE users who were confronted with complex energy networks. The original system allowed only 500 links and 20 demand growth projections.

- incorporated the newest version of the WASP program (WASP-III PLUS) as the ELECTRIC module of ENPEP. WASP-III Plus was developed by the IAEA for use in mainframe computers. The adaption of the model included conversion of the code to the PC environment and the introduction of additional ENPEP screens to allow the user to input new data items.

- updated the IMPACTS module to accommodate BALANCE networks with up to 1000 links. This was required because of the increased number of links in the BALANCE module.

- revised the ENPEP User's Manual to reflect program enhancements.

Near-Term Improvements

Based on requests from several users of the program, the following enhancements are being introduced:

- End of 1995:

  Finalize the current version of the program (Version 3.0) including:

  1) correct problems encountered during the conduct of the inter-regional training course on energy demand forecasting for nuclear power planning (MAED) held at ANL in Spring 1995.

  2) insure full transfer capability of data between ENPEP modules, particularly after having introduced WASP-III Plus as the ELECTRIC module.

  3) resolve pending problems encountered in the ELECTRIC and BALANCE modules.

- February 1996:

  Enhance the representation of the electric sector in the BALANCE module with the goal of making it consistent with the electric sector representation in the ELECTRIC module (WASP).

Long-Term Enhancements

As microcomputer software becomes more powerful and advanced, user-friendly environments (i.e. Windows) are considered state-of-the-art for PC applications. It has been realized that there is a need to develop a Windows version of ENPEP. Attempts in this direction have been initiated by the Russian Research Centre "Kurchatov Institute" which developed a prototype for the MACRO and DEMAND modules.

The ENPEP development team has set up the following guidelines for developing the Windows version of the program:

- the GUIDE Module functionality will constitute the basis of a Windows version of the BALANCE module in order to take advantage of the experience obtained during the development of the GUIDE module.

- the ELECTRIC module will take advantage of the developments made under the Interagency project on Data Bases and Methodologies for Comparative Assessment of Different Energy Sources for Electricity Generation (DECADES) in order to make use of the databases already developed.

- the IMPACTS module will be re-designed to take advantage of enhanced commercial software for handling databases and spreadsheets.

- the PLANTDATA, LDC, MAED and ICARUS modules will not be a part of the initial windows version of ENPEP

- a Beta version of ENPEP-Windows is proposed to be available in 1997.

TRAINING COURSES

As discussed earlier, several training courses on ENPEP have been organized by the World Bank/UNDP and the IAEA. Table 1 summaries the ENPEP training courses conducted to date and displays the number of experts and countries that have participated in each session of the course.

Table 1 ENPEP Training Courses

Year	Number of Participants	Number of Countries	Sponsoring Agency	Course Venue
1988	20	9	World Bank/UNDP	ANL, USA
1989	22	11	World Bank/UNDP	ANL, USA
1991	33	11	IAEA	ANL, USA
1992	37	12	IAEA	ANL, USA
1994	30	11	IAEA	Paks, Hungary

The number of trained experts in the use of ENPEP has been further increased when considering on-the-job training that has been provided by ANL/IAEA experts during the conduct of national training planning studies that were carried out under the regional World Bank/UNDP energy project previously mentioned and as part of the regular Technical Cooperation (TC) Programme of the IAEA.

ENPEP is also being used for mitigation analysis by several countries as part of the United States Country Studies Program (CSP). Several U.S. governmental agencies are sponsoring this analysis.

Table 2 lists countries in which ENPEP studies are currently being conducted along with the sponsoring agencies.

Table 2 Current ENPEP Country Activities

Sponsoring Organization	Active Country Analysis
IAEA	Belarus, Colombia, Indonesia, Peru, Poland, Pakistan, Romania
World Bank	Nepal, Pakistan, Philippines, Turkey, Uruguay, Zambia
Country Studies Program	Hungary, Kazakstan, Peru, Slovakia, Thailand, Ukraine, Venezuela

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ELECTRICITY AND HEAT ENERGY CO-GENERATION PROCESS MODELLING IN BELARUS

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Abstract

This paper describes the experience gathered in the application of the ENPEP package to the conditions of Belarus energy system, focusing on the principal problems encountered in modelling a system having an important component of co-generation systems to satisfy the demands for electricity and heat. The approach used to solve this problem and some recommendations for future enhancements of the ENPEP program are discussed. The preliminary results obtained with the use of the model, as well as further analyses expected to be conducted in the near future are also described.

1. INTRODUCTION

The energy system in Belarus was developing as a part of the integrated fuel energy complex of the former Soviet Union. The breakdown of the integrated energy system of the former USSR resulted in a situation in which the Belarus energy system became independent, but suffering from a deficit in supply, with a far-from-optimal structure of the generation power and one-way connection through power lines with the Northeast.

In 1993 the total final energy consumption was 20.9 MTOE (see Fig. 1). The share of electricity and heat was 55% of the total energy (about 13% for electricity and 42% for heat, respectively). The share of the other fuel types in the energy mix amounted to 10.5 MTOE (45% of the total).

2. ENERGY SUPPLY

The basic type of fuel used is gas (55% of total fuel consumption for heat and electricity production), while fuel oil is used as a reserve (31% accordingly).

TOTAL, MTOE	HEAT	ELECTRICITY	SOLID FUELS	OIL PRODUCTS	NATURAL GAS
20.90	8.6	2.8	1.6	5.6	2.3

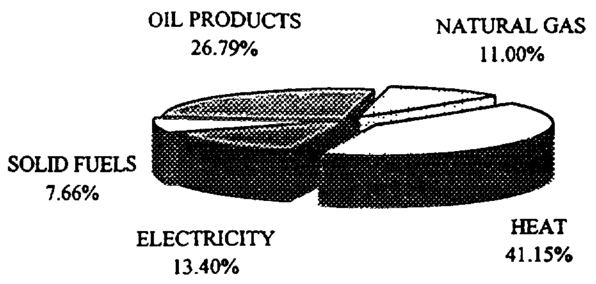

Fig. 1. FINAL ENERGY CONSUMPTION, 1993, MTOE

Fuel consumption in the energy sector was determined as 121.6 MBOE in 1993 (see Fig. 2). This includes:

27.2 MBOE of fuel for electricity generation at the power plant (22%);
41.1 MBOE for heat generation at the heat plants (34%);
53.3 MBOE for heat and electricity generation at the co-generation plants (44%).

TOTAL, MTOE	ELECTRICITY GENERATION	HEAT & ELEC. GEN.	HEAT GENERATION
121.60	27.2	53.3	41.1

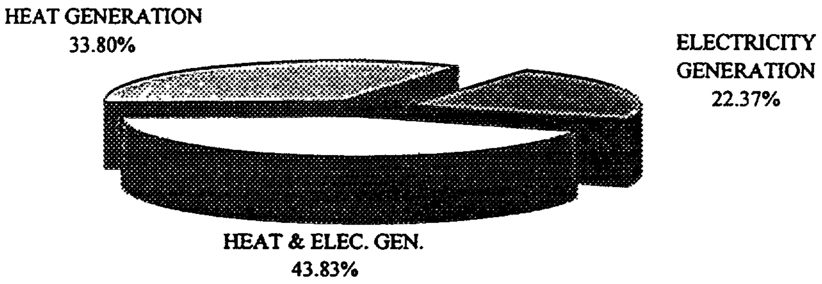

Fig. 2. FUEL CONSUMPTION IN THE ENERGY SECTOR, MBOE, 1993

3. ELECTRICITY

By 1993 the installed power capacity of electric power plants in Belarus reached 6921 MWt, but accounting for repairs, forced outages, unloaded and spinning reserves, the total available capacity was 5800 MWt . At the same time maximum demand for electric power was 7200 MWt. That is the deficit of electricity in 1993 was about 1500 MWt. However, as a result of the economic crisis and accompanying recession of consumption of all types of fuel and energy resources, including electric power, the generation power deficit has been reduced and is expected to decrease further to about 500-800 MWt in 1998. If the economic crisis continues, Belarus energy system will cease to be deficient.

As seen in Fig. 3, the gross electric power production in the country was 33.4 TWt.h (21.1 MBOE) and total consumption 39.7 TWt.h (27.4 MBOE). Generally, in 1993, Belarus energy system suffered deficit and was forced to import 14% (3.8 MBOE). At this time the losses were calculated as 9% (2.5 MBOE).

The specific fuel consumption for electricity generation is within the range of 292 - 297 kg. coe/kWt.h depending on the load, but it is necessary to note that such a small consumption was caused by peculiarities of accounting modes. Maximum electric power production occurs during winter and coincides with the maximum load of the central heating system.

TOTAL, MTOE	POWER PLANT	COGEN. POWER PLANT	IMPORT	LOSSES
27.40	10.8	10.3	3.8	2.5

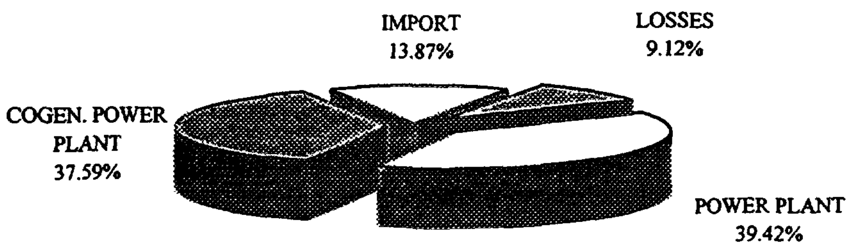

Fig. 3. ELECTRICITY PRODUCTION IN 1993, MBOE

4. HEAT DEMAND

The heating season in Belarus lasts from October until April. More than 50% of the households in the Republic are connected to the central heating system.

The gross heat production in 1993 was 68.9 MBOE distributed as shown in Fig. 4.

TOTAL, MTOE	COGEN. POWER PLANT	HEAT POWER PLANT	LOSSES
121.60	24.7	39.5	4 7

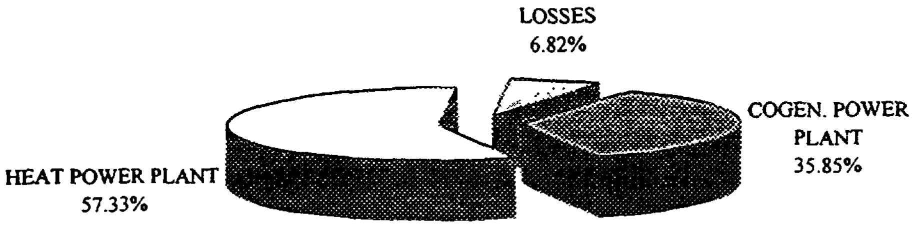

Fig. 4. HEAT PRODUCTION IN 1993, MBOE

Most of the co-generation plants are concentrated in large cities. Their specific fuel consumption for heat production is in the range 170-175 kg coe/Gcal. Heat transportation by heat networks causes about 7% losses. Central heating development in Belarus has gone beyond economically rational scale, as the expenses for heat production by heat plants, repairs of the heat networks, and the network losses exceed the benefits obtained from using power plants with co-generation of heat and electricity.

The equipment in the Belarus energy system is considerably worn out and obsolescent. For example the base equipment is 50-60% worn. A number of old power plants have exhausted their service life and need reconstruction or to be replaced, preferably with steam-gas power plants, that would enable combined production of heat and electricity.

5. FUTURE DEVELOPMENT OF THE HEAT AND ELECTRICITY SUPPLY SYSTEMS

The previous paragraphs illustrate the importance of co-generation systems within the energy system of Belarus and why current efforts are being undertaken in order to study their future development. For this purpose, a study is underway for analysing in detail the future requirements of primary energy and the corresponding development strategy of the energy system, including co-generation. ENPEP is being used as the main tool to conduct this study.

Some difficulties were experienced while applying the BALANCE module of ENPEP to the conditions of Belarus, in particular relating to the representation of co-generation process of electricity and heat. The reason for this problem is that BALANCE module has no direct opportunity to model the co-generation process as a type of facility that would allow the dispatch of the operation of these plants for heat and electricity production. In fact, BALANCE only permits dispatching of the electricity generation plants included in the "ELECTRIC" sector, but heat plants are not dispatchable in BALANCE.

To model the Belarussian heat and electric systems using BALANCE, only conventional electricity generating units were included in the electric sector dispatch. The different types of electricity units include existing gas and fuel oil units and candidate units using gas, coal, or nuclear fuel.

The co-generation processes were represented using multiple output link nodes which have fuel as an input and heat and electricity as output products. The electricity generated from co-generation processes is linked to a common allocation node which subtracts cogenerated electricity from the total requirements to be met by dispatchable units. The heat generated from co-generation processes is linked to a common allocation node. In this representation, co-generation processes compete with conventional heat boilers to meet the overall demand for heat (see Fig. 6).

It is also supposed that co-generation plants and heat generated plants use gas and fuel oil only, because these units are allocated in large cities and must therefore satisfy pollution regulations. In addition, the different types of co-generation units were described as old gas & fuel oil units and gas new/perspective units. The new units were separated as steam cycle blocks, gas-turbine heat utilisation installations, and gas-steam units (binary cycle units).

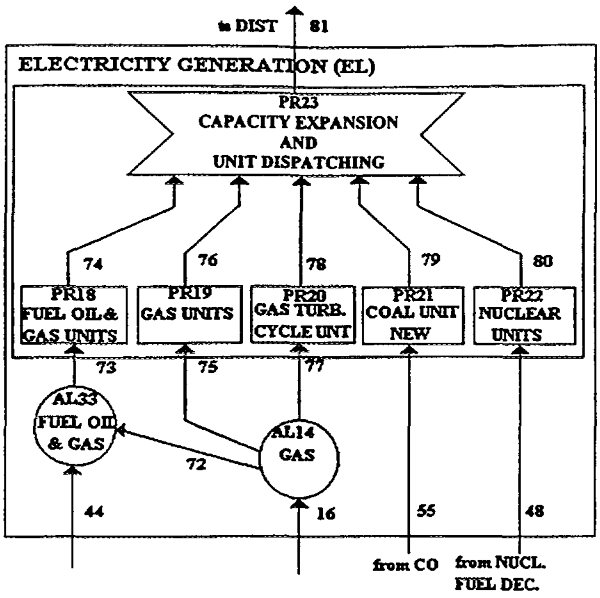

Fig. 5. Electricity Generation (EL) Sector of the Belarus Energy System

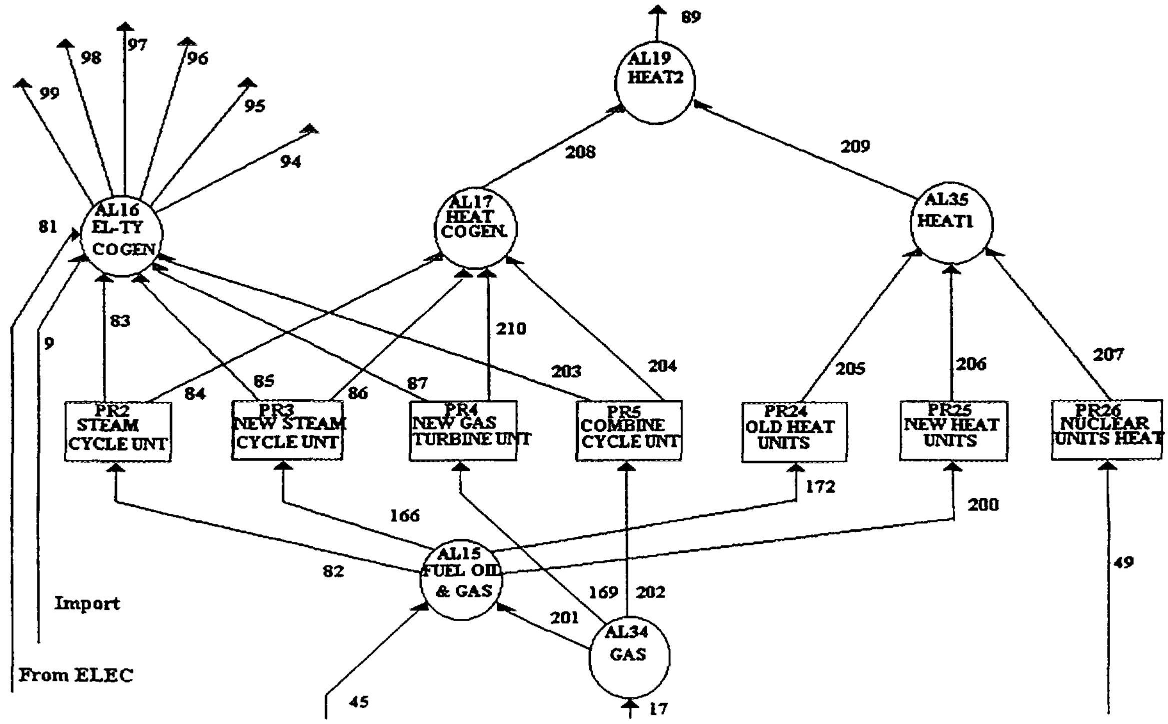

Fig. 6. Heat and Electricity Co-generation (HE) Sector of the Belarus Energy System

6. PROBLEMS ENCOUNTERED IN THE USE OF ENPEP

Among the difficulties encountered while applying ENPEP to the energy system of Belarus, it is necessary to note the following items:

- Modelling co-generation power plants regime process

Multiple Output Link nodes for electricity and heat in the BALANCE module do not automatically control the output shares based on changing demands for heat and electricity. In this respect, it is known that the shares of heat and electricity are not constant with time. In this case the overflow of heat links is possible. Consequently, it would be very desirable to model cogenerating processes accounting for the difference between quantities of heat and electricity supplied for different demand levels of heat and electricity.

- Modelling of price processes for heat and electricity at power plant

Since heat and electricity production by co-generation processes are more effective than separate generation of heat and electricity, it is necessary to reflect these differences by energy tariffs. At the same time it is desirable to remember that co-generation units are more expensive than usual electricity blocks.

- Determination of co-generation power plant efficiency

This question is connected with the problems that were mentioned above. The benefits obtained from using electricity production with heat utilisation and consumption depend on electricity level load as well as on heat level load. It is very desirable to model cogenerating processes accounting for the different efficiency for different demand level of heat and electricity.

DEVELOPMENT OF APPROACH AND PREPARATION OF INITIAL INFORMATION FOR FEASIBILITY INVESTIGATIONS OF THE INTRODUCTION OF NUCLEAR POWER IN BELARUS

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Abstract

The experience in using the MACRO, DEMAND and BALANCE Modules of ENPEP in the conduct of energy planning studies in the Republic of Belarus is described in this paper. The work was done in the framework of the IAEA Technical Co-operation project BYE/0/003 "Energy and Nuclear Power Planning Study for Belarus Using ENPEP". The paper presents results of the work undertaken by the members of the Belarus team for this project.

1. Background information about Belarus

Belarus has an area of 207,600 km^2, stretching 560 km from North to South and 650 km from East to West. It is bordered by Poland in the West, Russia in the East, Lithuania and Latvia in the North and Ukraine in the South. The Republic of Belarus occupies an advantageous position in the center of Europe. The main communications linking Western Europe and Russia pass through Belarus and Poland.

Extensive plains dominate the landscape. The highest elevation is only 307 meters above sea level. A chain of hills running latitudinal divides the country into a northern part, where rivers drain into the Baltic Sea, and a southern part that belongs to the Black Sea basin. The climate is mild continental and moderately wet, resulting in an abundance of marshy land that covers more than 20 percent of the country. Monthly average temperatures are in the range of -7 to +18 °C. Apart from potassium chloride and peat, Belarus lacks of significant mineral resources.

Belarus is a middle income country with a population of 10.3 million inhabitants and an estimated per capita income of USD 2,920 in 1992. In 1989, 78 percent of the population was of Belarus origin, 13% Russian, 4% Polish and 3% Ukrainian. Average population density is 49 persons per km^2. About 67% of the population live in towns and 33% in rural areas. The shift from rural to urban population was a gradual process. The forecast of population growth in Belarus shows very slow increase of the total population in the period 1993-2020.

The GDP behaviour during recent years is shown in Figure 1. The decreasing trend of GDP which started in 1991 is connected with the political situation and the reconstruction of the economic system.

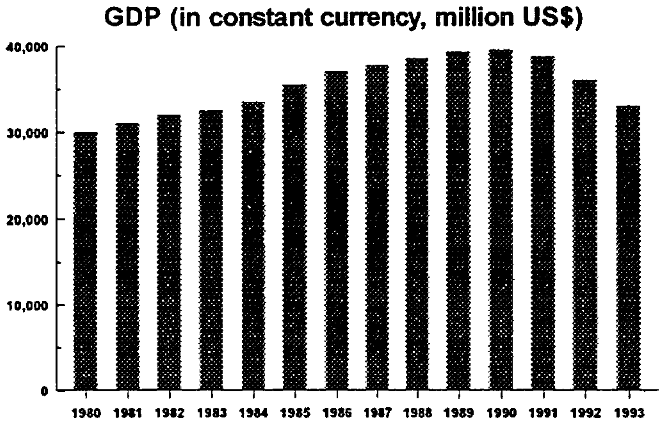

Fig. 1. Belarus GDP historical data

2. Current energy situation

Belarus has a very small amount of indigenous energy resources. Primary energy consumption in 1993 was 31.5 MTOE, of which less that 10% (2.8 MTOE) was produced in Belarus. The structure of domestic primary energy production is shown in Fig. 2.

TOTAL, MTOE	CRUDE OIL	NATURAL GAS	SOLID FUELS	HYDRO
3.71	2.6	0.3	0.8	0.01

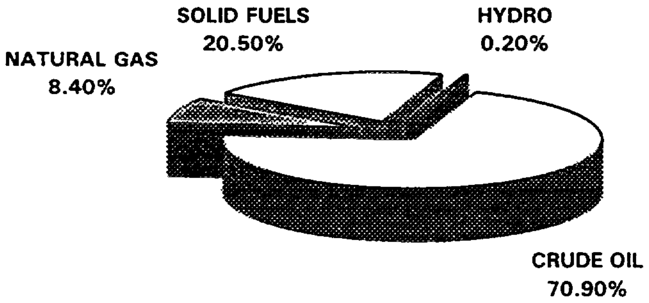

Figure 2. Domestic primary energy production

The structure of imported primary energy consumption is shown in Fig. 3, which illustrates the predominance of oil and natural gas in the energy mix.

TOTAL, MTOE	CRUDE OIL	ELECTRICITY	SOLID FUELS	NATURAL GAS	OIL PRODUCTS
28.7	12.2	1.5	0.6	13.0	1.4

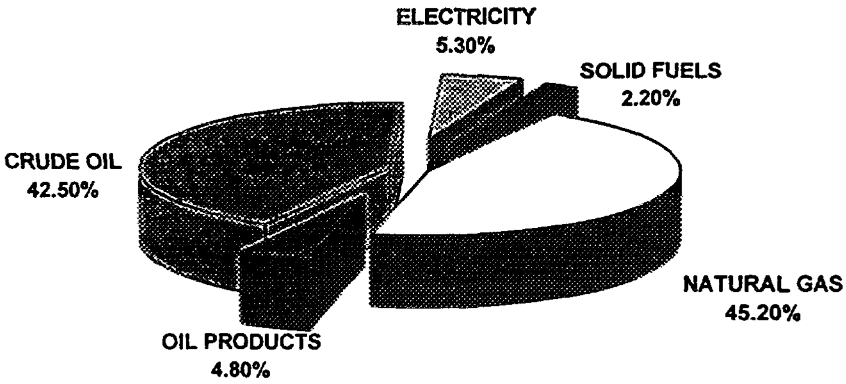

Fig.3. Imported primary energy consumption

The structure of production of secondary energy forms in Belarus is shown in Table 1 while the final energy consumption by energy type is shown in Fig. 4.

Table 1

Secondary Energy Production in Belarus in 1993 (MTOE)

ENERGY FORM	QUANTITY	USED FUEL		
		NATURAL GAS	FUEL OIL	SOLID FUEL
ELECTRICITY	2.9			
HEAT	9.4			
TOTAL	12.3	10.4	5.8	0.7
GASOLINE	1.8	CRUDE OIL		
KEROSENE	1.0			
DIESEL	3.4	13.5		
FUEL OIL	6.1			

The breakdown of the consumption of final energy by economic sector is shown in Fig. 5 through Fig. 9.

TOTAL, MTOE	HEAT	ELECTRICITY	SOLID FUELS	OIL PRODUCTS	NATURAL GAS
20.90	8.6	2.8	1.6	5.6	2.3

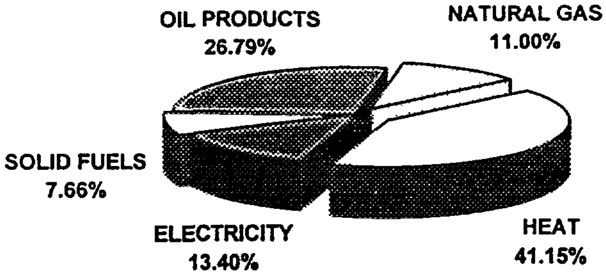

Fig. 4. Final Energy Consumption

TOTAL, MTOE	INDUSTRY	AGRICULTURE	HOUSEHOLD	SERVICE	TRANSPORT
2.80	10.5	4.5	3.0	1.5	1.5

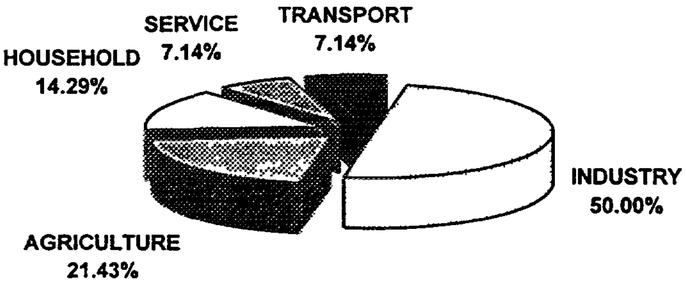

Fig. 5. Electricity Consumption by Sector

TOTAL, MTOE	INDUSTRY	AGRICULTURE	HOUSEHOLD	SERVICE	TRANSPORT
8.60	10.0	1.5	8.0	1.2	0.2

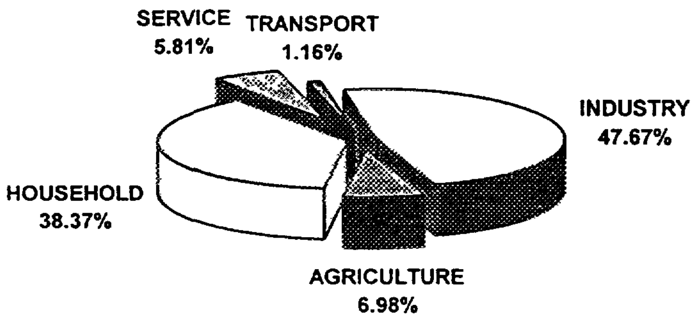

Fig 6 Heat Consumption by Sector

TOTAL, MTOE	INDUSTRY	AGRICULTURE	HOUSEHOLD	SERVICE	TRANSPORT
2.30	0.9	0.1	0.8	0.3	0.2

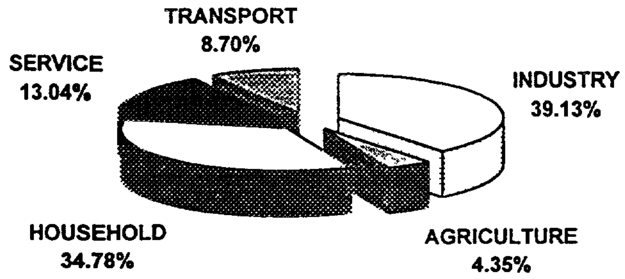

Fig. 7. Natural Gas Consumption by Sector

TOTAL, MTOE	INDUSTRY	AGRICULTURE	HOUSEHOLD	SERVICE	TRANSPORT
5.6	0.7	1.0	0.5	0.1	3.3

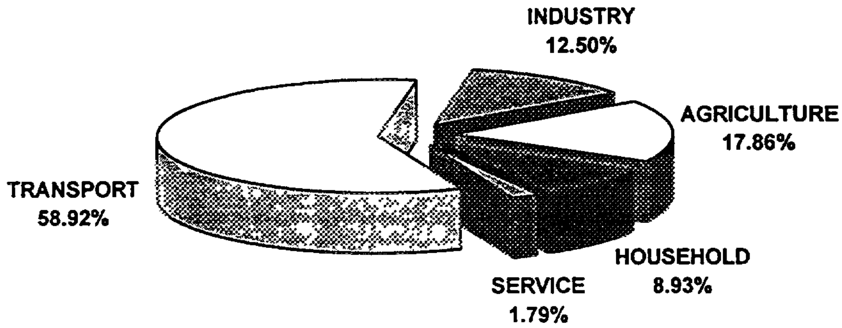

Fig. 8. Oil Consumption by Sector

TOTAL, MTOE	INDUSTRY	HOUSEHOLD	SERVICE
1.6	0.1	0.8	0.7

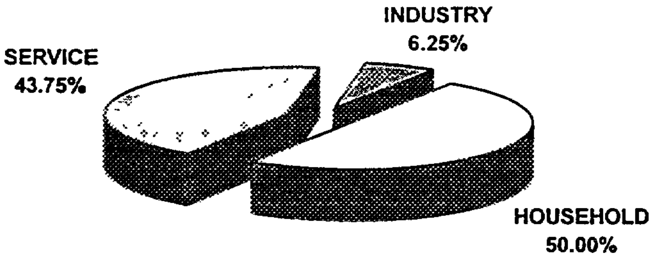

Fig 9. Solid Fuel Consumption by Sector

3. MACRO and DEMAND module results

The MACRO module has been used to calculate time dependency of the GDP Value Added by economic sector, namely: Industry, Agriculture, Household, Service, Transport, Export. These dependencies are shown in Table 2. The time period 1993 - 2020 was selected for the current study.

Table 2

GDP Growth Rate by Sector

YEAR	INDUSTRY	AGRI-CULTURE	HOUSE-HOLD	SERVICE	TRANS-PORT	EXPORTS	TOTAL
1994	-4.2	-2.0	-2.0	-3.0	-2.1	-3.5	-2.8
1995	-3.4	-1.0	-1.0	-2.0	-1.3	-3.0	-2.0
1996	-2.5	0.0	0.0	-1.0	2.4	-2.0	-0.8
1997	-1.1	0.5	0.6	0.0	0.9	-0.5	0.0
1998	0.2	1.5	1.0	0.0	1.9	-0.5	0.5
1999	1.4	0.9	-0.2	2.0	2.1	-0.1	1.2
2000	2.8	0.7	2.2	3.0	1.5	-0.1	1.9
2001	3.1	2.5	2.6	4.0	2.6	-0.1	2.8
2002	3.2	3.5	2.6	4.0	2.8	-0.1	3.1
2003	3.4	3.5	2.6	4.0	3.9	0.5	3.2
2004	2.9	3.5	2.6	4.0	3.9	1.0	3.3
2005	2.2	3.5	2.6	4.0	3.9	1.0	3.3
2006	2.0	4.0	3.2	4.0	3.4	1.1	3.3
2007	1.8	4.0	3.2	4.0	3.4	1.1	3.3
2008	1.8	4.0	3.2	3.0	3.4	1.1	2.9
2009	1.9	4.0	3.2	3.0	3.4	1.1	3.0
2010	1.9	4.0	3.2	3.0	3.3	1.6	3.0
2011	2.8	4.9	2.2	3.0	4.1	2.6	3.3
2012	2.9	4.9	2.3	3.0	3.2	2.6	3.3
2013	2.9	5.0	2.3	3.0	3.2	2.7	3.3
2014	3.0	5.0	1.6	3.0	3.2	2.7	3.3
2015	3.0	5.0	1.6	3.0	3.3	2.7	3.3
2016	3.0	4.5	1.6	2.0	3.3	2.5	2.8
2017	3.1	4.5	1.6	2.0	3.3	2.5	2.8
2018	3.1	4.5	1.6	2.0	3.3	2.5	2.9
2019	3.2	4.5	1.6	2.0	3.3	2.5	2.9
2020	3.2	4.5	1.6	2.0	3.3	2.5	2.9

The DEMAND module was used to develop projections of fuel, heat and electricity use by sector of demand. In each case, consumption was supposed to be directly proportional to changes of the macroeconomic variables defined in the MACRO module. As a result, the energy demand of all sectors match the trends of these variables, i.e., a decrease during the period 1993-1997 and then a gradual increase up to the end of the study period. The demands in the Agriculture, Transport and Service sectors increase faster than for the other sectors. The use of electricity in the Energy sector almost doubles from 1997 to 2020.

4. BALANCE module results

The BALANCE module was used to conduct an integrated analysis of energy supply and demand activities in Belarus. This integrated approach ensures that the quantities of fuel supplied and demanded are in balance and consistent with the costs of production, transmission and distribution of the energy carriers and the prices paid by the consumers.

BALANCE uses a non-linear, equilibrium approach to determine the energy supply/demand balance. In this formulation, an energy network is designed that traces the flows of energy from the primary resources (e.g. crude oil, coal) through conversion, transportation and distribution facilities up to the demand requirements by the consumers in final terms (gasoline for transportation) or in useful terms (e.g. residential hot water, industrial steam). Sub-models, called *nodes*, are used to represent different components of the energy system. The user connects these nodes by a set of *links*. Each link conveys two pieces of information from one node to another: price and quantity of the energy carrier flowing between the two nodes. All sectors of the energy supply and demand system are included in a BALANCE analysis. The user is free to define the sectors and the nodes and links that are in each sector to meet specific analysis needs.

The network created for the study of Belarus energy system using the BALANCE module is displayed in Fig. 10 through Fig. 16. The most salient characteristic particularity of this network is the existence of a centralized heat and electricity co-generation system, as shown in Fig. 10. About 50% of the total electricity demand and 40% of the heat demand are produced by this system.

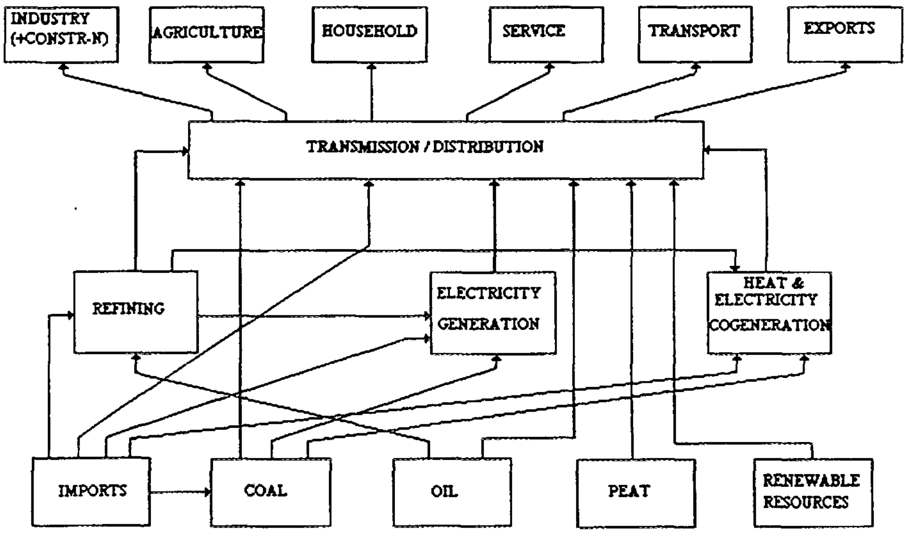

Fig. 10. Sectoral Structure of the Belarus Energy System

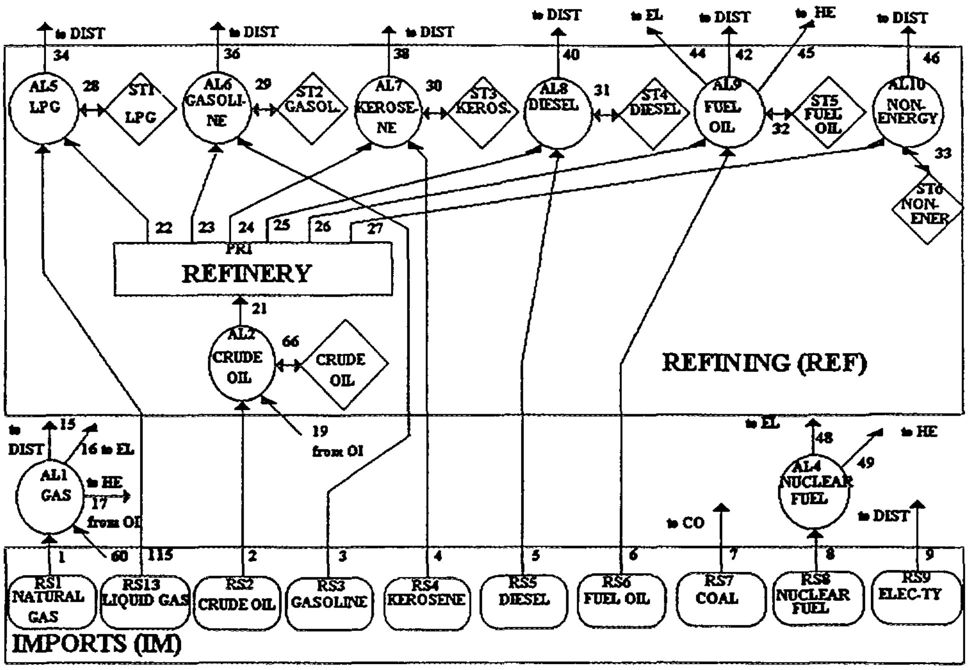

Fig. 11. Imports (IM) and Refinery (REF) Sector of the Generic Belarus Energy System

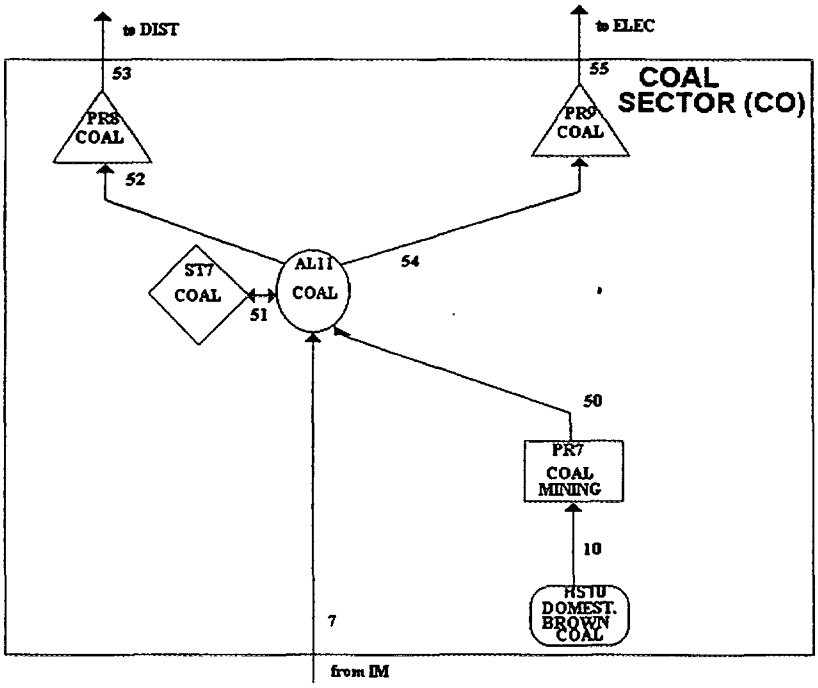

Fig. 12. Coal (CO) Sector of Belarus Energy System

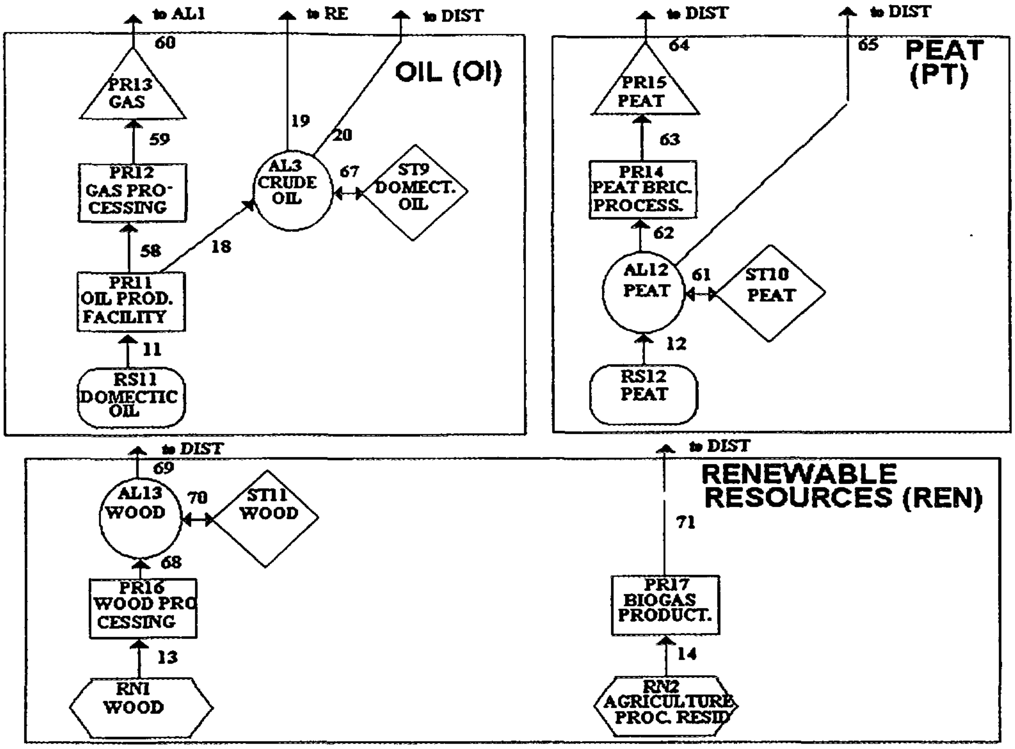

Fig. 13. Oil (OI), Peat (PT) and Renewable Resources of the Belarus Energy System

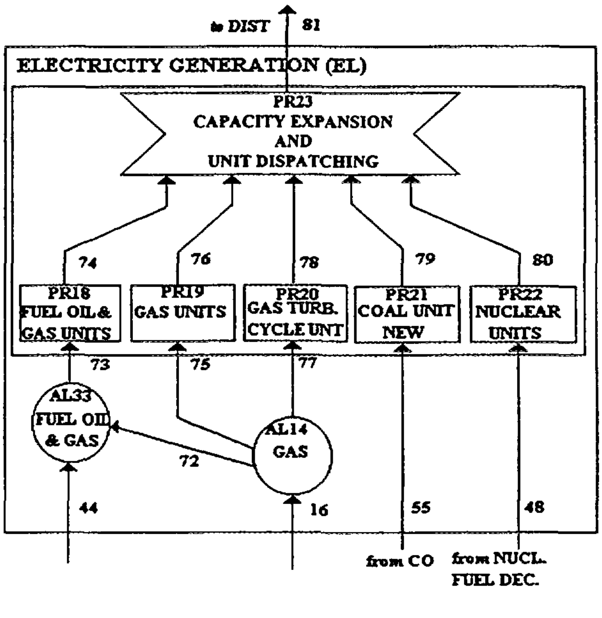

Fig. 14. Electricity Generation (EL) Sector of the Belarus Energy System

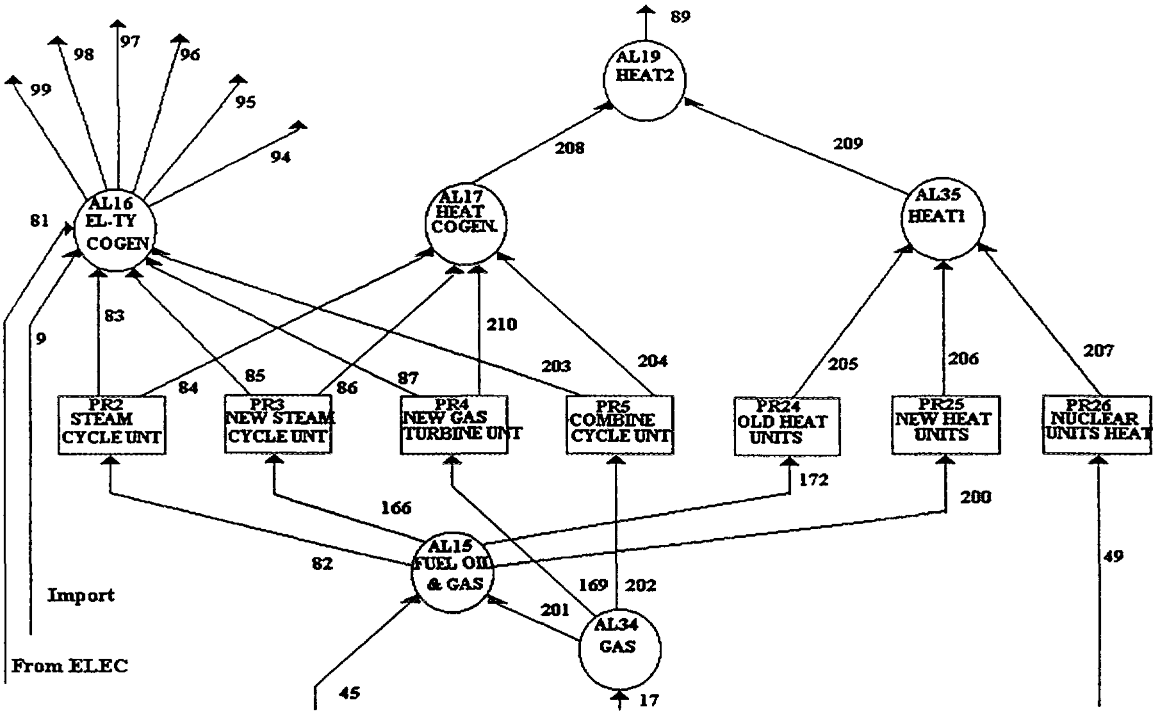

Fig. 15. Heat and Electricity Generation (HE) Sector of Belarus Energy System

INDUSTRY	94	100	112	106	116	121		130	136	142	145	150	155	160	
AGRY-CULTURE	95	101	113	107	117	122		131	137	165	146	151	156	161	71
HOUSEHOLD	96	102		108	118	123	127	132	138		147	152	157	162	
SERVICE	97	103		109	119	124		133	139		148	153	158	163	
TRANSPORT	98			110	120	125	128	134	140	143	149				
EXPORTS	99		114	111		126	129	135	141	144		154	159		

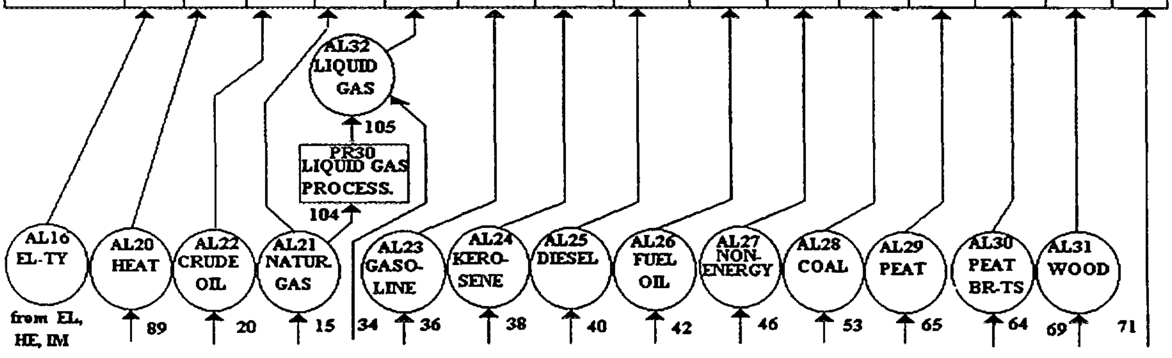

Fig. 16. Transmission and Distribution (TD) Sector of Belarus Energy System

As can be seen in the previous figures, multiple output nodes are used to represent resource processing facilities such as refineries and oil/gas separation plants. A one-level structure of final energy demand was used for this stage of the study, mainly due to the lack of demand projections in terms of useful energy. Table 3 shows the prices of the energy resources.

Table 3

Prices of Energy Resources ($/BOE)

RESOURCE	PRICE		RESOURCE	PRICE	
NATURAL GAS	IMPORTED DOMESTIC	11 8	NUCLEAR FUEL	IMPORTED	2
CRUDE OIL	IMPORTED DOMESTIC	8 3	ELECTRICITY	IMPORTED DOMESTIC	30 39
GASOLINE	IMPORTED DOMESTIC	25 25	HEAT	CPP HPP	26 40
KEROSENE	IMPORTED	20		NHPP	26
	DOMESTIC	20	WOOD	DOMESTIC	3
DIESEL	IMPORTED DOMESTIC	18 22	PEAT	DOMESTIC	
FUEL OIL	IMPORTED DOMESTIC	7 8	COAL	IMPORTED DOMESTIC	5 5

One of the difficulties encountered in the application of BALANCE to Belarus conditions was connected with the definition of the operation and maintenance (O&M) cost and the capital cost of energy sources. A special methodology was developed based on expert-estimated increase of prices by conversion processes and the relationship between O&M cost and capital recovery part of output prices.

Some interesting results achieved from the analysis conducted with BALANCE are given in Figures 17 and 18. As shown in Fig. 17, under the assumptions made about the economic characteristics of nuclear power plants, the analysis shows the possibility of introduction of nuclear power into the energy system of Belarus without altering the relative price of electricity against alternative energy carriers. This result need to be confirmed with further studies in which the energy demands are expressed in useful terms so as to effectively analyze the substitution process between energy carriers.

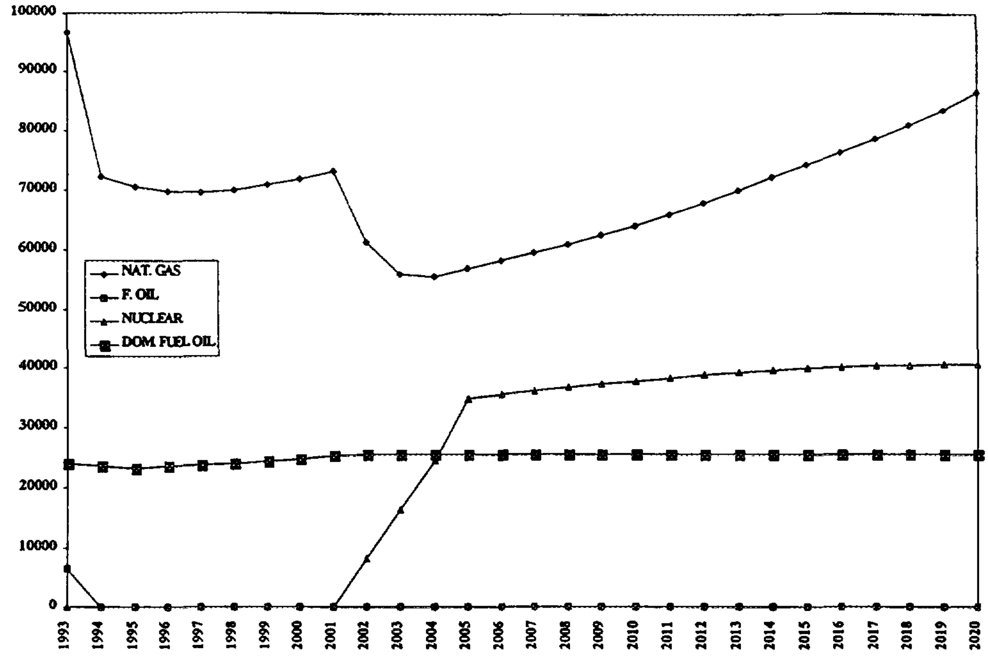

Fig. 17. Supply side of energy balance

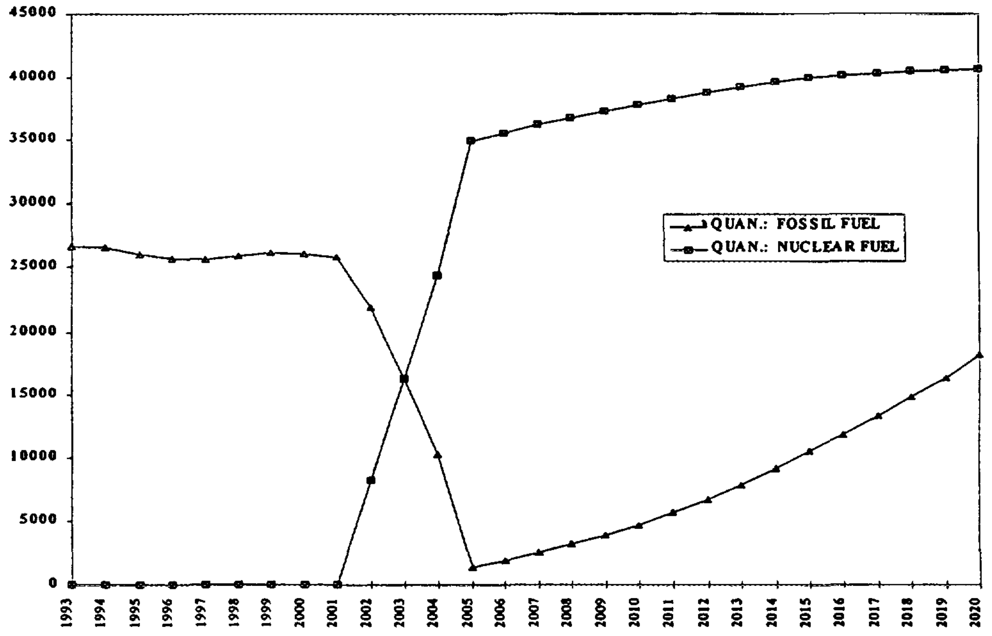

Fig. 18. Use of Fossil and Nuclear Fuel for Electricity Production

5. Conclusions

The following steps have been accomplished in the application of the ENPEP package to the analysis of Belarus energy system:

- the economic structure and statistical data have been adjusted for use by the MACRO and DEMAND modules;

- the network representing Belarus energy system for use in the BALANCE module has been developed taking into account the co-generation sector.

Initial calculations using the MACRO, DEMAND and BALANCE modules are carried out for the actual and expected economic conditions and the energy situation:

- energy demands of one-level structure (in terms of final energy) are calculated using the MACRO and DEMAND modules;

- energy balance information for the long term period is obtained for use in the other ENPEP modules.

The results of BALANCE provide a preliminary indication of the competitiveness of nuclear power in meeting the future requirements for energy and electricity services but these need to be confirmed by more in-depth studies. Further work will be connected with the development of a more complicated demand level structure by defining the demands in useful terms. The more detailed network structure will allow for analyzing the potential for fuel switching and the impact of demand side measures such as efficiency improvements.

The results of the analysis carried out with the BALANCE and ELECTRIC modules will be passed to the IMPACTS module of ENPEP in order to determine the environmental burdens and resource requirements associated with different energy and electricity systems configurations. These inter-linked analyses will serve as the basis for decision making on development strategies of the energy and electricity system of Belarus.

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IMPROVEMENTS TO THE IAEA's ELECTRIC GENERATION EXPANSION MODEL

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Abstract

This paper deals with the implementation of the IAEA's planning approach and software in Bulgaria. The problems encountered in the process are summarized, with emphasis on two of the limitations of the electric generation expansion model (WASP). The solutions found by Bulgarian experts to overcome these problems are also described, together with some comparative results of the tests performed.

1. INTRODUCTION

This paper aims at providing information on the use of IAEA planning approach and software in Bulgaria and some details concerning the introduction of IAEA's tools in Bulgaria, as well as the experience with WASP and ENPEP in Bulgaria since 1988.

As an introduction to the topics to be discussed, it is worth mentioning certain general aspects related to the use of IAEA models in Bulgaria, namely:

- The IAEA's planning software - WASP and ENPEP- are operative in several Bulgarian organisations / institutes;
- Different modules of IAEA's software are used in several official or non official investigations;
- The IAEA's planning software is known, verified and used often for research made on request by the Bulgarian Government and/or international or foreign financial institutions.

It should be noted that before 1980, several Bulgarian and Russian planning models were used in Bulgaria. These models were based mainly on linear optimisation and forecasts based on statistical figures. Since 1978, Bulgarian organizations have used the set of planning models - MACRO, MEDEE, MESSAGE, IMPACTS - that were originally developed by the International Institute for Applied System Analysis (IIASA).

The WASP model was introduced in Bulgaria in 1988/1989 as a result of the participation of a team of experts from ENERGOKIBERNETIKA in the IAEA's training course on Electric System Expansion Planning. At that time, the first official study using the IAEA's planning approach was performed, upon request of the Bulgarian Committee of Energy. Later, other studies were performed for the Bulgarian National Electric Company (NEC) and other organizations. In addition, some training courses were also organized to train national experts interested in using the WASP model, etc.

Training in the use of the ENPEP modules MACRO, DEMAND, MAED, BALANCE, PLANTDATA, LDC, ELECTRIC, ICARUS, IMPACTS was provided to Bulgarian Specialists during their participation in the IAEA Training Course on this subject at Paks, Hungary, 1994.

The time period of the introduction of IAEA's planning approach in Bulgaria coincides with the transition period from centrally planned to market economy. Meanwhile other models have been made available to Bulgaria, such as for example electric generation models obtained from France and from state Maine, USA; electricity/energy/environmental models obtained from EPRI, USA and the European Energy Commission (MARCAL/MACRO, EFOM/ENVIRONMENT with GAMS), etc.

In the beginning, the implementation of IAEA's software encountered misunderstanding and underestimation. Nowadays, due to several reasons, the IAEA's planning approach and software prevails over other models in Bulgaria.

During the several years of work with the electric system expansion planning model - WASP/ELECTRIC - different problems have been encountered. As it is known the model has some limitations, some of which were identified and dealt with, from the beginning, by Bulgarian specialists, for example:

1) static mode of modeling of power plants characteristics, which are maintained constant during all years of the planning study period;
2) modeling of maintenance as distributed into the year and average for all years which does not properly reflects the conditions of the Bulgarian power system;
3) missing of electricity production limitations on group or separate thermal power plants.

The first two of the above limitations are considered in this paper.

The implementation of electric generation expansion planning models in Bulgaria shows that the limitations mentioned above pose a problem for the representation of the conditions of the Bulgarian electric system. In our practice, most of the thermal power plant characteristics - minimum and maximum unit capacity, heat rate, FOR, operation and maintenance costs, etc. - change substantially along the years with deterioration of the plant performance as the plant becomes older. The reasons for this are: physical obsolescence of the devices, technology/technical/design features, and organisational and management weaknesses. Consequently, the performance values of the power plants during one maintenance period are changed, and the maintenance does not recover 100% of the values. As a result, after several years of utilisation, the average value of the above parameters in some Bulgarian thermal power plants is about 92-98% of the initial value. Owing to this problem, Bulgarian planners refused to work with a based on constant characteristics of PP (henceforth referred to as "static model") and distributed, average yearly maintenance.

The above explanation reveals the importance of modeling the power plant parameters in a dynamic way in long time electric generation planning studies.

There are several methods to overcome this limitation. One of these methods is to use dummy declared power plants (referred to as "PP" units), retiring the PP units at a certain time and putting into operation generation units for a plant type with modified values (referred to as "PP2" units). But the limitations on the number of thermal units which can be modeled, constrain the number of dynamically modeled units and the time intervals for dynamic changes. In addition, this method is exogenous and does not allow for a smooth change of the PP characteristics.

Another exogenous method is to use a series of model runs with different values of characteristics and extract some conclusions by combining the results. This method does not give a correct dynamic character of the behaviour of PP characteristics owing to the difficult task of making the input and output data, as well as the results, consistent.

A third exogenous method to overcome the two above stated limitations, is to have a set of several electric generation expansion planning models with different planning horizon and time unit. Another Bulgarian investigation shows that the third way is the best way, especially when the original model is complex enough and has run time and size limitations.

During 1989-1990 Bulgarian specialists from ENERGOKIBERNETIKA and other Institutes made a successful attempt to improve the electric generation model concerning the above discussed limitations. Two approaches were used to reach these goals.

2. 0 First approach to solve the problem:

The basic principle of the work was to keep all existing methods and tools, but incorporating new features and possibilities. During the development of the project the specialists performed an analysis of the model hypothesis, structure and consistency, analysis of software structure, sub-programs, model input, output and consistency, analysis of new ideas, model design, verification tests.

2.1 Dynamic behaviour of PP2

The WASP model consists of 7 main modules - LOADSY, FIXSYS, VARSYS, CONGEN, MERSIM, DYNPRO, REPROBAT - which are designed to be run in a step-by-step fashion, usually in sequential order, to determine the economically optimal expansion plan of an electricity generation system. Each module takes information mainly from the previous module and gives information mainly to the next module.

The input and output from FIXSYS and VARSYS are structured similarly, according to the principle of groups and types (of information). The input and output files are simple and easy to understand. A very important fact is that the algorithm (input/output data manipulation) is standard each year along the planning study period.

All this allows simple manipulation of the above described modules' information and modules' interconnections. Another convenient feature is that the values of all parameters of one power plant are described in one input record. As a result, it has been discovered that it is possible to model each thermal PP (TPP) each year with new values of parameters, such as that the old TPP is retired and a new TPP is put into operation in the next time interval with the same name, code and sequential number. After execution of the module 'description of old, existing TPP', every year the TPP has different characteristics and the module 'simulation of power plants operation' works with dynamic forecasted parameters and gives dynamic operation analysis and real dynamic optimisation at the end. In this case, the structure of the input files remains the same, only the file size increases. Similarly, the execution of the algorithm and sub-programs remains unchanged, only the execution time increases. There is no need to input new data types, new record types or new record size. In fact, data input and output remain the same, the data flow is the same as in the original code.

The results from this modified model and software are consistent with the results from other methods of dynamic generation expansion analysis. The difference between one run of the static and the dynamic model depends on:

- the number of TPP/units dynamically modeled; weight of cumulative, common capacity of dynamically modeled TPP/units in all electric generation system capacity;
- the mode of TPP modeling- each unit could be modeled separately as one TPP, or all similar units in one real TPP could be modeled in one multiple units TPP;
- the difference in values between static (PP) and dynamic (PP2) units;
- the number of years of operation with changed values for PP2 units.

The average difference between a run of the static and the dynamic model is around 10-20% as a structure and more as a quantity (costs, etc.). The difference changes from year to year. There could be different type (3-5%) and/or unit size of new capacities involved into the operation (4-11%), different age structure of the electric generation system (5-15%). Most of all, as a direct result, the schedule of TPP retirement is influenced (7-18% more capacities and 2-5 years anticipating before the basic static run schedule), and the schedule of new capacities involvement in the operation (1-4 years).

It should be pointed out that every case study has to be separately analysed and to keep in mind special assumptions, hypothesis, forecasts, etc. But the work performed, structure and approach of modeling are verified and valuable.

As a result of the above, Bulgarian WASP users have the possibility to investigate different trajectories of PP2 change, for one or several TPP, to check different forecast' methods and software. The planners can perform studies using input information as close as possible to reality and the result would be more adequate.

The important yield of this exercise was new quality of the software, model, analysis and conclusions.

2.2 Maintenance schedule

The problem of maintenance scheduling of TPP generation units is important in generation expansion planning/modeling. It is very important in Bulgaria due to the relatively large amount of old TPP capacities and the financial and organisational problems being faced during the transition period from centrally planned to a market economy. Nowadays, maintenance is planned by NEC and is performed by state and private companies. As the rules of the game are still not clear, the maintenance schedule and quality are strongly influenced. On the other hand the maintenance is sensitive to the generation mix, four (4) nuclear units of 440 MWe and two nuclear units of 1000 MWe, and to the requirements of nuclear fuel cycle (refueling, etc.) and lastly, to the requirements of modernisation of all nuclear units and a large portion of the other thermal units. These facts point out to the interest on the maintenance modeling.

The goal of the planners was to modify the maintenance algorithm of TPP used in WASP, at least for the largest thermal units. This would improve the quality of the generation simulation and planning study.

The practice in the Bulgarian system shows that the maintenance of most thermal plants and units is usually performed during the summer, and the remaining part of the capacities has a less weight and does not pose big financial, labour or organisational problems.

The WASP analysis schedules units for maintenance in a given month. As WASP can be run for up to 12 periods (i.e., the model time unit is a month), it is not possible to schedule a unit for maintenance in a given week. Our survey indicated that using the ICARUS model together with ELECTRIC provides a more accurate representation of the scheduling of units for standard maintenance.

The functional structure of the WASP model separates maintenance data input only in FIXSYS and VARSYS sub-modules, while the maintenance simulation is performed in MERSIM sub-modules. The maintenance data input and simulation are simple and standard.

The examined possibilities to improve maintenance modeling in the electric generation expansion model are:

1) giving the exact months during which the maintenance is planned this year;
2) giving the starting month and the duration of the current year maintenance.

In this modified model it is assumed that the beginning of the maintenance is the first day of the initial month. The user could give any kind of maintenance duration, scheduling and combinations between different TPP maintenance scheduling during one year and in the course of the years of the planning period.

Of course there are constrains on the number of allocated TPPs for which maintenance can be assigned and the number of years with allocated TPP maintenance. But there is at least one serious constrain- the user given maintenance schedule has to fulfil the free space between installed generation capacity of the electric system and the load. This has to be checked preliminary by the user when preparing the maintenance allocation during the year. This is very important due to possible time and labour lost from 'dummy' running (after 'electric system description' steps) two other modules to the 'simulation of electric generation operation' where analysis will point to the inconsistency.

The comparison of results from the original model run and the one with allocated maintenance shows that the main change is in the available thermal power capacity, in the capacity load factor and of course in the operation and maintenance costs during the time intervals along the year. The influence of the maintenance allocation depends on the following aspects:

1) the number of thermal PP/units allocated; weight of units capacity with allocated maintenance in relation to the total electric system generation capacity;

2) the number of years with allocated maintenance of TPP within the planning period;

3) the mode of TPP modeling as one or as multiple units PP.

When TPP are modeled as multiple units then the difference between the original and the allocated maintenance model is less than with model run using single unit modeling of TPP. The former analysis is not clear, not user friendly, allows disturbances and errors. The difference is small when there are small number of TPP with allocated maintenance.

The results could be identical on an annual basis, but have very different period-level results. The results can provide twelve different, new monthly pictures of TPP operation, new mode of operation of all TPP, not only of the allocated TPP. The difference between the original model and the one with allocated maintenance model could be in average from 30 to 50 % of the monthly TPP load factor. A similar difference is found for the working capacities and for operation and maintenance costs. All these are very important for planners working with yearly/monthly generation planning.

The above proposed modification of WASP model is very appropriate for planning studies covering a short term planning horizon or any planning horizon but with strong interest to the role of different maintenance allocations during the first several years of the planning period.

2.3 Conclusions

The analyses described above indicate that the modifications introduced to the WASP model are a convenient way for making a connection between long term and short term planning; they could serve as an intermediate step between both basic planning stages.

The modifications of the WASP model described above are serious and successful attempts by Bulgarian specialists to go in IAEA's planning approach and tools. The results are very useful.

3.0 Second Approach to Overcome the Problem

The work performed in trying to modify the WASP model, as described before, has shown that modeling of dynamic character of TPP2 and maintenance allocation inside the long term generation expansion model is a complex task with many side effects. These difficulties need high qualification and responsibility.

The other way to overcome the model weaknesses mentioned above and to perform full scale planning study is to use a set of several models for long term and short term. This was analysed in special investigation with ENPEP modules ELECTRIC and ICARUS, with electric generation operation model build by ENERGOKIBERNETIKA, with other Bulgarian and foreign models. The results from this research are under preparation to be published in the near future.

4.0 Common Conclusions to Both Approaches

The main conclusions could be stated as follows:

1) both approaches are valuable, each one has its advantages depending the goals and terms of the research;

2) the first approach could be used if there are a special interest and support to the modification work while the second approach is preferable when it is easy to obtain different models;

3) the first approach provides inside/endogenous decision of the problem; while the second one provides external/exogenous decision.

5.0 Conclusions

The work performed by the Bulgarian specialists and the experience gained in the use of the IAEA's planning approach and tools permits drawing the following conclusions:

1) The work of Bulgarian ENPEP' specialists and high level IAEA official support have an important role for positive results from IAEA's planning approach and software introduction in Bulgaria;

2) Bulgarian specialists succeed to win the public opinion and to introduce IAEA's approach within the Bulgarian Government sphere and as a result, when it is necessary to conduct planning studies, ENPEP is first in the list of candidates;

3) The main achievement of Bulgarian specialist work was learning new methodologies and skill, and the introduction of new planning approach in Bulgaria. A very important ancillary result of these activities was developing a set of modifications of the electric generation expansion planning model;

4) IAEA's planning approach and tools and especially ENPEP are convenient for electric planning studies for countries with economy in transition;

5) IAEA's planning tools and especially ENPEP have to be used only after serious training has been provided to national experts, otherwise the results are weak and fully.

Nowadays the Bulgarian economy and especially energy planning analysis requires:

- different models, methods, software tools;
- trained specialists for use of these tools;
- development of consistent planning systems and approaches.

There exists many possibilities to improve IAEA's models, methods and software which could be developed by the Agency in cooperation with interested users.

The future use of IAEA's planning approach and tools in Bulgaria depend mainly on the continuous work for increasing personal qualification of ENPEP users, and on the support that can be provided by the IAEA to Bulgarian specialists.

SOURCES:
1. WASP USER GUIDE.
2. ENPEP USER GUIDE.
3. 'ENERGOKIBERNETIKA' REPORTS.

XA9745296

HOW TO USE MAED WITH OTHER IAEA MODELS IN ENPEP

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Abstract

This paper provides an outlook of the energy situation in Croatia and describes the experience with the IAEA planning methodologies with focus on the MAED model. Furthermore, it suggests an approach to integrate the results of the MAED module of ENPEP with other modules (e.g. BALANCE) by means of commercial software (EXCEL Microsoft).

1. Introduction: Brief description of an ENPEP module

Many countries need to have access to financing from international organisations for the development of the energy sector (high intensive investment industry). But they also need some tools for proven investment in the energy sector. The IAEA tools (MAED, WASP and ENPEP) are free of charge and the support provided by the Agency includes the organization of training courses on the subject, as well as the "on line" help from many users. For these reasons it is reasonable to use these planning tools, but still some efforts are required to make them fully operative.

MAED is highly important for developing countries because one of the first problems that come up in the decision making process for establishing government policies is forecasting of the energy demand to be satisfied.

MAED is a model for energy demand forecasting. Its main purpose is to determine (in Module 1) the overall demand for energy by several sectors (manufacturing, agriculture, mining, construction, transport, household and service) and associated subsectors. Modules 2 and 3 allow to forecast the overall consumption of electricity in two sectors (manufacture + mining + construction + agriculture as the first sector, and transport + household + service as the second sector). It is also possible to split each sector into up to five subsectors according to the data available. This program uses a very good division of useful energy demand and it is very easy to establish a consistent energy network for the demand side. If appropriate data is used properly, it is possible to obtain important differences in the results.

The main disadvantage of MAED is the necessity of using many tools outside the model in order to prepare the required input data. The data for module 1 (overall energy sector forecasting) are prepared not only by the energy sector itself, but even by other institutions; thus, developing countries in general need to integrate inter-agency teams or channels of data exchange among several organisations. In that case, the probability of achieving good results is slightly lower than in the case when a single organisation does all the work. On the other hand, in the countries which have a certain experience in using MAED, it is possible that the whole work is done by one company, but the question of quality remains open. This is the only problem in working with MAED, and because of that, it is suggested to use of MAED in the first draft forecasting of the demand.

The MACRO-DEMAND-BALANCE modules of ENPEP require more knowledge and efforts for using these programs as tools for analysing the development of the energy system. In BALANCE it is necessary to have a thorough knowledge of the energy network, and only in that case, along with the experience from MAED, it is possible to put energy network in optimal size in BALANCE, for example. Econometric methods are one of the possibilities for defining the grow of a certain sector in MAED and also it is possible to use the same method in MACRO and DEMAND, and it is much easier to see rough results than in MAED.

In any case it is necessary to use ENPEP as an integrated program package and because of that it is useful for some modifications in the results.

According to the above, it is necessary to use some additional tools when interconnecting the results from MAED to MACRO-DEMAND-BALANCE, or when using MACRO-DEMAND for providing data for MAED. EXCEL 5.0 for Windows is used as a tool for this purpose. The choice of EXCEL 5.0 for Windows is simply because that program is included in Windows and is easy to use. There are tools for converting the data from MAED, dividing the data onto different sheets for each sector, and for chart presentation of the data for each sector.

2. Historic Development and Present Situation of Croatia Energy Sector

2.1 Primary Energy Consumption

The total energy consumption in Croatia, as well as the primary energy produced, decreased during the period from 1988 to 1989. The maximum consumption has been recorded in 1988 with 460 PJ, while in 1992 it decreased by about 31%. The consumption of all energy forms decreased, although there are differences in the rate of decline. (Table 2.1).

Liquid fuels have the largest share in the total energy consumption in Croatia. At the beginning of the period considered, this share was at the level of 45% while in 1992 it decreased to about 40% (see Fig. 1). The total primary energy consumption had declined over the period of five years up to the year 1992, but has increased in 1993 by 32%.

Table 2.1 : Primary Energy Consumption in PJ

PJ	1988	1989	1990	1991	1992	1993
Coal	36.86	36.13	34.7	22.03	17.80	15.84
Fuel Wood	23.59	23.11	22.68	15.64	13.56	12.92
Liquid Fuels	206.80	193.82	192.60	135.40	127.29	133.73
Natural Gas	100.52	105.90	98.22	87.80	90.53	98.49
Hydro Power	50.94	42.12	38.55	55.07	43.43	43.45
Nuclear Power	21.17	23.88	23.49	25.23	20.13	20.09
Electricity	18.76	19.82	17.53	10.61	3.27	1.63
TOTAL	458.54	444.78	427.14	351.78	315.94	326.14

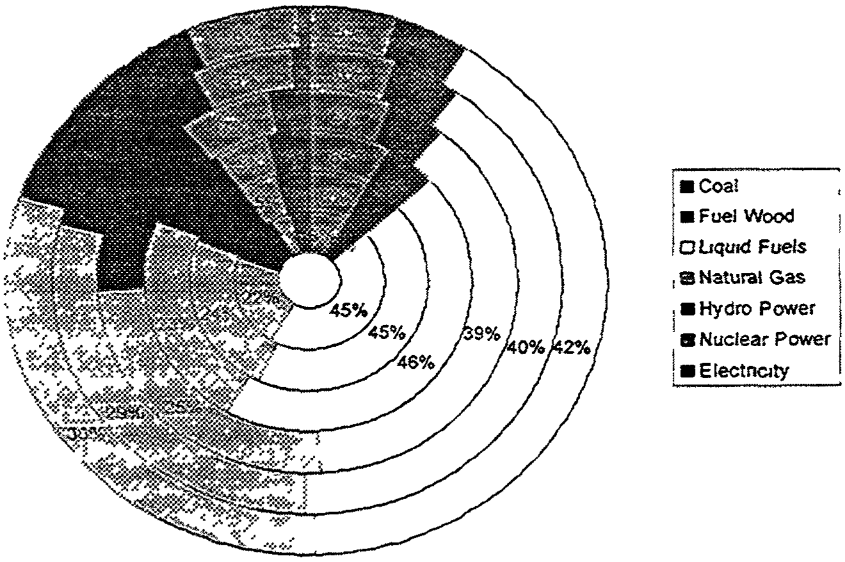

Fig 1 Structure of Energy Consumption

The electricity (in Table 2.1) is imported to the territory of the Republic of Croatia from other states.

In the Republic of Croatia, in 1993, the share of gas in the total primary consumption was 30%, but gas+fuel amounted to 72% of total primary consumption (see Table 2.1). It is expected that gas will cover 28% of primary consumption in 2010 year.

2.2 Final Energy Consumption by Sector

Table 2.2. shows the final energy consumption by sector and fuel. The final energy consumption has been classified in three economy sectors: industry, transport and other sectors which consist of households, services, agriculture and civil engineering. This table shows that the share of industry was significantly reduced and amounted to only 29%. The energy consumption in other sectors was at the level attained in the past two years (45%). Among the forms of energy that are used in transport - liquid fuels, electricity and coal, the oil derivatives are the most significant and have the share of 98% (the highest demand was realised in road transport: 81% of total consumption in the transport sector).

Table 2.2 : Final Energy Consumption in 1993

PJ	COAL	FUEL WOOD	LIQUID FUEL	GAS FUEL	ELECTRICITY	S & HW	TOTAL
INDUSTRY	3 24	-	7 17	10 91	10 79	17 89	50 0
TRANSPORT	-	-	43 57	-	0 83	-	44 4
OTHER SECTORS	1 21	9 99	23 77	15 61	22 11	5 43	78 12
TOTAL	4 45	9 99	74 51	26 52	33 73	23 32	172 52

2.3 The role of electricity in the final energy consumption

Electricity is one of the most significant energy forms in the Croatian energy system. It is being used in all sectors, in all industrial branches, railways, public transport, households, tertiary industry, civil engineering and agriculture.

Table 2.3 shows the structure of final energy consumption in the period 1988-1993. Although the share of liquid fuels in the total consumption is the highest, the significance of electricity is obvious since it represents almost one fifth of the energy consumed. The structure of final energy consumption changed during the period. The share of electricity grew from 18.3% to 20.8% in 1991 and to 19.9% in 1992, although the electricity consumption in this period declined by an annual average rate of 8.5%, from 13503 GWh to 9456 GWh in 1992. Electricity consumption decreased with a small percentage (0.9%) as compared to the year 1992. In 1993, electricity consumption amounted to 33.73 PJ or 9368 GWh and its share in the total was 19.5%, i.e. lower than in the previous two years but higher than the level registered at the beginning of the period.

Table 2.3. Final Energy Consumption Structure

Energy form	1988	1989	1990	1991	1992	1993
Coal	7.5	7.4	6.5	4.8	3.1	2.6
Fuel Wood	7.4	7.3	7.4	6.2	6.2	5.8
Liquid Fuels	42.0	42.1	43.3	41.1	42.8	43.2
Gaseous Fuels	11.9	12.0	12.0	14.6	15.4	15.4
Electricity	18.3	18.2	18.5	20.8	19.9	19.5

2.4 Consumption of Electricity by Sectors

Electricity consumption totalling 2480 GWh in 1960 increased to 15751 GWh in 1990 and fell to 11681 GWh in 1992. The total electricity consumption grew at an average rate of 6.3%, auxiliary demand 7.3%, and losses 5.6% for the period 1960-1990. The electricity growth rate in Croatia from 1960-1993 has not been steady; each time interval had its own characteristics.

Five periods can be distinguished in the total electricity consumption recorded from 1960 to 1993 regarding the level of electricity consumption:

1. In the period 1960-1975, the electricity demand growth rate was above 8.8%. The growth of the Croatian economy in this period was very high. Many energy intensive industries such as steel, aluminum, non-ferrous, chemicals, etc., were built during this period.

2. In the period 1976-1980, after the oil shock price crisis, the growth rate was lower (6.09%). The slowdown in growth resulted from the increase in oil and oil derivatives prices and consequently, energy prices.

3. In the period 1981-1985 the average electricity demand growth rate was 3.42%. The start of the energy crises was an introduction into the political crises which broke out in the period to follow.

4. The period 1986-1990 was the period of political, constitutional and economic crisis. The average electricity demand growth rate registered in this period was 1.59%, mainly due to the growth of electricity consumption in 1986.

5. The period 1991-1993 is the period of the war which affected, directly or indirectly, the entire country. Electricity consumption in 1993 amounted to 75% of the one recorded in 1990.

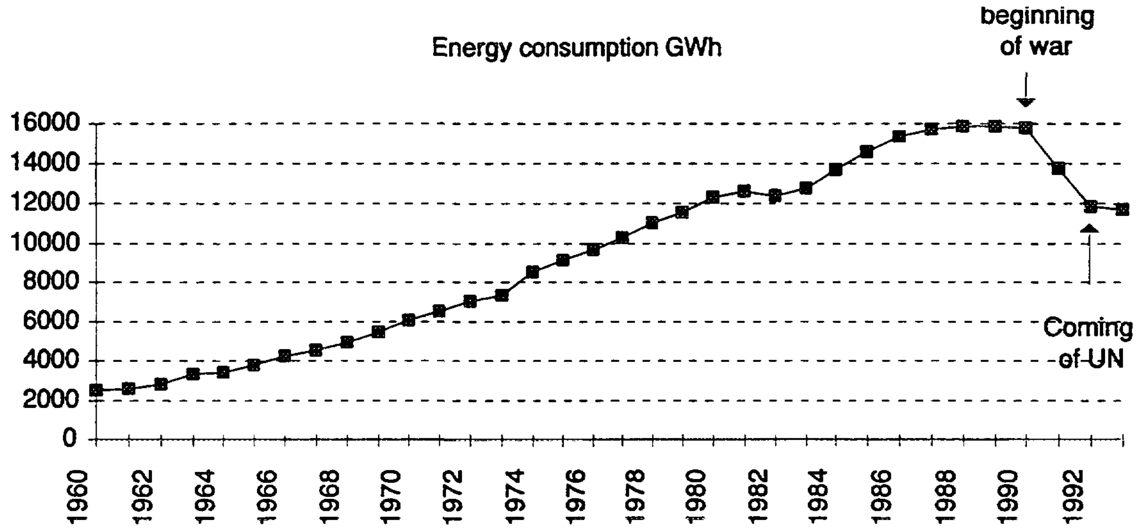

Figure 2.4. Electricity Consumption

HEP's (Croatian National Electricity) power generating installed capacity is 4309 MW. On the territory of other republics of the former Yugoslavia, according to the agreements on joint construction and exploitation of power generating capacities, 982 MW (included in total amount of capacities) or 22.7% power generating capacities was constructed. Capacities in Croatia together with the capacities built in other republics of former Yugoslavia meet about 10% more than the electric energy demand in Croatia in 1990.

Due to political changes, accompanied by the process of disintegration of the former Yugoslavia, Croatia has no access to major energy facilities. For instance, Croatia financed power generation capacities in the republics of the former Yugoslavia (Bosnia and Herzegovina, Serbia), while INA-Oil Industry (INA) lost 181 petrol stations along with the infrastructure in Serbia. The damages and losses on facilities in Bosnia and Herzegovina are not taken into account.

2.5 Organization of the Energy sector

Most of the energy sector in Croatia is organised into two state joint stock companies: INA Oil Industry for exploration, production, transmission and wholesale of gas, oil production and processing, and oil products trade, and Croatian National Electricity (HEP) for production, transmission, system management and distribution of the electrical energy.

The energy sector also includes:

- Adriatic Pipeline, (JANAF), for oil transportation; INA is the owner of 36% of the shares;
- 29 public city companies for distribution and sale of gas;
- "Tupljak" and "Vrbovo", coal mines;
- commercial stores for coal sale.

The private sector, with the exception of wood trade, has only recently joined the energy sector activities: oil product sale (petrol stations) and mini hydro-power plants construction and operation.

2.6 Institutional Setup

The Ministry of Economic Affairs is a governmental institution responsible for energy policy including: legislation, standardization, annual energy balances, energy strategies, regimes of export and import, development and organisation of the energy sector, approvals of development plans of electricity, tariffs, etc.

The Ministry of Finance is a governmental institution responsible for certain parts of the energy policy such as taxes, export and import regimes, duties, etc.

The State Office for Environment is a governmental body responsible for the energy environment policy.

The Energy Institute "Hrvoje Pozar" (HEP owned institute) is responsible for energy analyses and forecasts that are made for the Ministry of Economic Affairs on contractual basis.

2.7 Current Planning Procedures

The Ministry of Economic Affairs is responsible for energy policy, safety and reliability of energy supply, energy environment problems, energy development etc. On the other hand, the Energy Institute makes analyses, scenarios and prospects for the Ministry of Economic Affairs.

Planning documents include: Annual Energy Balance for the next year (government document), and Energy Strategies (government document; last was in 1991),

These documents and analyses are carried out in co-operation with large energy companies (INA - Oil Industry, HEP, Gas distribution Zagreb company, regional gas distribution utilities, etc.).

The energy data base and forecasting methodology are being developed in the Energy Institute. This institute uses rented mainframe computer for SIPRA model, for electricity planning. For other models, for instance WASP (Wien Automatic System Planning Package), ENPEP (Energy and Power Evaluation Program), MAED (Model for Analysis of the Energy Demand), a PC 386 is used. Croatia seeks to establish a system for using planning models such as ENPEP, WASP, and MAED for the energy sector. Several persons in different organisations (the Ministry of Economic Affairs, Energy Institute, Croatian National Electricity) have attended the IAEA training courses on the IAEA planning methodologies.

2.8 War damages

Croatia has suffered major damage during the war. The main damages in the energy sector are production interruptions and stoppages, reduced consumption, infrastructure losses and damages. The consequences of war damages are complex: direct war damages are those destructions that affected the infrastructure facilities and the equipment, while indirect ones are primarily damages due to production stoppages and the loss of market.

War destructions have heavily damaged many of INA's production, storage and selling facilities. The electric power system, facilities for production, transmission and distribution of the electric energy were destroyed. The direct damage in Croatia was estimated to over 622 million US dollars.

In the course of the homeland war (1991-1993), HEP and INA suffered direct damage in the energy sector, exceeding 2 billion US$ both in the Republic of Croatia and through the loss of the facilities and other buildings in Serbia and Bosnia and Herzegovina. Indirect damage is for the time being estimated at an additional 2 billion US$, but this amount varies depending on the methodology applied.[1]

3. Energy Problems at Stake

Electricity Supply

The Northern part of Croatia is connected to the UCPTE grid with a reliability of almost 100%. From that time there has not been a single blackout, and the frequency is normal. The Southern part of Croatia (Dalmatia) presently operates in an isolated system (waiting to be connected with the northen part of the country). The hydro power plants in that part of Croatia are not designed for that type of operation and, as a consequence, there had been 36 blackouts of 20 to 60 min. duration in 1993. By destroying the Peruca Dam, the Croatian system was seriously damaged. As a result, there was a reduction in power production of up to 40% in 1993. In 1994 HEP completed the first part of the "cross island interconnection" which is to partly solve the problem of electricity supply in Dalmatia. Today the Croatian electrical system meets the UCPTE requirements.

Quality of Supply

In Croatia, the quality of energy supply varies from region to region. The northern part is in a better position because of the diversity of energy sources: electricity, pipeline gas network, oil derivatives. In the southern part of Croatia the situation is somewhat different: electricity and oil derivatives are the major energy sources.

[1] These data are based on estimates carried out by INA and HEP.

4. MAED in Croatia

4.1 Present Use of the MAED Model[2]

The MAED program has been used in the Republic of Croatia since 1987. Module 1 is mainly in use, for the forecasting of the demand for energy and energy services.

In that period Mr. Damir Pesut from the Energy Institute Hrvoje Pozar (EIHP) (participant at the training course on MAED in 1985), key user of this program, made some modifications in the mainframe version (change of energy units, change a pipeline in electrical energy not on fuel, improved output data presentation, etc.). This modified version of MAED is called "SEKTOR" (SECTOR) and is mainly used for the energy demand forecasting (MODULE 1). Using this version of MAED, EIHP carried out forecasts of the energy demand in the Republic of Croatia.

In 1994 and 1995 experts from Croatia participated in the training course on WASP, ENPEP and MAED for the first time. As a member of these teams, the author was involved in certain studies in energy field, mainly related to the planning of the overall energy sector and to the demand forecasting. On the basis of this experience and a necessity to use other modules of ENPEP, it was found necessary to connect the results from MAED and MACRO-DEMAND-BALANCE.

Some parts of the complete ENPEP package that are seemingly "quick and dirty" were sometimes utilized to achieve some needed results. In addition, the Croatian team introduced some modifications in MAED results, so as to make them clearer and easier to understand. For the Ministry of Economic Affairs it is important to have tools for both static and dynamic evaluation of forecasting in energy sector, in short and long term planning. The tools that we use have to be comparative with the EIHP tools and also with proven results, and because of that we started to use MAED for forecasting. Moreover, we started implementing the other ENPEP programs in EIHP and the Ministry of Economic Affairs. Our goal is using the MACRO, DEMAND, BALANCE and IMPACT modules of ENPEP in several ways, but as a first step we did the same with MAED. All these activities are complementary with some other activities in the Ministry of Economic Affairs and reinforced by international organizations.

The use of gas is presently in "fashion" and according to that trend it is important to look into the main influence and possibilities of gas participation in the energy mix.

4.2 Modifications introduced to MAED

A change was made in the output file from Module 1: Z1F6XXX.rep (where XXX represents the number of the case). As it was mentioned before, the role of gas in the energy system in the Republic of Croatia is significant. The modification introduced in the report is for the purpose of determining how much gas would be necessary to satisfy the consumption in the future. Further developments will include the whole energy sector and the development of the type of fuel used in every sector.

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[2] All abbreviations hereof are taken from the publication: MODEL FOR ANALYSIS OF THE ENERGY DEMAND (MAED) Users' Manual for Version MAED-1, IAEA-TECDOC-386, Vienna, 1986.

All procedures are made as MACRO in Visual Basic for application on the following recommended hardware: 8 Mb RAM, 486/66, 1Mb on Hard Disk for program, software: WINDOWS 3.1 or higher, EXCEL 5.0 for WINDOWS or higher.

It is necessary to install that macro on PC, and it is recommended to put it into the subdirectory EXCEL\library and use it through Tools add_ins option, after MACRO will be put in tools new option Macro for MAED.

This part represents a short description (including instructions) of what MACRO does, and a description of the equation.

1. Retrieves data in EXCEL 5.0 as a text and converts it to a spreadsheet.
2. Computes some data in SI system unit (J - joule) and its potential.
3. Transforms one sheet into several sheets - one for each sector.
4. Calculations necessary for each sector.
5. Puts necessary data in one table.
6. Prepares a chart for each sector.

Detailed description:

1. Retrieves data in EXCEL 5.0 as a text and converts it to a spreadsheet
   MAED should be run first to produce the file with extension REP. Then start Windows, open EXCEL 5.0, and run macro Macro for MAED. Macro will open a menu for selecting files. Then the user selects a directory where the data from the MAED cases are saved, (file Z1F6XXX.REP) and selects one file. The MACRO procedure is organised to make all modifications that are necessary to shift from that file to EXCEL.

2. MACRO recalculates the output data into Joule units (J) when necessary
   MACRO uses the equations from EXCEL to transform data from calories to Joules.

4.3 Recalculation of sectors

MAED performs a detailed calculation for three main sectors: industry, household-service, and transport. Useful energy demand is very detailed for those three sectors and for that reason it is very useful for using in BALANCE. Alternative energy forms are divided into: fossil fuels, motor fuels, electricity, district heating, feedstock, metal coke and soft solar. Some sectors are related to only few types of fuel and such relation is very useful for the ENPEP chain: MACRO-DEMAND-BALANCE.

Agriculture, Mining, Construction

Energy demand of Agriculture, Mining and Construction is calculated based on the Value Added of the respective sector. The improved calculation made in MACRO for these three sectors is divided into two parts; Agriculture and Mining are calculated together in the same way, but the calculation for Construction is somewhat complicated because the energy consumption is significant in technology.

Agriculture, Mining: Energy demand calculations for Motor Fuel, Electricity and Fossil Fuel were made for motive power, specific use of electricity and thermal use, respectively. For that reason the use of gas in agriculture and mining is forecasted on the same basis (through Value Added), but only as a part in fossil fuel.

Construction: Construction is more complicated because it uses gas for technology (e.g. production of bricks) and for thermal uses. It is necessary to calculate two different parts for fossil fuel. As we can see, in this case it is reasonable to calculate the construction separately from other sectors. Furthermore, development can mean fuel switching (a change from fuel to gas). In this case we can calculate what we want by putting it in BALANCE as a new type of a gas consumer and we can see in a very simplified manner, the influence of a certain development. Of course, the influence of fuel switching can be analysed in a much more complex way in BALANCE, but certain estimates can be done here as well.

Transport

Up to now, the transport sector uses the following energy forms: motor fuels, electricity and steam coal. It is possible to substitute all three types of fuel by gas, in public sector and in freight transport.

The total requirements for freight transport are calculated based on the value added of the productive sectors, i.e.:

$$TKFRT = CTKFRT(1) + CTFRT(2) * (Y - (YB + YSER))$$

TKFRT = TOTAL TON KILOMETRES
Y = GDP
YB= VALUE ADDED FROM CONSTRUCTION
YSER= VALUE ADDED FROM SERVICE
CTKFRT= COEFFICIENTS

These calculations are based on the possibility of using gas in the truck transport as part of the total transport by truck.

$$TDTRUG = TKTRU * DTRUG / DTRU * .001$$

TDTRUG= CONSUMPTION OF GAS FROM TRUCK IN LONG DISTANCE
TKTRU = TON KM BY TRUCK
DTRUG = ENERGY INTENSITY OF TRUCK BY GAS
DTRU = ENERGY INTENSITY OF TRUCK BY MOTOR FUEL .

The same equation is used in local truck transport.

Energy demand calculations made for Transport predict the use of gas for mass transport (in Italy 300000 buses use LPG) in both intercity and intracity traffic.

It is necessary to provide some additional data regardding the specific consumption per vehicle, and the ratio of buses using gas to the total buses.

In the output data there is:

PASSENGER TRANSPORTATION, INTERCITY:
TOTAL ACTIVITY (%)
CAR
0 BUS
0 TRAIN
STEAM
DIESEL
ELECTRIC
0 PLANE
PASSENGER TRANSPORTATION, URBAN:
TOTAL ACTIVITY (%)
CAR
MOTOR FUEL
ELECTRIC
0 MASS TRANSIT
MOTOR FUEL
ELECTRIC

SUMMARY OF DETAILED INPUTS INTO MAED/TABLE
ENERGY INTENSITY (AND LOAD FACTORS) ASSUMED:
YEAR:
FREIGHT TRANSPORTATION (kWh/TKM):
TRUCK
LOCAL
LONG-DISTANCE
0 TRAIN
STEAM
DIESEL
ELECTRIC
0 BARGE
0 PIPE
PASSENGER TRANSPORTATION, INTERCITY
CAR
(P/CAR)
0 BUS
(P/BUS)
0 TRAIN
(P/TRAIN)
STEAM
DIESEL
ELECTRIC
0 PLANE
(% OF SEATS OCCUPIED)
PASSENGER TRANSPORTATION, URBAN (kWh/PKM):
CAR
(P/CAR)
MOTOR FUEL
ELECTRIC
0 MASS TRANSIT
MOTOR FUEL
(P/BUS)
ELECTRIC
(P/TRAIN)

consumption of gas for bus in intercity transport =

$$TGBU * PGBU * TMFIP * PBU / DBU / LFBU / 100$$

TGBU = consumption per bus per km,
PGBU = ratio of bus running on gas to total bus,
DBU = consumption per bus per passensger and km,
LFBU = number of passengers,
TMFIP = total consumption in intercity bus transport,
PBU = ratio of intercity by bus.

The same equations are used for the mass transport in intracity, exchanging the appropriate data on intracity transportation.

Service and Household

Service and Household are basically one sector in MAED, but the demand calculations are made independently. Household and Service carry a significant difference compared to other sectors, as the growth rate in service and household are much higher than in other sectors. In addition, the use of new materials, appliances, equipment and other facilities in these sectors can also make a difference between new and old buildings.

Service: The Service subsector is divided into two parts. One part is the area constructed before the base year, and the other is the new area constructed after the base year. This was done so that it would be possible to change a consumption per square meter during the study period.

Gas is consumed for heating and for air-conditioning, and it is also possible to use it in new and old service buildings with different specific consumption. Gas that is consumed for district heating represents only a part of the whole district heating. Calculations of the gas consumption in air-conditioning serves only for the purpose of the control of the total amount of gas.

Household: The energy consumption is calculated in households for the total consumption in single family houses, apartments and in room heating dwellings. In this case it is very difficult to put the distribution of gas into different categories.

Calculation for different categories is a very useful step, but it is much more important for working in BALANCE.

Manufacture

Manufacturing is divided into four subsectors: basic materials, machinery, consumer goods and miscellaneous. Separate data for these four subsectors is not provided in the MAED output file, and because of this it is useful to make modifications in the manufacturing sector.

In manufacturing, energy is used for three main purposes: motive power, specific use of electricity and thermal uses.

At the present stage, the only modification made is the one related to using gas as a substitution for motor fuels, as a part of fossil fuels and for district heating.

5. CONCLUSIONS

The intention of this presentation was to promote the use of the ENPEP program package for the purpose of energy planning and to show that it is possible to adapt the results coming from one program for the requirements of the other.

In the Republic of Croatia, MAED is used for energy forecasting, but because of the complexity of requirements that are put before the Ministry of Economic Affairs, more complex tools are needed. ENPEP also includes MACRO-DEMAND-BALANCE, which can also be used for energy planning, but M-D-B is very complex and therefore it is not suitable for the decision makers' use (MD).

Because of that and other problems it was necessary to create an auxiliary program that enables the use of the MAED results and their presentation in a suitable form that can serve as a preparation for the introduction of the M-D-B as the main tools for the energy planning.

In the author's opinion, a team of experts and decision makers should be created for the application of these programs, in order to guarantee successful implementation.

As an important component in the process, it is suggested that the implementation of the BALANCE network is made at three levels:

1. A simple scheme of a static type - for the decision makers, so that they could easily see the effects of the short term economic measures (e.g. the effect of taxes on the consumption etc.). *Users*: DMPO - it could be reached through BALANCE or MAED modifications.

2. A more complex scheme which would include all sources, transformations and consumption, divided as in MAED. *Users:* the Ministry of Economic Affairs and various institutes.

3. A detailed scheme which would include all deposits, buildings (objects) and consumers. *Users:* scientific and research institutions.

There are several goals that should be reached by this approach, but the most important ones are:

1. Reaching the results in a relatively short time with relatively small amount of errors, and at the same time, the introduction of tools used for energy planning.

2. Systematic introduction of the M-D-B tools for energy planning, with MAED as an auxiliary tool.

It is believed that using this approach it is possible to avoid the problems faced by the planner when a BALANCE-type program is used: it is hardly possible to control the results and the errors in the scheme by a complex scheme (such as BALANCE).

By making a shift from MAED to BALANCE in a few steps it is possible to develop tools needed by all experts who deal with the energy planning. A precondition for successful implementation and application of the procedure, is to use, as much as possible, the same data in all phases, so as to minimize the time needed for data collection. That is the basic reason to use, as much as possible, the MAED data in the future development of BALANCE.

By presenting this work, we want to examine its accuracy and usefulness in a wider circle of experts in ENPEP, and to evaluate the possibility to distribute it in its final form through the IAEA, if it would raise enough interest.

XA9745297

LONG TERM GENERATION PLANNING IN CYPRUS

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Abstract

The Wien Automatic System Planning (WASP) model has been used for carrying out generation expansion planning studies in Cyprus since many years. This paper focuses on the problems encountered in the use of the model and illustrates these problems by means of a case study, specially developed for this purpose. Suggestions for future improvements of the model are also made in this paper.

1.0 Introduction

Studies to determine the long-term generation planning of the Electricity Authority of Cyprus (EAC) are carried out using the WASP or ELECTRIC module of the ENPEP package. After determining the least-cost solution of the generation system development for the next 20 to 30 years (which is precisely the reason why the ELECTRIC module is used for this kind of exercise) the operating and capital costs are evaluated. This is done in order to arrive to an investment plan, which covers usually a period of 10 years and to calculate tariffs and prepare Income Statements, Balance Sheets and Source and Application of Funds (Figure 1).

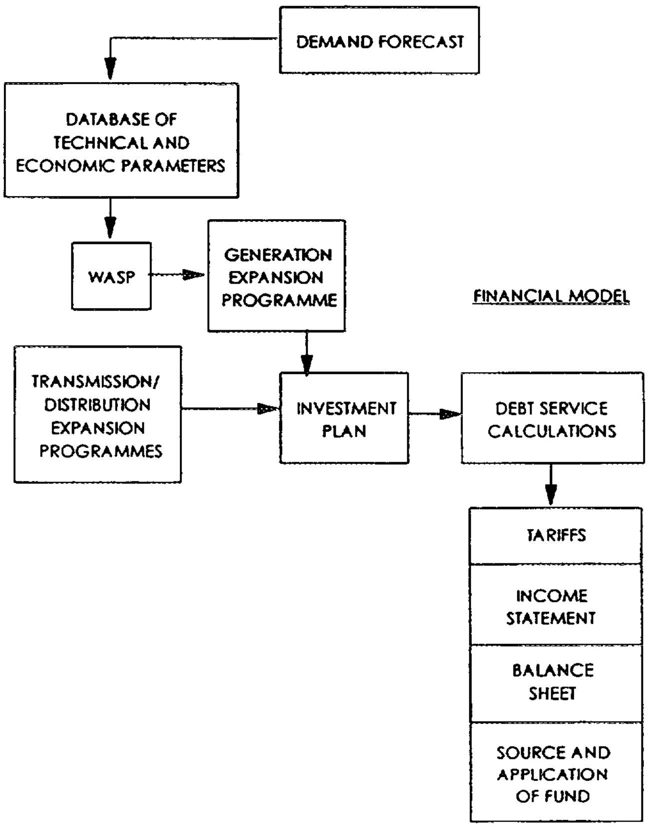


Figure 1. Expansion Programme Model

In addition to the expansion programme, the results of the ELECTRIC or WASP computer runs are used for calculating the fuel cost of the existing power stations of the system, for inclusion in the financial model.

However, in running the WASP package various problems are encountered; more specifically these problems are related to the attempt to transfer data (both technical and economic/financial) to other computer packages especially spreadsheets and graphics.

2.0 Generation Expansion Programme of Cyprus

To illustrate the exercise carried out using the WASP package and to explain the problems encountered, as mentioned above, the planning study carried out in order to determine the type of generating units and the planting sequence for the new power station at Vasilikos will be briefly described.

In order to meet the growing demand for electrical energy and to replace generating plant which has reached the end of its useful life, EAC decided in 1993 to proceed with the construction of an oil-fired power station at Vasilikos, on the south coast of Cyprus, with an initial installed capacity of 240 MWe comprising 2 x 120 MWe units (Figure 2).

These units are scheduled to be in commercial operation before the end of 1998. This new station will be further developed by the installation of four additional 120 MW units, ultimately increasing is total capacity to 720 MW (6 x 120 MW units).

A comparative study of different scenarios of the expansion programme for the years 1994 - 1998 was carried using WASP. More specifically, since the new power station will not be commissioned before 1998, the principal objective of the study was to determine how is the demand to be met in the years 1994-1998 and how will this influence the generation expansion programme afterwards?

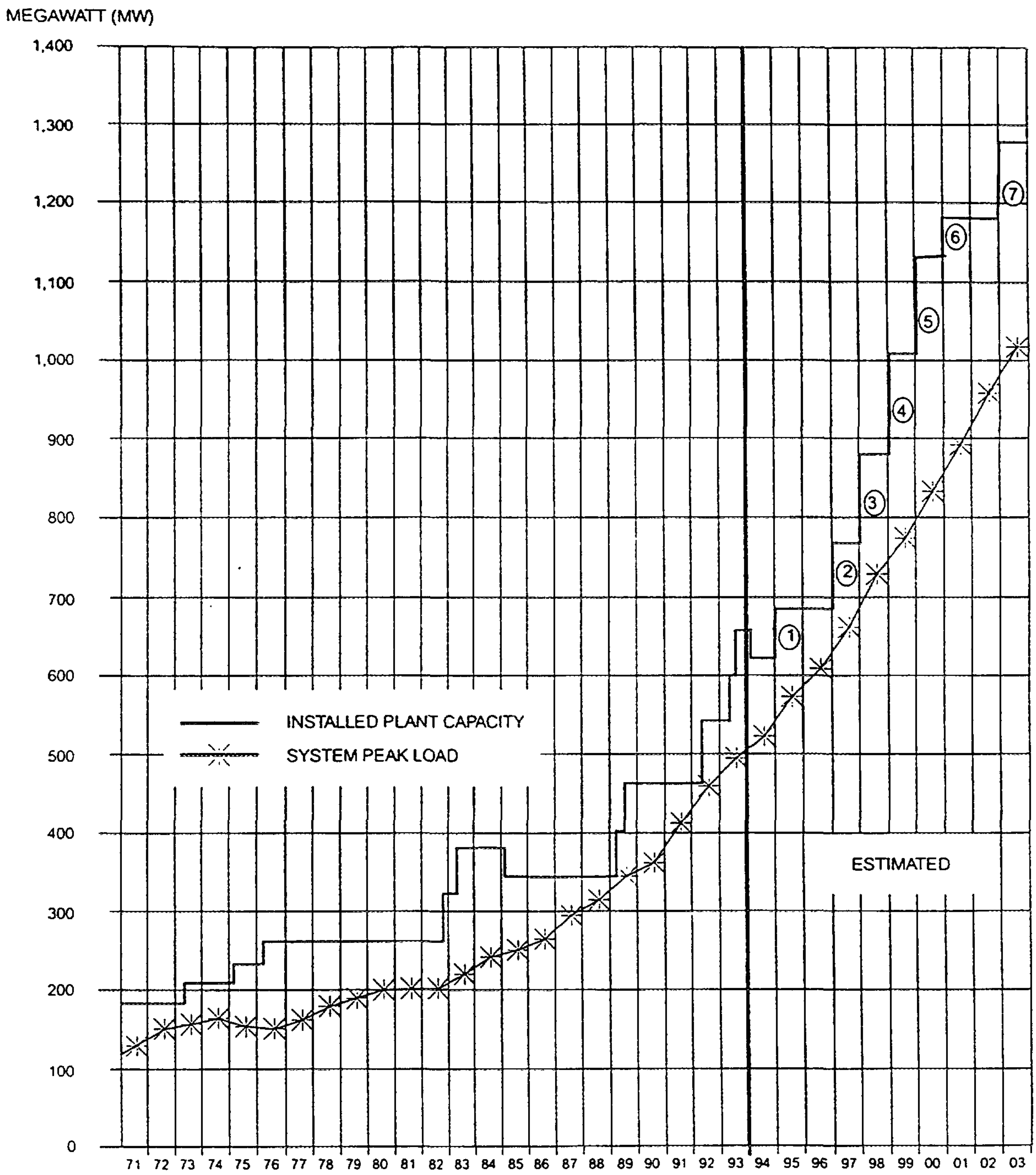
The only generating plant that can be installed before 1998 is gas turbines (G.T.) which in our case can be purchased, installed and commissioned in 2 years, compared to 4 - 5 years required for a steam plant.

3.0 Load Forecast and Generation Systems till 1998

The expected annual gross generation and maximum demand of the power system is shown in Table 1.

Taking 1994 as the base year and considering that 4 - 5 years are required for the construction and commissioning of a new power station, the Vasilikos Power Station will not operate before the end of 1998.

SYSTEM MAXIMUM DEMAND AND GENERATION PLANT INSTALLED CAPACITY



RESERVE MARGIN (%)	14.1	18.2	9.2	12 0	20.1	26 6	33 8	31 1	21.9	22.1

NOTES

(1)	2 X 37.5 MW GT	- 1995
(2)	2 X 37.5 MW GT	- 1997
(3)	1 X 120 MW STEAM UNIT (NEW STATION)	- 1998
(4)	1 X 120 MW STEAM UNIT (NEW STATION)	- 1999
(5)	1 X 120 MW STEAM UNIT (NEW STATION)	- 2000
(6)	1 X 120 MW STEAM UNIT (NEW STATION) 2 X 30 MW UNITS DECOMMISSIONED AT MONI	- 2001
(7)	1 X 120 MW STEAM UNIT (NEW STATION) 2 X 30 MW UNITS DECOMMISSIONED AT MONI	- 2003

Figure 2.

Table 1
Actual and forecast energy generation and system maximum demand

	YEAR	GROSS GENERATION (GWh)	MAXIMUM DEMAND (MW)
ACTUAL	1979	977,3	194
	1980	1 034,4	198
	1981	1 060,4	199
	1982	1 140,3	220
	1983	1 206,4	235
	1984	1 249,9	240
	1985	1 319,8	254
	1986	1 433,4	274
	1987	1 570,1	294
	1988	1 731,6	321
	1989	1 868,5	344
	1990	2 038,5	387
	1991	2 148,4	426
	1992	2 473,9	483
	1993	2 645,8	505
FORECAST	1994	2 882,0	539
	1995	3 122,7	584
	1996	3 377,1	632
	1997	3 647,9	683
	1998	3 936,5	737
	1999	4 243,6	794
	2000	4 567,3	841
	2001	4 911,3	904
	2002	5 277,8	972
	2003	5 668,1	1 044
	2004	6 082,7	1 120
	2005	6 518,0	1 200
	2006	6 981,6	1 285
	2007	7 472,5	1 376
	2008	7 995,3	1 472
	2009	8 550,2	1 574
	2010	9 138,8	1 683

In the period 1994 - 1997 the generation system will consist of:

Dhekelia Power Station	:	6 x 60 MW	=	360 MW
Moni Power Station	:	6 x 30 MW	=	180 MW
Gas Turbines(*)	:	4 x 37.5 MW	=	150 MW
TOTAL				690 MW

(*) G. T. 3 & 4 were commissioned in March 1995

Using the installed capacity listed above and the load forecast of Table 1 the reserve margin (R.M.) of the system will be as detailed in Table 2.

As can be seen in Table 2, the reserve margin (R.M.) during the years just before the commissioning of the new power station will be very low, namely below 20%; which is the minimum acceptable level for an isolated system such that of Cyprus. More precisely, for the years 1996 and 1997, the R.M. will be 9.2% and 1% respectively. This means that there will be an increase in the value of the Loss of Load Probability (LOLP) of the system and, consequently, an increased risk of load shedding.

Furthermore, the ratio of the capacity of the G.T. to the total installed capacity is 21.7% which is considered satisfactory. It should be stressed here that the G.T. are used to cover the reserve margin and for peak lopping. Therefore, the G.T. are economical when they operate only for a few hours a day and do not generate more than 5% of the total annual system demand. In isolated systems (e.g. in Bermuda, Israel, Jordan, Sri Lanka) the G.T. and other peak lopping units comprise less than 20% of the total installed capacity.

Table 2 Reserve Margin of the System

Year	Maximum Demand (MW)	Installed Capacity (MW)			Reserve Margin (%)	GT / Installed Capacity (%)
		S.U.	GT	Total		
1994	539	540	75	615	14.1	12.2
1995	584	540	150	690	18.2	21.7
1996	632	540	150	690	9.2	21.7
1997	683	540	150	690	1.0	21.7

4.0 Solutions Considered

Using the above assumptions, three scenarios were considered:

- the first one, is for two more G.T. to be commissioned in 1997.
- the second one, is avoiding commissioning of new generating plant before the commissioning of the new station.
- the third one, is delaying the construction and commissioning of the new station till the year 2000 and meeting the increased demand by installing G.T.

4.1 Scenario 1

Before commissioning the new station and in order to meet the increased demand, G.T., only, can be added to the generation system.

Since 2 years are required for the procurement, installation and commissioning of the G.T., the earliest the new G.T. can be added to the system is at the end of 1996/beginning of 1997. In case of installing at the beginning of 1997, two (2) G.T. of 37.5 MW each (similar to those already installed) the R.M. for this year will be 12%. In order to reach a R.M. of

20%, four (4) new G.T. must be installed, that is there will be a total of 8 G.T. installed. In such case the ratio of the G.T. capacity (300 MW) to the total installed capacity (840 MW) for the year 1997 will be 38%, which is considered very high and it must be ruled out.

The solution for the scenario 1 is for two (2) G.T. to be installed in 1997 and the new power station to be commissioned in 1998. The WASP optimal solution for this scenario is shown in Table 3. The objective function for the installation of new generating units of gross capacity 1516 MW, till the year 2020, is USD 2 685 million.

Table 3

SCENARIO 1
ANNUAL ADDITIONS: CAPACITY (MW) AND NUMBER OF UNITS

NAME			GT2	0120	012I
SIZE (MW)			38	114	114
YEAR	% LOLP	CAP			
1992	1 158	0	*	*	*
1993	043	0	*	*	*
1994	891	0	*	*	*
1995	267	0	*	*	*
1996	1 145	0	*	*	*
1997	456	76	2	*	*
1998	147	114	*	*	1
1999	056	114	*	1	*
2000	019	114	*	1	*
2001	025	114	*	1	*
2002	106	0.	*	*	*
2003	098	114	*	1	*
2004	049	114	*	1	*
2005	034	114	*	1	*
2006	021	114	*	1	*
2007	029	114	*	1	*
2008	025	114	*	1	*
2009	020	114	*	1	*
2010	029	114	*	1	*
2011	029	0	*	*	*
2012	029	0	*	*	*
2013	029	0	*	*	*
2014	029	0	*	*	*
2015	029	0	*	*	*
2016	029	0	*	*	*
2017	029	0	*	*	*
2018	029	0	*	*	*
2019	029	0	*	*	*
2020	029	0	*	*	*
TOTAL		1444	2	11	1

4.2 Scenario 2

In this scenario no additional G.T. will be installed. In such a case the generation system will be as shown in Table 2 and in 1997 the R.M., will be only 1%. This, as already mentioned, will mean an increased probability of load shedding. However, it will be necessary to commission two 120 MW oil-fired units in the new station in 1998 in order to have a R.M. of at least 20%. The WASP solution for the second scenario is shown in Table 4. The objective function for the installation of new generating units of gross capacity 1560 MW is USD 2 714 million.

Table 4

SCENARIO 2
ANNUAL ADDITIONS: CAPACITY (MW) AND NUMBER OF UNITS

NAME			GT2	0120	012I
SIZE (MW)			38	114	114
YEAR	% LOLP	CAP			
1992	1 158	0	*	*	*
1993	043	0	*	*	*
1994	891	0	*	*	*
1995	267	0	*	*	*
1996	1 145	0	*	*	*
1997	4 047	0	*	*	*
1998	110	228	*	1	1
1999	043	114	*	1	*
2000	122	0	*	*	*
2001	151	114	*	1	*
2002	068	114	*	1	*
2003	057	114	*	1	*
2004	030	114	*	1	*
2005	023	114	*	1	*
2006	102	0	*	*	*
2007	017	228	*	2	*
2008	086	0	*	*	*
2009	011	228	*	2	*
2010	019	114	*	1	*
2011	019	0	*	*	*
2012	019	0	*	*	*
2013	019	0	*	*	*
2014	019	0	*	*	*
2015	019	0	*	*	*
2016	019	0	*	*	*
2017	019	0	*	*	*
2018	019	0	*	*	*
2019	019	0	*	*	*
2020	019	0	*	*	*
TOTAL		1482		12	1

4.3 Scenario 3

It is assumed in this scenario that the new station cannot be commissioned before the year 2000. In such a case the only alternative is the installation of more G.T. in order to meet the demand till the commissioning of the new station in 2000. From 1997 to 2000 seven (7) more G.T. must be installed. The WASP solution for this case is shown in Table 5. The objective function for the installation of new generating units of gross capacity of 1504 MW is USD 2 668 million.

Table 5

SCENARIO 3
ANNUAL ADDITIONS: CAPACITY (MW) AND NUMBER OF UNITS

NAME:			GT2	0120	012I
SIZE (MW)			38	114	114
YEAR	% LOLP	CAP			
1992	1.158	0.	*	*	*
1993	.043	0.	*	*	*
1994	.891	0.	*	*	*
1995	.267	0.	*	*	*
1996	1.145	0.	*	*	*
1997	.025	152.	4	*	*
1998	.042	38.	1	*	*
1999	.019	76.	2	*	*
2000	.008	114.	*	*	1
2001	.018	114.	*	1	*
2002	.010	114.	*	1	*
2003	.010	114.	*	1	*
2004	.059	0.	*	*	*
2005	.032	114.	*	1	*
2006	.023	114.	*	1	*
2007	.033	114.	*	1	*
2008	.025	114.	*	1	*
2009	.023	114.	*	1	*
2010	.019	152.	1	1	*
2011	.019	0.	*	*	*
2012	.019	0.	*	*	*
2013	.019	0.	*	*	*
2014	.019	0.	*	*	*
2015	.019	0.	*	*	*
2016	.019	0.	*	*	*
2017	.019	0.	*	*	*
2018	.019	0.	*	*	*
2019	.019	0.	*	*	*
2020	.019	0.	*	*	*
TOTAL		1444	8	9	1

4.4 Summary of Results

Table 6 summarizes the optimum solution for each of the above cases. As it can be seen the least cost solution is to delay the operation of the new station till the year 2000 and instead to install seven new G.T. (Scenario 3). However if the specific cost per kW installed is taken into account, then the least cost solution is not to install any additional G.T. but to proceed with the commissioning of 2 units at the new power station.

Table 6

Summary of WASP Results

Description	Installed Capacity of New Units (MW)	Objective Function M$	Specific Cost $/KW
1. Installation of 2 G.T. in 1997	1516	2 685	1771
2. No G.T.	1560	2 714	1740
3. Delaying the New Station till 2000	1504	2 675	1779

5.0 Financial Considerations

Based on the three scenarios discussed, forward estimates for the 10-year period 1994 - 2003 were prepared as illustrated in Tables 7 to 9. In these estimates the total capital expenditures are presented in Cyprus Pounds. The cash flows include inflation, which is 3% per annum for the foreign part and 4% p.a. for the local part.

In the forward estimates, the expenditure for the new plant (new power station and new G.T.) as well for new projects in the existing power stations are included.

The cash flow for the steam/oil-fired 120 MW units is 5 years and for the G.T. is 2 years.

A summary of the forward estimates for the three scenarios is shown in Table 10. It must be pointed out that the smallest value of the total amount of expenditures is for the scenario 2, namely, no addition of new G.T. and the new power station to be commissioned in 1998.

Table 7

GENERATION DEPARTMENT
FORWARD ESTIMATES 1994-2003

Annual Expenditure (CYP '000)

	TOTAL		1994		1995		1996		1997		1998		1999		2000		2001		2002		2003	
	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L
1 DHEKELIA P S																						
BFOTs 7&8	1085	725			900	600	185	125														
EFFLUENT TREAT PLANT	250	100	250	100																		
SUBTOTAL (1)	1335	825	250	100	900	600	185	125														
2 MONI P S																						
ENVIRONMENT	300	0	300	0																		
GASOIL SUB PIPELINE	130	525			90	360	40	165														
STORES	0	20				20																
SUBTOTAL (2)	430	545	300	0	90	380	40	165														
3 GAS TURBINES																						
G T 3&4	12056	1550	12056	1550																		
G T 5&6	19728	3837					14692	2851	5036	986												
SUBTOTAL (3)	31784	5387	12056	1550	0	0	14692	2851	5036	986	0											
4 NEW P S (VASSILIKO)																						
UNITS 1&2 (2*120MW)	76980	49040			11700	5100	28620	18360	29540	19150	7120	6430										
UNIT 3 (1*120MW)	35762	18609					9747	1760	8442	2738	10283	7394	7291	6716								
UNIT 4 (1*120MW)	36771	19388					1352	0	8633	1826	8752	2861	10556	7710	7479	6991						
UNIT 5 (1*120MW)	39019	20978									1441	0	9187	1989	9217	3105	11193	8342	7982	7542		
UNIT 6 (1*120MW)	40158	21773											1479	0	9425	2070	9528	3227	11557	8658	8171	7817
SUBTOTAL (4)	228691	129788	0	0	11700	5100	39718	20120	46615	23714	27596	16685	28513	16415	26121	12167	20719	11570	19539	16200	8171	7817
TOTAL GENERATION (5)	262240	136545	12606	1650	12690	6080	54635	23261	51651	24700	27596	16685	28513	16415	26121	12167	20719	11570	19539	16200	8171	7817

Table 8

GENERATION DEPARTMENT
FORWARD ESTIMATES 1994-2003

Annual Expenditure (CYP '000)

	TOTAL		1994		1995		1996		1997		1998		1999		2000		2001		2002		2003	
	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L
1 DHEKELIA P S.																						
BFOTs 7&8	1085	725			900	600	185	125														
EFFLUENT TREAT PLANT	250	100	250	100																		
SUBTOTAL (1)	1335	825	250	100	900	600	185	125														
2 MONI P S																						
ENVIRONMENT	300	0	300																			
GASOIL SUB PIPELINE	130	525			90	360	40	165														
STORES	0	20				20																
SUBTOTAL (2)	430	545	300	0	90	380	40	165														
3 GAS TURBINES																						
G T 3&4	12056	1550	12056	1550																		
SUBTOTAL (3)	12056	1550	12056	1550																		
4 NEW P S (VASSILIKO)																						
UNITS 1&2 (2*120MW)	76980	49040			11700	5100	28620	18360	29540	19150	7120	6430										
UNIT 3 (1*120MW)	35762	18609					9747	1760	8442	2738	10283	7394	7291	6716								
UNIT 4 (1*120MW)	36771	19388					1352	0	8633	1826	8752	2861	10556	7710	7479	6991						
UNIT 5 (1*120MW)	37883	20183							1390	0	8950	1907	8984	2983	10829	8026	7731	7287				
UNIT 6 (1*120MW)	39019	20978									1441	0	9187	1989	9217	3105	11193	8342	7982	7542		
SUBTOTAL (4)	226416	128198	0	0	11700	5100	39718	20120	48005	23714	36545	18592	36018	19398	27525	18123	18924	15609	7982	7542		
TOTAL GENERATION (5)	240237	131118	12606	1650	12690	6080	39943	20410	48005	23714	36545	18592	36018	19398	27525	18123	18924	15609	7982	7542		

Table 9

GENERATION DEPARTMENT
FORWARD ESTIMATES 1994-2003

Annual Expenditure (CYP '000)

	TOTAL		1994		1995		1996		1997		1998		1999		2000		2001		2002		2003	
	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L	F	L
1 DHEKELIA P.S.																						
BFOTs 7&8	1085	725			900	600	185	125														
EFFLUENT TREAT PLANT	250	10)	250	100																		
SUBTOTAL (1)	1335	825	250	100	900	600	185	125														
2. MONI P.S.																						
ENVIRONMENT	300	0	300	0																		
GASOIL SUB PIPELINE	130	525			90	360	40	165														
STORES	0	20				20																
SUBTOTAL (2)	‹30	545	300	0	90	380	40	165														
3 GAS TURBINES																						
G T 3&4	12056	1550	12056	1550																		
G.T 5, 6, 7, 8	39456	7674					29384	5702	10072	1972												
G T. 9	9933	1936					4897	950	5036	986												
G T 10&11	20513	4030							10072	1971	10441	2059										
SUBTOTAL (3)	81958	15190	12056	1550	0	0	34281	6652	25180	4929	10441	2059										
4 NEW P.S.(VASSILIKO)																						
UNIT 1 (1*120MW)	43951	25248			1591	0	10425	2673	10426	4155	12600	9758	8909	8662								
UNIT 2 (1*120MW)	36771	19388					1352	0	8633	1826	8752	2861	10556	7710	7479	6991						
UNIT 3 (1*120MW)	37883	20183							1390	0	8950	1907	8984	2983	10829	8026	7731	7267				
UNIT 4 (1*120MW)	39019	20978									1441	0	9187	1989	9217	3105	11193	8342	7982	7542		
UNIT 5 (1*120MW)	32925	14476													1517	0	9742	2152	9836	3350	11830	8974
UNIT 6 (1*120MW)	21695	5705															1568	0	10058	2233	10069	3472
SUBTOTAL (4)	212245	105978	0	0	1591	0	11777	2673	20448	5981	31742	14526	37636	21344	29042	18123	30233	17781	27877	13125	21899	12446
TOTAL GENERATION (5)	295968	122538	12606	1650	2581	980	46283	9615	45628	10910	42183	16585	37636	21344	29042	18123	30233	17781	27877	13125	21899	12446

Table 10

Forward Estimates 1994 - 2003 (CYP'000)

Description	Total Amount	Foreign	Local
1. Installation of 2 G.T. in 1997	398 785	262 240	136 545
2. No. G.T.	371 355	240 237	131 118
3. Delaying the New Station till 2000	418 506	295 968	122 538

6.0 Problems in using WASP

One of the problems encountered in using the WASP is to transfer the data into spreadsheets. The data most frequently required to be reproduced are capital expenditure and fuel costs.

The capital expenditure is usually needed in the form of forward estimates similar to the ones shown in Tables 7 to 9 where the element of inflation is added. This is required to calculate the cash flows required and thus arranging for financing the various projects.

In addition, the energy output by plant evaluated by REMERSIM is used to calculate the fuel costs for each power station. Again, these figures are used for budgetary purposes, i.e. estimating the expenditure for fuel during the next 5 - 10 years.

The transfer of data from WASP to spreadsheet cannot be done automatically and it is therefore time consuming. Furthermore, WASP lacks a graphics package and therefore any graphs must be drawn using other computer software e.g. POWER POINT or HARVARD GRAPHICS.

On the subject of simulating the operating conditions of the power plants some difficulties are encountered. Of course, the purpose of WASP, and ENPEP in general, is the long term planning for an electric system but in order to give a realistic picture, in the short-term at least, questions about operating conditions, maintenance periods must be answered.

Usually the load duration curve of a normal year is used but not too many details can be calculated since in the WASP package the year can only be divided into twelve periods.

This is partly overcome by using the ICARUS package, but if reconciliation with real operating conditions could be achieved, more information for short term (2 to 5 years) planning would be readily available.

7.0 Suggestions for WASP/ENPEP Improvements

- Use S.I. units throughout, for example heat rates to be in kJ/kWh and not kcal/kWh.

- Make possible the transfer of data from WASP to spreadsheets; perhaps this can be made possible if WASP, and ENPEP, can operate in the Windows environment.

- Include a graphics package in ENPEP in order to generate directly graphs and other figures.

- Determine maintenance periods and other operating conditions in WASP.

THE IMPACT OF A CARBON TAX ON GREEK ELECTRICITY PRODUCTION

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Abstract

The impact of proposed carbon taxes on the electric power industry, using the Greek power system as a case study, is investigated in this paper. It uses the WASP model for electric generation capacity expansion to explore the optimal expansion path under alternative carbon tax scenarios and to estimate their impact on CO_2 and other types of emissions and on electricity production costs. The findings suggest that low carbon taxes would lead to a considerable reduction of the use of conventional lignite fired power plants counterbalanced predominantly by natural gas fired plants. High carbon taxes (100-200 US dollars per ton of carbon) would lead to a drastic reduction of the use of conventional lignite fired power plants which would be mainly replaced by coal or lignite fired technologies with CO_2 removal capabilities, which are not available today but might become available within the time horizon of the present study. Hydropower and renewable sources would be the second least-cost alternatives to lignite under both low and high tax scenarios.

The study provides evidence that carbon taxes also result in significant increases in the cost of producing electricity, implying adverse economic effects on electricity consumers and the Greek economy in general.

I. INTRODUCTION

In 1990, the Inter-Governmental Panel on Climate Change (IPCC) presented a comprehensive report on the nature and the consequences of global warming, reflecting thus the worldwide growing concern about the possible and undesirable impact of the Greenhouse Effect. Carbon dioxide (CO_2) emissions were recognized as being the main contributors to man-induced climate change. They are produced primarily from the burning of fossil fuels, a great proportion of which being used in electric power generation.

In 1990, for example, electricity generation was the major contributor (32%) to CO_2 emissions in countries of the European Community (EC) while transport, industry, residential/ commercial and the energy sectors were responsible for 23%, 20%, 21%, and 4%, respectively. In Greece, for the same year, the electricity sector has contributed by 50% to CO_2 emissions, which represents the highest percentage compared to other EC member states [Commission of the European Communities (CEC), 1991], while transport, industry, residential/commercial and energy sectors were responsible for 18%, 10%, 19% and 3% respectively. In Greece, the electricity sector should play an important role in reducing CO_2 emissions.

Although EC countries contribute to almost 13% of the global CO_2 emissions, compared to 23% for the United States, 5% for Japan and 25% for Eastern Europe and the former USSR, the joint Energy/Environment Council, at its meeting on 29 October 1990, suggested to stabilize CO_2 emissions in the EC at 1990 levels by the year 2000 (CEC, 1991). One of the key elements of the strategy to limit CO_2 emissions in the EC and worldwide is the introduction of a carbon tax, i.e., a tax based on the carbon content of fossil fuels. Carbon tax is an economic tool which is considered to have many advantages compared to other policies. It (a) allows the internalization of external costs and is in line with "the polluter pays" principle; (b) minimizes total CO_2 emissions control costs; (c) provides an economic incentive to adopt cleaner technologies and energy conservation techniques; (d) can be easily adjusted to new circumstances in order to be continuously effective; and (e) raises revenues that can be used for environmental purposes or be redistributed to avoid undesired distributional effects. As a result, several countries like Sweden, Finland and the Netherlands have already adopted carbon taxes while the United States and the EC are seriously examining a number of tax options.

This paper examines the effects of several proposed carbon tax rates on the electric power industry in Greece - the main contributing sector to emissions of CO_2, nitrogen oxides, sulfur dioxides and dust. It investigates whether tax rates would lead to technological changes in the structure of the industry and what would be the exact effect on the level of CO_2 and other types of environmental burdens. It also assesses the impact of carbon taxes on the optimum, i.e., least-cost, electricity expansion plan in terms of costs (control costs plus tax charges). The analysis is based on an adapted economic-engineering model for electricity generation capacity expansion which allows for a rich and detailed description of available technologies and takes explicitly into account the specific technical and economic characteristics of the sector, providing thus highly reliable results.

Section II summarizes the cost and performance characteristics of alternative technologies and provides a forecast of electricity demand. Section III presents the optimal expansion plans under alternative carbon tax scenarios and their impact on costs. General conclusions and some policy implications are given in the final section.

II. THE ECONOMIC-ENGINEERING MODEL

The well known planning tool Wien Automatic System Planning Package (WASP) is the economic-engineering model utilized in this study. WASP uses probabilistic estimation of production costs, amount of energy not served and reliability of the electricity system, together with the dynamic method of optimization for comparing the costs of alternative system expansion policies [3]. In particular, the dynamic programming approach determines the implementation of new generating units in the system and finds the optimum expansion policy under a number of operational, environmental and other constraints.

III. DATA

Before running WASP, collection of information is necessary, i.e., information on site-specific energy sources, present structure of electricity generation, economic and technical data for the initial stage (base year) and the planning period. The implementation of the model also requires the specification of capital investment costs of the expansion candidates, operating costs of existing and candidate units, cost of unserved energy, discount rates, escalation parameters and information related to the constraints to be imposed to the solution of the problem.

At the end of 1993, the mainland (interconnected) power system of the only producer and distributor of electricity in Greece, namely the Public Power Corporation (PPC), was composed of 32 thermal and 43 hydroelectric units, located in West Macedonia, Southern and Central Greece. Thermal units account for 90% of the total production of electricity, of which 78% is generated by lignite fired plants. The lignite mines owned by PPC are located in Northern Greece (Macedonia) and Southern Greece (Megalopolis). Additional lignite mines are being developed in the same areas in order to supply new lignite fired units. Exploration of new lignite reserves are carried out nationwide by PPC and the Institute of Geological and Mineral Research (IGME). In 1991, the economically recoverable lignite reserves were estimated at 4000 million tons (550 millions TOE) [17].

In 1993, hydropower had an installed capacity representing approximately 30% of the total capacity and accounted for only 8% of the total generation of electricity. The potential of hydropower is estimated at 20 x 10^6 MWh per year while the potential of windpower is estimated to exceed 5 x 10^6 MWh per year in the mainland Greece and the Aegean islands. In order to take into account the uncertainty of these estimates, for the needs of the study, it was assumed that approximately 16 x 10^6 MWh can be produced by hydropower and renewable sources. [21] Heavy fuel oil is used in steam power stations which are located near the large consumption areas of Athens (Aliveri and Lavrio) and accounts for about 12% of the produced electricity. In 1990, CO_2 emissions, as measured by PPC, amounted to 35460 thousands of tons (kton).

The objective function used in the WASP model can be written as:

$$L(x) = \sum_{t=1}^{T} [(E_{j,t} - S_{j,t}) + (F_{j,t} + NF_{j,t} + M_{j,t})]$$

The various cost components of WASP objective function L(x) are calculated in ways that account for: (1) the characteristics of the electric load forecast, and the characteristics of thermal, nuclear and hydroelectric plants; (2) the stochastic nature of hydrology (i.e., hydrological conditions); and (3) the cost of energy not served. Specifically:

1. The load is represented by the peak load, the energy demand for each period, and the shape of the corresponding inverted load duration curve. Nuclear and thermal plants are described in terms of maximum and minimum generating capacities, plant life for each expansion candidate, heat rate at annual maximum capacity and incremental heat rate between minimum and maximum capacities, annual maintenance requirements (i.e., scheduled outages), failure rate (i.e., forced outage rate), capital investment costs for the expansion candidates, variable fuel costs, fuel inventory costs and non-fuel operation and maintenance costs (fixed and variable).

2. The capacity of hydroelectric plants is assumed to be totally reliable with no associated costs for the use of water. The stochastic nature of the hydrology is introduced through the hydrological conditions or equivalent years of water inflow (dry year, average year, wet year). The probability of occurrence of each hydrological condition is determined from the statistical information which applies to the whole hydroelectric system. On the basis of this probability, the capacity and energy available from each hydroelectric project is specified. The probabilistic simulation approach is used to calculate the energy generated by each unit in the system.

Table 1a lists the basic economic and technical data of the existing units in the system while Table 1b shows the data of existing and candidate units. Since the present analysis was conducted in constant prices (1993), fuel prices and prices of other products or services included in O&M variable and fixed costs, are assumed to remain constant over the period of the study (1955-2025), implying that relative prices remain unchanged. Three hydrological conditions are considered and their probability of occurrence is 45%, 30% and 25% for dry, average and wet condition, respectively.

With respect to capacity constraints, it is required that the installed capacity in the critical period is above 20% of the peak load demand for the period 1995-2015 and above 15% of the peak load demand after the year 2015. Similarly, the maximum acceptable reserve margin (b_t) should be 50% of the peak load for the period 1995-2005, 40% for the period 2005-2015, and 35% after 2015. Finally, the annual loss of load probability should remain below ca. 0.5% (1.825 days per year).

The main forecasting data that includes data for potential expansion candidates, peak load and demand, is presented in Table 2. The electricity demand of the mainland GPPC system raised from 29,600 GWh in 1990 to 32,400 GWh in 1993, with a peak load of 5.5 GW. The basic load demand for this particular study is expected to grow by an average rate of 3% for the next decade and will decrease gradually to less than 2% during the last decade of the study. This represents an average growth rate of 2.1% per year over the 30 years of the study.

Table 1a
Technical and Economic Data of GPPC Existing Generating Units

Location of Power Station	Fuel Type	Installed Capacity (MW)	Heat Rate (kcal/kWh)	CEC (kg/MWh)	FOR* (%)	Non-Fuel O&M Costs Variable** ($/MWh)	Non-Fuel O&M Costs Fixed** ($/KWyr)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
West Macedonia	Lignite	3683	2650	1320	5-13	1.4	20
Southern Greece	Lignite	850	2860	1450	10-15	4.0	30
Central Greece	Heavy fuel oil	830	2360	900	10-17	1.0	28
	Hydro	2524	-	-	-	-	7.2

Notes:

* The Forced Outage Rate (FOR) associated to the individual generating units varies from unit to unit. The table reflects the range of variation rather than the exact figure; estimated FORs from Vassos et.al. (1993).

** Variable operation and maintenance (O&M) costs include the cost of FGO sorbent, lubricants, consumable supplies, water, etc. Fixed O&M costs includes wages and salaries, insurance, etc.

Table 1b
Fuel Cost and Annual Maintenance Schedule of GPPC
Existing and Candidate Units

Fuel Type	Fuel Cost ($/Gcal)	Maintenance (Weeks)
Lignite (West Macedonia)	4.10	6
Lignite (Southern Greece)	5.00	6
Heavy Fuel Oil	8.75	4
Natural Gas	15.00	4
Coal	7.26	6
Uranium	7.00	8

Table 2
Characteristics of the Expansion Candidates and Predicted Peak Load and Demand

Plants by type of fuel	Heat Rate (kcal/kWh)	Capital Cost ($/kW)	Carbon Emission Coefficient (kg/MWh)	FOR (%)	Non-Fuel O & M Costs: Variable ($/MWh)	Non-Fuel O & M Costs: Fixed ($/kW/year)	Predicted Peak Load & Demand: Year	Peak (MW)	Demand (TWh)
Lignite	2600	2000	1320	10	1.4	20.0	1993	5500	32.4
Coal-N*	2350	1450	940	10	2.8	26.4	2000	6365	38.5
Coal-R**	2300	1765	187	10	2.8	26.4	2005	7130	43.1
Natural Gas	1850	850	400	6	1.2	21.6	2010	7950	48.1
Oil	2200	1150	850	8	1.2	24.4	2015	8860	53.6
Nuclear	2550	2900	-	12	1.6	48.0	2020	9790	59.2
Renewables							2025	10700	64.7
Hydro	N/A	Site Specific	-	-	-	7.2	-	-	-
Wind	N/A	1120	-	-	-	7.2	-	-	-

Notes:

* New coal or lignite technology of conventional type.

** Coal gasification technologies. Cost and performance data come from Vejtasa and Shulman (1989); the table reflects only the figures for a 20% CO_2 reduction.

In addition to the existing fuel-types, the study considers: (1) natural gas, nuclear power, traditional coal (Coal-N), new coal or lignite (Coal-R) technologies with CO_2 removal capabilities; (2) the power units which are presently under construction; and (3) units that are presently retired or that will be retired in the course of the study period. The retirement was assumed to occur 45 years after the initial operation of each unit. In addition, a discount rate of 6%, which has been used by PPC until the end of 1993, was applied for all costs (capital and operational expenditures and the cost of unserved energy). The cost of unserved energy selected was 2 US$/kWh.

IV. RESULTS

The objective of the study was to evaluate the impact of different carbon tax policies on the optimum expansion plan in Greece. The analysis of the GPPC interconnected power system was carried out using the WASP-III model for the planning horizon 1995-2025 and under seven alternative scenarios classified into three general categories: (1) business-as-usual scenario; (2) low carbon tax scenarios; (3) high carbon tax scenarios.

Business-as-usual expansion scenario (Scenario I)

Under this scenario, usually called reference or business-as-usual scenario, no tax on CO_2 emissions is imposed. As a result, the optimum (least-cost) plan is obtained by assuming that all potential candidates (Table 2) are equally treated on the basis of only economic and technical considerations. Table 3 presents the optimal production of electricity by fuel type.

Table 3

Production of Electricity by Fuel-Type (in GWh) and Emissions (in kton)
Scenario I (Business-as-usual)

	2000 (GWh) (%)	2005 (GWh) (%)	2010 (GWh) (%)	2015 (GWh) (%)	2020 (GWh) (%)	2025 (GWh) (%)
LIGNITE	27270 70.8	30103 69.8	33389 69.4	37970 70.8	34078 57.6	41115 63.5
NATURAL GAS	2916 7.6	2848 6.6	3110 6.5	2947 5.5	6962 11.8	6335 9.8
OIL	3163 8.2	3065 7.1	2575 5.4	3078 5.7	7419 12.5	6530 10.1
COAL-R	- -	- -	- -	- -	- -	- -
HYDRO-RENEWABLES	5141 13.4	7104 16.5	9006 18.7	9605 17.9	10721 18.1	10720 16.6
TOTAL PRODUCTION	38490 100.0	43120 100.0	48080 100.0	53600 100.0	59180 100.0	64700 100.0
CO_2 Emissions (kton)	39283	46427	51872	59988	64132	69762

The figures in this table display the following results: First, in terms of the optimal expansion production (Table 3), lignite fired plants account for 70.8% of the total generation in 2000 and for 63.5% in 2025, hydropower and other renewable sources account for 13.4% in 2000 and 16.6% in 2025. The low fuel cost of indigenous lignite makes it very attractive for the power sector in Greece; however, lignite fired plants contribute the most to the increase of CO_2 emissions. On the other hand, hydro and renewables, which are carbon free energy sources, are cost-effective options even under the business-as-usual scenario; thus, limiting the increase of CO_2 emissions

Secondly, the contribution of oil and natural gas fired units is small (15.8% and 19.9% in 2000 and 2025, respectively) but necessary for meeting the demand of electricity. Natural gas will be introduced only in 1996 at the Agios Georgios plant, an oil fired plant that is being converted into a gas fired plant. The utilization of oil fired units has been reduced over the past decades and will continue to diminish until 2015.

However, as lignite reserves deplete, oil technologies seem to compete successfully with traditional coal candidates and are introduced in the last years of the study. Thus, traditional coal technologies are not included in the basic expansion path. Nuclear power is also considered as a cost-effective option for the power sector in Greece. Since both natural gas and oil have a lower CO_2 emission coefficient than lignite, their contribution to the concentration of carbon in the atmosphere is comparatively less.

In general, the business-as-usual expansion path (Scenario I) for the study period (1995-2025) is characterized by:

(1) A predominance of lignite fired units for the production of electricity; and

(2) A significant increase of CO_2 emissions from 39,283 KT in 2000 to almost 70,000 kton in 2025. Reaching the 1990 level would require to cut by 49% the CO_2 emissions of 2025.

Low carbon tax scenarios

The impact of a carbon tax will depend, among other things, on the level of the tax, the available technologies, and their associated cost for producing electricity as well on the energy resource endowments of the country. On the assumption that all potential candidates (Table 2) are considered, we examine first the impact of three low carbon tax rates:

- a tax of 5 US$ per ton of carbon (scenario II),
- a tax of 25 US$ per ton of carbon (scenario III) and
- a tax of 50 US$ per ton of carbon (scenario IV).

Table 4 shows the least cost expansion plans under these three low tax scenarios.

The comparison of these results with those obtained under Scenario I shows that conventional lignite production decreases under the three low tax scenarios but this reduction becomes significant only after the year 2015. Specifically, the production of electricity by lignite fired plants accounts for ca. 70% of the total production in 2000 and diminishes to 52.6% under Scenario II, 43.1% under scenario III, and 36.8% under scenario IV in 2025. Lignite fired plants contribute the more to the growth of CO_2 emissions and are therefore affected even by the lowest carbon tax rate. In 2025, lignite production under Scenario II is 17.2% lower than its business as usual level.

The operation of oil fired units which are the second major contributor to CO_2 emissions in the Greek power system is also reduced under the low tax scenarios. By the year 2025, oil will account for ca. 3% of the total production under all three scenarios.

Table 4
Production of Electricity by Fuel Type and Emissions under the Low-tax Scenarios

	Scenarios	2000 (GWh) (%)	2005 (GWh) (%)	2010 (GWh) (%)	2015 (GWh) (%)	2020 (GWh) (%)	2025 (GWh) (%)
LIGNITE	II	27270 70,88	961 67,1	31687 65,9	34387 64,2	33268 56,2	34055 52,6
	III	27270 70,8	27642 64,1	27780 57,8	28317 52,8	28035 47,4	27888 43,1
	IV	26830	26742	25940	25137	24710	23845
NATURAL	II	3771 9,8	4643 10,8	4263 8,9	6509 12,1	12635 21,4	17335 26,8
	III	3771 9,8	5937 13,8	5745 11,9	11888 22,2	13287 22,5	15334 23,7
	IV	4142	5288	8225	14068	16495	18188
OIL	II	2313 6,0	2390 5,5	2544 5,3	1417 2,6	2010 ,4	2023 3,1
	III	2313 6,0	2415 5,6	3155 6,6	1815 3,4	1920 3,2	1840 2,8
	IV	2382	2420	2515	2105	1880	2115
COAL - R	II	-	-	-	-	-	-
	III	-	-	-	-	3672 6,2	7352 11,4
	IV	-	-	-	-	3745	7432
HYDRO-RENEWABLES	II	5136 13,3	7160 16,6	9586 19,9	11287 21,1	11267 19,0	11287 17,4
	III	5136 13,3	7126 16,5	11400 23,7	11580 21,6	12266 20,7	12286 19,0
	IV	5136	8670	11400	12290	12350	13120
TOTAL PRODUCTION		38490 100	43154 100	48080 100	53600 100	59180 100	6470 100
CO_2 Emissions		kton (*)	kton (*)	kton (*)	kton (*)	kton (*)	kton (*)
	II	39529 11,5	42177 18,9	45758 29,0	49234 38,8	50727 43,1	53657 51,3
	III	39529 11,5	40975 15,6	41728 17,6	43722 23,3	44688 26,0	45931 29,5
	IV	39157 10,4	39532 11,5	39731 12,0	40650 14,6	41561 17,2	41991 18,4

Note (*): Percent changes as compared to the 1990 level (35460 ktons)

The expected reduction of the use of lignite and oil is mostly counterbalanced by an increasing penetration of natural gas technologies but also by hydropower and other renewables which contribute to 17.5% of the total production in 2025 under scenario II, 19% under scenario III, and 20.3% under scenario IV. A minor but increasing penetration of coal or lignite technologies with CO_2 removal capabilities (Coal-R) is also observed as of 2020 under scenarios II and III. It should be noted that nuclear power is not a least cost option under the three low tax scenarios.

As expected (see Table 4), CO_2 emissions are reduced under the three low tax scenarios compared to the business as usual scenario. In 2025, the reductions amount to 23.1% under scenario II, 34.2% under scenario III and 39.8% under scenario IV compared to scenario I. However, CO_2 emissions keep growing compared to the 1990 level which is the level targeted for stabilizing CO_2 emissions.

High carbon tax scenarios:

As part of the study, it was also investigated the impact of three high carbon tax rates:

-a tax of 100 US$ per ton of carbon (scenario V),
-a tax of 150 US$ per ton of carbon (scenario VI), and
-a tax of 200 US$ per ton of carbon (scenario VII).

Table 5 shows the least expansion paths under these three scenarios.

A detailed inspection of the figures in this table shows a drastic reduction in conventional lignite generation. In 2025, lignite generation accounts for only 24.9%, 8.1% and 4.4% of the total production under scenarios V, VI, and VII respectively. In addition, oil generation under scenarios VI and VII disappears from the mix of generating technologies after 2020.

These drastic reductions in conventional and oil generation are mainly counterbalanced by an increasing penetration of lignite or coal technologies with CO_2 removal capabilities, and not by natural gas as it was the case under the low tax scenarios. The use of natural gas which is a low but not carbon free option, has been highly restricted by the year 2025 under the high tax scenarios as compared to the low tax scenarios. Moreover, the results show an increased penetration of hydropower and renewables to counterbalance the reduction of conventional lignite and oil generation; actually, all hydro and renewable sources available for electricity generation are included in the optimal plans by the year 2025. On the other hand, nuclear power is not included in the optimal plans even under the highest tax rate.

Table 5 indicates that high carbon taxes are quite effective in reducing CO_2 emissions at their 1990 level during the period 2000-2005 and even in reducing them by additional 10-12% afterwards. The high taxes produce considerable reductions of CO_2 emissions compared to the 1990 level: 51.5% and 57.9% under scenarios VI and VII, respectively, in 2020.

Table 5
Production of Electricity by Fuel-Type
and Emissions under the High-tax Scenarios

	Scenarios	2000	2005	2010	2015	2020	2025
		GWh %	GWh %	GWh %	GWh %	GWh %	GWh %
LIGNITE	V	23070 59,9	21849 50,7	18701 45,1	18740 45,4	17563 42,8	14072 36,5
	VI	21581 56,1	19850 46,0	15925 38,4	13905 33,7	5680 13,9	5250 13,6
	VII	20819	17710	12559	8758	4480	2850
NATURAL GAS	V	5170 13,4	6480 15,0	6655 16,0	6540 15,8	7155 17,5	7068 18,3
	VI	6525 17,0	6310 14,6	6910 16,7	6040 14,6	10850 26,5	9495 24,6
	VII	7135	7071	7108	6845	6917	7212
OIL	V	2954 7,7	4247 9,8	3018 7,3	2785 6,7	2849 -7,0	3410 8,8
	VI	2818 7,3	2908 6,7	3787 9,1	2835 6,9	- -	- -
	VII	3240	3885	3745	3410	-	-
COAL - R	V	- -	- -	6580 15.6	12315 29.8	18190 44,4	24150
	VI	- -	3507 8.1	8332 20.1	15372 37.2	28470 48,1	35275 54,5
	VII	-	3507	11240	20387	33353	39528
HYDRO RENEWABLES	V	7294 19,0	10544 24,5	13126 31,6	13220 32,0	13423 32,7	14000 36,3
	VI	7566 19,7	10545 24,5	13126 31,6	15448 37,4	13980 34,1	14480 37,6
	VII	7296	10947	13428	14000	14430	15110
TOTAL PRODUCTION	All	38488 100	43120 100	41500 100	41285 100	40990 100	38550 100
CO_2 Emissions		kton (*)	kton (*)	kton (*)	kton (*)	kton (*)	kton (*)
	V	37310 5,2	35149 -0,9	31219 -12,0	32093 -9,0	31940 -9,9	31542 -11,1
	VI	33563 -5,3	31924 -10,0	28657 -19,2	26126 -24,3	17199 -51,5	17404 -50,9
	VII	33170 -6,5	30260 -14,7	24800 -30,0	21270 -40,0	14917 -57,9	14039 -60,4

Notes (*): Percent changes as compared to the 1990 level (35460 ktons)

Figure 1 presents the time paths of CO_2 emissions under scenario V in comparison with scenario I and the 1990 emission level.

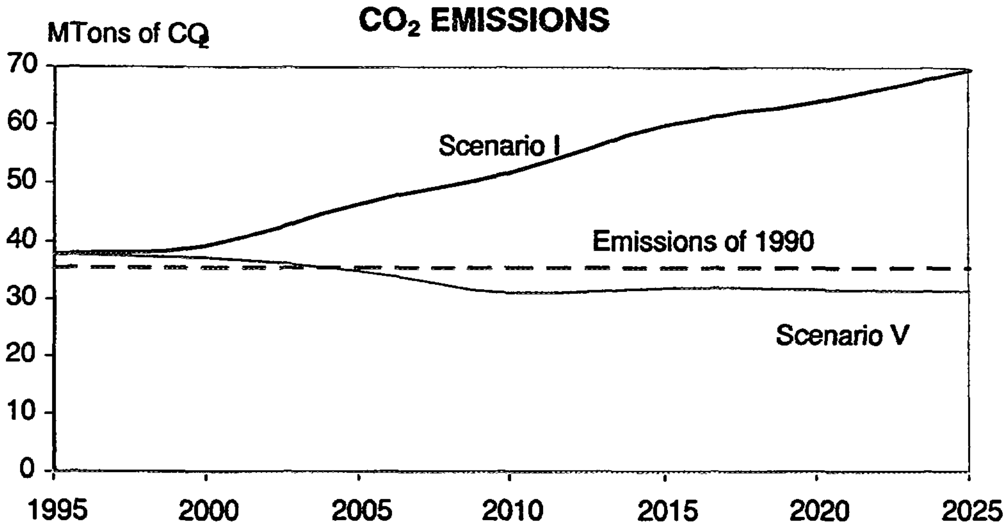

Figure 1. CO_2 under different Scenarios.

The impact of carbon taxes on other externalities

A secondary effect of imposing carbon taxes is the reduction of other types of emissions such as nitrogen oxides (NO_x), sulphur dioxide (SO_2) and dust. The level of NO_x , SO_2 and dust under the reference case, the low and the high tax scenarios are presented in table 6. The figures in the table indicate that the reduction of NO_x, SO_2 and dust compared to the level of the business-as-usual scenario is significant in the last years of the study. In addition, it should be noted that since lignite, oil and natural gas generation are substituted by lignite or coal-R generation and by hydro and renewables generation under the high tax scenarios, NO_x and SO_2 emissions are reduced drastically.

The impact on the cost of producing electricity

Carbon taxes increase fuel costs and the total cost of producing electricity. By increasing fuel costs, carbon taxes induce the adoption of low or carbon-free generating technologies which are however, characterized by higher costs, as Table 2 indicates.

Consequently, the present value of the total costs of the optimum expansion path under the alternative tax scenarios is expected to increase due to the higher cost of the new mix of generating technologies induced by the carbon taxes. It will also increase because of the taxes paid on uncontrolled emissions.

Table 7 presents the increase of the fuel cost of one kWh and in the present value of total costs which reflects both the emission control cost and the taxes paid on uncontrolled emissions. The figures in the table indicate significant increases in the total costs of 17% to 259% under a 5 US$ and a 200 US$ tax per ton of carbon. Apparently, carbon taxes lead to a heavy burden on the Greek electricity industry and its final consumers with further adverse economic effects on the competitive position of Greece's industries and on the Greek economy in general. Carbon taxes need thus to be designed with great care in order to be environmentally efficient and at the same time to limit their adverse economic effects. It is important in this sense, as also indicated by the Commission of the EC (1991-8), that "the particular situation of each Member state would need to be taken into account in the final choice of solution. In introducing such a tax it will be necessary to provide for its temporary suspension and for modification of the rate in the light of economic developments and progress towards the stabilization objective". For Greece who has serious economic problems, these considerations become very essential.

The results of this study were based on several assumptions about technical and economic parameters drawn from highly reliable information provided by international sources and studies, and from accumulated experience of the Greek electric power industry. However, the sensitivity of the results to some central parametric assumptions have been investigated.

Data Sensitivity

In the basic analysis presented before, it was assumed that the relative fuel prices remain constant over the study horizon. However, if the demand for natural gas increases at the international level, its price will rise. The results of the sensitivity analyses show that an annual increase of up to 2% in the (real) price of natural gas would make this alterative less attractive than lignite or coal-R technologies and would lead to a greater penetration of hydropower and renewables. Increases in the price of natural gas under the high tax scenarios would reinforce the results described above. The investigation of similar increases in the price of oil indicates a similar pattern of changes.

It was also investigated whether nuclear power - a carbon free technology - might be considered as the least cost option under the highest tax scenario (Scenario VII) if its capital cost is reduced. The results show that when the cost of capital is reduced to 2500 US$/kW, nuclear power becomes more attractive for system expansion than lignite or coal-R technologies and thus becomes part of the optimal solution after 2005. The result is an additional reduction of CO_2 emissions and a small reduction of total costs. However, we still believe that a cost of capital of the level of 2900 $/kW is a more appropriate assumption for the Greek electric power system.

On the demand side, two major issues would need to be discussed: improvements of the efficiency of electricity generation plants and price-induced conservation caused by the carbon taxes.

Following the oil crisis of 1973, there have been increases in the price of electricity, resulting in significant improvements in the efficiency of electric power stations. If this tendency continues in the future, it might result in a lower growth rate of electricity demand.

On the other hand, as demonstrated by the present study, carbon taxes increase the cost of electricity. The higher the carbon tax is, the greater the increases in the price of electricity are. Such increases will reduce electricity demand and make carbon taxes more effective. Our previous analysis provides the upper limit on CO_2 emissions and total costs of producing electricity under different carbon tax rates. Should the growth of electricity demand be lower, due to efficiency improvements, price (tax) and induced conservation, CO_2 emissions and total cost would be lower, too. A sensitivity analysis on the growth rate of electricity demand confirms this expected finding.

Table 6
NOx, CO_2 and Dust Emissions under alternative Scenarios

kton

Scenarios	2000			2010			2020		
	NOx	SO_2	Dust	NOx	SO_2	Dust	NOx	SO_2	Dust
II	53,0	198,5	251,1	57,5	212,2	276,6	62,7	222,0	305,6
III	53,0	198,5	251,1	57,3	212,7	273,5	56,8	204,6	261,7
IV	52,0	196,9	250,9	53,7	198,7	253,9	48,7	177,8	225,3
V	49,6	186,0	235,5	50,1	198,1	222,5	44,6	168,6	209,8
VI	47,9	167,3	220,7	44,5	156,6	203,1	43,4	153,2	197,1
VII	47,8	171,8	217,4	43,8	154,0	198,5	35,3	126,1	154,8

Table 7
Impact of Carbon Taxes on the Fuel and Total Cost of Electricity (kWh)

Scenarios	Tax Rates ($/ton of Carbon)	Percentage Increase in the Fuel Cost of 1 kWh (1993=100)[1]				Total Cost Increase [2]	
		Lignite	Nat. Gas	Oil	Coal-R	US$ million	%
II	5	27	8	11	18	2013	16.5
III	25	86	16	34	26	5169	42.4
IV	50	163	26	63	35	8367	68.6
V	100	310	46	110	53	15963	130.4
VI	150	460	65	178	72	25516	209.2
VII	200	610	85	230	90	31539	258.6

Notes:

1. Calculations were done assuming an exchange rate of 250 drachmas per US$ in 1993. They also take into account the specific consumption of each type of fuel per kWh.

2. Total cost increases are expressed in Present Value Terms.

V. CONCLUSIONS

This paper has attempted to evaluate the impact of carbon taxes on (i) the technological structure of the electric power industry; (ii) the level of CO_2 and other types of externalities, and (iii) the total cost of generating electricity. The evidence provided by the study indicates that carbon taxes induce a technical restructuration of the industry towards less polluting technologies but at significant cost increases. Specifically, the findings have shown that:

- The imposition of low carbon taxes (5-50 US$ per ton of carbon) results in a considerable reduction in the use of conventional lignite fired plants which is counterbalanced mainly by natural gas fired plants, followed by hydropower and renewables. The growth of CO_2 emissions is slowing down but their level is well above the 1990 level. NO_x, SO_2 and dust emissions are also reduced, especially after 2015.

- Imposing high carbon taxes (100-200 US$ per ton of carbon) results in drastic reduction in the use of conventional lignite and oil generation counterbalanced predominantly by lignite or coal technologies with CO_2 removal capabilities, followed by all available hydropower and renewable sources. Under the high taxes, natural gas is loosing its benefit over lignite or coal-R technologies. CO_2 emissions and other emissions are also reduced drastically. Significantly, a tax of 100 US$ per ton of carbon would stabilize CO_2 emissions at their 1990 level during the period 2000-2005 and would even reduce them from this level thereafter. Higher taxes would result in a more significant reduction of CO_2 emissions.

- Carbon taxes increase the cost of producing electricity significantly. Low taxes result in cost raises ranging from 17% to 69%, while higher taxes lead to cost increases up to 259%. This growth of the cost implies that further adverse economic effects might affect the competitiveness of the Greek industries, especially the electricity-intensive ones, and of the Greek economy in general.

- Improvements of energy efficiencies and conservation techniques can increase the effectiveness of carbon taxes in reducing CO_2 emissions and reducing electricity production costs.

- In general the results provided by the present analysis indicate that the level of a carbon tax should be designed with great care so that it is efficient in reducing CO_2 emissions. At the same time, it should not create any significant adverse effects on the electric power industry and the economy. The findings of the study also suggest more research and development in the field of lignite or coal-R technologies, hydropower, renewable sources, energy efficiency and conservation techniques.

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UTILIZATION OF THE ICARUS MODEL BY THE ELECTRICITY AUTHORITY OF CYPRUS AND ITS LIMITATIONS

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Abstract

This report describes the principal uses of the ICARUS model at the Electricity Authority of Cyprus (EAC). The problems encountered in the application of the model at EAC are highlighted, together with some suggestions for future improvements of this model.

1.0. ICARUS Utilizations

The ICARUS model is utilised by the Electricity Authority of Cyprus (EAC), together with WASP, for the study of EAC Generation Development Projects. ICARUS is mainly used for the estimation of the energy generated in the next 5-10 years by each power station, the fuel required by type of plant, the cost of fuel, the reserve margin, the maintenance schedule and the loss-of-load probability (LOLP). The module is also used for the calculation of marginal cost of generation in combination with another computer program (PCCM) that has been obtained from Electricité de France (EDF).

2.0. Problems Encountered and ICARUS Limitations

Unfortunately we were not able to use the new version of ICARUS as the computer stalled every time we attempted to load data. We rely on the old version which has the following limitations:

2.1. Input of Data

2.1.1. Input of data is character position sensitive and thus, it is easy to make mistakes, resulting in errors in the output which are difficult to trace.

2.1.2. The input of the Load Duration Curve (LDC) requires considerable preparation and is a tedious task.

2.1.3. The units of measurement and currencies require converting to USA units, e.g. kcal into BTU, etc.

2.1.4. Identical generating units have to be input one by one.

2.2. Output Report

The output file has a standard format and cannot easily imported into a spreadsheet file for customised reporting and printing.

3.0. Reconciliation with actual operating conditions

3.1. The maintenance schedule of the units should take into account practical restrictions such as no more than 1 or 2 units could be out for maintenance in each power station at the same time since the manpower in each power station is restricted.

3.2. Identical generating units are in practice run uniformly producing more or less the same energy output, while ICARUS produces different output from each unit.

4.0. Suggested Program Improvements

4.1. The module (ICARUS) should operate under the PC Windows environment and be able to interact with other Windows programs.

4.2. There should be portability of input and output data into spreadsheets, for easy preparation of data input and for further analysis of output and customised reporting.

4.3. It would be useful if analysis for typical days of the season, i.e. working days, weekend days, peak days, etc., were made possible using ICARUS.

In order to do this, the input for the LDC would be useful if it were hourly peak demand load or normalised load over the year which is available from the System Dispatch Centre.

Following this, there should be made possible to calculate marginal costs per hour for typical days of the year, using the screening curves of the units, which will be a very useful output.

EAC uses the marginal costs for the calculation of electricity tariffs.

4.4. There is no need to input each generating unit separately as a number of units are identical in capacity and characteristics. Units of the same type and size should be inputed in groups.

The output results should be given in unit groups, not individual units, in order to avoid the problems of different outputs by each unit as mentioned above.

4.5. The units of measurements and currencies should be selectable as applicable to each country.

4.6. Proper manual for ICARUS should be available for the training of staff in operating and understanding the program.

4.7. Printing of the output should be more flexible by allowing certain parts of the output file to be printed as required.

HUNGARIAN EXPERIENCE IN USING THE IAEA PLANNING METHODOLOGIES

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Abstract

The Hungarian Power Companies Ltd. has been using the IAEA planning methodologies since 1985 when it acquired the WASP model. Since then this model has been applied on a regular basis to determine the least cost expansion plan of the power generating system of the country. This report describes this experience as well as the application of the WASP model for other types of studies.

1. INTRODUCTION

In the last decade, the Hungarian economy has been restructured following the political changes which occurred in the country. As a result, a great deal of the former regulations existing in the country have been replaced by market rules. In the energy field, new laws were introduced (mining, gas, electricity laws). A new organisation, the Hungarian Energy Office, has been created to regulate the energy monopolies (gas and electricity). In addition, the Hungarian Power System was partly privatized in the course of 1996 and this process will continue in 1997.

This situation will lead to the creation of a new Grid Code in 1996 and therefore long-term generation planning activities have to be reorganised. The procedure for long-term energy planning with a partly privatized system differs significantly from the one applied to a centrally planned economy. As a consequence, a new long term planning system has to be identified and long-term contracts (e.g., fuel supply contract, generation capacity contract) will have to be developed. Every two years, the least cost capacity expansion plan will be re-assessed and submitted to the Hungarian Energy Office. The Energy and Power Evaluation Program (ENPEP) will be the core of long-term planning activities, but several additional tools will be connected to ENPEP. This new system has not been fixed yet.

2. ENERGY PLANNING IN HUNGARY

Energy planning in Hungary has a long tradition. There is a very good statistical system in Hungary for energy and economic matters. Several institutes (universities, research institutes, etc.) and companies (oil-mining, electricity companies, etc.) work together in long-term energy planning. The Ministry of Industry and Trade (MIT) and the Ministry of Environment Protection (MEP) are responsible for energy planning at the governmental level. The Hungarian Power Companies (HPC) have been using WASP for 10 years and the other modules of ENPEP for another 5 years. The current version of the LDC and ICARUS modules of ENPEP were developed by a Hungarian team under sponsorship by HPC, the World Bank and the IAEA. Further improvements to ENPEP (e.g. the WASP-IV version of ELECTRIC) are also sponsored by HEP and the IAEA.

Currently, national generation plans are calculated by means of the WASP module of ENPEP for the Ministry of Industry and Trade. In addition, national wide environmental protection plans are calculated using the BALANCE and IMPACTS modules of ENPEP for the Ministry of Environment Protection.

3. MOST IMPORTANT APPLICATIONS OF WASP AND PROPOSALS FOR FURTHER DEVELOPMENT

The Hungarian Power Companies Ltd. (MVM - Magyar Villamos Múvek Rt.) have been using WASP since 1985 but it took several years to learn its use. It is now the official tool for the examination of MVM's long-term generation expansion plan. WASP studies were performed every year.

Decision makers have accepted the WASP models to the extent that, in recent years, no long-term generation expansion decision has been made without undertaking a WASP study. In addition to the normal use of this tool, several other areas have been examined, e.g., to determine the most economical retirement programme of old power plants, to identify a strategy for environmental protection, and to assess the impact of a new pumped-storage power plant on the economy. For these purposes, WASP input data have been manipulated in order to get an acceptable approximation of the problem.

3.1 Retirement programme

Numerous retirement programmes have been examined and WASP was used to determine the present value of total costs of the optimal expansion plan in each case. Naturally, the best retirement programme is the one that leads to the lowest present value. Although it is possible to reduce the theoretical number of alternative retirement programmes, based on the technical and economical parameters of the existing units, this method is very time consuming since it involves a relatively large number of WASP optimization runs.

3.2 Environment control

For this study, the addition of an environment control device to a power plant is expressed by an increase of fixed and variable costs. The environmental emissions were calculated based on the specific emission coefficient for each technology and the amount of fuel consumed by each plant. This procedure enabled to determine the correlation between the different environmental protection strategies, the reduction of environmental pollution and the associated costs. On the basis of this information, the most acceptable solution can be identified.

3.3 Pumped storage power plant

WASP-III does not include the direct representation of pumped-storage plants but this problem can still be solved by manipulating the input data. According to this the pumped-storage power plant is represented by special (fictitious) gas turbines. The data on investment cost, IDC (Interest during construction), number of units and output capacity of the fictitious gas turbines are the real numbers related to the pumped-storage plant. However, the fuel price of the fictitious gas turbines is a parametric value.

The loading order of the gas turbines changes according to the fuel price. On one hand, the electricity generation of the gas turbines which represent the pumped storage power plant are calculated by WASP according to the fuel prices. On the other hand, one should calculate the production cost of the power plants that are expected to provide the energy required by the pumping cycle of the pumped storage plants. (The generation of the power plants used to provide the pumping requirements of the pumped storage plants has to be higher because of the losses of the pumped storage power plant.)

A pumped-storage power plant can be economical under the following conditions:

- If the electricity production of the fictitious gas turbines plus the losses of the pumped storage power plant is equal to the additional electricity generation of the power plants used to provide the pumping requirements of the pumped storage plant; and

- The incremental production cost of the units used to provide the pumping requirements is less or equal to the production cost of the fictitious gas turbines, taking into consideration the overall efficiency of the represented pumped storage plant.

The solution applies to a given unit size, unit number and year. This process has to be repeated several times in order to get an overall solution.

3.4 WASP development proposals

The three examples previously mentioned demonstrate that several modifications of WASP are desirable. The question which remains open is whether it is worthwhile to automatize all procedures.

On the basis of the Hungarian experience, further improvements of WASP may include the following:

- determination of the retirement strategy;
- calculation of the environmental control; and
- modelling of pumped-storage plant.

4. BALANCE-IMPACTS APPLICATION AND DEVELOPMENT PROPOSALS

Limited experience has been accumulated for the use of BALANCE and IMPACTS as compared to WASP. In recent years, several studies have been performed in connection with the national environmental protection program. The impact of carbon taxation and different environmental rules has been examined.

4.1 Environmental emission calculations

In the different studies carried out for the country, the following environmental emissions of the energy/electricity sector have been considered:

- particulates for electric sector,
- SO_2 for electric sector,
- NO_x for electric sector,
- CO_2 for electric sector,

In the different studies carried out for the Hungarian system emission of all pollutants will decrease in the future. The exception is for CO_2 which will increase with the demand for energy. This figure stresses the need for sustainable development and compatibility with the development priorities at the national level. It is therefore advisable to begin the carbon emissions cautiously. These are referred to as "no regret" projects in which no conflicts with development priorities arise. In principle, carbon reductions should be achieved by controlling the sources of emissions or by enhancing carbon sinks.

Projects to reduce carbon emissions through increased efficiency include the following:

- Reduce carbon emissions by saving imported oil or electricity through improved efficient technologies which are (foreign) investment intensive;
- Invest in reducing power supply system losses or modernize to make them more efficient;
- Conserve fossil fuel resources such as coal and gas to be used mainly when they are domestically available;
- Reduce methane emission from gas flaring, reduce leakage from gas pipelines and coal mines, etc.;
- Reduce biomass burning by providing or developing cooking stoves.

Projects to enhance diminishing of carbon emissions, include the following:

- preservation of existing forests;
- rehabilitation of degraded forests (afforestation projects), and conservation of agricultural lands for plantations.

4.2 BALANCE-IMPACTS development proposals

Unfortunately, the current version of ENPEP does not allow to export the WASP results to BALANCE. In addition, the BALANCE model also performs plant dispatching but using a different algorithm which leads to less accurate results than in WASP.

As a general conclusion, it can be stated that BALANCE and IMPACTS provide good results. This follows from the basic characteristics of these two modules. BALANCE has been designed to provide forecasts of the supply/demand balance while IMPACTS is a very useful and comprehensive tool, which can determine the environmental impacts of the energy/electricity sectors and select the optimal control technologies for the reduction of environmental pollution.

Extended experience has been gathered at Argonne National Laboratory in cooperation with the IAEA with data applicable to different country studies. It would be useful to publish the description of the several cases developed during the execution of these studies. The corresponding reports should describe the planning activity step by step.

ENERGY END USE STATISTICS AND ESTIMATIONS IN THE POLISH HOUSEHOLD SECTOR

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Abstract

The energy statistics in Poland was in the past concentrated on energy production and industrial consumption, but little information was available on the households energy consumption. This data unavailability was an important barrier for the various analyses and forecasting of the energy balance developments. In the recent years some successful attempts were made to acquire a wider and more reliable picture of household energy consumption. The households surveys were made and some existing data were analyzed and verified. The better and more detailed picture of households energy use was in this way constructed. The breakdown of energy consumption by end-use categories (space heating, water heating, cooking, electrical appliances) was quite reliably estimated. Important international cooperation and guidance was used in the course of Polish households energy consumption research.

1. POLISH ENERGY STATISTICS IN THE PAST (IN THE CENTRALLY PLANNED ECONOMY CONDITIONS)

Energy statistics in Poland was in the past concentrated on the monitoring of energy production and industrial consumption. Little research was made and little information was available on the households energy consumption. A similar situation existed in relation to the data for the services sector and private agriculture. This situation was in general more or less typical for all centrally planned economies, where the economic systems and statistical procedures were built around standard guidelines.

The energy production processes, energy transformation processes and energy consumption by state-owned enterprises of industry, transport and agriculture were subject to the very detailed data collection. All (around 10,000 in number) Polish state enterprises submitted the detailed questionnaires on the energy matters, which were obviously only a small part of all statistics.

The national statistical system attempted to monitor in detail the various elements of the state-owned enterprises activities. All those detailed data were of course necessary in the conditions of centrally planned economy where all the economic decisions were taken at the government level and the government institutions were de facto super-managers of the enterprises.

At the same time the energy consumption of households, private agriculture and services sector was never surveyed in the sufficient detail. The central planning authorities just estimated in some general way the annual energy requirements of these sectors, allocated to them more or less the estimated amounts of fuels and did not show any special interest in the real patterns of consumption, despite the large inefficiencies and large energy saving potentials in these sectors. For example, in the annually published statistics [1], which is the basic Polish energy statistical yearbook until now, there is a large general category of "Other consumers". This category, which consists of households, services, private agriculture and some miscellaneous activities, is just the residue of energy consumption which remained after measuring the consumption by state-owned enterprises. For this category only one column of data is presented while the data on industrial enterprises (state-owned as well as those which were recently commercialized or privatized) are disaggregated and presented on about 40 pages of the book. Such difference in the level of detail can not be assessed as normal when the "Other consumers" use approximately 40% of Total Primary Energy Supply or 55% of Total Final Consumption of energy in Poland. So, roughly speaking, one half of the energy consumption was decomposed into 200 detailed columns of data and, about the other half, everything what was known in the framework of official statistics, represents just one column!

Moreover, even the extensive statistics on industrial energy consumption are not fully useful for modern energy planning and forecasting, because the data are collected at the level of enterprises and at the level of product, in order to calculate the physical energy intensities of production processes and to monitor the physical performance of the enterprises. The energy consumption data are not collected by such end-use categories which are applied by ENPEP and other modern energy planning tools.

2. OBJECTIVES OF COLLECTING THE HOUSEHOLD ENERGY DATA

Collection of statistics is not a job for itself. The statistics typically provides important assistance in the development of national energy policy, in identifying inefficiencies and energy saving possibilities, and in analyzing historical trends. Projects such as the current IAEA Technical Cooperation for Poland on energy planning using the ENPEP package cannot be reasonably conducted without reasonable statistics.

The households energy consumption data should generally be collected in such a manner as to allow to obtain not only very general figures but also some disaggregations, as for example:

- urban versus rural consumption,
- disaggregation by end-use categories (space heating, water heating, cooking, electrical appliances).

Lack of properly disaggregated data from household sector was in Poland a serious barrier for the analyses and forecasting of the energy demand and energy balance. There were no reliable figures even to respond to very important questions such as:

- how much would the energy consumption change if the houses were provided with better insulation?
- will it be reasonable and economic to heat some group of buildings with district heat or with individual heating installations?

- what will be the consequences on energy consumption of the gradual introduction of new equipment (e.g. automatic washing machines, compact fluorescent lamps)?

Even some very basic and apparently easy questions could not be answered without uncertainty, for example:

- how many flats in Poland are supplied with district heat?
- how many dwellings use wood as energy source and how much wood?
- how many flats have electric boilers for hot water?

3. ENERGY STATISTICS ADJUSTMENT TO THE REQUIREMENTS OF A MARKET ECONOMY

The transition to the market economy caused that the energy statistics, as well as the whole national statistical system, had to be seriously reconstructed. The growing international exchange of information, scientific research requirements on an international level, need for more reliable forecasting, commercial value of the information and, last but not least, Poland's aspiration for European Union, OECD and International Energy Agency membership, made it inevitable that the energy statistics had to be reconstructed to the patterns of Western World.

This reconstruction is completed for the most important elements. The reconstruction task was quite complicated because several important elements were very different in the Polish methodology as compared to international methodologies, namely:

(1) different classification of economy sectors and industry branches,

(2) different treatment of some energy transformation processes,

(3) major gaps in the statistics for households, agriculture and services energy consumption,

(4) lack of energy prices statistics,

(5) application of different units of measure.

In order to solve the problem of household energy data unavailability, some studies and projects were conducted in the recent years by the Energy Information Centre, with the participation of Central Statistical Office and some other institutions. The results of these studies have led to a significant enhancement of the knowledge of the energy consumption by households.

4. INTERNATIONAL INSPIRATION FOR POLISH RESEARCH

At the beginning of the described studies, the general analysis of the available publications from OECD countries brought among others the following conclusions:

(1) Many countries have a better knowledge of its household energy consumption than Poland, and this is particularly true for almost all developed countries,

(2) this knowledge is essential for better understanding, analyzing and forecasting of this sector developments,

(3) there is no uniform method to acquire this kind of information, but the two most promising methods are typically: (i) sample surveying of households, and (ii) combining of the various information found in housing statistics, equipment statistics, technical literature etc.

The achievements of two important foreign institutions inspired largely the Polish research of household energy consumption. These institutions are: Eurostat (Statistical Office of the European Communities) and Lawrence Berkeley Laboratory (the well-known scientific centre in the USA). Polish research has largely benefited from studying their publications and from personal discussions with the experts of both institutions. Additionally, the Commission of the European Communities has granted Poland some financial means to help conduct the sample survey of households.

Eurostat's publication "Energy Consumption in Households" [2] is an excellent example of the international research in this subject. The book contains the results of the project conducted by 11 European Community member states and by Eurostat. The aim of the project was to collect a reliable and comparable set of household energy consumption data. Within the project, each of the participating countries has collected the prescribed set of data, but not in a standard way. The countries were advised by Eurostat (and probably the full data collection just for the purpose of this project would be in most cases impossible) to use as much data as possible from existing sources, and conduct special surveys only in order to collect the data unavailable and those, which in spite of being readily available, seemed to be highly inaccurate or uncertain. The data finally collected, verified and published, though they contain some gaps for some countries, are really impressive and are the proof that in a properly organized framework such data collection is not a very difficult problem.

Because of the fundamental meaning of the book on "Energy Consumption in Households" and particularly the applied set of indicators, one of the aims of the Polish data collection task was the preparation of Polish data in such a way to make them compatible and easily inclusive to the "Energy Consumption in Households". In the working file "Data on Small Energy Consumers, Poland, Years 1992 and 1993" [6] the reader can see that 90% or more of the Eurostat's data are already collected for Poland. In this regard, one small step of the many steps towards European Union's membership was done.

The second inspiration for the household energy research came from the International Energy Studies Group of Californian Lawrence Berkeley Laboratory (LBL). This team, led by Dr Lee Schipper, is internationally known for their research on energy consumption patterns in many countries of the world. The authors of this team have been deeply investigating the Polish energy consumption for some recent years, publishing on this subject several reports and papers, among which [3] and [4]. This group of scientists, visiting Poland several times and discussing frequently with the Polish researchers, did much in order to convince Polish specialists that the research of household energy consumption and the knowledge of household energy consumption patterns is equally as important as the detailed knowledge of industrial consumption. As a result, some kind of positive feedback has been created between their research and the Polish studies: first, the LBL team has shown how much can be understood even from initially scarce Polish data; second, they inspired Polish researchers to go more deeply into the subject; third, both sides benefited largely and equally from the other party studies.

5. "DATA ON SMALL ENERGY CONSUMERS " - CONTENTS OF THE WORKING FILE

The systematic collection of Polish household energy data had the aim of constructing the possibly wide and possibly reliable information set on the energy consumption and on the related facts which influence the consumption levels and consumption patterns. The constructed set of data (or its various sections) will then be useful for various research and forecasting projects, among which the ENPEP project is currently most important. The household data in this framework were first collected for the year 1992, which is the base year of ENPEP calculations for Poland.

The long-term intention is to collect the same set of data for each year, however it must be understood that the accuracy of some data will not be equal from year to year (for example, some data can be directly surveyed in some years and only extrapolated in others). Also the time delay for full data collection is rather long which is always the typical problem with any detailed statistics. The current practice is that data are normally collected one year after the year investigated, so now we have only the data for 1992 and 1993, and complete 1994 data will be ready at the end of 1995.

The household energy consumption file contains the following sections:

Section L - data on population,
Section M - data on dwellings,
Section E - electricity consumption,
Section G - gas consumption,
Section C - data on space heating,
Section W - data on water heating,
Section K - data on cooking,
Section D - summary of household energy consumption,
Section U - data on household equipment,
Section S - data on personal cars and motor fuels consumption.

Further parts of the file contain also some data on services sector and private agriculture, but these sections are less detailed and more tentative. Less data are as yet known on these sectors - the households sector investigations were assigned the higher priority. Of these additional sections however Section R - energy consumption in the private agriculture - is particularly important from the household research viewpoint because for rural agricultural households it is typically extremely difficult to break down the consumption for household purposes and for agricultural production purposes. In Poland, and not only in Poland, those data are partially mixed or known only in total. Ideally, the energy consumption data for the farms should be fully broken down between the two uses, but usually the breakdown can be only very roughly estimated. For example, we roughly estimate that at the private farms which normally have the single electricity meter, 70% of total electricity consumption goes for household purposes and 30% for production purposes. This breakdown seems "the best guess" but at the current stage of the research we cannot in any way guarantee that the real breakdown is not 60-40% or 80-20%.

6. THE TECHNIQUES OF DATA COLLECTION

Thee basic techniques were used for the data collection, namely:

(1) searching the available publications or the statistical files,

(2) bottom-up reasoning and calculations,

(3) direct surveys.

The existing publications and more detailed statistical files can be extremely useful because they contain in many cases very valuable information on the subject. This is particularly true for the information on dwellings and other energy-related subjects which is present among many other kinds of information in the books, brochures and reports of Central Statistical Office. Two sources of problems are however associated with such type of information: (i) in the very detailed files it is not easy to find what is needed - the information with which we are dealing was originally collected for purposes other than energy-related, and (ii) typically it is not collected on a year-by-year basis but, as for example with the national census, only every 10 years. Anyway, the existing reports and selected files of the Central Statistical Office were reviewed in order to find the energy-related information. This task was generally fruitful.

Regarding the bottom-up reasoning and calculations, this is the powerful method of estimation which was largely used for Sections C, W and S, where little direct data are available. This technique is in general easy because it is based on simple calculations like calculating the energy consumption by multiplying the number of objects of the relevant class by the average annual fuel or energy consumption of a single object. The single object is here a dwelling, a car etc. While everything seems fairly easy, the real trouble is associated with the fact that the simple raw data are not readily available. Nobody knows accurately in Poland how many flats are heated with district heat (because the definitions are not clear and because the state-owned housing is not properly managed) as well as nobody knows accurately in Poland how many personal cars are really on the roads (the car registration certainly contains quite many liquidated cars) and how many kilometres they really travel per year.

Therefore the bottom-up reasoning and calculation technique requires some necessary, sometimes a bit doubtful, assumptions but anyway with various data comparisons and confrontations seems to give quite good results.

As to the direct surveys method, one fundamental survey of household energy consumption was conducted and analyzed by Central Statistical Office, with the participation of Energy Information Centre. The sample of 5151 urban households and 3861 private farms was surveyed with the 4-page questionnaire covering the important aspects of household energy consumption. The survey brought many fundamental results as to the amounts of energy consumed, household energy consuming equipment, etc. The results of the survey were published by Central Statistical Office [5].

The survey questionnaire (slightly different in urban household version and in rural household version) contained the following parts:

(1) general characteristics of dwelling and inhabitants,

(2) data on electric equipment,

(3) description of building and specification of energy carriers used for each end-use category,

(4) amount of fuels and energy consumed in the year's period,

(5) car(s) owned and amounts of motor fuels consumed,

(6) energy saving methods and possibilities in the surveyed dwelling.

The surveying project proved to be important and fruitful, although it did not bring any revolutionary results and was not free from some misunderstandings and weak points. The main problem with designing such surveys is that it is extremely difficult to find a balance between: (i) keeping it sufficiently wide to cover the subject, and (ii) keeping it sufficiently simple to ensure understanding of questions and the will of cooperation from the respondents.

The household survey did not bring any revolutionary results, mainly because the most important data were already known from the literature and from the bottom-up reasoning and calculation approach. The survey results however: (i) confirmed much of the previously known or estimated information, (ii) made some of the results more accurate, and (iii) found some important facts which were not covered previously by any other means of data collection.

7. CONCLUSIONS

- Each country should have the fairly detailed data on household energy consumption. Knowledge of these details is essential for better understanding, analyzing and forecasting of the energy demand.

- The household energy data can be collected by direct surveys, by bottom-up reasoning and calculations, and by searching the various existing sources. All methods are complementary, and the use of all methods is advised in order to construct a good data base.

- Poland has already constructed the household energy data set which is almost sufficient for international comparisons and almost sufficient for the requirements of ENPEP planning.

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ENERGY DEMAND FORECASTING METHOD BASED ON INTERNATIONAL STATISTICAL DATA

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Abstract

Poland is in a transition phase from a centrally planned to a market economy; data collected under former economic conditions do not reflect a market economy. Final energy demand forecasts are based on the assumption that the economic transformation in Poland will gradually lead the Polish economy, technologies and modes of energy use, to the same conditions as mature market economy countries. The starting point has a significant influence on the future energy demand and supply structure: final energy consumption per capita in 1992 was almost half the average of OECD countries; energy intensity, based on Purchasing Power Parities (PPP) and referred to GDP, is more than 3 times higher in Poland. A method of final energy demand forecasting based on regression analysis is described in this paper. The input data are: output of macroeconomic and population growth forecast; time series 1970-1992 of OECD countries concerning both macroeconomic characteristics and energy consumption; and energy balance of Poland for the base year of the forecast horizon.

1. Background

A typical energy demand forecasting procedure [1] assumes the following steps:

1. Estimation of the base year useful energy demand as a product of base year energy consumption and conversion device efficiency .
2. Assessment of the improvements in conversion device efficiency over the planning period.
3. Estimation of changes in the useful energy requirements in future years.
4. Determination of the relationship between macroeconomic characteristics and energy consumption growth for each demand category.
5. Determination of the future useful energy demand as a product of the base year useful energy demand, total improvement of conversion device efficiency, and economic growth parameter.

Concerning the data normally used for forecasts, it is necessary to point out that:

- It is inappropriate to use Polish statistical data to describe historical macroeconomic behaviours and energy use/production relations. The country is in a transition phase from a centrally planned to a market economy: data collected under former economic conditions do not reflect a market economy.
- Reliable end-use energy demand data are not available since the first surveys concerning energy use in households and public sectors were conducted in 1994.
- The only available model for macroeconomic growth forecasting is the SDM-NE (Simulation Dynamic Model of National Economy) model. The output of the model for every branch (global output, value added, investments, etc.) is expressed in monetary terms.

A typical energy demand forecasting procedure cannot be applied properly, in Poland, because of:

- the unreliability of the relationship between macroeconomic conditions and energy consumption growth;
- the insufficient knowledge about conversion device efficiency;
- the lack of information concerning improvements in device efficiency and altering of useful demand requirements in future years.

2. Approach

Final energy demand forecasts are based on the assumption that the economic transformation in Poland will gradually lead the Polish economy, technologies and modes of energy use, near to the conditions of mature market economy countries.

After the economic "shock therapy" of 1989 and early 1990, which brought in a severe contraction of economic activity, the economy stabilised in 1992 and 1993. Energy and electricity prices increased rapidly in 1990 and 1991 (see Fig. 1 to Fig. 4). The growth of prices was moderate in the following years and it can be expected that the prices will not increase so rapidly in the future. Market oriented economies will have an increasingly influence in Poland in the coming years.

The starting point has a significant influence on the future energy demand and supply structure. As it is shown in Fig. 5 and Fig. 6, final energy consumption per capita in 1992 was almost half the average of OECD countries and electricity consumption was almost three times lower. In Poland, energy intensity, based on PPP and referred to GDP, is more than 3 times higher (Figs. 7, 8), and electricity intensity is almost 3 times higher.

The major assumption of the approach is that the relationships between final energy demand growth and macroeconomic growth characteristics in Poland, during the period 1995-2020, will be similar to the ones that existed in developed countries during 1976-1992.

The approach may be formulated as follows:

1. Energy/electricity demand forecast is based on regression analysis relating energy demand and macroeconomic characteristics.
2. Macroeconomic and population growth is defined exogenously using output from the SDM-NE Model.
3. Specification and estimation of parameters to be used in the regression analysis equations are based on developed (OECD) countries data; for selection of countries-analogues time series 1970-1992 were used, for specification and parameter estimation time series have been shortened to 1976 - 1992 to avoid taking first oil crisis data.
4. The macroeconomic and energy sector characteristics of Poland are used for the base year.

Fig. 1 Indices of Coal Prices, 1985 =100

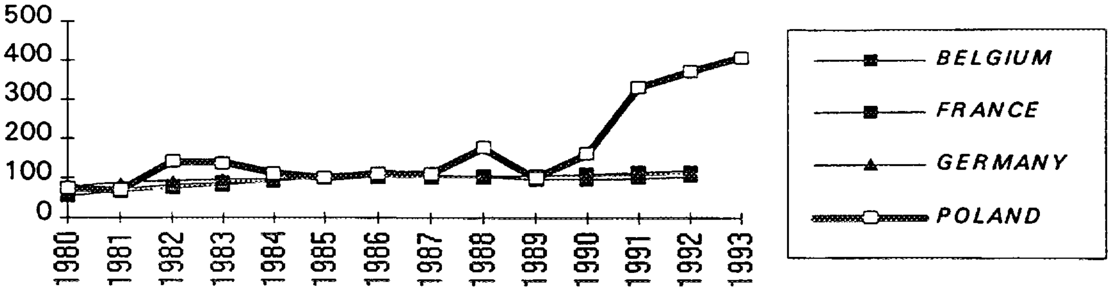


Fig. 2 Indices of Oil Products Prices, 1985 =100

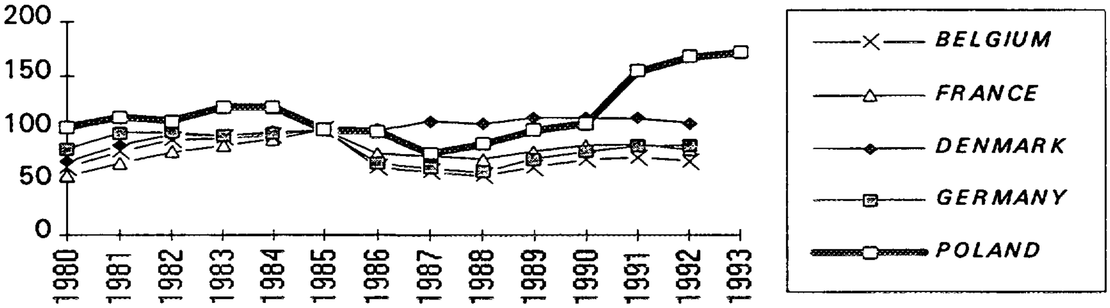


Fig. 3 Indices of Natural Gas Prices, 1985 =100

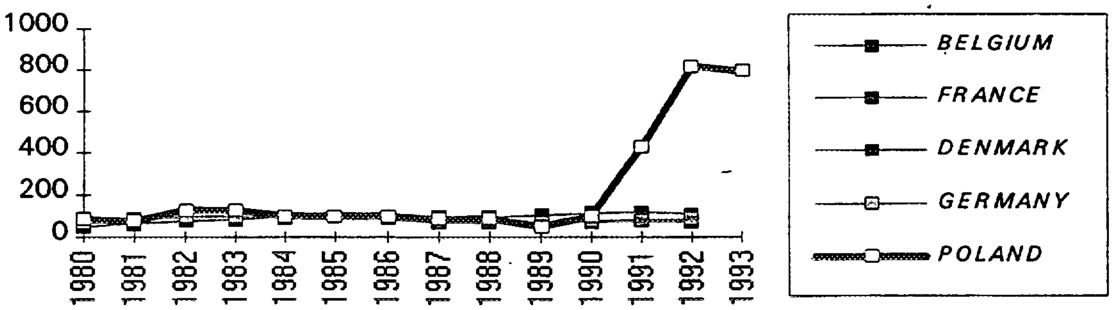


Fig. 4 Indices of Electricity Prices, 1985 =100

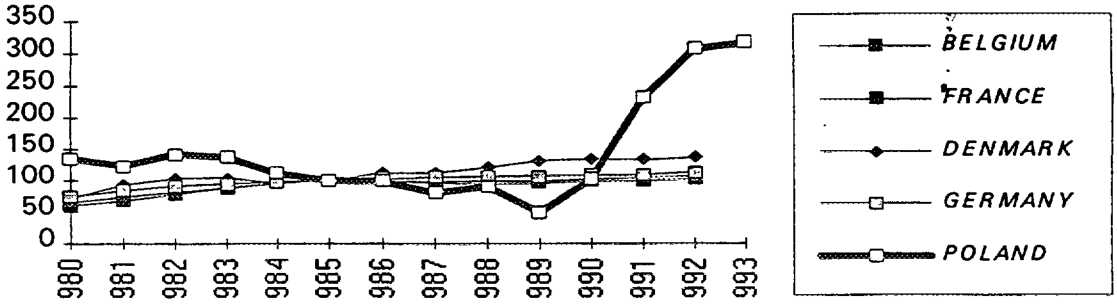


Fig. 5 Final Energy Consumption per

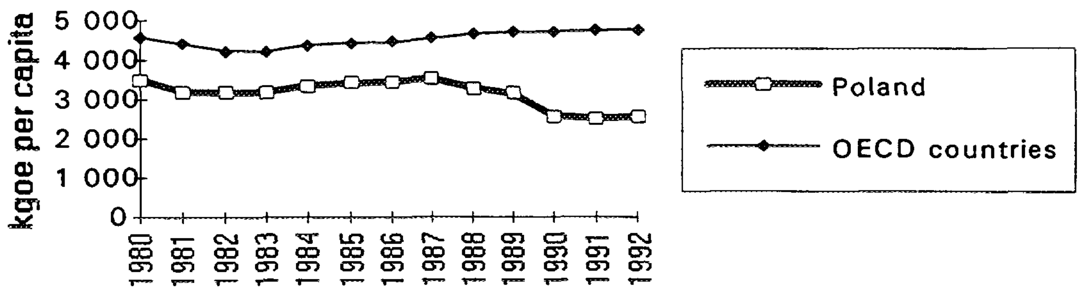


Fig. 6 Electricity Consumption per capita

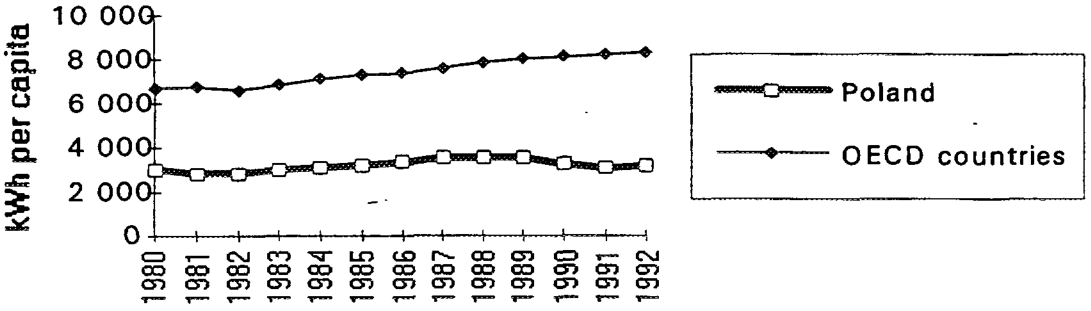


Fig. 7 Final Energy Intensity,

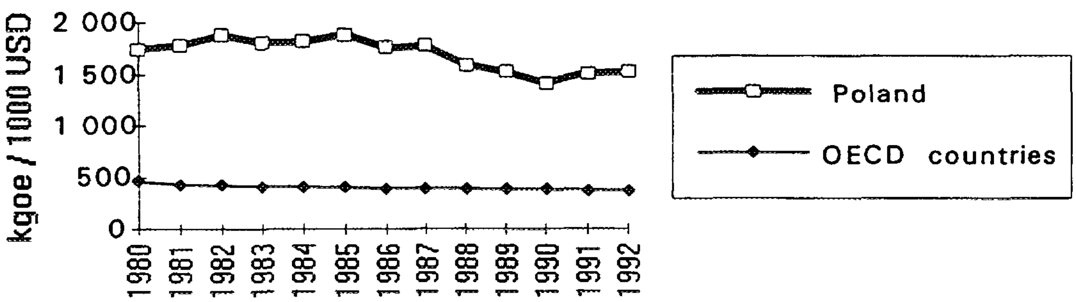
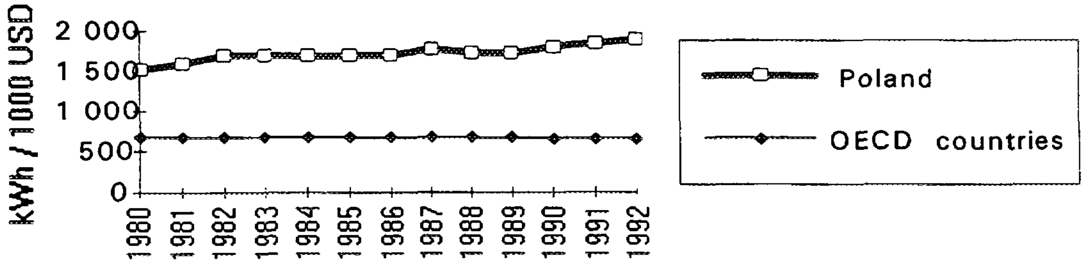


Fig. 8 Electricity Intensity,



Finally, the method of energy demand forecasting leads to define variables and parameters in the formula:

$$\Delta E_{i,k} = (1+\Delta A)^{\alpha} \times (1+\Delta B)^{\beta} \times Q-1 \qquad (1)$$

where i is the energy carrier subscript; k is the national economy sector subscript; A and B are macroeconomic variables; α, β and Q are parameters; Δ is a symbol of increment. Q is a parameter describing all other (besides A and B) factors influencing the energy demand growth. It describes both technical and organisational standards of the given sector and conservation programmes in energy use.

3. Data Sources

The basic source of statistical data used for forecasting were the publications of the International Energy Agency:

- "National Accounts" volume II, OECD, Paris, Department of Economics and Statistics;
- "Energy Balances of OECD Countries", OECD, Paris;
- "Energy Prices and Taxes", OECD, Paris.

In addition, several time series and other data were used, such as:

- "Industrial Structure Statistics", OECD, Paris;
- "Year Urbanization Prospects", United Nations, New York, 1991;
- "World Development Report- Workers in an Integrating World", 1995, Oxford University Press.

These and other Polish sources have determined both energy carriers and economy sectors aggregation:

Economy Sectors:

- Heavy Industry: Iron and Steel, Chemical, Non-Ferrous Metals, Non-Metallic Minerals,
- Manufacturing - Other Industry Sectors, including Mining and Quarrying,
- Transport,
- Agriculture,
- Commerce and Public Sector,
- Households.

Energy Carriers:

- Coal - Hard Coal, Lignite, Patent Fuel, Coke, Coke Oven Gas, Blast Furnace Gas,
- Oil - Crude Oil, Petroleum Products,
- Other Solid Fuels - Peat&Wood, Non-Commercial Fuels, Biomass, etc.,
- Gas - Natural Gas, Gas Works Gas,
- Electricity,
- Heat.

4. Countries-Analogues Set

First preliminary steps led to excluding several countries from the full list of OECD countries. These countries were:

- Iceland, Ireland and Luxembourg because their population was more than 10 times lower than in Poland;

- Australia, Canada, New Zealand and USA which are countries with quite different geographical and economic conditions;

- Turkey because of statistical data shortage and some inconsistency in the time series:

For the remaining 16 countries, 1970-1992 time series of energy use/supply and macroeconomics indices were investigated (Figs. 9-12). As expected, for the base year (1970), energy production for many countries was similar to the Polish one, i.e., a significant share of coal. There were however some exceptions:

- The contribution of gas is important in the Netherlands, and relatively important in Austria and Italy;

- Norway, where oil and gas are also significant, and Switzerland have a great hydropower potential.

During the next step, changes in energy use/supply structure between 1970 and 1992 were considered. One should note that the energy supply structure in Poland has practically remained unchanged from 1970 to 1992, and that, for the foreseeable future, the Polish economy will remain coal intensive. The share of coal production decreased more than 10 times in Belgium, Denmark and Japan, more than 20 times in The Netherlands; coal has been replaced by nuclear energy in Belgium and Japan, and by oil and gas in The Netherlands and Denmark. In light of these changes, these countries were also excluded from further comparisons.

Therefore, for regression analysis, eight countries remained as analogues: Finland, France, Germany, Great Britain, Greece, Portugal, Spain and Sweden.

Fig. 9 Primary Energy Production Structure, 1970

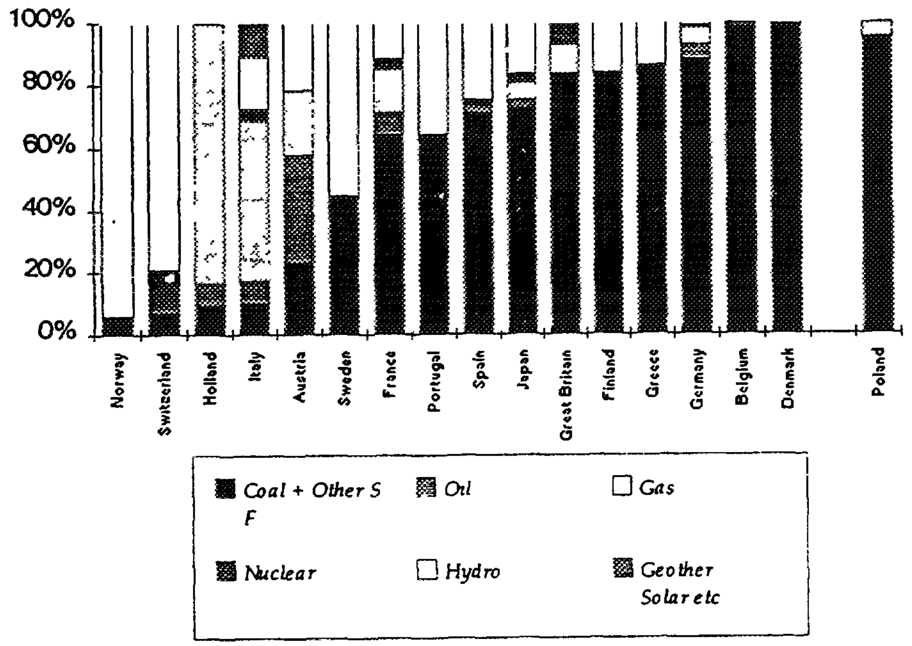


Fig. 10 Primary Energy Production Structure, 1992

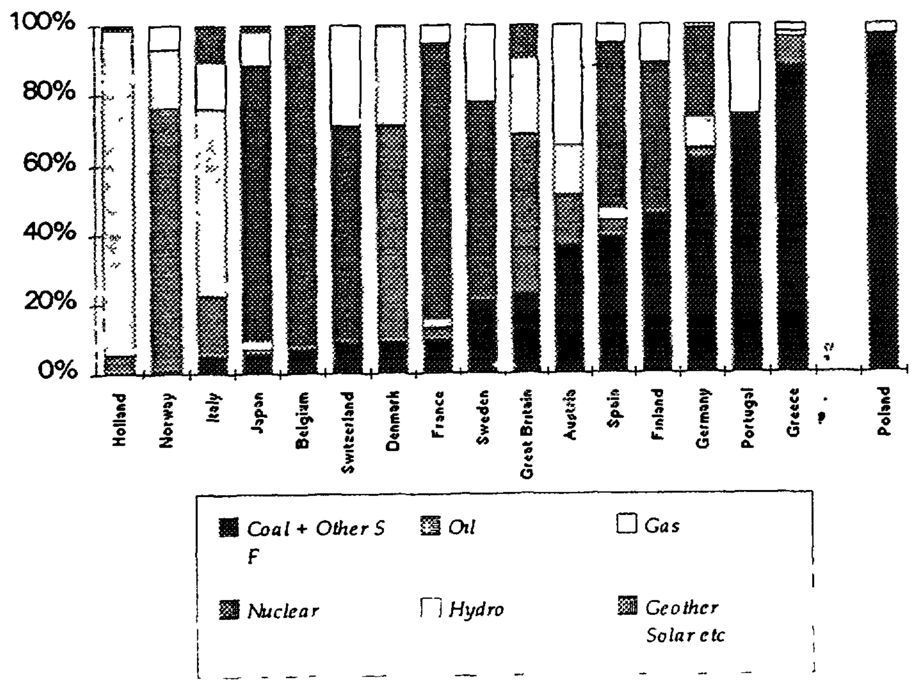


Fig. 11 Primary Energy Supply Structure, 1970

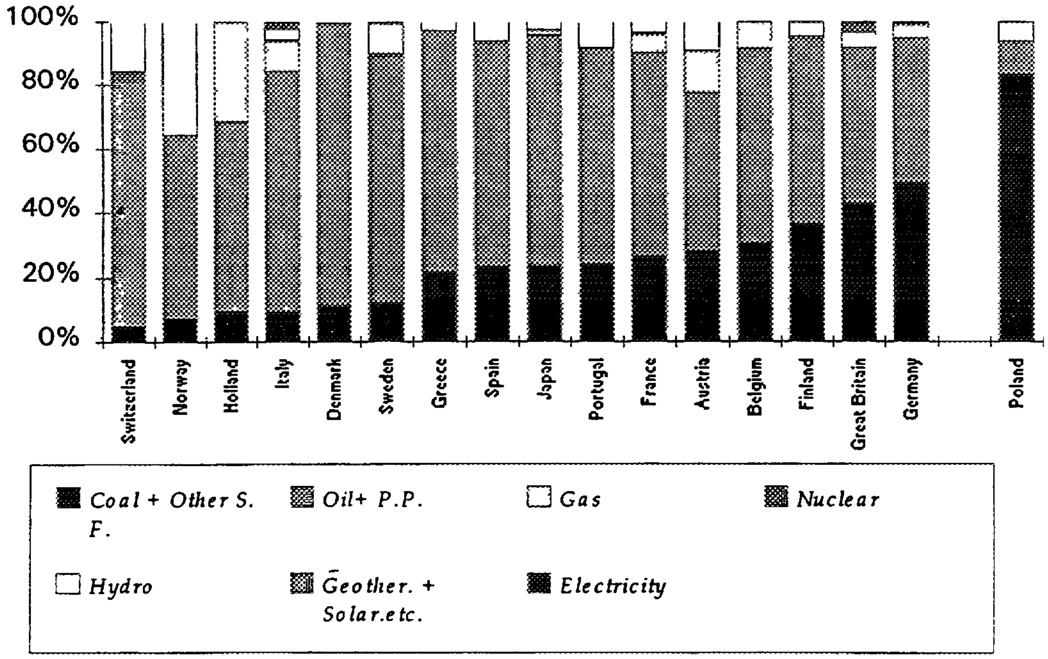
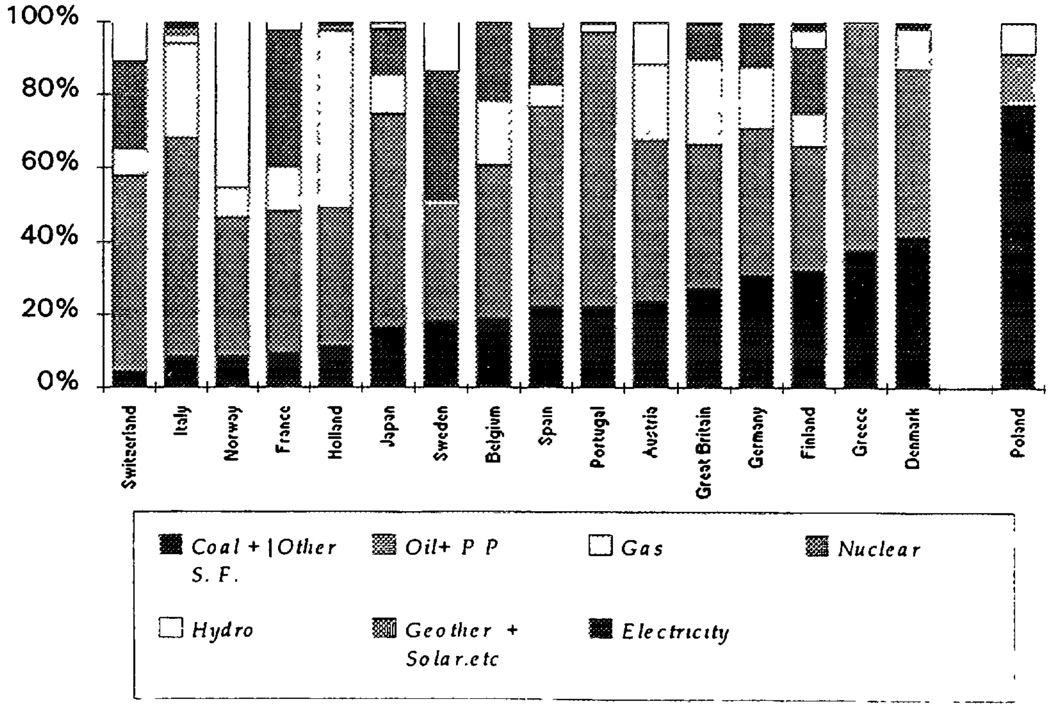


Fig. 12 Primary Energy Supply Structure, 1992



5. Algorithm

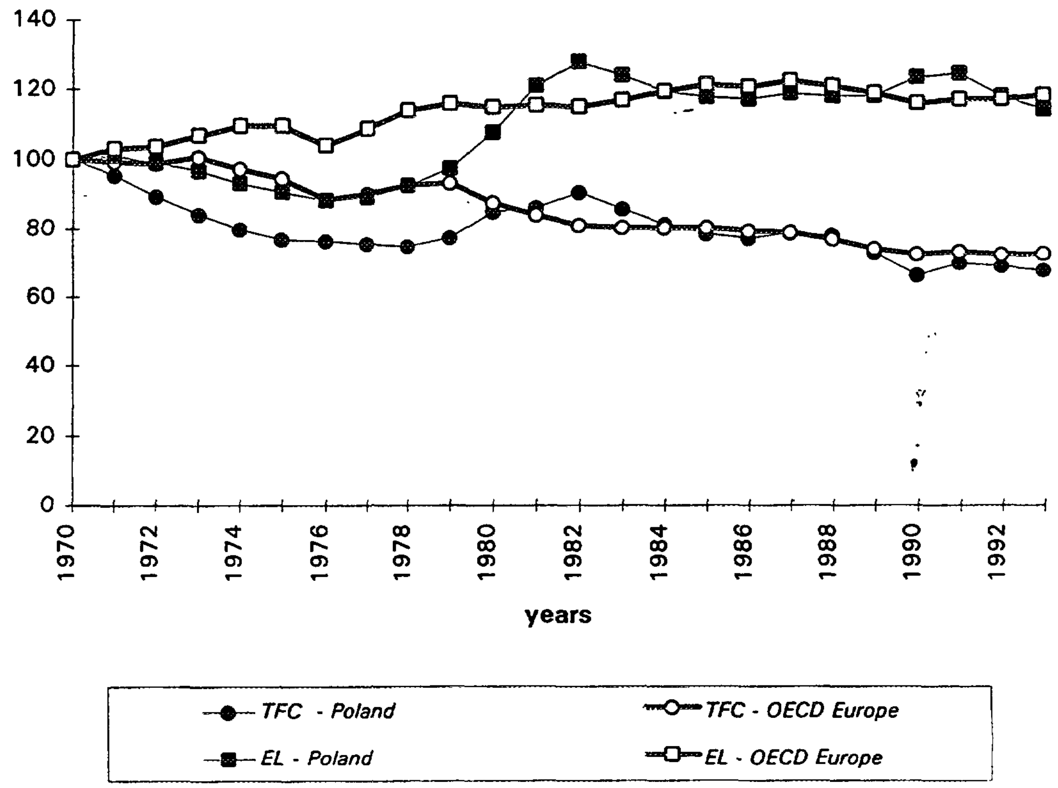
Estimation of equation (1) is conducted in three stages:

1. Specification of variables and estimation of parameters for electricity;
2. Specification of variables and estimation of parameters for the rest of energy;
3. Breaking down of the rest of energy demand growth by energy carriers.

There are several reasons for distinguishing electricity from all other types of final energy. For many purposes electricity cannot be practically replaced by any other energy carrier (lighting, electrical appliances, electromechanic devices, electrolyses, etc.). It is chosen as the most comfortable energy carrier, although it may be more expensive (washing machines with electrical water heating). As a consequence, electricity consumption and electricity intensity steadily increases all over the world while entire final energy intensity decreases. As an illustration, indices of final energy and electricity intensity in Poland and in the European countries of the OECD are shown in Fig. 13.

The following macroeconomic characteristics were taken into consideration: *GDP* - Gross Domestic Product, *VA* - Value Added in a particular sector, *INV* - Investment Level, INV_{-1} - Investment Level with one-year lag, and *POP* - Population.

Fig. 13 Final Energy / Electricity Intensity Indices (1970 = 100)



Electricity

A three-step estimation procedure was developed which combines historical data from the eight selected countries and Polish forecast data from the most realistic scenario.

1. Equation (1) is estimated for each of the eight selected countries using time series data from 1976 to 1992. The specification of the final regression equation takes into consideration:

   - the goodness of fit between the empirical data and theoretical curves;
   - the similarity of predicted energy growth relative to the observed growth with the analogue country;
   - sensible values of parameters α, β, and Q (in Table 1 parameter α connected to value added growth in heavy industry for Portugal has negative sign).

Table 1 Estimation of Parameters for Electricity Demand Forecast in Industry

	Finland	France	Germany	Great Britain	Sweden	Greece	Spain	Portugal
	VA	VA	VA	VA	VA	VA	VA	VA
	INV(-1)	INV(-1)	INV(-1)	INV(-1)	INV(-1)		GDP	
α	0.6717	0.4804	0.4769	0.2021	1.0141	1.0143	0.2575	-0.0370
β	-0.0276	-0.0197	-0.2515	0.0705	0.0482		-0.6272	
Q	1.0121	1.0017	0.9932	0.9907	0.9804	0.9961	1.0363	1.0413

2. Forecasts using Polish data are generated from the parameters for the eight countries. In this step, tables of energy/electricity demand growth for each economy sector are built and next, some countries are excluded from the list of analogues. One takes into consideration mainly the consistency of predicted energy growth relative to the expected growth in Poland (in Table 2, the growth of electricity demand in the commercial sector calculated upon the time series of Greece amounts to 14.554 which is rather unlikely).

After the second step only five analogues countries were retained: Finland, France, Germany, Great Britain, Sweden. Besides Finland, all these countries have a heavy industry.

3 Energy growth forecasts are averaged across countries and used as a dependent variable for estimating equation (1). This regression is performed over the forecast period using data from the macroeconomic model for Poland. Specified variables A and B, and estimated parameters α, β, and Q are used for energy/electricity demand growth forecast for all macroeconomic scenarios.

Table 2. Estimation of Parameters for Electricity Demand Forecast in Commerce & Public Sector

	Finland	France	Germany	Great Britain	Sweden	Greece	Spain	Average
Time Series	**POP**	**VA**	**POP**	**POP**	**VA**	**POP**	**POP**	
	VA	**INV(-1)**	**VA**	**VA**	**INV**	**GDP**	**GDP**	
α	7.3313	0.7919	-3.0462	3.8147	-0.0423	-0.2624	-4.0717	
β	0.4789	-0.1055	1.8561	0.2808	0.1769	1.7553	-0.0052	
Q	1.0172	1.0289	0.9694	1.0005	1.0413	1.0324	1.0771	
1993	1.000	1.000	1.000	1.000	1.000	**1.000**	1.000	1.000
1994	1.035	1.032	0.980	1.010	1.053	**1.115**	1.069	1.042
1995	1.073	1.066	0.968	1.021	1.108	**1.222**	1.143	1.086
1996	1.116	1.101	0.956	1.034	1.163	**1.320**	1.220	1.130
1997	1.170	1.151	0.966	1.052	1.219	**1.427**	1.302	1.184
1998	1.241	1.225	1.017	1.077	1.281	**1.598**	1.387	1.261
1999	1.327	1.320	1.106	1.108	1.345	**1.816**	1.479	1.357
2000	1.420	1.421	1.200	1.141	1.414	**2.084**	1.575	1.465
2001	1.515	1.524	1.294	1.172	1.484	**2.362**	1.679	1.576
2002	1.611	1.627	1.378	1.202	1.557	**2.655**	1.790	1.689
2003	1.710	1.733	1.456	1.232	1.632	**2.970**	1.908	1.806
2004	1.812	1.841	1.530	1.261	1.711	**3.309**	2.034	1.928
2005	1.917	1.954	1.602	1.289	1.793	**3.675**	2.169	2.057
2006	2.018	2.071	1.674	1.315	1.878	**4.073**	2.319	2.192
2007	2.122	2.193	1.744	1.341	1.967	**4.504**	2.479	2.336
2008	2.231	2.320	1.813	1.366	2.059	**4.970**	2.650	2.487
2009	2.343	2.453	1.881	1.392	2.156	**5.476**	2.833	2.648
2010	2.460	2.591	1.947	1.417	2.256	**6.023**	3.028	2.817
2011	2.594	2.735	2.007	1.446	2.361	**6.612**	3.228	2.998
2012	2.734	2.885	2.065	1.476	2.470	**7.249**	3.442	3.189
2013	2.880	3.042	2.121	1.506	2.584	**7.938**	3.670	3.391
2014	3.033	3.205	2.177	1.535	2.703	**8.683**	3.913	3.607
2015	3.193	3.377	2.231	1.566	2.827	**9.487**	4.172	3.836
2016	3.360	3.555	2.284	1.596	2.956	**10.356**	4.448	4.079
2017	3.535	3.742	2.335	1.627	3.091	**11.292**	4.742	4.338
2018	3.719	3.937	2.385	1.658	3.232	**12.301**	5.056	4.613
2019	3.910	4.140	2.432	1.690	3.379	**13.387**	5.391	4.904
2020	4.110	4.352	2.479	1.721	3.533	**14.554**	5.748	5.214
growth rates 1992 / 1970	4.2	4.51	2.64	1.95	3.1	**4.98**	6.3	

Other energy carriers

The estimation procedure for the other five energy carriers (coal, natural gas, petroleum products, other solid fuels, heat) is similar to the one for electricity. The only difference takes place in the 3rd step: averaging energy growth across countries and estimation of parameters are separated by a procedure of determination of the energy carriers shares in each economy sector over the whole period of the studies.

Energy carriers shares

An "S"-country has been created- with the total sum of consumption of the five energy carriers across Finland, Germany, Great Britain, and Sweden (France was excluded as a country that improperly shows its heat use). In developing the procedure of breaking down energy carriers the following facts were taken into account:

- a significant share of heat in the base year in industry, manufacturing, commercial and residential sector (see Table 3 comparing the shares in Poland and "S"-country),
- a relatively small share of oil products, especially in industry, manufacturing and commercial sector.

Table 3. Shares of Energy Carriers

			Coal	Natural Gas	Heat	Other solid fuels	Oil products
Heavy Industry	Poland	1993	0.490	0.130	0.346	0.001	0.034
	"S"-country	1976 1992	0.480 0.365	0.081 0.252	0.000 0.006	0.005 0.005	0.434 0.373
Manufacturing	Poland	1993	0.268	0.060	0.597	0.019	0.055
	"S"-country	1976 1992	0.250 0.262	0.052 0.263	0.006 0.031	0.075 0.123	0.618 0.320
Transport	Poland	1993	0.036	0	0	0	0.963
	"S"-country	1976 1992	0.038 0.001	0 0	0 0	0 0	0.962 0.999
Agriculture	Poland	1993	0.218	0.051	0.097	0.105	0.529
	"S"-country	1976 1992	0.099 0.042	0.002 0.035	0 0	0 0.051	0.899 0.872
Commerce & Public Sector	Poland	1993	0.718	0.096	0.163	0.022	0
	"S"-country	1976 1992	0.439 0.203	0.147 0.258	0.012 0.086	0.025 0.023	0.377 0.427
Households	Poland	1993	0.472	0.140	0.275	0.107	0.006
	"S"-country	1976 1992	0.351 0.183	0.085 0.381	0.011 0.063	0.031 0.031	0.523 0.341

As it is improbable to reduce considerably the use of district heating and to expect a significant increase of oil import, the rules of sharing energy carriers were the following:

- changes of coal, natural gas, and other solid fuels shares in the whole planning study are equal to the ones of S-country during 1976 - 1992;
- shares of oil products remain at their 1993 level;
- shares of heat supplement to 100%.

5. Results

The results of the model consist of determining explanatory variables and parameters of equation (1). The results for electricity are shown in Table 4.

Table 4. Results of estimation of equation (1) for electricity

Industry	$\Delta E = (1+\Delta VA)^{0.3576} * (1+\Delta INV_{-1})^{0.0433} * 1.00064 - 1$
Manufacturing	$\Delta E = (1+\Delta VA)^{0.0351} * (1+\Delta INV_{-1})^{0.1775} * 1.02908 - 1$
Transport	$\Delta E = (1+\Delta INV_{-1})^{0.0328} * 0.99952 - 1$
Agriculture	$\Delta E = (1+\Delta VA)^{0.5256} * (1+\Delta INV)^{-0.0740} * 1.01956 - 1$
Commerce & Public	$\Delta E = (1+\Delta VA)^{0.3091} * (1+\Delta INV_{-1})^{-0.0120} * 1.03522 - 1$
Households	$\Delta E = (1+\Delta POP)^{21.51} * (1+\Delta GDP)^{-0.3189} * 1.00637 - 1$

As an illustration of the final energy demand growth forecast for realistic scenario, predicted values for Heavy Industry and Commercial and Public Sector are shown in Fig. 14 and 15. Final energy elasticity (including electricity) is 0.236, electricity elasticity is 0.874.

Figures 16 and 17 compare energy and electricity intensities of 5 countries-analogues in 1970 and Poland in 1993. As expected, the energy intensity in 1993 for Poland was approximately 15% higher than for Finland in 1970, and 55% higher than the average intensity of 5 countries.

Figures 18 and 19 compare intensities of 5 countries in 1993 and evaluated intensities for Poland in 2020 (OP - Optimistic Scenario; RE - Realistic Scenario; PE - Pesimistic Scenario). One can note that the technology gap in energy use between countries-analogues and Poland shrank, especially for the optimistic scenario.

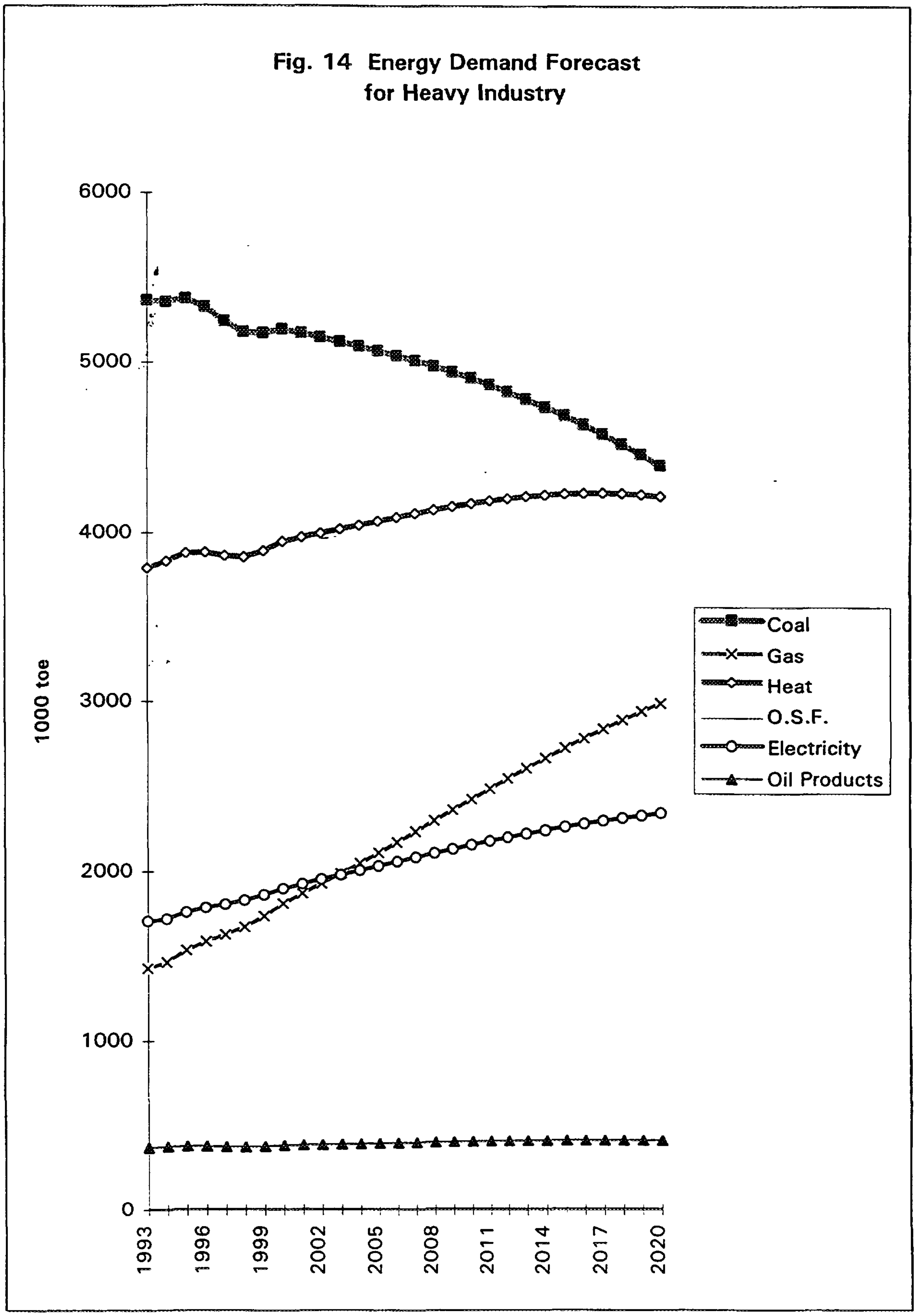


Fig. 14 Energy Demand Forecast
for Heavy Industry
6000
5000
4000
3000
2000
1000
0
1000 toe
1993
1996
1999
2002
2005
2008
2011
2014
2017
2020
Coal
Gas
Heat
O.S.F.
Electricity
Oil Products

Fig. 15 Energy Demand Forecast for Commercial Sector

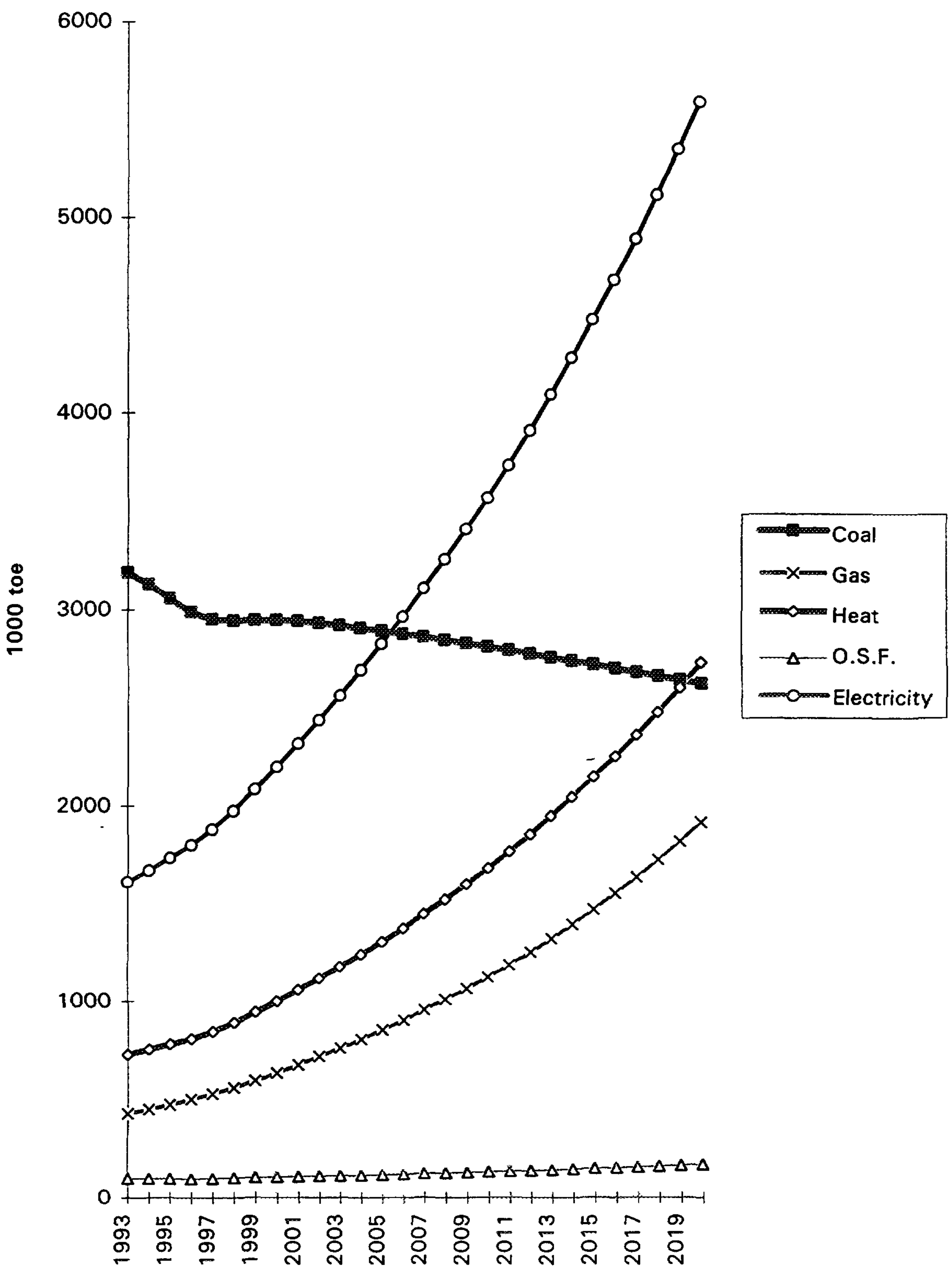


Fig. 16 Energy Intensities 1970

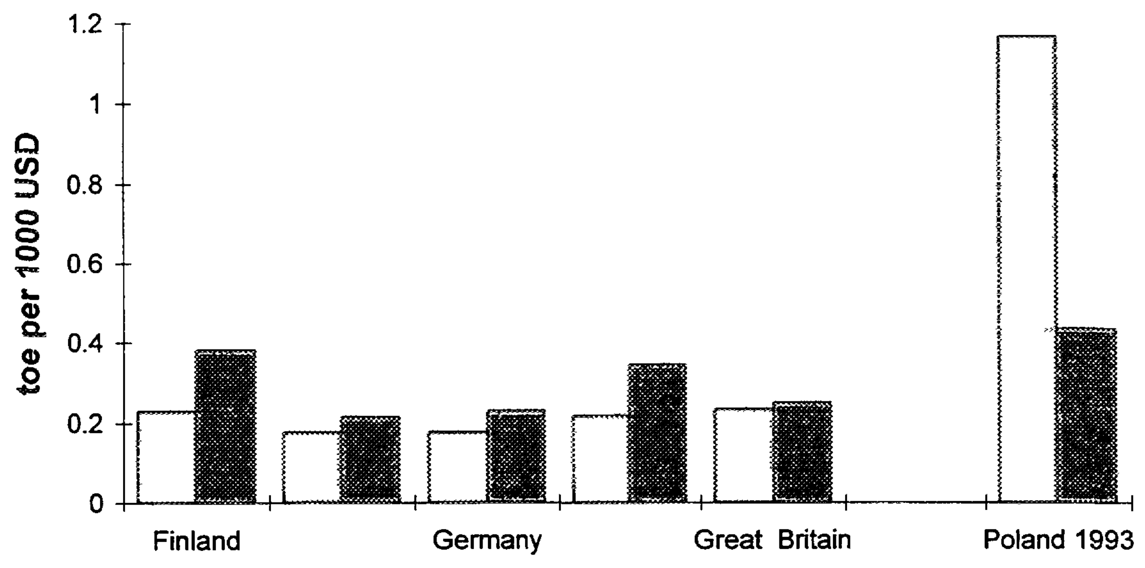


Fig. 17 Electricity Intensities 1970

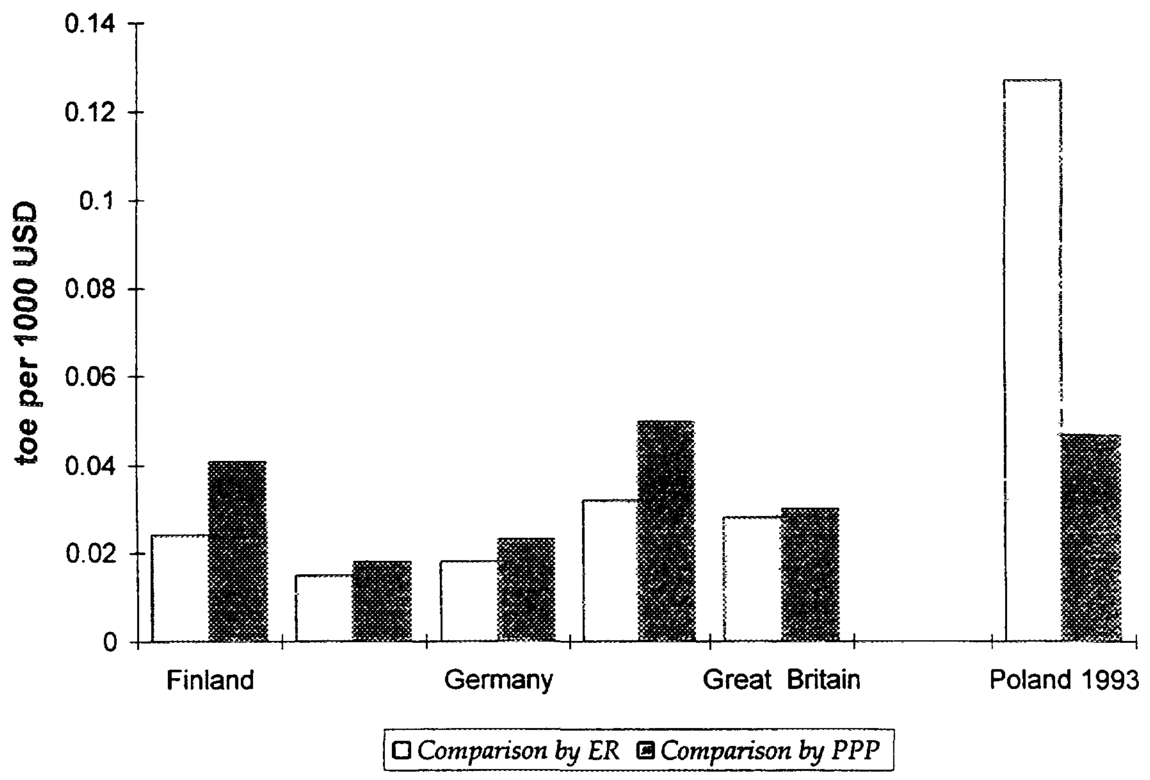


Fig. 18. Energy Intensity 1993

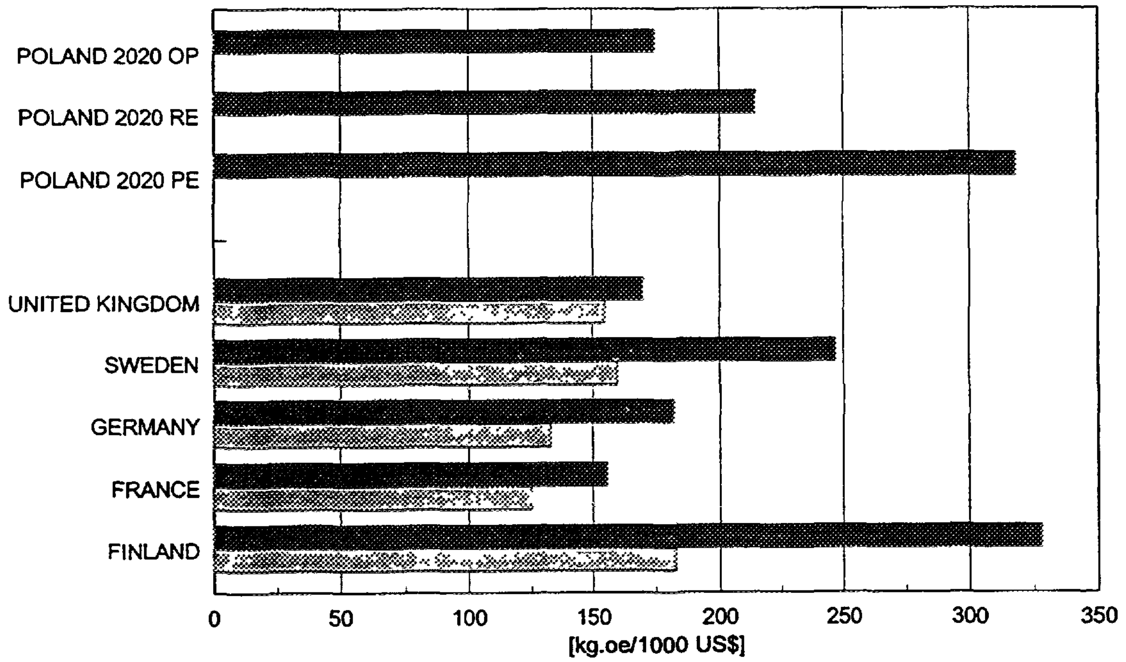
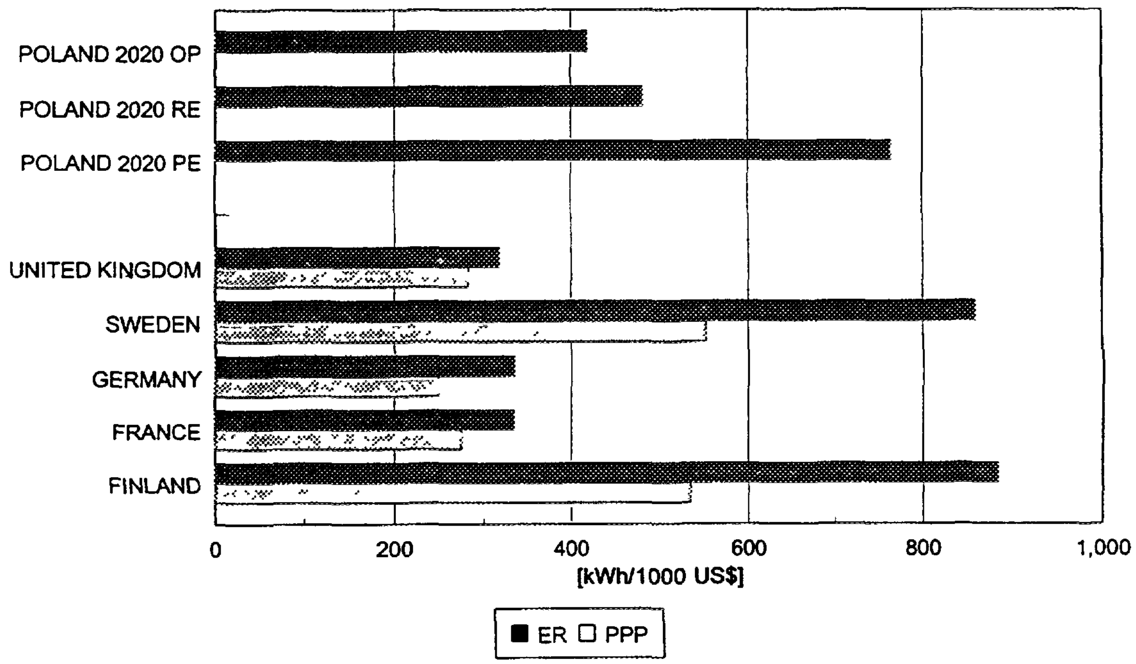


Fig. 19. Electricity Intensity 1993



6. Conclusions

The method of energy demand growth forecasting combines mathematical expressions in regression analysis equations and a planner intuition. The model fulfills basic principles of good long-term forecasting [1], namely:

Identify causality- energy demand growth is created by economic activity; the starting point is strictly defined.

Be reproducible- the method is described in mathematical definitions and several heuristic assumptions; it can be applied by another experienced planner, as well as to another country in transition.

Be functional- it is used for determining energy demand growth in Poland for 1994-2020 in conducted studies by using the BALANCE Module.

Test sensitivity- the model allows to reflect in energy demand growth different scenarios of macroeconomic growth, with faster or slower economy transformation.

Maintain simplicity- the model takes into account only basic appropriateness in energy demand growth, it is simplified according to data availability and reliability.

Reference

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Expansion Planning for Electrical Generating Systems - A Guidebook. IAEA, TRS No. 241, Vienna, 1984

XA9745303

COAL SECTOR MODEL: SOURCE DATA ON COAL FOR THE ENERGY AND POWER EVALUATION PROGRAM (ENPEP)

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Abstract

Coal is the major primary energy source in Poland and this circumstance requires that the data on coal supply for use in energy planning models should be prepared properly. Economic sectors' development depends on many factors which are usually considered in energy planning models. Thus, data on the development of such sectors as coal mining should be consistent with the economic assumptions made in the energy planning model. Otherwise, coal data could bias the results of the energy planning model. The coal mining and coal distribution models which have been developed at the Polish Academy of Sciences could provide proper coal data for use in ENPEP and other energy planning models.

The coal mining model optimizes the most important decisions related to coal production, such as coal mines development, retirement of non-profitable mines, and construction of new mines. The model uses basic data forecasts of coal mine costs and coal production. Other factors such as demand for coal, world coal prices, etc., are parameters which constitute constraints and requirements for the coal mining development. The output of the model is the amount of coal produced and supply curves for different coal types. Such data are necessary for the coal distribution model and could also be used by ENPEP.

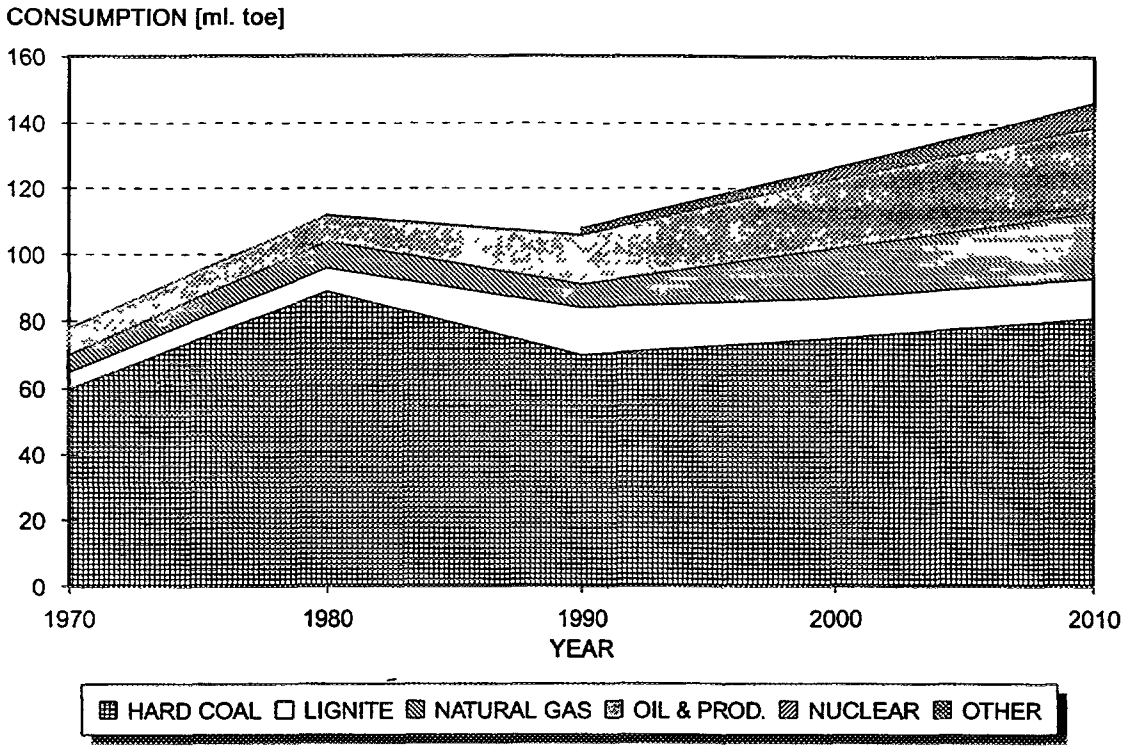
This paper describes the model, its structure and how the results of the model could serve as coal-related data for ENPEP. Improvement of some input data forms of the BALANCE module of ENPEP are also suggested in order to facilitate data preparation.

1. INTRODUCTION

Hard coal is the major component of the Polish primary energy supply and presently represents about 67% of the total primary energy. This share should diminish in the future (Fig. 1), although the amount of coal consumed is expected to increase.

Research on the future of large systems such as the energy supply/demand system requires considerable amount of data of various kind. Models, like ENPEP which deals with integrated systems, need to be provided with data on primary energy supply. The data on coal supply to be used by energy systems models, need to be elaborated carefully since minor distortions could lead to improper results. The wide range of data are required. These range from the characteristics of primary energy supply technologies (the SPSEK system used in Poland) through costs and production of specific fuels (IPM for power generation planning) or supply curves (ENPEP).

Fig. 1 PRIMARY ENERGY SUPPLY in POLAND



Data on fuel supply sectors are usually prepared under different projects and constitute one fixed set of data. The underlying assumption is that the sectors will be relatively stable and therefore the data associated to these sectors will not need any modification. This might be the case for small and not very relevant supplies or stable sources such as coal imported from major coal exporting countries. Any other supply sector should be considered as variable with possible modifications of its structure, level of production, costs, etc. The different factors which cause these changes are usually considered within the energy planning models (by means of scenarios). The data on primary energy supply required for such models should be coherent with the values of these factors.

On the other hand, there are other factors which are not considered in the energy planning models, but which are specific to the fuel supply sectors. In case they are considered as relevant factors, the modeler should try to establish a link between the corresponding factor and the other known factors considered in the energy planning model in order to establish consistent scenarios. For example, in the case of Poland, the extent of coal mines' saline waters utilization programme could be associated with an appropriate environmental protection scenario in the energy planning models.

Another way of preparing consistent data on primary energy supply is to use separate (satellite) models which focus on the analysis of the problems specific to these sectors. Such models became more important since the transformation of the economy and the restructuring of the sectors stimulate significant structural changes.

The system for coal sector modelling is being developed to analyze coal industry perspectives. It consists of databases and three groups of models (Fig. 2). These models are the coal mining model (supply model), the coal consumption model (demand model) and the market equilibrium models. Presently, the system comprises databases and two models: coal mining and coal distribution (an early version of market equilibrium model). These are sufficient for the present research on energy and economy systems. Currently, the development of demand models is limited by the lack of the data required, especially on coal demand and prices. The future development of the system is directed towards demand modelling and improvement of the links with models of energy system, electricity generation and national economy models.

2. COAL MINING MODEL

During the period of centrally planned economy, coal mining was exploited to produce as much as possible, regardless of efficiency and costs. The result is that no single coal mine was profitable at the beginning of the economic reforms in 1990. Presently, with a low demand for coal, mines remain with problems of economic efficiency. This situation could change if demand for coal raises because of an increasing industry production or/and heavy winters. The coal quality, not quantity, would then become a major issue. The problem of coal mining viability for the long term is therefore crucial for the prospects of the Polish energy system.

The coal sector (Fig. 3) is represented by a set of mines producing different types of coal, and by major consumers divided into four groups: households, industry, coke ovens and power generation. Some mines continue to operate as usual; others might benefit from the construction of fines beneficiation or desulphurization plant. Supply could be supported by construction of new mines and imported sources. However, both imports and exports are limited. Coal production and consumption are one of the major sources of pollution. The protection of the environment is implemented thanks to technologies of salinated waters utilization and emission reduction.

The coal mining model (Fig. 4) has to consider major economical and environmental issues of the present and future development of coal mining and coal consumption. Those coal mines which remain after some others have been shut down are expected to be profitable without being subsidized. Therefore one should establish plans for restructuring of mines within the next twenty years. The basic data needed are estimates of mines production and economic factors for the period 1993-2010.

The model involves several stages. The first step is to forecast costs and revenues of the mines. There is a need to adjust costs to the changes in price structure. The major component of operating costs, e.g., labor, materials and energy costs, are expected to rise to the world market level. Prices of energy (electricity, natural gas) which are controlled by the state, have risen more than five times since January 1990. Other prices should not rise as much; labor costs could increase proportionally to consumption, which in turn depends on the gross national product (GNP) increase. Costs of supporting materials and equipment have already reached the world market prices. The differences in expected increments of the operating costs require the adjustment of the forecasts which are estimated at present market prices. The model performs this adjustment on the basis of mining cost structure and assumed price increases. Capital and investment costs are calculated considering mines' own funds and loans as the source of investments funds. The sum of operating and capital costs gives a primary estimation of the cost of coal production. The revenues of coal mines are calculated on the basis of prices which are expected on the domestic market. There is a presumption that the prices will be equivalent to coal export prices (at the mines' mouth). Other forecasts of domestic coal prices are estimated from a coal distribution model. These sources determine the level of prices, the structure - relations for different coal quality are adjusted according to the commonly approved rules. They allow to estimate coal prices depending on their ash and sulphur content, heat value, grade.

Coal is not uniform in quality and should therefore be divided into classes (coal fuels) according to their characteristics. Quality parameters such as ash and sulphur content, heat value could be used as criteria of classification. If some of the input data are obtained from another model, the classification criteria and the number of coal categories should be established according to the requirements and properties of the recipient model. For example, for the analysis of power station supply, other measures like emissions of particulates and SO_2 are recommended.

The calculation of both costs and revenues allows to make a first assessment of coal costs. The final assessment requires solution by the model, as it includes costs of mine waters desalination and investment of coal fines beneficiation or coal desulphurization.

Coal mines in the east region of Upper Silesia Coal Basin discharge a lot of saline waters to rivers. Presently, only a small fraction is neutralized. The model was prepared to select technologies of water desalination, taking into account the economic and limited possibilities of application of these technologies. For example, the cheapest re-injection technology requires particular geological conditions of surrounding rocks. The results of the model provide the capacities for each technology and the schedule of construction.

Another factor which could affect coal mines efficiency is the program of coal desulphurization and fines washing. Coal from the Upper Silesia basin has a relatively high sulphur content. Burning of this coal for electricity production causes large emissions of SO_2. The model considers construction of abatement plants for specific mines. Data needed are the expected costs and quality of raw and produced coal for two variants of mine development, namely with or without additional preparation plant (coal fines' washing or desulphurization). The economic performances of these abatement technologies are added to the values of costs and revenues previously obtained. The model considers environmental constraints, i.e., emission limits for power stations. The costs of emission reduction are compared with the costs of coal beneficiation which improves coal quality and therefore lowers emissions. This segment was established in order to consider new regulations that reduce substantially emission limits. Therefore the model is able to analyze the influence of the regulations on the demand for coals of different quality.

FIG.2. STRUCTURE OF THE COAL SECTOR MODEL.

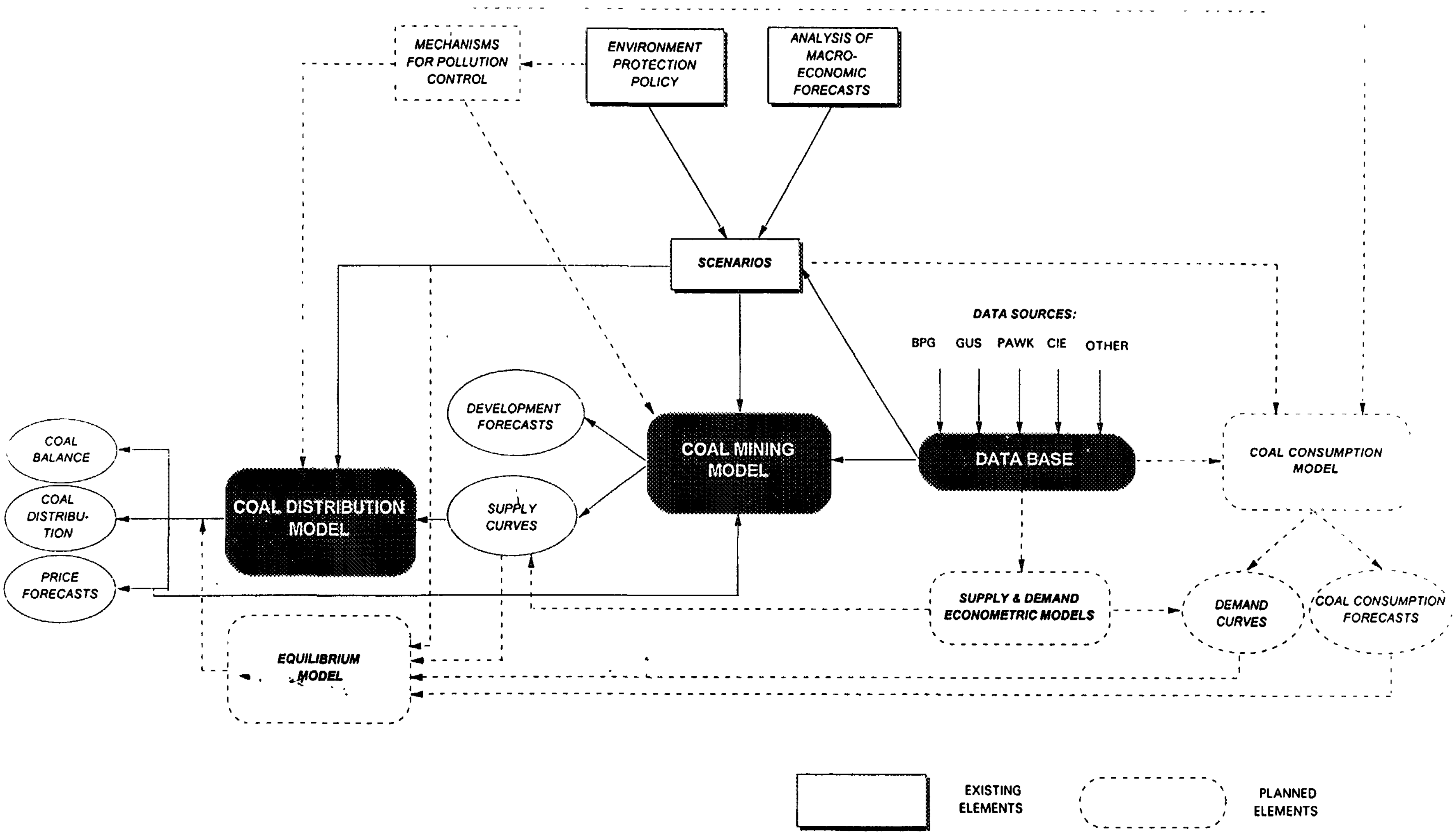


FIG.3. REPRESENTATION OF COAL PRODUCTION AND CONSUMPTION IN COAL MINING MODEL.

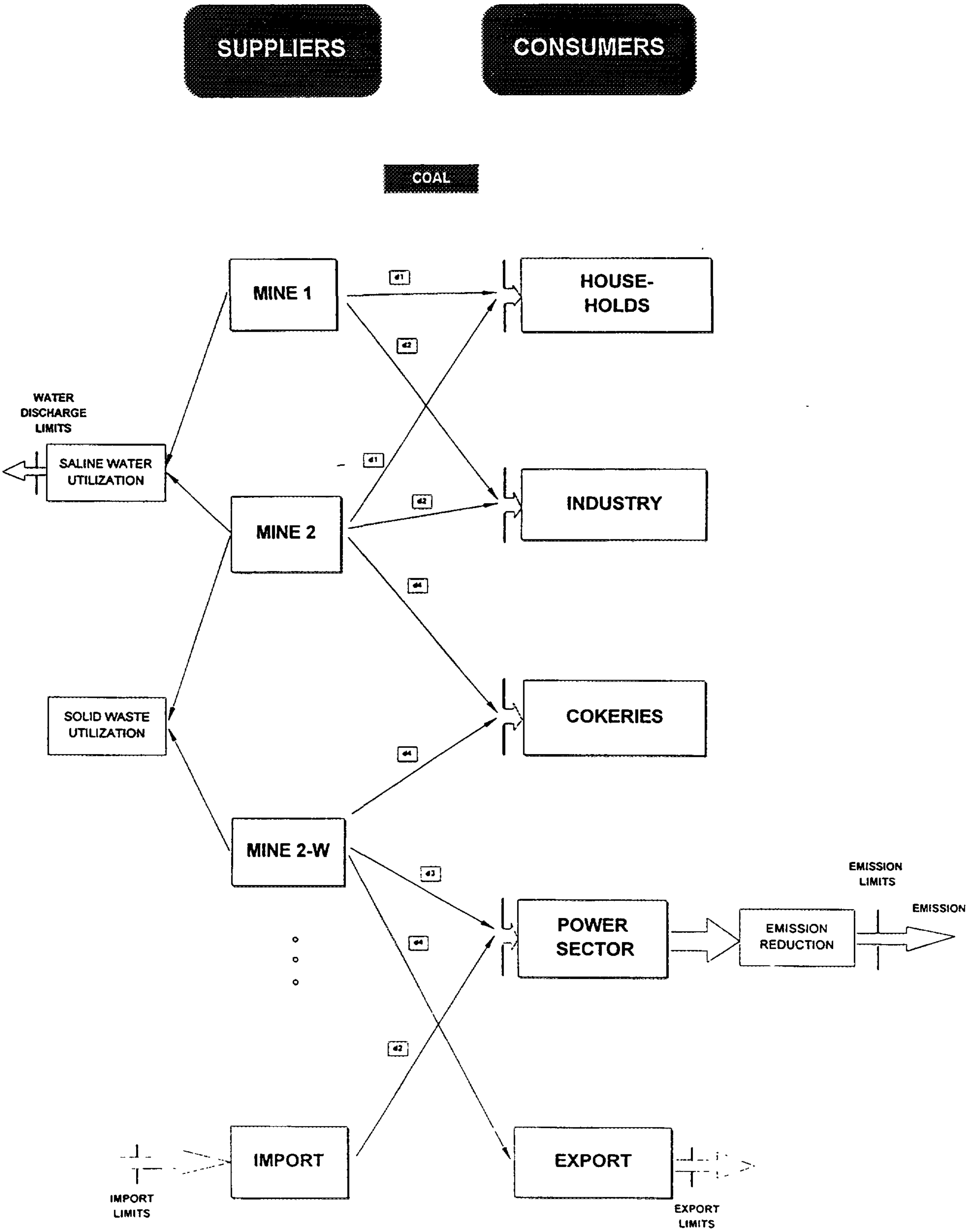
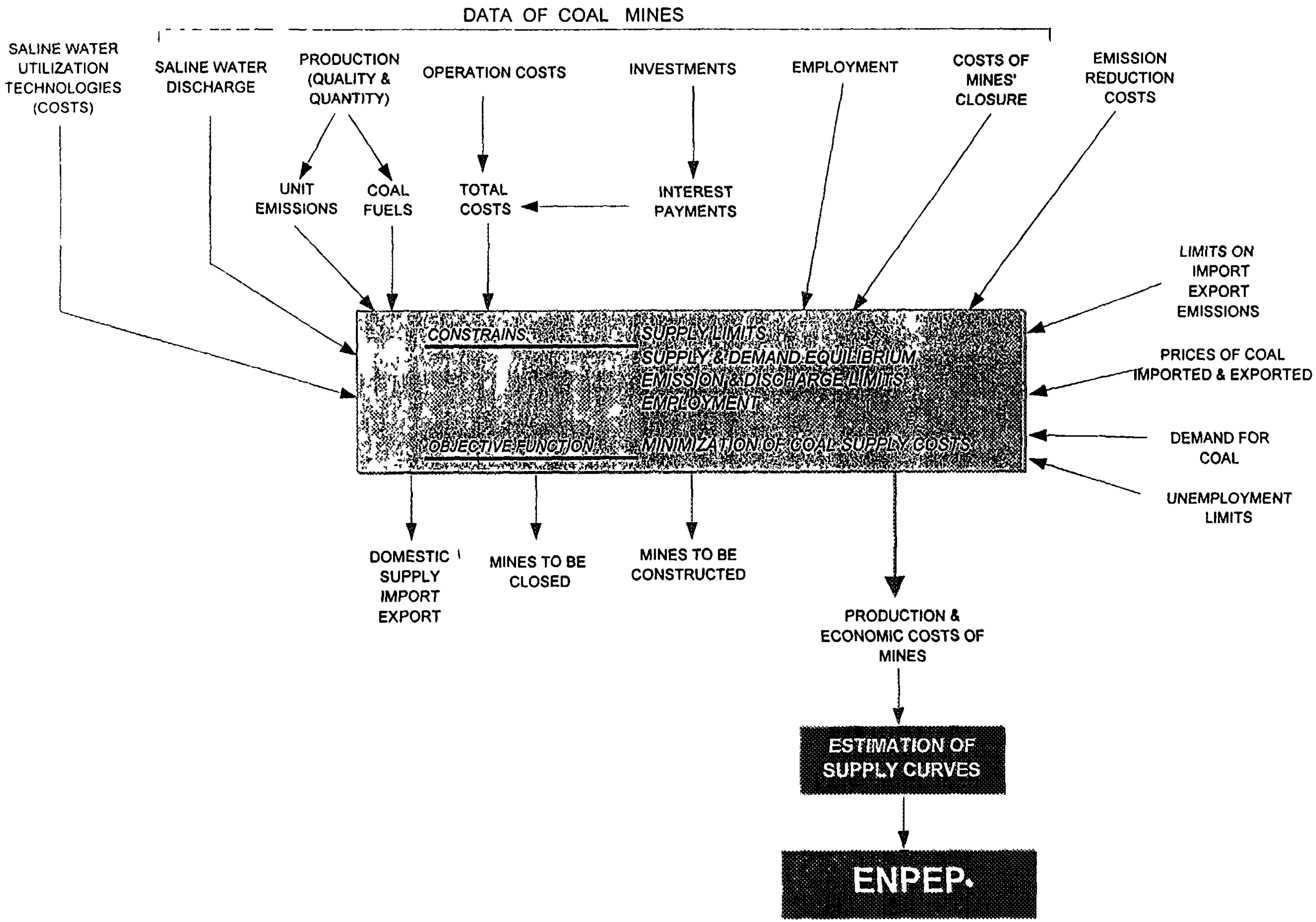


FIG.4. STRUCTURE OF THE COAL MINING MODEL.



The resulting changes of the efficiency of coal mines is calculated and the values are used by the model to identify those mines that might be unprofitable and should be closed. Final values of costs are also used for the estimation of the supply curves.

Coal demand is one of the constraints of the model which distinguishes domestic coal from imported coal. The comparison of the costs for domestic and imported coal allows to identify the mines that could efficiently supply the domestic market.

The problem of closing unprofitable mines needs some explanation. Shutting down a mine requires special funds devoted to technical and social issues. The impact of a closure should be limited by the implementation of other measures, e.g., to limit the problem of unemployment, one could develop programmes for training the staff for new jobs and/or develop special retirement programmes. The costs arising from these measures are, in some cases, comparable to the subsidies granted to allow some mines to run. A rational decision in this case could be to postpone the closing of the mine. In the model, the decision criteria for shutting down a mine is the comparison between the subsidies necessary to maintain it in operation and the costs generated by its closure. One constraint could be a limit of the unemployment rate. As a result, the model is able to identify the mines to be closed and the time it should occur.

The macro- and micro-economic conditions in which the model simulates coal mining development are represented in different scenarios that take into account prices for exported and imported coal, domestic demand, costs increase, interest rate. Data are taken from other models, from programmes concerning the development of the energy sector, or from authors own judgment. The number of scenarios varies depending on the number of decision factors to be analyzed.

The discounted cost of coal supplied for domestic consumers is the objective function of the model. It uses the General Algebraic Modelling System software (GAMS) and mixed integer programming.

Results of the model are indications for retirement or construction of new mines, capacities of technologies, level of production, costs, etc. For this specific subject, coal supply curves are to be considered. Figures 5 and 6 present examples of such curves.

Figure 5 shows the differences between curves established for two scenarios, lower and upper. The lower scenario corresponds to a low GDP increase, limited imports and implementation of basic environmental protection measures. The upper scenario corresponds to a higher GDP increase, absence of import limits and strict environmental protection requirements. The largest difference between the total costs for the two scenarios is more than 10%, which is substantial for a major source of primary energy.

Figure 6 presents curves established for diverse years for the same scenario. The difference here is much more in the capacity of supply rather than in the associated costs. Both cases show that data on coal supply for ENPEP should be prepared with great care.

Fig. 5 SUPPLY CURVES
coarse coal, 2005

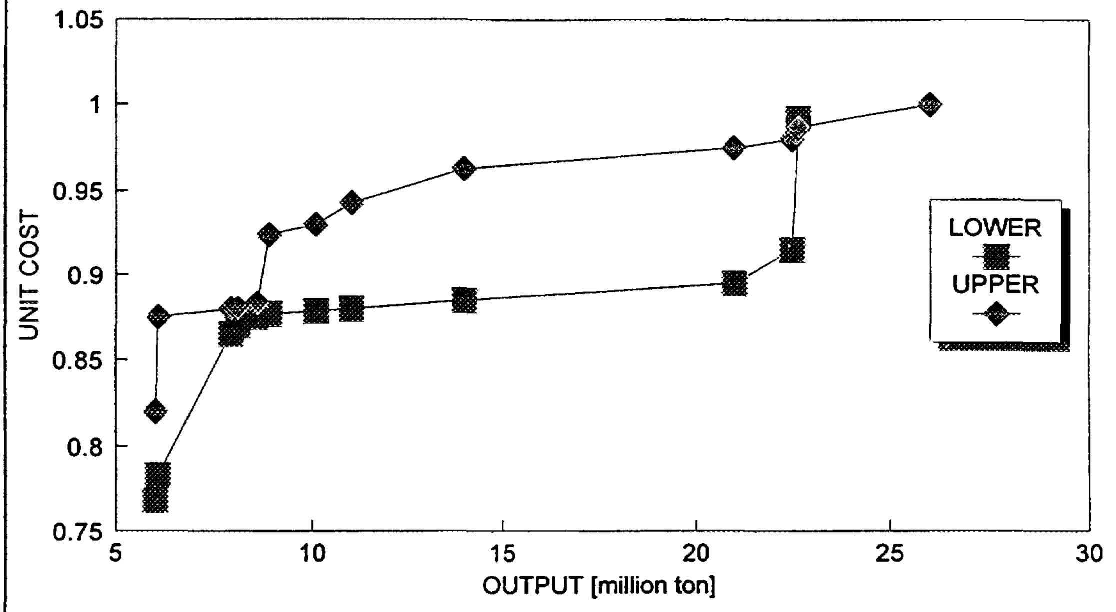
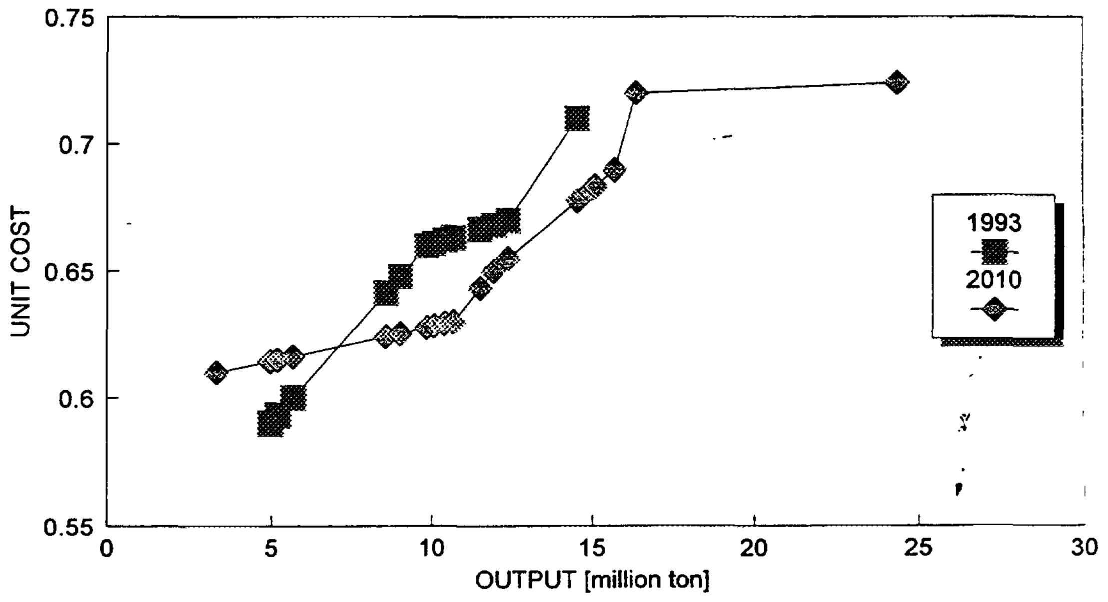


Fig. 6 SUPPLY CURVES
fine coal, UPPER Scenario



3. ESTIMATION OF DATA FOR ENPEP

The results of the coal mining model comprise data on expected production and its costs. These should be prepared according to the requirements of the ENPEP package. For coal, the depletable resource input form (B021) should be used.

Since the formula used in ENPEP for supply curves is not a straight estimation of data for a specific year and scenario, the following method should be used. It uses data on coal production and costs extracted from the coal mining model previously described. Using these data, the following procedure is performed for each scenario and type of coal separately:

1. For each year, the supply curves are estimated trough the second order polynomial function:

$$P_t = A_t + B_t \times Q_t + C_t \times Q_t^2$$

where:

P_t-	- coal price at time *t*,
Q_t	- coal production at time *t*,
A, B, C	- coefficients.

2. The intercept value is subtracted from cost data:

$$\bar{P}_t = P_t - A_t$$

3. The relative differences between intercepts of the base year and subsequent years are associated with R_t parameters (form B022),

$$R_t = \frac{A_t - A_1}{A_1}$$

4. The modified costs and the respective output for all years are gathered in one set and are used for determining the values of the coefficients B and C of the supply curves. The equation used to estimate these coefficients can be expressed as:

$$\bar{P}_t = B \times Q_t + C \times Q_t^2$$

And the final supply curve is represented by the formula:

$$P_t = A_1 \times (1 + R_t) + B \times Q_t + C \times Q_t^2$$

The above procedure allows to use the ENPEP form B021 to represent primary energy supply curves. The following example was prepared on the basis of fine coal data. ENPEP requires data (actually R_t coefficients) for every year of analysis. Therefore, the real case needs interpolation of the results of the coal mining model to obtain raw data for estimation of coefficients.

A first estimation of supply curves gives the following results:

1993: P_t=0.5234 + 0.0142*Q_t - 1.2 10^{-4} * Q^2_t R_t=0
1995: P_t=0.5555 + 0.0109*Q_t - 3.4 10^{-5} * Q^2_t R_t=0.0613
2000: P_t=0.4428 + 0.0241*Q_t - 6.1 10^{-4} * Q^2_t R_t=-0.1540
2005: P_t=0.5284 + 0.0116*Q_t - 1.6 10^{-4} * Q^2_t R_t=0.0096
2010: P_t=0.5741 + 0.0082*Q_t - 7.4 10^{-5} * Q^2_t R_t=0.0967

The R_t factors were calculated using ENPEP form B022.

The supply curve has the following form:

$$P_t = 0.5235*(1+R_t) + 0.01632*Q_t - 3.7\cdot10^{-4}*Q^2$$

Figures 7.1 and 7.2 show the results of the procedure for this sample case, i.e., supply curves for the different years. The last supply curve does not fit precisely into the data, but generally follows the trends of the detailed supply curves. In some cases, it could not be used as input data for ENPEP.

In order to facilitate input of the supply curves, introduction of new BALANCE forms (or improvement of the current form B021) is suggested. The form should allow to input coefficients of supply curves (possibly third order polynomial) for each year of the analysis (or certain years with interpolation performed by BALANCE). The annual capacity (available amount) of fuel supply should be additional data in this form. These two elements (supply curve coefficients and capacity) give the possibility to input any kind of data of fuel or other energy supply processes.

Another possibility that does not require estimation of supply curves, is to use the BALANCE form B023 which was actually prepared for renewable sources. The data to be supplied in this form are the capacities and costs of coal mines. Since these data do not change over the time, they could be applied only in case of coal supply that does not change costs and has a stable capacity.

5. SUMMARY

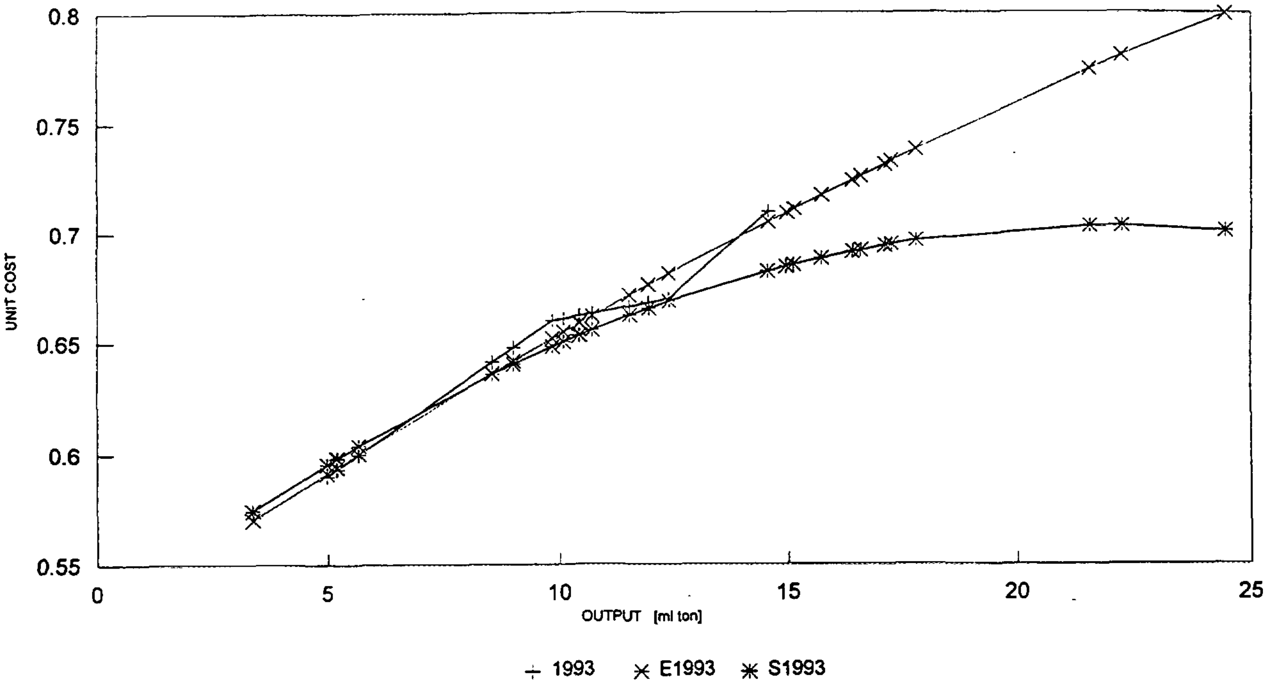
The paper presents the coal mining model developed in Poland and which can be used to provide data associated to the coal sector that are consistent with the ENPEP requirements and the scenarios applied in ENPEP studies.

The coal model considers the principal problems related to coal mining development and therefore the results represent possible variation in coal prices and production. These data are used to estimate coal supply curves as required as input to ENPEP.

Because the procedure of data preparation would not be satisfactory in some cases, it is suggested to add new data entry forms in the ENPEP package.

Fig. 7.1 SUPPLY CURVES

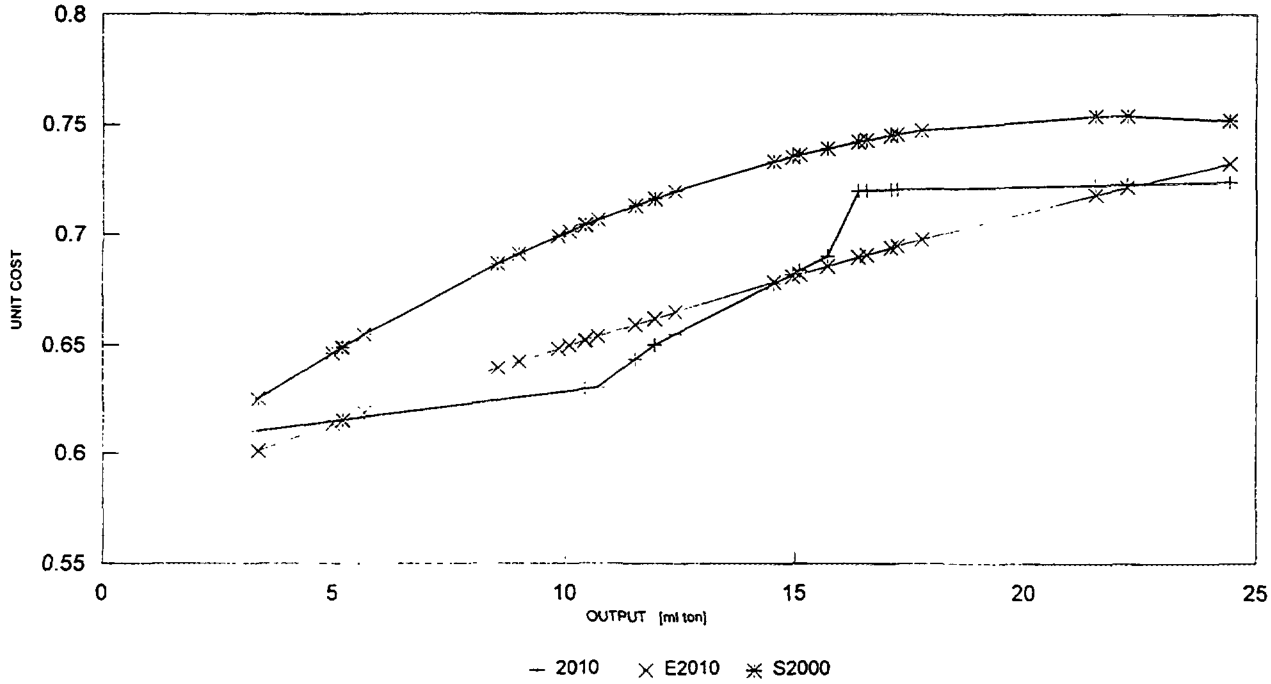
fine coal, 1993, UPPER scenario



1993 - DATA oF 1993; E1993 - ESTIMATED CURVE of 1993
S1993 - SUPPLY CURVE for ENPEP

Fig. 7.2 SUPPLY CURVES

fine coal, 2010, UPPER scenario



2010 - DATA of 2010, E2010 - ESTIMATED CURVE of 2010
S2010 - SUPPLY CURVE for ENPEP

BALANCE: HYDROELECTRICITY IMPACTS ON ENERGY SYSTEMS

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Abstract

The VALORAGUA[1] computer model was developed by Electricidade de Portugal (EDP) in order to determine the optimal operation strategy of a mixed hydro-thermal power system with an important share of hydroelectricity generation such as the one of Portugal. The model has become the main tool used by EDP for planning the development and operation of its power system. In recent years, EDP has acquired the ENPEP package and has become acquainted with its use for integrated energy and electricity planning. The main goal of this effort has been to incorporate in EDP's planning procedure an integrated approach for determining the possible role of electricity in meeting the overall requirements for energy of the country, with due account to the impacts (resource requirements and environmental emissions) of alternative energy and electricity systems. This paper concentrates on a comparison of the results of the BALANCE module of ENPEP for the electricity sector against the simulation results provided by VALORAGUA. Suggested improvements to the methodologies in order to overcome the divergences in results from these two models are also advanced in the paper.

NATIONAL ENERGY PLANNING

In Portugal the establishment of a national energy planning and an energy policy involves several organizations. These include the Presidency, several ministries and research organizations, and the agencies in the energy sector that are responsible for the various forms of energy. Representatives from these various agents integrate an Executive Commission, in which the planning work is carried out for submission to the Government. The structure for national energy planning and the various organizations involved are illustrated in Figure 1.

The methodology adopted for national energy planning in Portugal has a dual approach. Integrated analysis of the overall energy sector is based on forecasts for the evolution of the demand/supply balances, taking into consideration all forms of energy simultaneously. The aim of this analysis is to provide overall strategies for the energy sector. Based on these overall strategies, for each energy sector (oil, electricity, coal, etc.) a more detailed analysis is conducted with emphasis on the determination of an equilibrium between the demand and the supply alternatives available of the sector. Figure 2 illustrates this dual approach.

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[1] VALORAGUA means value of water in Portuguese

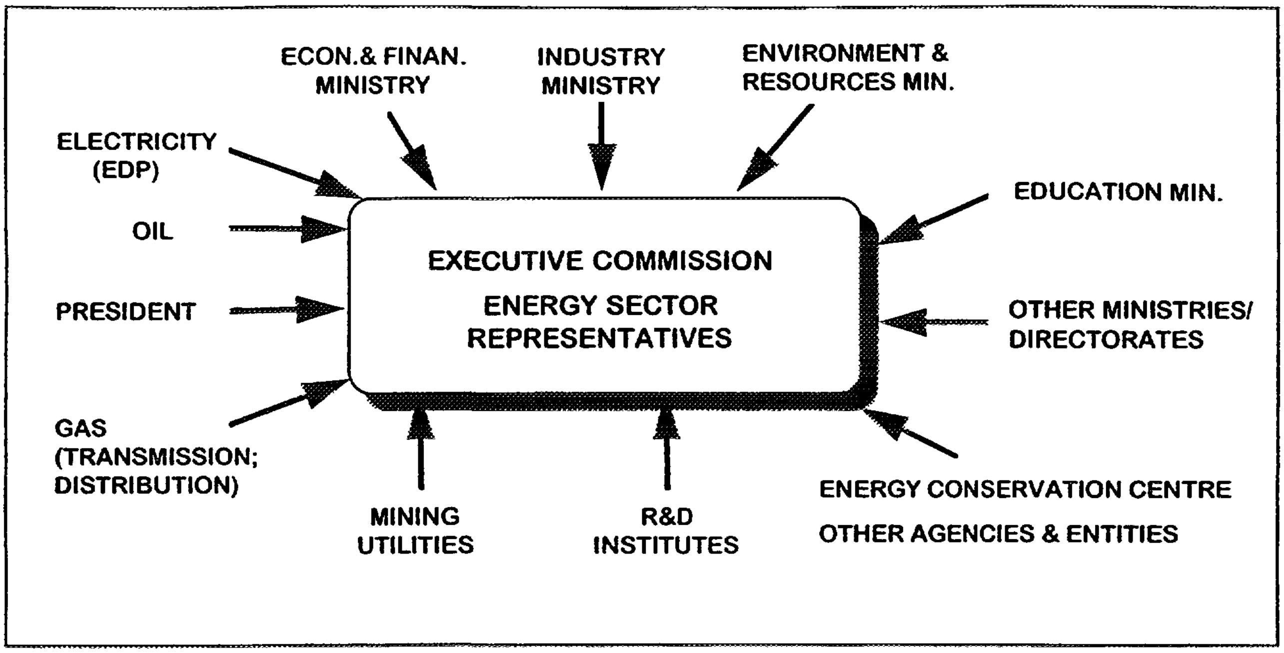

Fig. 1 National energy planning organization

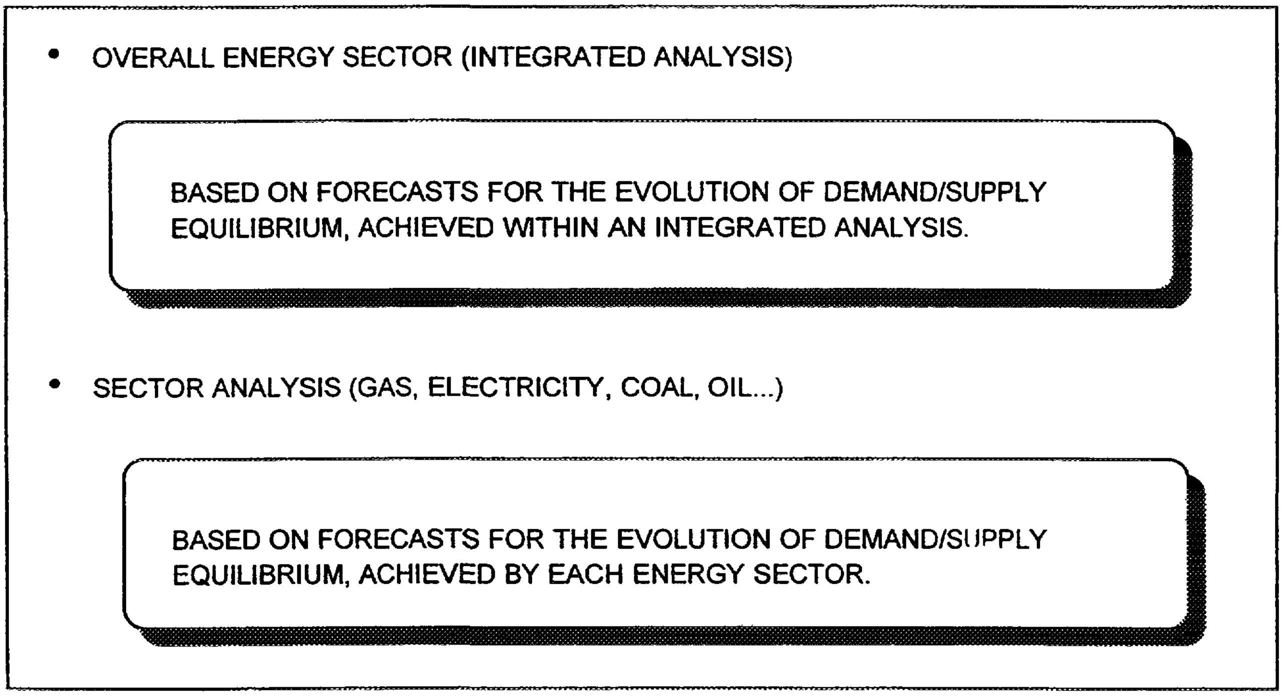

Fig. 2 National energy planning methodology

At the level of the integrated approach, scenarios of macroeconomic development are the basis of the analysis, considering also demographic information and the technological evolution in industry. At the demand side, an analysis of the future energy requirements is performed by means of econometric models. This demand is confronted with selected supply alternatives in order to optimize the long-term evolution of the energy network. The impacts of the proposed strategies for developing the energy sector are then evaluated in order to determine any possible violation of a set of constraints associated with these startegies. Risk analysis of the solutions is also carried out to determine any foreseeable problems that may be encountered in implementing the proposed plans. Before initiating the process of formulating energy policies, a final verification is made in order to determine whether the plan would comply with regulations arising from international agreements (e.g. the European Union energy and environmental Directives) and any other constraints. At each level of verification, it may be necessary to correct some of the initial hypotheses for the sector's evolution if the proposed plan does not meet certain constraints. The above process is illustrated in Figure 3.

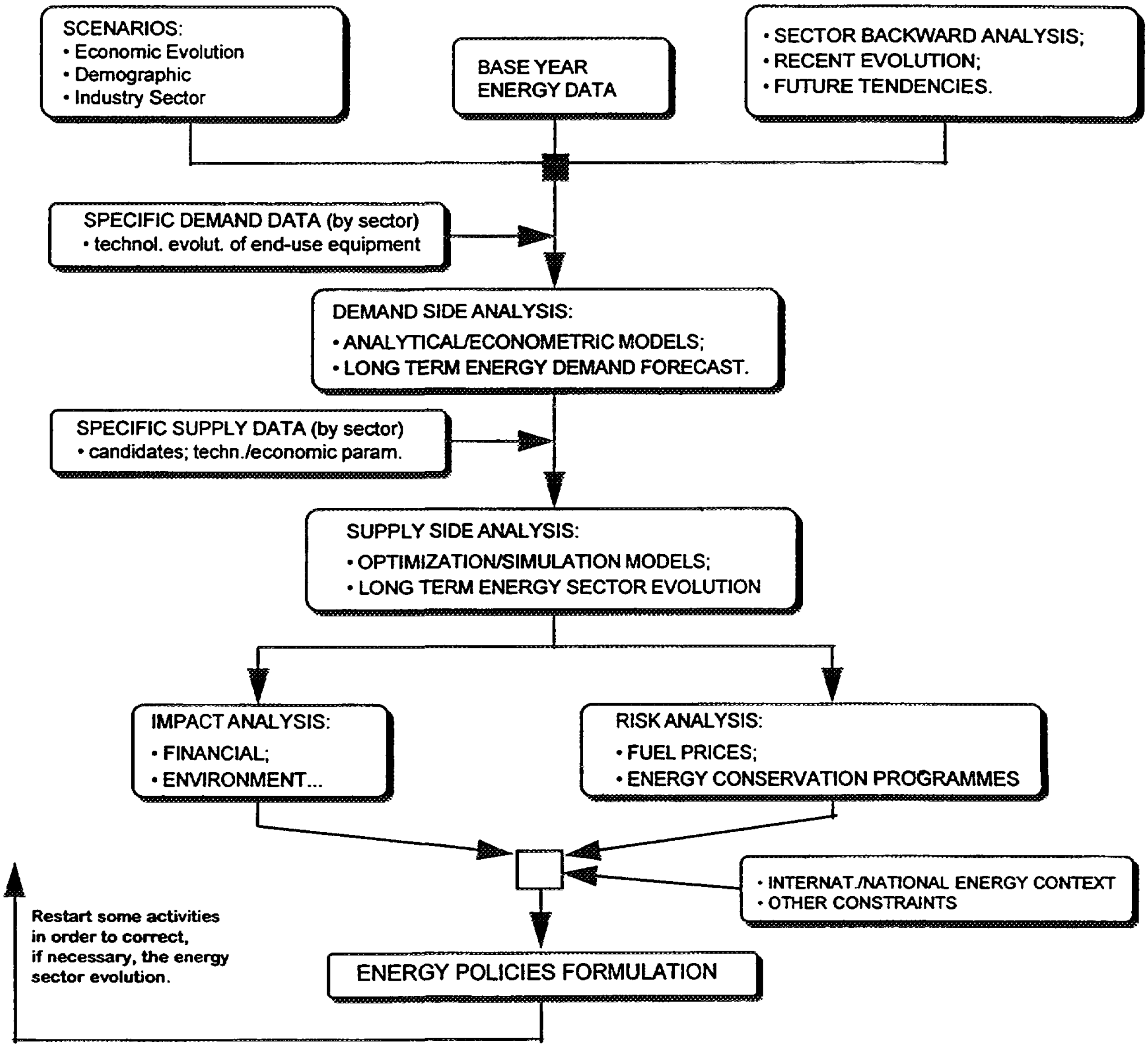

Fig. 3 Integrated planning approach

The sector approach implies a more detailed analysis of the expansion and operating strategy of each sector, taking into account the available supply and demand options and the applicable constraints for development of the given sector. The individual results for each sector must be subject to a coherence analysis in order to ensure that development of all sectors is made in a consistent basis and is also complying with the results of the integrated approach previously mentioned. If coherence is not achieved, some sectoral activities need to be analyzed again. Before formulating energy policies, if overall coherence is not achieved, it may be necessary to restart some activities in order to correct the initial trend for energy sector evolution. Figure 4 shows the various steps connected with this process.

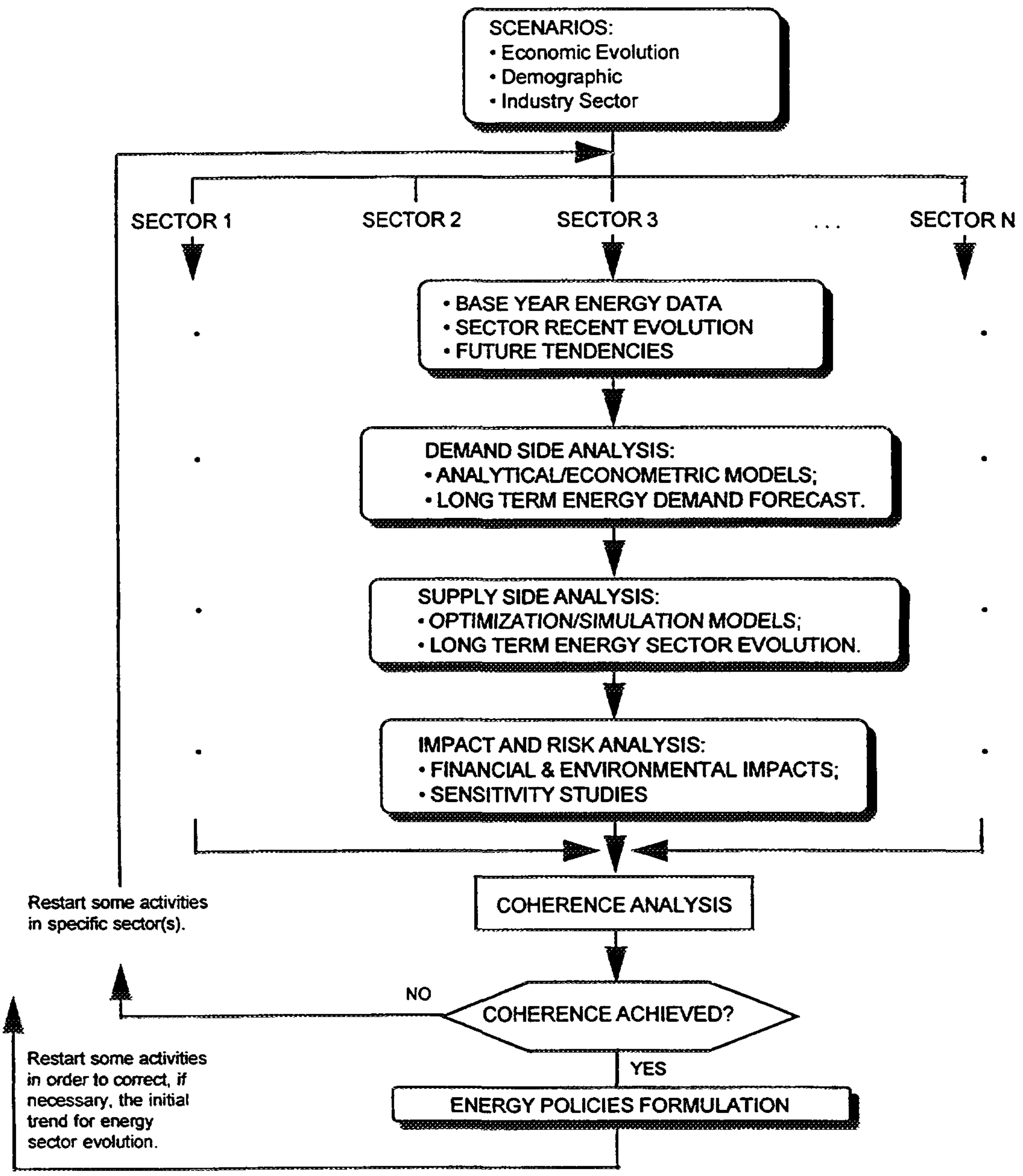

Fig. 4 Sectoral planning approach

However, in line with the market economy principles, the liberalisation movements are affecting the energy sectors everywhere, namely the state owned services such as the electricity and gas sectors. Thus, within the framework of energy planning studies, the independent approaches are becoming more and more important due to the restructuring, reorganisation and privatisation tasks that currently affect the energy sector. So, and once more, it should be stressed the importance of the "coherence analysis" tasks before the formulation of appropriate energy policies.

THE IMPORTANCE OF HYDRO RESOURCES

The Portuguese energy system is a small one when compared with the overall European Union energy system (1.5% of total final energy consumption of the EU). With no primary energy resources, namely the ones that are generally considered the support of the energetic systems (oil, coal and gas), Portugal is considered as a "price-taker" in terms of energy supply. The hydro resources are the most important endogenous energy resources, with a significant share (about 40% share in average of hydroconditions) on the total electricity generation. To give an idea of the current importance (unfortunately, decreasing in the future) of hydro in Portugal, Figure 5 shows the estimated structure of the investment costs associated with the electric sector development.

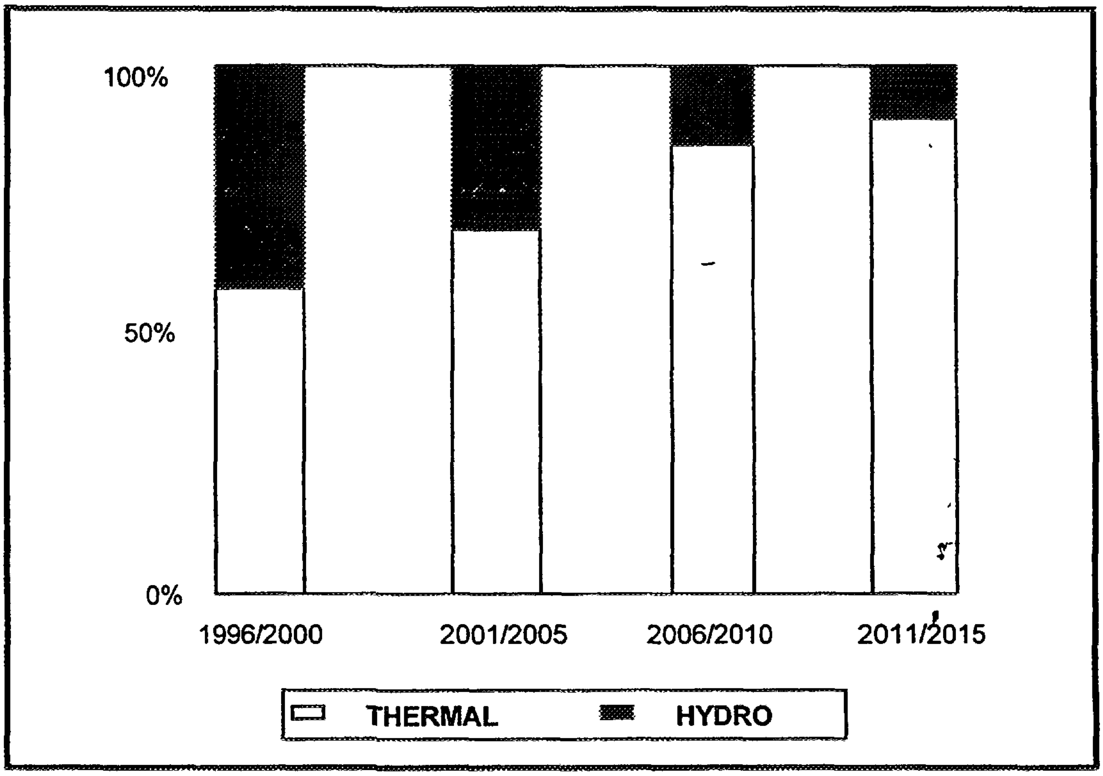

Fig 5 Distribution of investment costs of the electric power system

One of the most important constraints that must be taken into consideration is the obligation of complying with strict existent environmental rules, particularly having in mind the dependence of hydroelectricity generation on the year of rainfall (herewith referred to as hydro condition) and its consequence on the generation to be provided by the thermal component of the power system. For instance, and due to very different hydro conditions, the thermal power plant emission levels can vary in a 40% range or more as it can be observed in Figure 6. Such impacts on the environmental side of the energy sector evolution can be observed in any future configuration of the power system and, with a lesser importance, on the overall energy system.

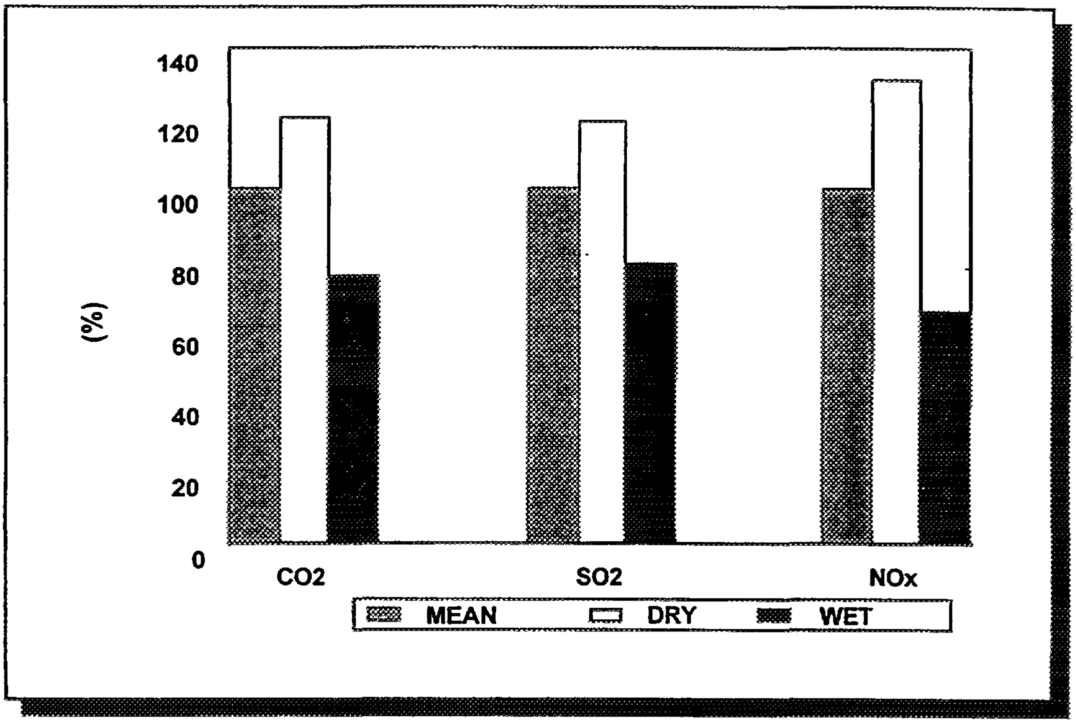

Fig. 6 Hydrological influence in atmospheric emissions

MODELING OF HYDRO RESOURCES: "BALANCE" VERSUS "VALORAGUA"

When a sector detailed analysis is performed, the supply side studies are based on the use of several computer tools, with the WASP and VALORAGUA models being intensively used for such purposes.

The VALORAGUA model was developed by Electricidade de Portugal (EDP) in order to determine the optimal operation strategy of a mixed hydro-thermal power system with an important share of hydroelectricity generation such as the one of Portugal. When properly used in combination with the WASP model (IAEA's model for long term expansion planning), VALORAGUA will lead to an optimal expansion plan and operating strategy for the power system. Thus, the economic advantage of mixed hydro-thermal power systems having an important hydro component is fully exploited.

Because of the nature of the problem being solved by VALORAGUA and the degree of detail used, some important information can be determined in relation to the solution of the management problem. In fact, and as an example, the power output allocated by each hydro plant to meet the demand in each load step can be obtained. For the sake of simplicity, in this document all hydro energy was aggregated into three load steps (peak, intermediate and base hours) and, for two different stages of the power system evolution. The results of the run of VALORAGUA are presented in Figure 7. As can be seen in this figure, a greater concentration of hydro generation at peak hours is foreseen (total capacity allocated for peak demand is duplicated in a 20-year period) with the consequent reduction during off-peak hours.

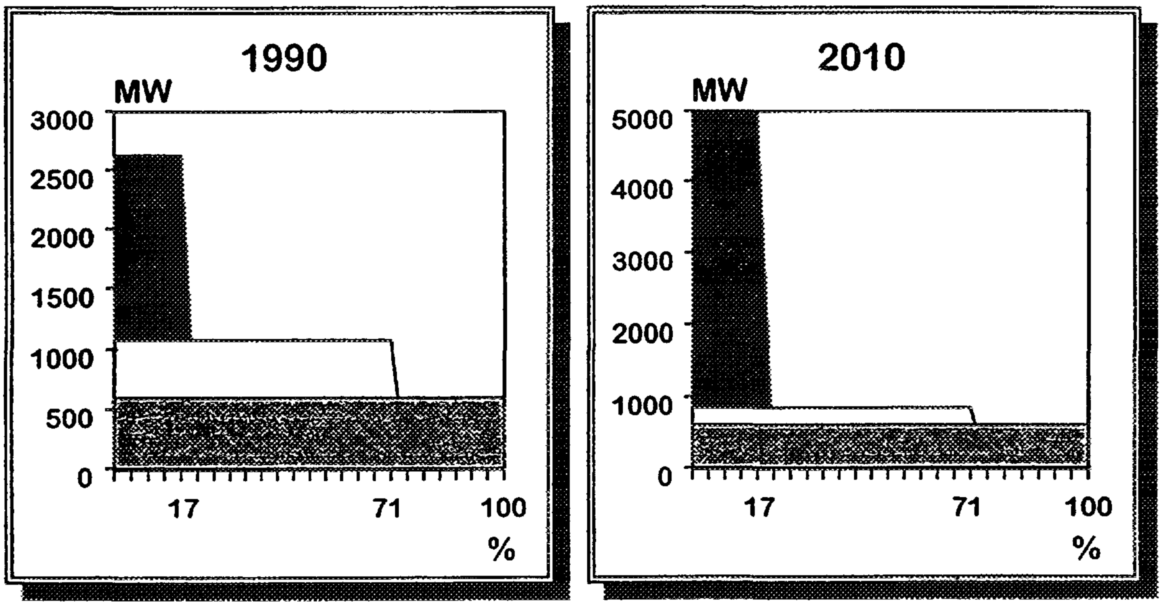

Fig. 7 'VALORAGUA' Hydro energy allocation

On the other hand, either within the framework of integrated planning approach (Fig. 3) or within the coherence analysis in the sector by sector approach (Fig. 4), the BALANCE module of ENPEP package is used. Being a model to be applied for overall energy systems analysis, the description of the electric sector behaviour in BALANCE is less accurate in comparison with other power system models such as the ones above referred to.

Consequently, the hydro energy allocation provided by BALANCE (see Figure 8) is completely different to the previous one analysed with the VALORAGUA model for the same power system configurations. All hydroelectricity is allocated at base hours of the load diagram leading to an inappropriate contribution of hydro energy during peak hours. This result is a straightforward consequence of the merit order criterion assumed by BALANCE and the almost non existence of variable costs for hydro plants.

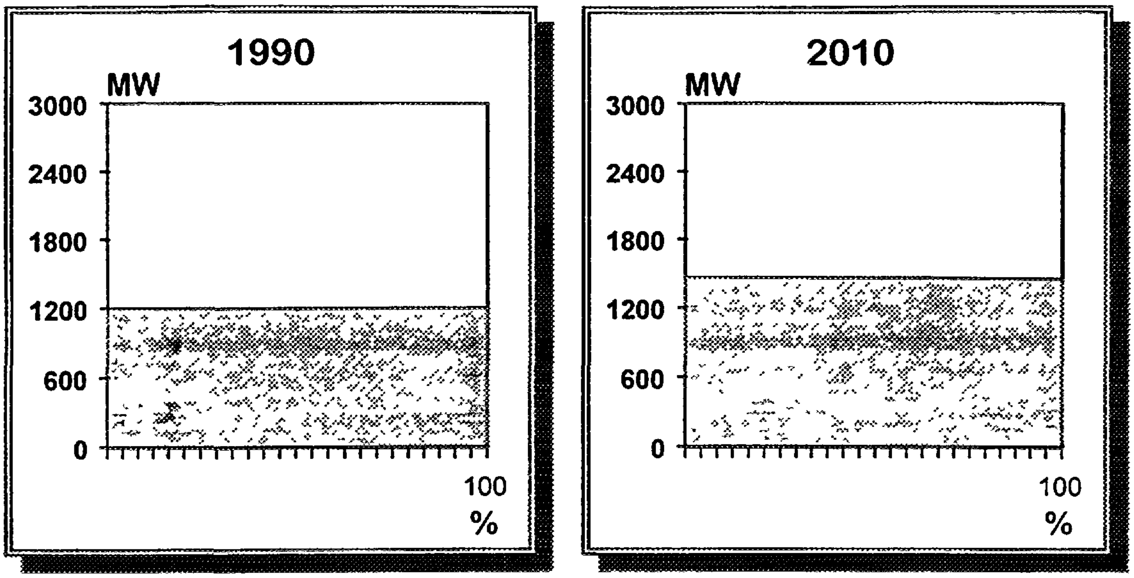

Fig. 8 'BALANCE' Hydro energy allocation (case "A")

From a comparison of the results obtained from VALORAGUA and BALANCE for one possible future configuration of the power system ("2010"), some findings should be pointed out:

- The inappropriate allocation of hydro energy leads to an inefficient use of resources, namely the thermal units with very low utilization factors in order to meet peak demand;

- The warning messages related to unserved demand provided by the BALANCE model for all future power system configurations are meaningless because there is no hydro capability to meet the demand during peak hours (about 70% of hydro capacity is not used);

- On the other hand, the output prices associated to the overall electric sector, also including the transmission and the distribution systems, are correct. Thus, BALANCE permits a fair competition between alternative energy forms at the level of final energy.

Within the framework of an energy model like BALANCE, the competition between different technologies using different energy forms are established at the final utilisation energy markets. As examples, one can point out the space heating market both in the domestic and services sectors or the steam demand in the industrial and services sectors. Depending on the markets involved and associated with the level of useful energy consumption, electricity is available at different voltage levels and at different prices as pictured in Figure 9. As can be observed, all fixed and variable costs associated with different processes in the energy chain are taken into consideration at the level where competition exists. Consequently, one important feature when running such type of models, is the appropriate cost allocation over all energy technologies/processes considered.

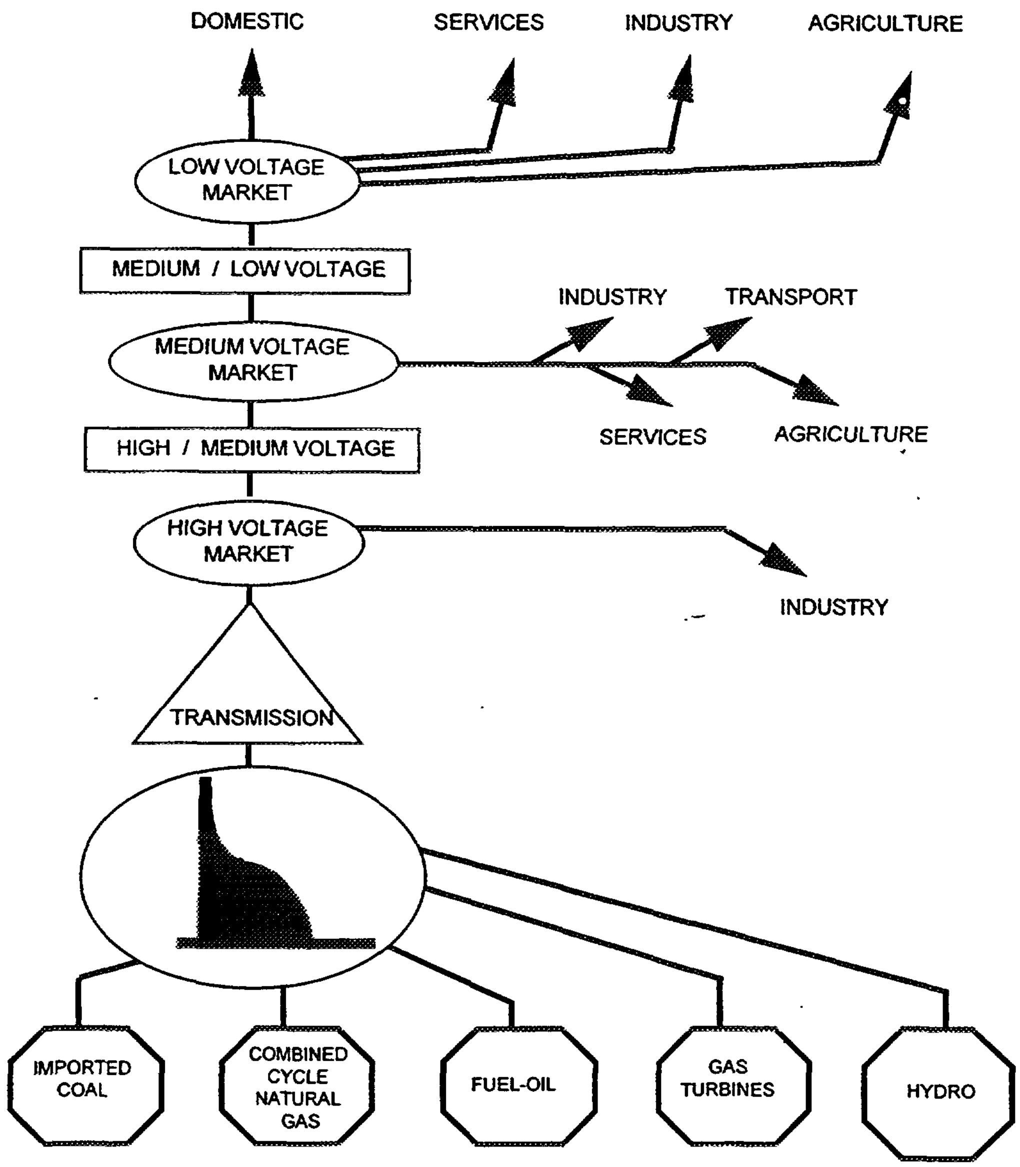

Fig. 9 Electric sector network

In order to overcome the erroneous messages “installed capacity is not enough to meet the demand“ that are provided by the BALANCE model in relation to the operation of the electric power sector, the following approach was analysed:

- Based on the results obtained from a detailed model such as VALORAGUA, several hydro plants are considered. Each one will correspond to an aggregation in terms of energy generation and power output provided during peak, intermediate and base hours;

- Associated to each of those “hydro plants“ a fictitious higher value for the variable operating and maintenance costs is considered;

- The previous definition for the "hydro variable costs" has to be adjusted during successive runs in order to get an appropriate allocation for the hydro sub-system generation. This a direct consequence of the merit order approach used in the BALANCE model.

When such approach is applied in running BALANCE, some of the "modified" hydro plants are loaded at different positions in the load duration curve as can be seen in Figure 10. As a result, a better allocation of hydro resources is achieved, namely in the future power system configurations.

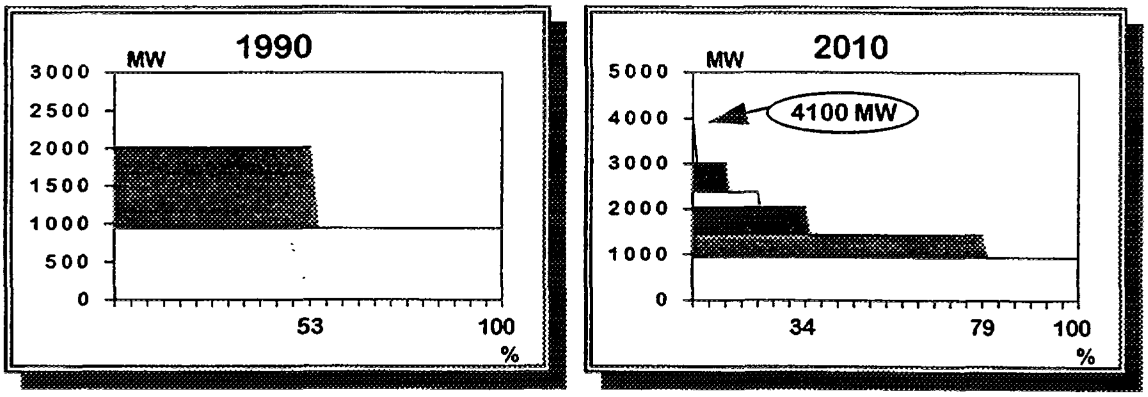

Fig. 10 BALANCE hydro energy allocation (case "B")

To establish a comparison between the VALORAGUA results and the ones obtained from BALANCE after the assumptions above mentioned, the contribution of the entire hydro system is aggregated in three load steps, equivalent to peak, intermediate and base hours as presented in Figure 11. It can be observed in this figure that the contributions of hydro resources during off-peak periods are essentially the same and that only a small difference in the maximum hydro power output appears. Obviously, a better thermal dispatch is also obtained with BALANCE in this case.

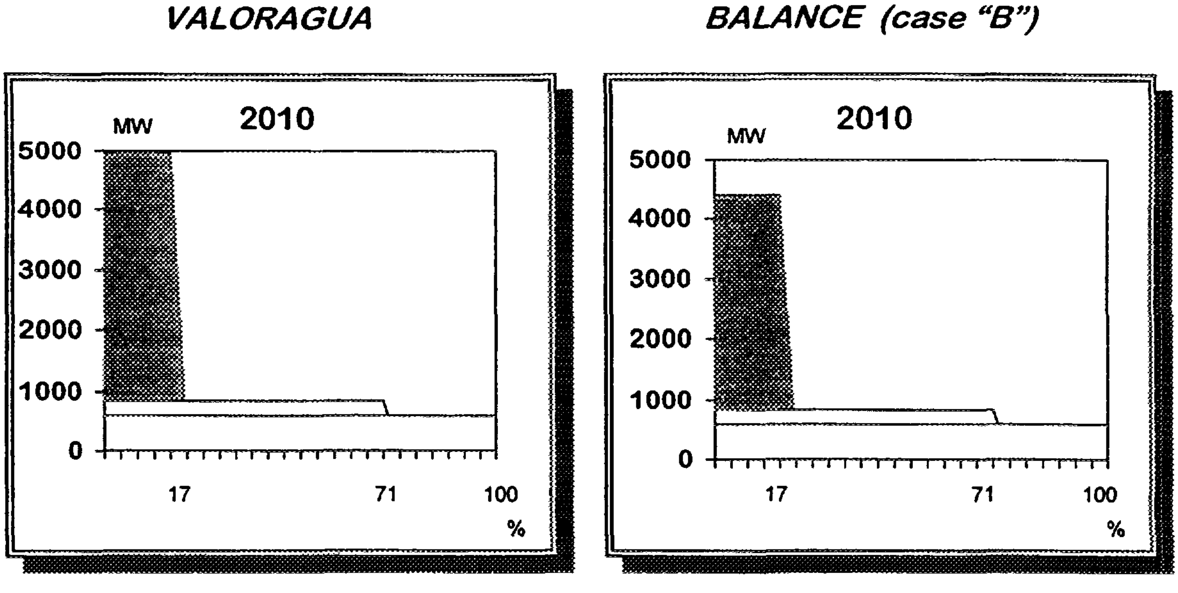

Fig. 11 Comparison of VALORAGUA and BALANCE results based on "new' approach

In conclusion, the application of the modified approach for running the BALANCE model as discussed above, one can note the following main findings:

- The proposed approach leads to a better allocation of supply resources to meet the electricity demand;

- There is no need for more installed capacity in the power system in order to meet the same forecasted demand as it was the case with the standard BALANCE model runs;

- However, because of the assumption of "hydro variable costs", higher electricity prices are obtained at the level of final energy use, leading to a distortion on the competition among different energy forms.

HOW TO ACHIEVE A COHERENT ENERGY SUPPLY/DEMAND BALANCE

A proper supply resources allocation is achieved in the electric power sector with the procedures here above suggested. However, the main drawback is a higher electricity price at different markets (see Fig. 9). As a direct consequence of less competitive electrical energy (in average and only at the generation level, electricity prices are higher around 30%), the total expected electricity demand will decrease as shown in Figure 12.

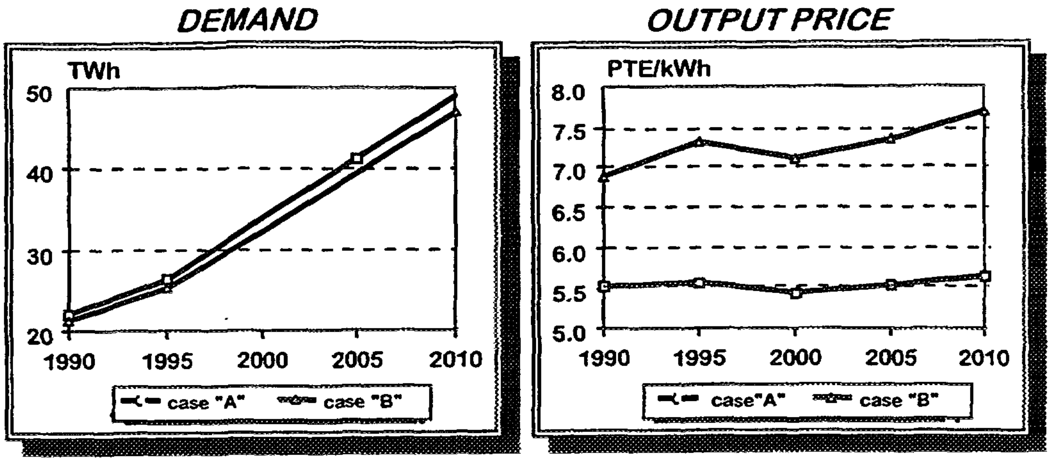

Fig. 12 BALANCE results for the Electric sector

In terms of the overall energy sector, it can be observed a lower share of electrical energy in the total final energy consumption when the two case studies performed with BALANCE model are compared (see Figure 13):

- In "case A" the associated costs of supply resources were well defined and a fair competition is established at the final energy use markets. However, from BALANCE model outputs warnings are obtained about unavailable capacity to meet the forecasted demand .

- In "case B", where the variable O&M costs of hydro plants are modified in order to obtain a more appropriate allocation in the load duration curve, the corresponding share of electricity to meet the overall requirements for final energy in the country is lower.

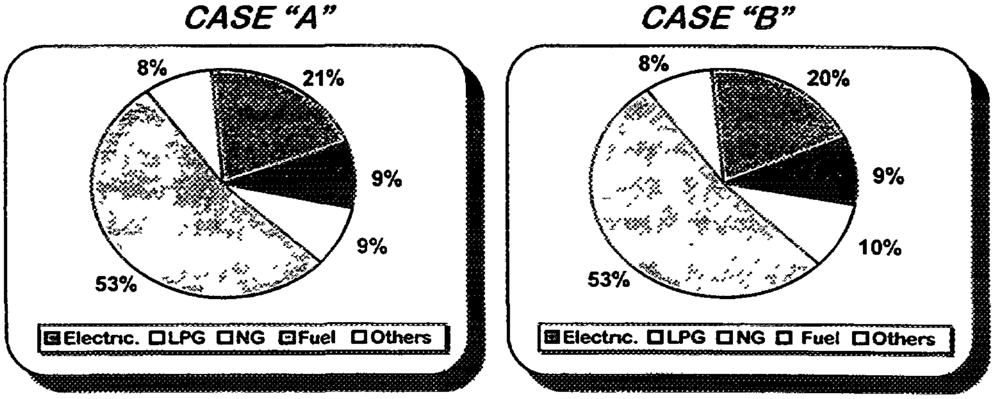

Fig 13 Structure of final energy consumption

In conclusion, the following methodology is here proposed in order to overcome the problems related with an inappropriate allocation of hydro resources within the energy sector:

1) Taking into consideration other detailed hydro-thermal simulation models and the approach here referred to as "case B", the BALANCE module can be used in order to verify system power balance equations (supply = demand) .

2) Having satisfied the equation for the time period associated with the planning horizon, that is to say, for all power system configurations, the BALANCE model should be used with correct costs definition in order to avoid distortions in the competition among different forms of energy.

Two objectives are achieved with such methodology (even acknowledging that a greater effort is required to conduct several additional runs): fair share for the different energy forms used in the energy market; avoided investment costs in more power stations related with inappropriate use of hydro resources .

SUGGESTIONS FOR METHODOLOGICAL IMPROVEMENTS

In order to avoid either divergence in the results from the BALANCE and VALORAGUA models, or even the distortion in the competition level for meeting the demand for final energy, some possibilities/ideas are presented, as follows. Taking into due account the estimated effort, two cases of improvements are suggested.

"EASY WAY"

Supposing that the methodological approach suggested by this paper (run the BALANCE model under "case A" and "case B" as previously discussed) is accepted, several runs of the

BALANCE model should be performed in order to get an acceptable solution of the dispatching problem over the planning period as previously emphasized.

If time-dependent hydro "O&M variable costs" definition is available, the check of the balance supply/demand resources in the power sector over the study period will lead a considerable reduction of the needed effort.

"HARD WAY"

A more elegant approach would be the modification of the logic embedded in the BALANCE model for the dispatching problem in order to properly allocate the hydro energy under the load duration curve. Dependent on the hydro plant characteristics, namely the ones relating to the available energy and power output, a better dispatch of existing plants can be achieved if other methods such as the one used in the WASP model (MERSIM module) is applied. Obviously, such a suggestion infers a greater effort in terms of resource person requirements.

The above suggestions are summarised in Figure 14.

- *"EASY WAY"*

  USING PREVIOUS METHODOLOGY, BUT ALLOWING
  THE POSSIBILITY OF DEFINING TIME-DEPENDENT
  "hydro variable costs"

  — FEW RUNS ARE NECESSARY TO CHECK THE DISPATCHING PROBLEM FOR THE ENTIRE PLANNING PERIOD —

- *"HARD WAY"*

  TO IMPLEMENT A NEW ELECTRICAL DISPATCH ROUTINE
  IN A WAY THAT EACH HYDRO PLANT (or a set of plants)
  WILL BE ALLOCATED ACCORDING TO THEIR
  TECHNICAL "PERFORMANCE"
  (ENERGY/POWER OUTPUT)

  ex: *MERSIM* logic for hydro dispatch;
  SEGMENTATION METHOD (*SEGMET*) ...

Fig. 14 Suggested Enhancements to the BALANCE Approach

If it is decided to make substantial improvements on the logic of the BALANCE model of the ENPEP package, and in order to take into consideration recent changes that involve the energy sector in general, further suggestions for enhancements are listed as follows:

A. Within the re-structuring processes occurring in the electricity and gas sectors world-wide, the role assumed by Independent Producers (IPP's) in the operation of the power system is rapidly growing. As a consequence, the number of Power Purchase Agreements (PPA's) between producers and the organisations responsible for the operation of the grid is growing. In such type of contracts, several constraints are imposed either to the IPP or to the grid manager. One very common constraint is linked to the obligation of "minimum supplies" or "minimum utilization factor" for those power stations with the consequent impacts on the primary energy resources. In this way, such capability once introduced in the BALANCE model will certainly enhance its possibilities of application to several energy systems.

B. Constraints affecting power systems operation are strongly dependent on particular situations of the country or region. Sometimes such constraints are in conflict with the economic merit order rule embedded in most of the energy/power system models thus, affecting their application to specific situations. In order to overcome such difficulties, the possibility of considering a "user merit order" in BALANCE model will be an additional feature to face some particular energy sector constraints.

C. Finally, a completely different approach is suggested for handling the electric sector in the BALANCE model, as followes. One can assume the existence of different electricity markets in terms of generation: the peak hours market; the base hours market; the intermediate hours market. The types of candidates competing for large utilization factors (base load plants) are different, in terms of economic and technical characteristics from the plants competing during the peak hours (peaking plants). The remaining capacity of the baseload plants not used during the baselaod hours for any reason (wet hydrological year, increase in fuel costs,...) could be used during the intermediate zones of the load diagram. Following this reasoning, the power plants will compete to meet the demand in each of these electricity markets taking into account all relevant technical and economic variables. That is to say, the competition will be based on total generation costs (investment included) instead of variable operating costs. In this way, the typical load base plant will not be competitive at peak hours due to high investment costs and low utilization factors when compared with peaking units such as gas turbines.

Some of these ideas are summarized in Figure 15.

OTHER IMPROVEMENTS
CONCERNING ELECTRIC SECTOR

- POSSIBILITY OF DEFINING *"MINIMUM QUANTITY" CONSTRAINTS* (PPA'S)
- POSSIBILITY TO CONSIDER *"USER MERIT ORDER"* INSTEAD OF "ECONOMIC MERIT ORDER" WITHIN DISPATCH PROBLEM
- POSSIBILITY OF *COMPETITION AMONG FUTURE CANDIDATES (INVEST + FUEL + O&M costs). NEW METHOD ?*

Fig. 15 Further suggestions for improvements of the Electric sector representation in BALANCE

PROBLEMS FACED WITH THE USE OF THE WASP MODEL IN LEAST COST AND ALTERNATIVE ELECTRICITY SYSTEM EXPANSION PLANNING IN ROMANIA

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Abstract

Romanian experience with the use of IAEA planning methodologies was effectively initiated in 1989 with the launching of a Technical Cooperation project of the IAEA for the study of the energy demand and optimal expansion plans for the electricity generation system. The experience gathered during this project was crucial for the Romanian experts who conducted the studies. As a result, now Romania has a team of well trained experts in the use of the IAEA planning models.

This paper describes the principal problems faced by Romanian planners in the use of these models with emphasis on the WASP package. Suggestions for future enhancements of the package are also part of this report.

1. INTRODUCTION

The WASP model has been used since 1985 for power generation expansion planning studies in Romania. At the beginning, performances were low because only few national experts had attended the training courses organized by the IAEA (from the 3 persons who attended up to 1989 only one was involved in energy planning) and the poor available equipment, i.e., computers. After 1990, the number of people involved in such courses increased and studies were launched in collaboration with the IAEA in order to implement the ENPEP methodology in the planning procedure for energy matters. Once the Romanian institutes were equipped with personal computers, other studies were launched using the WASP model. Since the beginning of 1995, an upgraded and user friendly version of this model, WASP-III Plus, has been used frequently and successfully.

Following the serious changes that occurred in the Romanian economy, the economic parameters, e.g., prices, rates of exchange, inflation rates, faced extraordinary modifications which had an impact on the least cost expansion planning studies of the electric power system. This forced the Romanian institutes to launch such studies every year compared to every 2-2.5 years as it is the use in countries with stable economies. At the same time the results of the local studies were compared with those performed by foreign companies that use other models.

Currently, the WASP model is being used frequently in energy planning by a very well trained team of experts from the Institute of Power Studies and Design (ISPE) and the results are used by the Romanian Electricity Authority in order to obtain funds to either rehabilitate the existing plants or to complete plants under construction.

2. CHARACTERISTICS OF THE ROMANIAN ELECTRIC POWER SYSTEM AND THEIR IMPACT ON THE USE OF WASP

The Romanian electric power system is characterized by some specific features which have a direct impact on the use of WASP for determining the optimal schedule of power plant additions and for analyzing alternative expansion plans.

These specific features are:

1) The installed capacity in Romania exceeds by far the maximum electricity demand (about 20,000 MW compared to a peak load of 9,000 MW). In reality, the available capacity is by far lower (only about 16,700 MW) which still means a rather large reserve capacity. This unused capacity needs to be put into production and eventually, new capacity will have to be added according the expected future demand (Fig. 1).

2) The structure of thermal units differs very much according to their power output, the type of fuel used, the type of unit (condensing, condensing and extraction, back-pressure), the technical and economic parameters, the available performance parameters, etc. It is therefore necessary to separate the number of units in numerous different types in order to have a realistic approach. It happened that the number of acceptable groups of thermal units was limited by the model (Fig. 2).

3) The Romanian system has a very important rate of co-generation units. In 1994, co-generation plants contributed to 38% of the thermal installed capacity. The WASP model does not allow the representation of co-generation units properly. For this reason, it is necessary to perform specific analyses outside the model and then incorporate them in WASP (Fig. 3).

A co-generation unit with condensing and extraction of P nominal capacity is modelled by dividing it into two units:

- a back-pressure unit with the maximum capacity equal to the minimum power output ($P_{1\,min} = P_{1\,max}$) and representing the heat generated by the unit;
- a condensing unit with $P_{2\,min} = 1$ MW and $P_{2\,max} = P - P_{1\,max}$ (Fig. 2).

4) Hydro power plants represent almost 30% of the installed capacity and almost a quarter of the electricity generation. It is necessary to perform detailed analyses in order to have a good presentation of data for hydro power plants in WASP. At present, these analyses are being performed using the VALORAGUA model with the assistance of experts from the IAEA and the Argonne National Laboratory (Fig. 4).

5) Thermal plants, especially lignite fired units, have a significant unavailability rate. The reasons are diverse:

- Long period of operation;
- Poor quality of the equipment;
- Use of fuel different from the fuel the plant was designed for (fuel oil with 3.5% sulphur content, low heat content for lignite: 1600 kcal/kg, reduced pressure of natural gas in winter , etc.);
- Co-generation units operated to provide less heat than their designed capacity.

In view of the above, it was necessary to study the possibility of improving overall plant performance. For this purpose, the expansion candidates defined in the VARSYS module, corresponded to some rehabilitated condensing units (either coal or fuel oil fired) with an installed capacity bigger than 200 MW. Rehabilitation of the plants was either to extend their life time or to improve their efficiency. This main problem encountered corresponds to the possibility of the non-correlation that may occur between the year in which the rehabilitated unit (defined in VARSYS) was selected as part of the optimal solution and the year the same unit, non-rehabilitated, was retired in FIXSYS (Fig. 5). But this problem can be solved by means of iterations, once the optimal solution is obtained.

6) The poor data base of technical and economic parameters of existing plants that was available imposed extra burdens on the part of the WASP user as data needed to be completed and therefore leads to a significant waste of time necessary for the least cost development study.

Figure 1 Evolution of the Loss of Load Probability (LOLP)

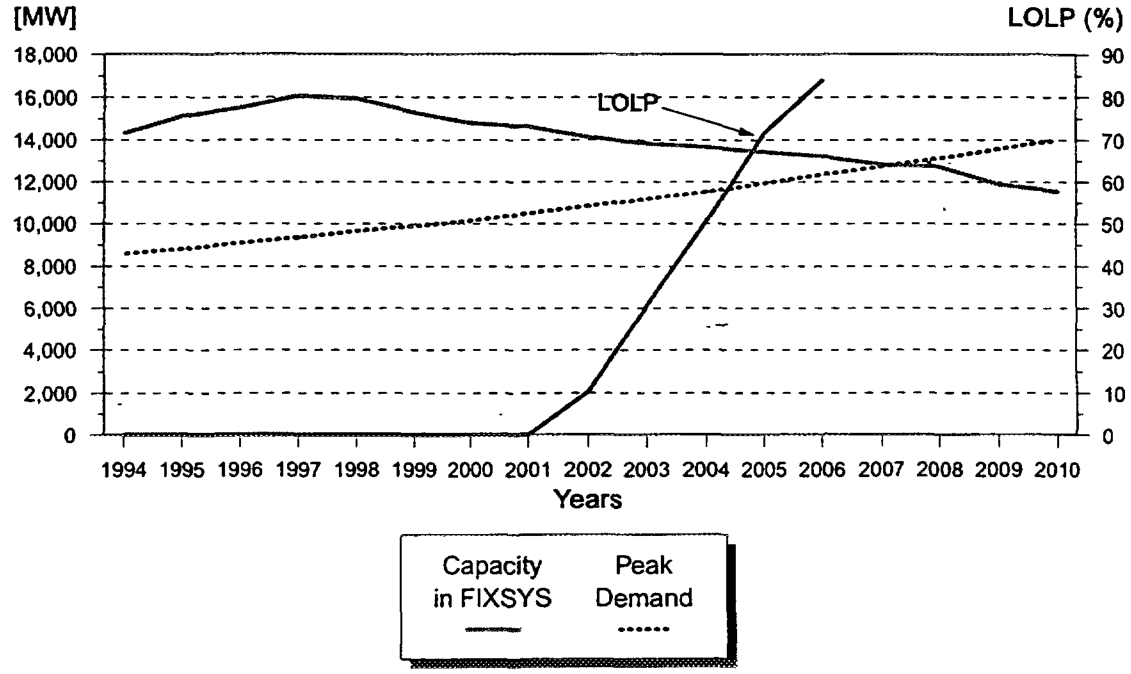
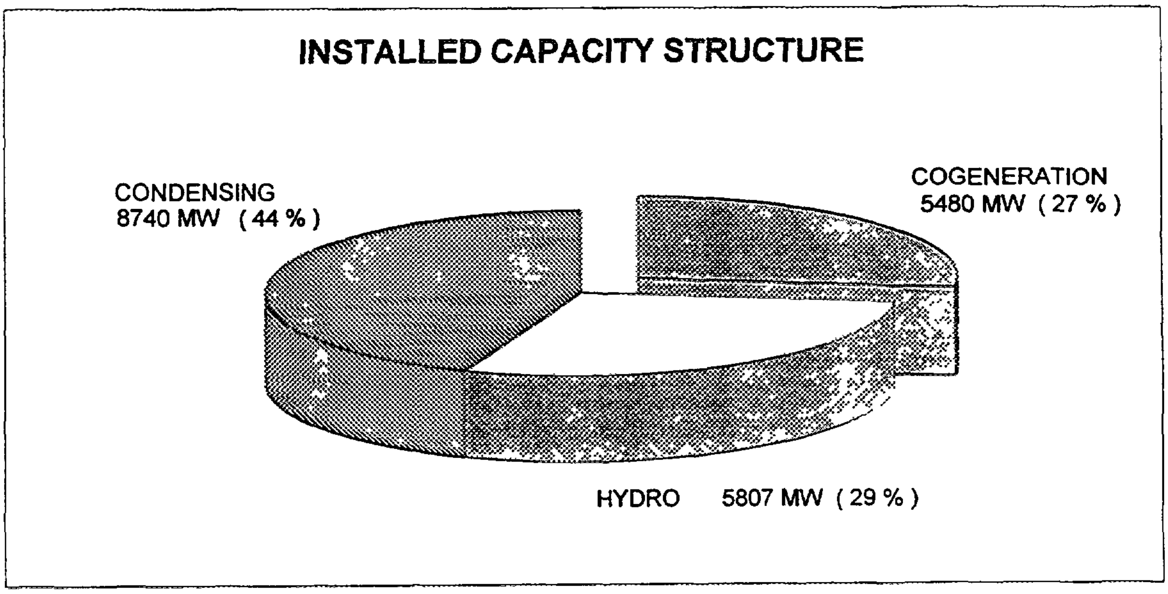


FIGURE 2 FIXED SYSTEM INPUT DATA INFORMATION
THERMAL POWER PLANTS -

NR. CRT.	NAME	NR. OF SETS	MIN. LOAD MW	CAP-CITY MW	BASE LOAD HEAT RATE	AVGE INCR HEAT RATE	FUEL COST CENTS/ MILLION DMSTC	FUEL TYPE	FRCD OUT-AGE RATE	DAYS SCHL MAIN	MAIN CLAS	O&M (FIX)	O&M (VAR)
1.	L100	4	56.	94.	2648.	2198.	1108.0	1	6.0	46	100.	1.00	1.40
2.	L200	2	66.	187.	2580.	2197.	1108.0	1	7.0	51	200.	.80	1.40
3.	BZ20	2	102.	148.	2996.	2446.	1251.0	2	7.0	51	200.	.74	1.90
4.	BO21	2	74.	175.	3069.	2388.	1206.0	2	7.0	51	200.	.74	1.90
5.	B210	3	51.	182.	2867.	2220.	1161.0	2	7.0	51	200.	.95	1.50
6.	B330	1	150.	262.	2541.	2279.	1259.0	1	6.0	55	300.	.80	1.50
7.	P150	0	80.	130.	2401.	2217.	741.0	6	8.5	46	200.	1.84	1.80
8.	M210	6	63.	145.	3170.	2717.	805.0	6	7.0	53	200.	1.21	1.90
9.	I100	2	63.	72.	3483.	2699.	1056.0	4	10.0	46	100.	1.84	1.80
10.	I315	2	89.	241.	3671.	2966.	1056.0	4	6.0	47	300.	1.90	2.00
11.	D200	2	107.	132.	5268.	3611.	1039.0	4	35.0	53	200.	1.15	2.00
12.	R200	1	72.	108.	4052.	3131.	931.5	4	35.0	53	200.	1.15	2.00
13.	R A1	2	143.	224.	3508.	3143.	914.0	4	30.0	47	300.	1.15	2.00
14.	R A2	2	143.	224.	3454.	3056.	914.0	4	15.0	55	300.	1.15	2.00
15.	T A1	3	141.	220.	3760.	3378.	983.0	4	30.0	47	300.	1.15	2.00
16.	T A2	2	141.	220.	3457.	3042.	1013.0	4	15.0	55	300.	1.15	2.00
17.	T A3	0	183.	295.	2968.	2564.	1000.0	4	8.0	55	300.	1.15	2.00
18.	N 12	0	630.	630.	2914.	2914.	63.0	0	8.0	45	700.	3.13	.11
19.	TH A	7	28.	28.	1540.	1540.	1169.0	3	3.5	35	50.	1.57	1.50
20.	KH25	5	20.	20.	4500.	4500.	1169.0	3	3.5	40	50.	1.57	1.50
********	********	********	********	********	********	********	********	********	********	********	********	********	********
21.	TH50	29	15.	15.	1820.	1820.	1169.0	3	3.5	40	50.	1.57	1.50
22.	KH50	23	1.	16.	4200.	4200.	1169.0	3	3.5	40	500.	1.57	1.50
********	********	********	********	********	********	********	********	********	********	********	********	********	********
23.	TH00	8	35.	35.	1820.	1820.	1169.0	3	5.0	47	100.	1.29	1.50
24.	KH00	8	1.	40.	3900.	3900.	1169.0	3	5.0	47	100.	1.29	1.50
25.	TH 5	4	40.	40.	1820.	1820.	1169.0	3	5.0	47	100.	1.57	1.50
26.	KH 5	4	1.	50.	3900.	3900.	1169.0	3	5.0	47	100.	1.57	1.50
27.	KC12	2	9.	9.	5000.	5000.	1175.0	5	10.0	49	100.	3.00	2.70
28.	KC25	2	18.	18.	5000.	5000.	1175.0	5	10.0	49	100.	3.00	2.70
29.	TC50	26	15.	15.	2350.	2350.	1175.0	5	10.0	49	100.	3.00	2.70
30.	KC50	18	1.	16.	5500.	5500.	1175.0	5	10.0	49	50.	3.00	2.70
31.	TC00	2	30.	30.	2350.	2350.	1175.0	5	10.0	49	100.	3.00	2.70
32.	KC00	2	1.	60.	4200.	4200.	1175.0	5	10.0	49	100.	3.00	2.70
33.	21 M	0	137.	191.	2595.	2390.	773.0	6	7.0	51	200.	1.91	1.20
34.	31 I	0	205.	290.	2773.	2389.	1050.0	4	8.0	55	300.	1.00	2.00
35.	2 BZ	0	130.	189.	2612.	2203.	1259.0	2	7.0	51	200.	.74	1.90

0	NUCL	NUCLEAR	5	CGLI	COGENER. LIGNITE
1	CDNG	CONDENSING NAT.+GAS	6	CDHC	CONDEN.HARD COAL
2	CDOG	CONDEN.OIL+NAT.GAS	7	IMNG	IMPORTED NAT.GAS
3	CGOG	COGENER.OIL+NAT.GAS	8	IMCO	IMPORTED COAL
4	CDLI	CONDEN. LIGNITE	9	IMOI	IMPORTED OIL

FIGURE 3 INSTALLED CAPACITY AND ELECTRICITY GENERATION BY POWER PLANT TYPE ROMANIA 1994



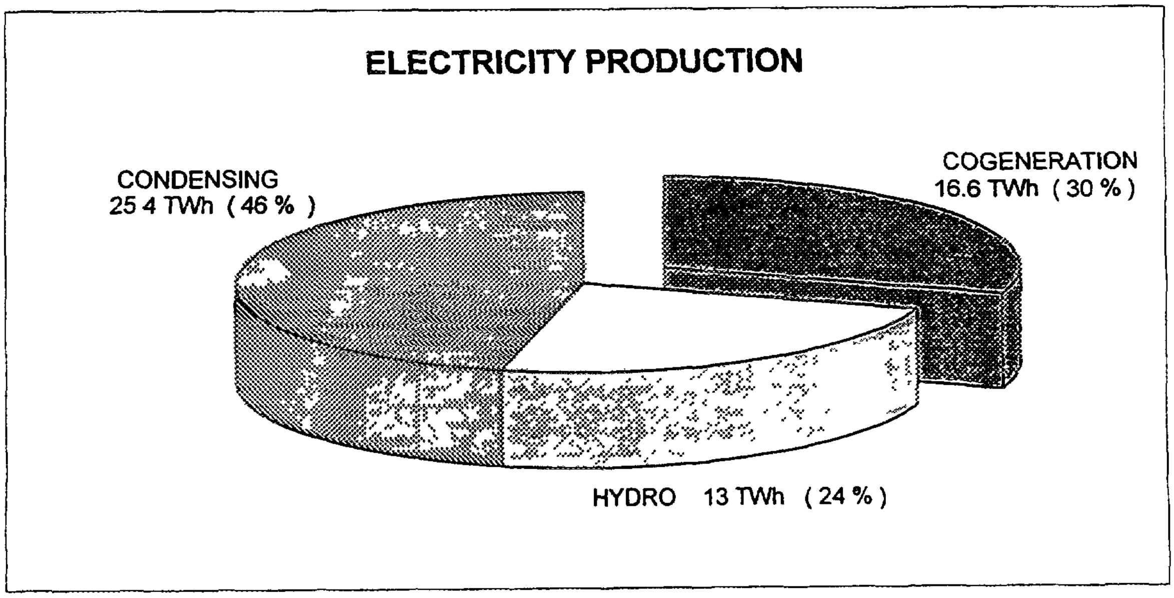
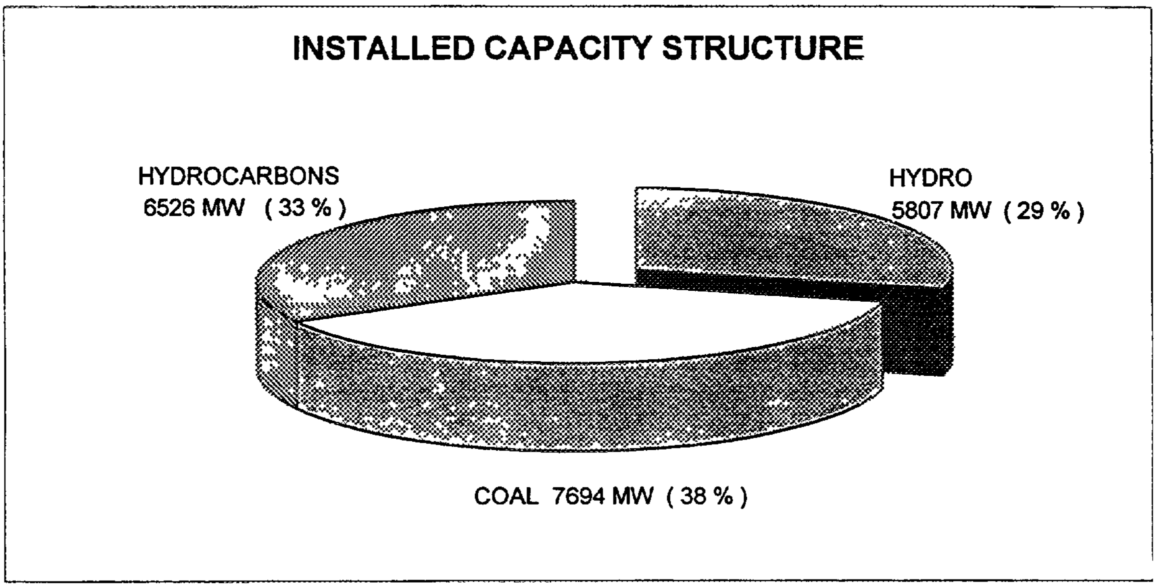


FIGURE 4 INSTALLED CAPACITY AND ELECTRICITY GENERATION BY FUEL TYPE ROMANIA 1994



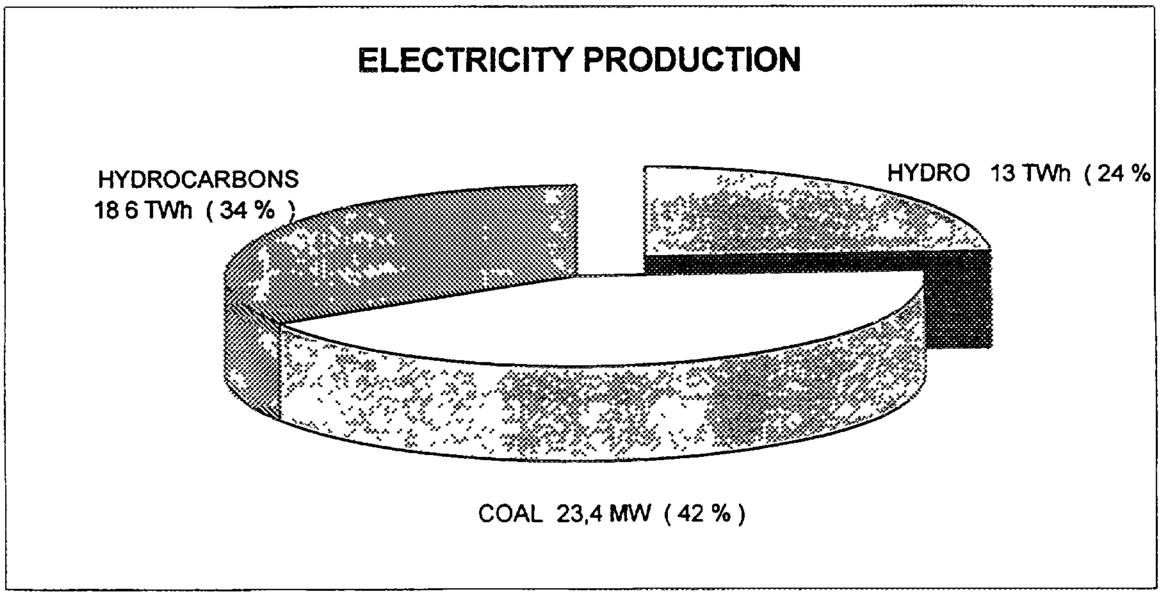


FIGURE 5 SUMMARY OF CAPITAL COSTS OF ALTERNATIVES IN $/KW

STUDY PERIOD 1995 - 2020
PLANNING PERIOD 1995 - 2020 (26 YEARS)
RATE OF INTEREST APPLIED TO ALL LOCAL CAPITAL = 10.00
RATE OF INTEREST APPLIED TO ALL FOREIGN CAPITAL = 10.00

THERMAL PLANT	CAPITAL COST (DEPREC. PART) LOCAL	CAPITAL COSTS (NON-DEPREC. PART) LOCAL	FOREIGN	PLANT LIFE YEARS	INCL. IDC %	CONSTR. TIME YEARS
20BZ	137.7	.0	.0	21	4.13	1.00
210B	168.1	.0	.0	21	4.11	1.00
210M	216.2	.0	.0	14	8.08	2.00
315I	380.4	.0	.0	14	8.08	2.00
B TG	933.3	.0	.0	25	11.92	3.00
50TC	1769.7	.0	.0	30	8.08	2.00
50TK	1769.7	.0	.0	30	8.08	2.00
LIGN	1862.9	.0	.0	30	19.21	5.00
HUIL	1819.6	.0	.0	30	19.21	5.00
FGD5	1620.3	.0	.0	30	19.21	5.00
N345	2484.6	251.0	.0	30	20.96	5.50
CC 6	955.6	.0	.0	25	19.21	5.00

3. SOLUTIONS TO PROBLEMS FACED WITH THE USE OF WASP

While implementing the WASP model, other problems occurred, not necessarily connected to the specific conditions of the Romanian electric power system:

1) Impossibility to retire some candidate units defined in VARSYS with a shorter lifetime than the study period.

In order to solve this problem, the following procedure has been applied:

- Candidate plants with a shorter lifetime than the study period are defined both in VARSYS in FIXSYS, but keeping to zero the number of units in FIXSYS;
- A WASP optimization is performed to determine the optimal solution;
- If the candidates are part of the optimal solution and their lifetime expires before the end of the study period, the years of commissioning and retirement of the units are set in FIXSYS;
- The optimization process is repeated (in this case the number of units of the VARSYS candidate is kept to zero in the CONGEN runs).

2) Impossibility to perform a direct transfer of data from MAED to WASP. The problem may be solved by copying some files.

3) A disagreement appears when data are transferred from WASP to ICARUS: a unit that has been selected in the optimal solution in WASP for a certain year appears in ICARUS with electricity generation, already in the last period of the previous year. Therefore, after having transferred data from WASP to ICARUS, the commissioning years should be checked and modified for the last period of the previous year.

4) To calculate the fuel consumption of each thermal plant type it is necessary to define the corresponding heat rates in the REMERSIM run. This definition can be easily done using the ELECTRIC forms for case studies containing less than 12 candidates. However, for a case study with 12 candidates in VARSYS, the heat rates can only be entered using the editor.

5) When a case is copied from another one, stored on a diskette or on the hard disk, it is sometimes necessary to run again the modules from the very beginning wasting the time spent for the initial case optimization.

6) When a case is copied from another one, retirements and new units for the last 10 years of the study period are often cancelled. It is therefore necessary to type these data in FIXSYS once again.

7) For generating units using several types of fuel (coal+natural gas, etc.), the unit of measure of fuel consumption should not be the "ton" (1,000 kg) but a conventional unit (e.g. tce - ton of coal equivalent, toe - ton of oil equivalent).

4. PROBLEMS NOT SOLVED

Some problems cannot be solved and are related to the capabilities of the last version of the program (WASP-III Plus), namely:

1) It is not possible to calculate the total capital cost in REPROBAT (including Fuel Inventory Cost) for a planned nuclear unit from FIXSYS if it has "0" fuel type.

2) It is possible to calculate the total capital cost in REPROBAT only for one planned unit, even if there are several units of the same type in FIXSYS that have different commissioning years.

For a 30 year maximum study period (very suitable for the electric sector) and for a number of maximum 12 thermal candidates (also very convenient when rehabilitation of existing units is necessary to be considered as expansion candidates), it becomes very difficult to determine the optimal expansion plan because of the limits imposed in the program concerning the maximum number of configurations per year (300) and the maximum number of configurations (3,000) for the whole period of the study.

5. OTHER SUGGESTIONS FOR IMPROVEMENT OF WASP

As a conclusion, some suggestions for improving the WASP model are the following:

1) A better representation of co-generation plants with variable operating performance during the year (the solution adopted by some users to utilize the position of one of the equivalent hydro power plants is not acceptable, particularly for power systems, such as the Romanian one, for which hydro plays an important role in electricity generation).

2) An increase of the maximum number of configurations per year and of the maximum number of configurations over the whole period, accordingly.

3) To allow the definition of the unit of measure of heat rates (in MERSIM) to calculate the fuel consumption (for later inclusion in the REPROBAT report), as one of the conventional units (tons of coal equivalent or tons of oil equivalent). This would be very useful since it is very likely that power systems include at least one thermal unit using more than one type of fuel. If this improvement is implemented, the algorithm of the model can be modified in order to calculate the total annual fuel consumption, which is a very important piece of information for planning purposes.

4) To have a systematic list of thermal plants (in FIXSYS and VARSYS) which would allow the user to insert a any plant in any place of the list.

5) When a candidate plant is deleted, this information should be transmitted to the economic elements of DYNPRO.

6) It should be easy to perform sensitivity analyses for different discount rates if the program requests Net Overnight Costs and Discount Rate instead of Depreciable Capital Cost (including IDC) and Interest During Construction (% of total Capital Cost) in DYNPRO (option No. 3).

XA9745306

USE OF ENPEP FOR DEVELOPING A STRATEGY FOR THE ENERGY AND ELECTRICITY SYSTEM IN ROMANIA

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Abstract

In Romania, the energy and electricity sector needs to be restructured and modernized to meet the requirements of both market economy and environmental protection. For these reasons, Romania has shown some interest in launching ENPEP studies. In the frame of a technical cooperation project between the Romanian Ministry of Industry, the International Atomic Energy Agency (IAEA) and the Argonne National Laboratory (ANL), MAED and ELECTRIC (WASP) models have been used since 1990 to determine optimal expansion plans of the electric power system.

After the successful conclusion of the testing of BALANCE and IMPACTS models under Romania's conditions, these models are now being used for planning the development of the energy system. In order to adapt the models to the particular conditions of Romania, an attempt was made, in cooperation with the International Atomic Energy Agency (IAEA) and Argonne National Laboratory (ANL), to find proper solutions to allow the modelling of specific processes and to overcome some restrictions of the models. This paper presents some of these solutions and suggestions for further improvement of the models.

1. ENERGY DEMAND FORECAST

For forecasting energy demand, ENPEP offers two alternatives:

- the MAED model
- the MACRO-DEMAND chain

1.1 MAED Model

The MAED alternative is utilized to perform detailed forecasts of integrated energy and electricity demand, as well as of the electric load curve of the power system. This model can be run easily and provides results within a short time. However, some problems have been encountered while applying the model to Romania's conditions. These are as follows:

(a) MAED could allow a better modelling if the energy demand of industry was distinctly determined by the main sub-branches: basic materials, machinery & equipment, non-durable goods, other industries. This would enhance the modelling of the structural changes that might affect the industry during the period of the study and might lead to significant changes of the values of the constant parameters to be defined for the base year of the study.

(b) In the current version of MAED, the evolution of some demands, such as the requirements for coke, feedstocks or freight transportation, is modelled through linear regression equations. Such type of modelling presents a problem, particularly for economies in transition. For example, in Romania, since 1989, very important changes have affected the evolution of the demands mentioned above and the implementation of the current MAED methodology would have altered the results of the analyses. Therefore the following procedure was adopted for the Romanian case study:

- the evolution of the coke and feedstocks demand has been treated as an energy consumption of the base materials industry (for the base year);
- the evolution of the freight transportation demand has been partially corrected by modifying the linear regression parameters so that the results are as close as possible to the forecasts made by special institutes.

However, this procedure is considered as an interim solution. It is therefore suggested to provide as an option the possibility of using a time-dependent evolution of these demands. In this case, the users would define the corresponding values for each reference year.

(c) Another problem in the use of the MAED model arises from the particularity of Romania in utilizing district heat supply in agriculture, construction and mining. MAED does not allow to deal with this form of energy for these three consumption sectors. Therefore, they were included in "thermal uses" for the base year and the results of the analyses were then processed outside the model by including as part of the fossil fuel demand of these sectors, the amount of district heating required by the sectors. This procedure is rather complicated. Therefore, a solution to this problem should be incorporated into the model.

(d) Concerning the MAED reports obtained, it would be useful to have the final energy demand presented separately for residential and services, which currently are lumped into a single entry. A similar recommendation can be made for other sectors such as agriculture, construction and mining, at least in Tables 3A, 3B, 4A and 4B.

1.2 MACRO-DEMAND Modules

(a) The MACRO-DEMAND alternative does not lead to credible outcomes in the case of Romania since:

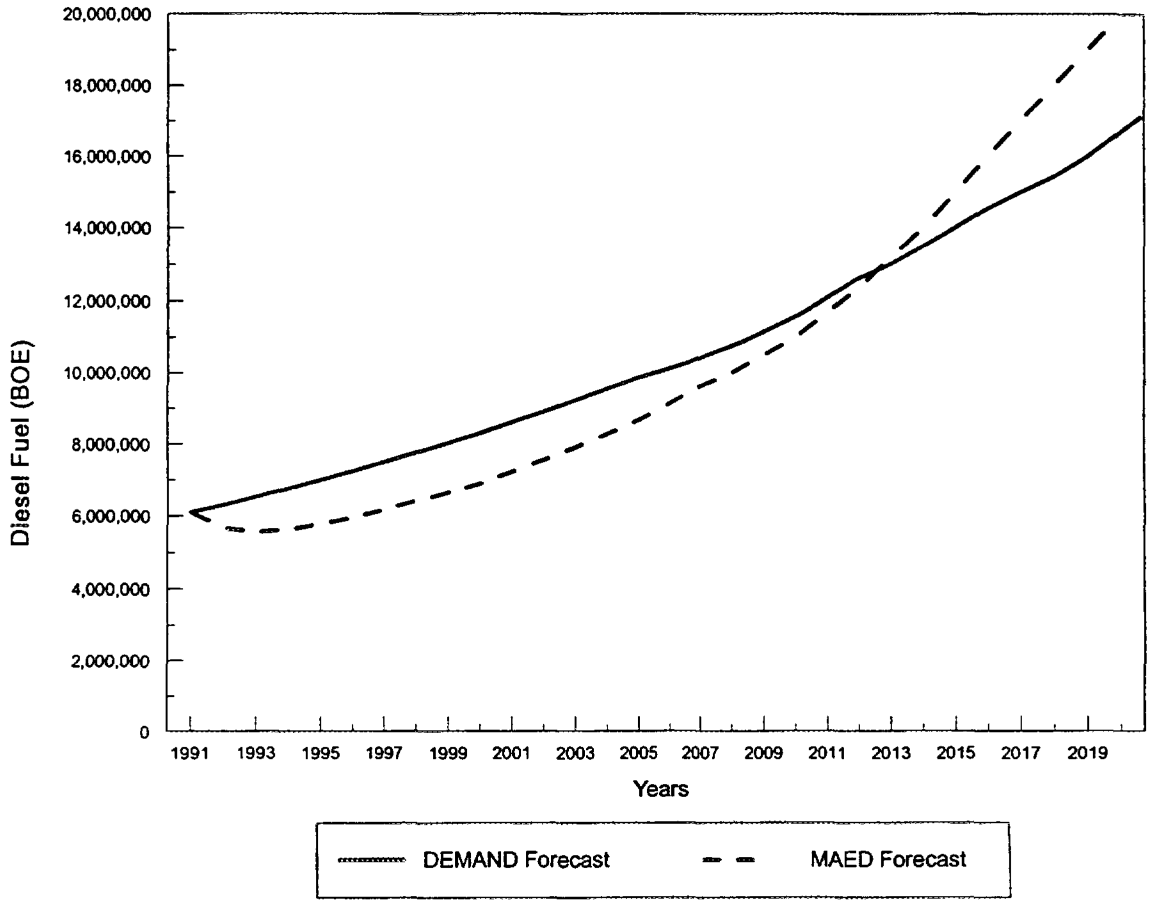
- the interval 1989-1995 is too short to provide a consistent forecast over 30 years;
- the evolution of the parameters up to 1989 is much different from the evolution after 1989;
- even if the above problems are specific to countries in economic transition, the DEMAND model uses the following equation to determine the evolution of energy demand:

$$\text{energy growth rate} = (1+M_{rate1})^a \times (1+M_{rate2})^b \times (1+M_{rate3})^c - 1$$

where the elasticity coefficients a,b,c are kept constant throughout the period of the study leading to inaccuracies as the one illustrated in the diagram shown in Figure 1.

It is therefore recommended to modify the model in order to allow the user to establish the energy demand evolution with different elasticity coefficients for different time intervals (from 1 year to 5 or 10 years) according to the user preferences.

Figure 1 EVOLUTION OF AGRICULTURE DIESEL DEMAND



(b) The DEMAND model allows forecasts by consumption sectors and by types of fuel. Unfortunately, it does not show how these estimates are framed within the general development trends for the country which is very important for forecasting studies. The DEMAND report output should be reorganized in order to provide additional information such as the total level of energy demand by energy types and consumers and important macroeconomic parameters such as energy per capita, electricity per capita, energy versus GDP, etc.

2. LOAD CURVES FORECAST

The MAED model is used for forecasting the electric load curves that are necessary for the analysis of the future development of the power generating system. For a better modelling of the evolution of load curves in countries with four distinct seasons, it would be useful if the model could allow one typical curve for each month or at least for each season. This is the case of Romania where preparation of the input information for MAED requires manual handling of the available data.

The LDC model is utilized for short-term forecast of load curves, by processing statistical data through the whole electricity system. The load curves so obtained are used as input data for the ICARUS model in order to establish the least operating costs of the plants monthly and quarterly. However, the division of the calendar year in months in the LDC model does not follow the same rule as in ICARUS. Therefore, after transferring data from LDC to ICARUS, the user should modify the imported information in order to find as many parameters of the load curves forecast in LDC. It would be preferable to have among all ENPEP modules that utilize electric load curves, a complete compatibility of these curves which would facilitate the automatic transfer of data, thus improving the quality of the analyses.

3. DEMAND/SUPPLY BALANCE

Up to now, the BALANCE model has been used to determine the impact of different strategies of new power plants development programs, cogeneration and district heating, on the cost of fuel supply and emissions of air pollutants.

In this respect, it was necessary to perform a proper modelling of the Romanian electric power system which consists of more than 28% of hydro power plants with important water storage lakes and short-term water storage lakes. Thermal power plants represent almost 42% of the total supply, with mostly cogeneration plants (residential, mixed residential/industrial or industrial cogeneration plants). One particularity of these cogeneration plants is that 80% are equipped with condensation units and with adjustable extractions and can therefore participate, in periods of low heat consumption, to the marginal reserve of the electric power system, even for covering the electricity demand.

In addition to the co-generation system, the Romanian energy system has an important district heating network. Modelling the electric power system and the heat supply system requires a proper modelling of the sources and the way they are used to meet the thermal energy demand of different types of customers.

The experience accumulated with the use of the BALANCE model allowed to identify its limits, to propose solutions for solving different problems and suggestions for improving the model.

3.1 Modelling of Cogeneration

The problem of modelling the cogeneration and district heating system under steam and hot water, is that BALANCE cannot model the operation of cogeneration units which represent the combined generation of heat and electricity.

District heating (steam and hot water) can be supplied by both heat plants and cogeneration plants.

Heat plants were classified into nine categories according to the type of fuel and the type of consumer. In the energy network, they are modelled through a conversion process as listed in Table 1.

Cogeneration plants were modelled taking into consideration: the type of fuel (lignite, hydrocarbons), the supplied consumers (residential, agriculture, chemistry, energy, other industries), the owner of the plant (RENEL or self-producers), the modality of generating thermal power (either cogeneration or steam and hot water boilers).

Table 1. Representation of the heat plants in the energy network

Process name	Type of fuel	Type of customer	Process type and number	Input line	Output line
LPR & S	lignite	residential	PR 27	482	484
LPOI	lignite	other industries	PR 26	481	483
CPAG	hard coal	agriculture	PR 55	129	142
CPOI	hard coal	other industries	PR 96	222	223
HPR & S	hydrocarbons	residential	PR 82	251	259
HPAG	hydrocarbons	agriculture	PR 81	252	261
HPCH	hydrocarbons	chemical industry	PR 84	249	254
HPOI	hydrocarbons	other industries	PR 83	250	255
HPEY	hydrocarbons	energy sector	PR 80	253	264

Several alternatives for modelling cogeneration units were examined in order to express their particularity of generating combined electricity and heat. Two of the alternatives were especially relevant:

a) Operation of the cogeneration units in order to meet the power load, the loading being performed according to the electricity demand (Figure 2).

b) Operation of the cogeneration units to meet the heat load, the loading being performed according to the users heat demand (Figure 3).

Figure 2 MODELLING OF THE COGENERATION UNITS OPERATION FOR COVERING POWER LOAD

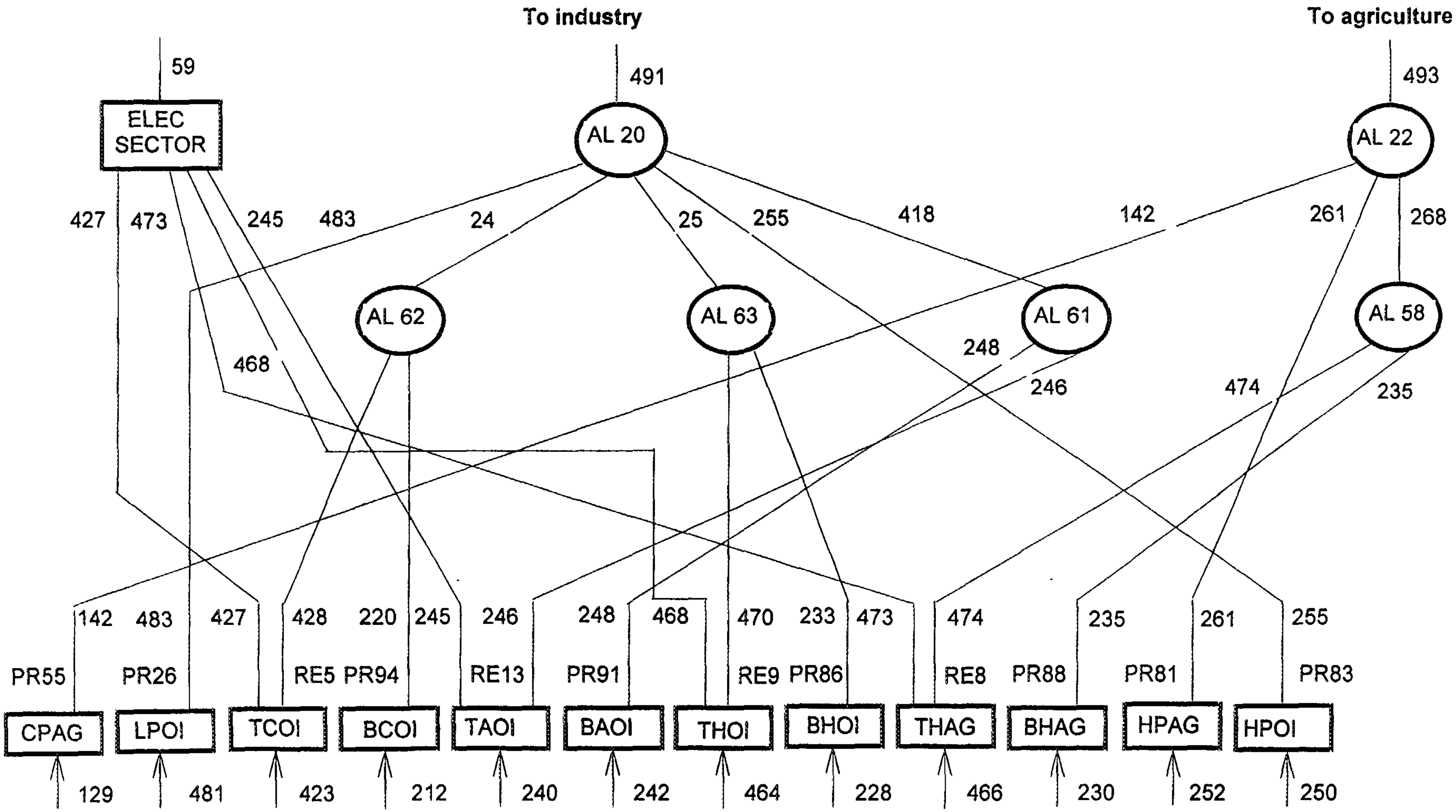
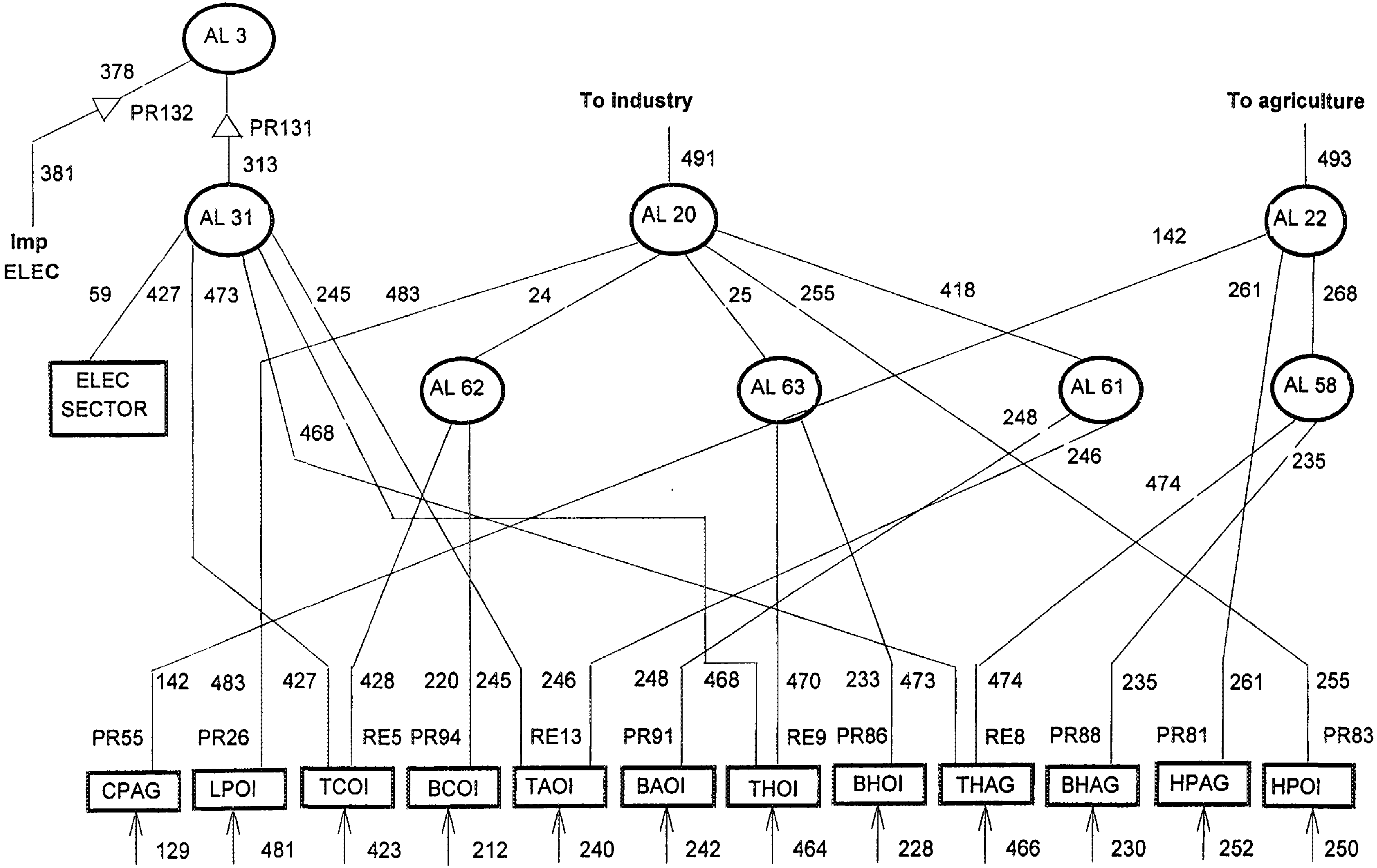


Figure 3 MODELLING OF THE COGENERATION UNITS TO COVER HEAT DEMAND



(a) Modelling of the cogeneration units operation for covering power load

This approach amounts to modelling the cogeneration units integrated into the electric sector and takes into account the fact that cogeneration plants are equipped with cogeneration units running at the bottom of the heat load curve and with peak boilers. It also considers the decrease of thermal power demand in all consumption sectors, except for the residential and the services sectors, due to the economic depression. Consequently, a great number of cogeneration units would run at partial loads. Cogeneration units were modelled by means of two types of equivalent units, as follows:

- Equivalent cogeneration units producing electricity, strictly correlated with the thermal power demand;
- Equivalent cogeneration units operating only under condensation duty.

Having in mind all these measures for modelling cogeneration plants, the following processes were used:

- Conversion process (PR) for modelling steam and hot water boilers used to cover the peak area of the heat load curve (see Table 2);

- Multi-output process (RE) and equivalent cogeneration units for modelling the operation of the cogeneration units running under cogeneration duty. The equivalent cogeneration units are under the control of "ELEC" allocation node of the plants electric load according to the incremental production cost. The equivalent cogeneration units belong to the electric sector and produce only electricity; they represent the cogeneration units from the electric point of view. To model the thermal power production from the cogeneration units, a multi-output process is thus defined. Within the multi-output process, the power load controlled by the electricity allocation process "ELEC" must be covered so that it controls the fuel supply. Table 3 lists the multi-output process utilized for modelling cogeneration plants while Table 4 displays the equivalent cogeneration units.

- The equivalent condensation units utilized for modelling the part of the cogeneration units running under condensation duty. The condensation equivalent units belong to the electric sector and are controlled by "ELEC" allocation node of the plants power load. They model the electric power and have technical and economic parameters of the cogeneration units under condensation duty. Table 4 shows the equivalent condensation units.

Within this energy network, the thermal power production of cogeneration units was controlled by the power load by means of the "ELEC" allocation process.

If the cogeneration units running costs are lower than those of the condensation units, they will be selected to operate at the base portion of the load curve. In this particular case, the units heat and electric capacity, operating under the cogeneration duty, will correspond to each plant for maximal capacity. The decision on supplying customers with thermal power from different sources has been modelled through a range of decision and allocation processes (see Figure 2).

Table 2. Modelling of the peak boilers from cogeneration plants

Type of equipment	Process name	Type of fuel	Type of customers	Process type and number	Input line	Output line
1. RENEL owned	BCRS	lignite	residential & services	PR 93	211	219
	BCCH	lignite	chemical industry	PR 95	213	221
	BCOI	lignite	other industries	PR 94	212	220
	BCEY	lignite	energy industry	PR 92	210	218
	BHRS	hydrocarbons	population & services	PR 87	229	234
	BHAG	hydrocarbons	agriculture	PR 88	230	235
	BHCH	hydrocarbons	chemical industry	PR 85	227	232
	BHOI	hydrocarbons	other industries	PR 86	228	233
	BHEY	hydrocarbons	energy industry	PR 89	231	236
2. Self producers	BACH	hydrocarbons	chemical industry	PR 90	241	247
	BAOI	hydrocarbons	other industries	PR 91	242	248

Table 3 Modelling of the cogeneration unit to cover Power Load: Modelling of the heat generation

Type of equipment	Process name	Type of fuel	Type of consumers	Process type and number	Input line	Outputs	
						Heat	Fuel for electricity
						Number of lines	Number of lines
RENEL owner	TCR&S	Lignite	Residential	RE4	424	430	429
	TCCH	Lignite	Chemical industry	RE14	215	207	206
	TCOI	Lignite	Other industries	RE5	423	428	427
	TCEY	Lignite	Energy industry	RE6	426	434	433
	THR&S	Hydrocarbons	Residential	RE7	465	23	472
	THAG	Hydrocarbons	Agriculture	RE8	466	474	473
	THCH	Hydrocarbons	Chemical industry	RE11	224	226	225
	THOI	Hydrocarbons	Other industries	RE9	464	470	468
	THEY	Hydrocarbons	Energy industry	RE10	467	476	475
Self producers	TACH	Hydrocarbons	Energy industry	RE12	239	244	243
	TAOI	Hydrocarbons	Other industries	RE13	240	246	245

Table 4 Modelling of the cogeneration units to cover Power Load: Modelling of the electricity generation

Type of units	Type of consumers	Fuel type	Process number	Process name	Input line	Output line to "ELEC." node
A. In operation in 1991	Other industries	**Hydro-carbons**	234	THIB	468	469
			155	THIB 72	468	469
1. Equivalent cogeneration units	Population & services		178	THRB 73	472	469
			179	THRB 74	472	469
			180	THRB 75	472	469
			181	THRB 76	472	469
1.1 RENEL's owner	Other industries		156	THIB 77	468	469
			157	THIB 78	468	469
			158	THIB 79	468	469
	Residential & services		182	THRB 80	472	469
			183	THRB 81	472	469
	Chemical industry		160	THIP 82	225	469
			161	THIG 83	225	469
			162	THIR 84	225	469
			163	THIR 85	225	469
			164	THIO 86	225	469
	Other industries		165	THII 87	468	469
			166	THIV 88	468	469
			167	THIB 89	468	469
	Population & services		184	THRP 90	472	469
			185	THRG 91	472	469
			186	THRR 92	472	469
			187	THRI 93	472	469
	Agriculture		188	THAR 94	473	469
	Energy industry		189	THER 95	475	469
			190	THEO 96	475	469
			191	THEN 97	475	469
			192	THES 98	475	469
	Population & services	**Lignite**	142	TCII 146	429	51
	Chemical industry		143	TCIO 147	206	51
			144	TCIO 148	206	51
	Other industries		145	TCIG 149	427	51
			146	TCID 150	427	51
			147	TCIV 151	427	51
			148	TCIS 152	427	51
	Population & services		149	TCRC 153	429	51
			150	TCRO 154	429	51
	Chemical industry		151	TCRO 155	206	51
	Population & services		152	TCRI 156	429	51
			153	TCRB 157	429	51
	Energy industry		154	TCYB 158	433	51
1.2 Self producers	Chemical industry	**Hydro-carbons**	168	TACH 1	243	469
			169	TACH 2	243	469
			170	TACH 3	243	469
			171	TACH 4	243	469
			172	TACH 5	243	469
			173	TACH 6	243	469
			174	TACH 7	243	469
			175	TACH 8	243	469
	Other industries		176	TAIO 1	245	469
			177	TAIO 2	245	469

Table 4 (Cont.)

Type of units	Type of consumers	Fuel type	Process number	Process name	Input line	Output line to "ELEC." node
2. Equivalent condensing units	Electricity	**Hydro-carbons**	235	KHO5	455	456
			236	KHO5 1	455	456
			119	KHO1 101	455	456
			120	KHO1 102	455	456
2.1 RENEL's owner			121	KHO1 103	455	456
			122	KHO1 104	455	456
			123	KHO1 105	455	456
			114	KHO2 106	455	456
			115	KHO2 107	455	456
			116	KHO2 108	455	456
			117	KHO2 109	455	456
			118	KHO2 110	455	456
			111	KHO3 111	455	456
			112	KHO3 112	455	456
			113	KHO3 113	455	456
			97	KHO4 114	455	456
			98	KHO4 115	455	456
			99	KHO4 116	455	456
			100	KHO4 117	455	456
			101	KHO4 118	455	456
			102	KHO4 119	455	456
			103	KHO4 120	455	456
			104	KHO4 121	455	456
			105	KHO4 122	455	456
			106	KHO4 123	455	456
			107	KHO4 124	455	456
			108	KHO4 125	455	456
			109	KHO4 126	455	456
			110	KHO4 127	455	456
			87	KHO5 128	455	456
			88	KHO5 129	455	456
			89	KHO5 130	455	456
			90	KHO5 131	455	456
			91	KHO5 132	455	456
			92	KHO5 133	455	456
			93	KHO5 134	455	456
			94	KHO5 135	455	456
			95	KHO5 136	455	456
			96	KHO5 137	455	456
			81	KHO6 140	455	456
			82	KHO6 141	455	456
			83	KHO6 142	455	456
			84	KHO6 143	455	456
			85	KHO6 144	455	456
			86	KHO6 145	455	456

(b) <u>Modelling of the cogeneration units operation for covering heat load</u>

Modelling cogeneration plants was performed similarly to other generation plant alternatives except for the equivalent co-generation units. These were modelled by means of the multi-output process where the input link is represented by the fuel required by the plant and the output links are divided into heat and electricity.

Heat production is the priority link and for this reason it will control the fuel supply of the multi-output process. The typical feature of this diagram is the removal of the equivalent cogeneration units from the electric sector (Table 5). The heat production of these units will depend on the customers demand and the relative cost of heat compared to other sources. The electricity output will be linked with heat production.

Consumers supply with heat from different sources has been modelled by means of allocation and decision processes (Figure 3).

Table 5 Modelling of the cogeneration units to cover heat demand: Modelling of the electricity generation in condensation

Type of units	Type of consumers	Fuel type	Process number	Process name	Input line	Output line to "ELEC." node
2. Equivalent condensing units (cont.) 2. 1 RENEL's owner (cont.)	Electricity	**Hydro-carbons**	235	KHO5	455	456
			236	KHO5 1	455	456
			119	KHO1 101	455	456
			120	KHO1 102	455	456
			121	KHO1 103	455	456
			122	KHO1 104	455	456
			123	KHO1 105	455	456
			114	KHO2 106	455	456
			115	KHO2 107	455	456
			116	KHO2 108	455	456
			117	KHO2 109	455	456
			118	KHO2 110	455	456
			111	KHO3 111	455	456
			112	KHO3 112	455	456
			113	KHO3 113	455	456
			97	KHO4 114	455	456
			98	KHO4 115	455	456
			99	KHO4 116	455	456
			100	KHO4 117	455	456
			101	KHO4 118	455	456
			102	KHO4 119	455	456
			103	KHO4 120	455	456
			104	KHO4 121	455	456
			105	KHO4 122	455	456
			106	KHO4 123	455	456
			107	KHO4 124	455	456
			108	KHO4 125	455	456
			109	KHO4 126	455	456
			110	KHO4 127	455	456
			87	KHO5 128	455	456
			88	KHO5 129	455	456
			89	KHO5 130	455	456
			90	KHO5 131	455	456
			91	KHO5 132	455	456
			92	KHO5 133	455	456
			93	KHO5 134	455	456
			94	KHO5 135	455	456
			95	KHO5 136	455	456
			96	KHO5 137	455	456
			81	KHO6 140	455	456
			82	KHO6 141	455	456
			83	KHO6 142	455	456
			84	KHO6 143	455	456
			85	KHO6 144	455	456
			86	KHO6 145	455	456

3.2 Modelling of Heat Plants

Heat plants may use several fuel types (e.g., a lignite fired heat plant may be provided with both lignite as main fuel and with either fuel oil or gas for the start up or flame stability). This feature was also modelled in the energy network using a special representation for these plants.

In BALANCE, the PR conversion process nodes which model heat plants accept only one input element, i.e., only one type of fuel. In order to solve this problem, multi-input (MI) process type nodes have been inserted in the energy network to simulate the fuels mixing process for producing thermal power.

3.3 Modelling of Hydroelectric Plants

Within the electric sector of the BALANCE model, hydro power plants with storage reservoirs are modelled only by considering the electricity annual production. These plants operate at base load. This leads to certain alterations of the participation of the different groups of plants in the electricity demand supply since the role of hydro power plants in setting up the peak load and the system reserve margin is not considered.

In order to adjust, to a certain extent, the mode of representation of hydro power plants in the BALANCE model, the results from the WASP model regarding the operation of hydro power plants were analyzed for the same study period and electricity demand. Using the values for the average hydrological condition, it was then defined a hydro unit operating at base load in accordance with the BALANCE model methodology.

The difference between the capacity of hydro power plants involved in the load curve in WASP and the capacity of the unit defined according to the BALANCE methodology, was considered as representing the reserve. This reserve was divided into several modules defined as pseudo thermal units but with the economic and availability parameters of hydro plants and a heat ratio 20% higher than the highest heat ratio of real plants.

Another possibility consists of using the loading order to model the operation of hydro power plants in the peak area of the load curve. This solution has the inconvenience that the loading order can not be modified over the study period. Moreover, since the structure of the thermal units changed with the time (because of the addition of new units and retirement of old units) the position of hydro power in the load curve changes. This can easily modify the hydro electric energy generated each year.

This procedure did not solve the problem. Therefore, an enhancement of the model is recommended to allow a proper modelling of hydro power plants.

3.4 Other Problems

The electric load curve in the BALANCE model keeps the same shape throughout the study period. This does not reflect the reality, especially in countries in economic transition. For a 30 year study period, the difference between the maximum peak load obtained with BALANCE and the one obtained with MAED can reach 20% at the end of the study period.

Therefore, the model would need some modifications to allow a proper modelling of the load curve.

It is suggested to double the number of graphs for output-writer options and to avoid the restriction on the maximum number of lines that can be utilized (in the version utilized for the present study, the limit was 12).

4. IMPACTS ANALYSIS

Up to now, the IMPACTS model has been used to establish the emissions of pollutants in the air by the electric power sector, thermal power plants, the residential sector, the services and transportation sectors. The energy input data are usually imported from the WASP model for the electric sector and from the BALANCE model for the other sectors.

4.1 Data Imported from Other Modules

When the data is imported from both WASP and BALANCE to IMPACTS, in the screen assignment of generic facility data, different import facilities have the same IMPACTS number. To avoid this problem, it should be noted that import facilities are considered as copies and should be retyped at the end of the list in the row of free impacts numbers. Once these operations are done, data is imported a second time from WASP and BALANCE.

4.2 Rehabilitation of Older Plants

The scope of the rehabilitation of thermal power plants is to improve either both or one of the following, namely the technico-economical performances and the reduction of air pollutants. The improvement of the control devices efficiency cannot be dealt with by the IMPACTS model. Therefore, it would be useful to introduce the possibility to modify the parameters in the Generic Facility Database over the study period.

4.3 Other Problems

It would be useful if the IMPACTS module were modified to provide a report of the total operation and maintenance costs of the facilities, the cost of control devices, as well as the shares of each of these costs in the total. This information would be useful in order to compare the alternative solutions and to put in evidence, for instance, the influence on the costs of the fuel sulphur content, etc.

5. CONCLUDING REMARKS

The use of the ENPEP package in the planning activities of Romania has permitted to align the planning methodology with the international standards and to enhance the capabilities of the Romanian experts. Among the projects that will be launched making use of these models, the most important ones are the following:

- "Development of a fuel policy / energy demand and supply study for Romania" financed by the European Commission PHARE program and with the technical support of the ANL in collaboration with ISPE;

- "Country study Climate Change" financed by EPA-USA and coordinated by the Ministry of Water, Forests and Environmental Protection of Romania, the analyses of greenhouse gas mitigation options being elaborated by ISPE using BALANCE and IMPACTS methodologies

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ENPEP EXPERIENCE IN THE RUSSIAN FEDERATION AND PROSPECTS FOR FURTHER APPLICATIONS

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Abstract

The present paper deals with general aspects of ENPEP applications in Russia. Great interest exists in Russia in studying the well-established and sound methodology of energy planning that is offered by ENPEP. Since Russia is a country in economic transition moving from a centrally planned economy to a market oriented one, modifications of the methodology and practices of energy planning are necessary. The possibility of using ENPEP for launching new studies was therefore interesting. The first Russian ENPEP study focused on the Far-East Region of Russia. It was carried out by a team of Russian experts who participated in the Interregional Training Course on "Integrated Energy and Electricity Planning for Nuclear Power Development with Emphasis on the ENPEP Package" held at the Argonne National Laboratory (ANL), USA, in 1992. A second ENPEP application was completed for the St.-Petersburg region at the Institute of Nuclear Reactors, Russian Research Centre "Kurchatov Institute", Moscow. The third ENPEP study described in the paper was conducted by a team of Russian experts who participated in the Interregional Training Course on "Electric System Expansion Planning", ANL, 1993. This study focused on the Central Power Pool of Russia. The present paper is divided into three parts. Some background economical information on Russia is given in Part 1. The core of the paper is represented by Part 2 which describes the characteristic features of the ENPEP studies that have been conducted in Russia as well as the experience gained through these studies. The last part presents some suggestions on further applications of ENPEP in Russia, especially with respect to broadening its use in order to cover the entire country.

1. BACKGROUND INFORMATION ABOUT RUSSIA AND ITS ENERGY SECTOR

1.1. General Overview

Russia is a large country occupying the Eastern part of Europe and the Northern part of Asia. In the North, the border of the country is the Arctic Ocean, Finland being the farthest north-west neighbour. At the West and Southwest, the country is surrounded by the newly independent states all former members of the Soviet Union, with Kazakhstan being the largest of them. The South region of Russia has a common border with Mongolia and China. The Eastern border of the country is the North Pacific Ocean with Japan and the Alaska State of the USA being the nearest neighbours. Russia has an area of about 17 million km^2. The country is divided into numerous administrative units: provinces and republics. The regions of the country differ significantly by area, the natural conditions, the ethnical origins and the composition of the population, and the economic development.

According to the latest statistics [1, 2], the population of Russia amounts to about 150 million inhabitants. The average population density in the country is 8.7 inhabitants per km^2. This number varies significantly from region to region with more than 100 inhab./km^2 for some provinces in the European part of Russia to less than 1 inhab./km^2 in the large territories of Siberia. The development of the population over the last decade and the structure of the population are shown in Table 1.1.

Table 1.1. Major Characteristics of the Population of Russia [1, 2]

Year	Population (million)					
	TOTAL	Urban	Rural	Men	Women	Density (inhab./km^2)
1985	143.8	104.1	39.7	66.9	76.9	8.42
1986	145.1	105.7	39.4	67.7	77.4	8.50
1987	146.3	107.1	39.2	68.4	77.9	8.57
1988	147.4	108.4	39.0	69.0	78.4	8.63
1989	148.9	109.2	38.8	69.4	78.6	8.72
1990	148.5	109.8	38.7	69.7	78.8	8.70
1991	148.7	109.7	39.0	69.9	78.8	8.71
1992	148.6	-	-	-	-	8.70
1993	148.4	-	-	-	-	8.70

The GDP (Gross Domestic Product) parameters are summarized in Table 1.2 [1, 2]. These data are based on the most recent official statistics. The data clearly reflect the economic crisis accompanying the process of economic reforms. The GDP values have been declining since 1990, with the most important decline (proportionally) between 1991 and 1992. The overall inflation index has been considerably growing since 1990 and reached a peak of 2000%/a, equivalent to approximately 20% per month, in 1992. Lately, the macro-economic parameters evolved positively, but at this early stage, one can hardly assert that the recovery from the crisis has started. The structure of GDP for 1993 is given in Table 1.3 and Fig. 1.1.

Table 1.2. Russian GDP [1, 2] (billion Russian Rubles)

	1989	1990	1991	1992	1993
In current prices	-	626.3	1300	19992	162300
In constant 1991.	1677	1493	1300	1060	933
% of previous	-	89.0	87.1	81.5	88
Inflation index, %	-	-	238	1886	-

Table 1.3. GDP structure in 1993 [1,2]

Industry	Construction	Agriculture	Transport	Other
40.0%	12.5%	25.0%	5.4%	17.1%

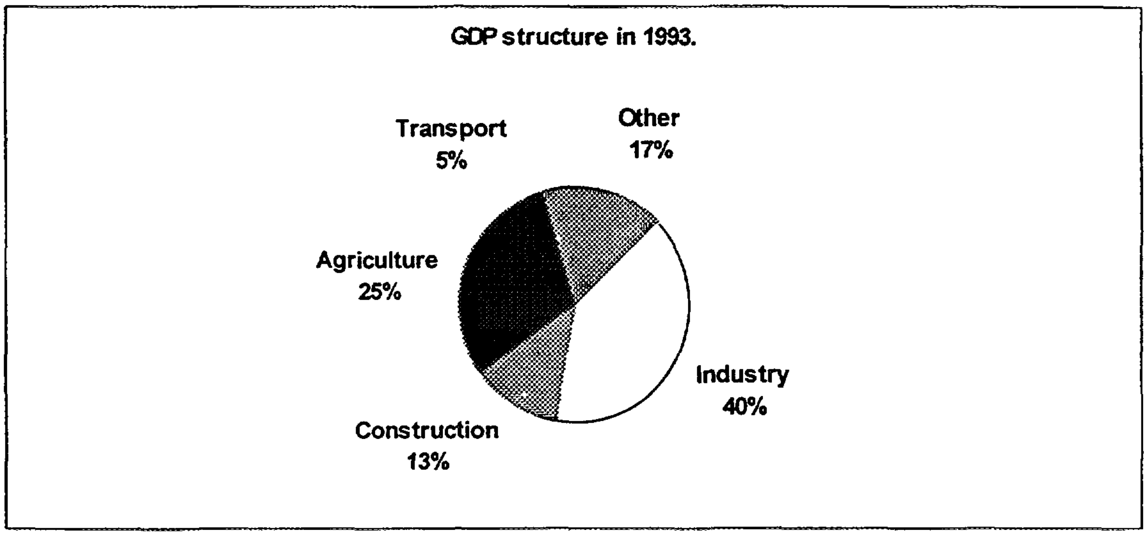

Figure 1.1.

1.2. Energy Sector

In 1993, the overall production of primary energy resources in Russia[4] amounted to 1528 million ton of coal equivalent (tce). The main energy resources were:

Gas:	618 billion cubic m or 711 million tce
Oil:	351 million t or 502 million tce
Coal:	299 million t or 203 million tce
Hydro energy:	174.1 TWh(e) or 54 million tce
Nuclear energy:	119.2 TWh(e) and 4.0 Pcal(th) or 38 mill. tce
Other resources: (wood, peat, shale)	20 million tce

The breakdown of energy supply by resource type is shown in Fig. 1.2. This figure shows, that the Russian energy sector relies primarily on fossil fuels. The share of nuclear energy in the total energy supply is only 2%. Hydroelectricity, which is the only meaningful renewable resource in Russia, contributes to 3% of the total energy production.

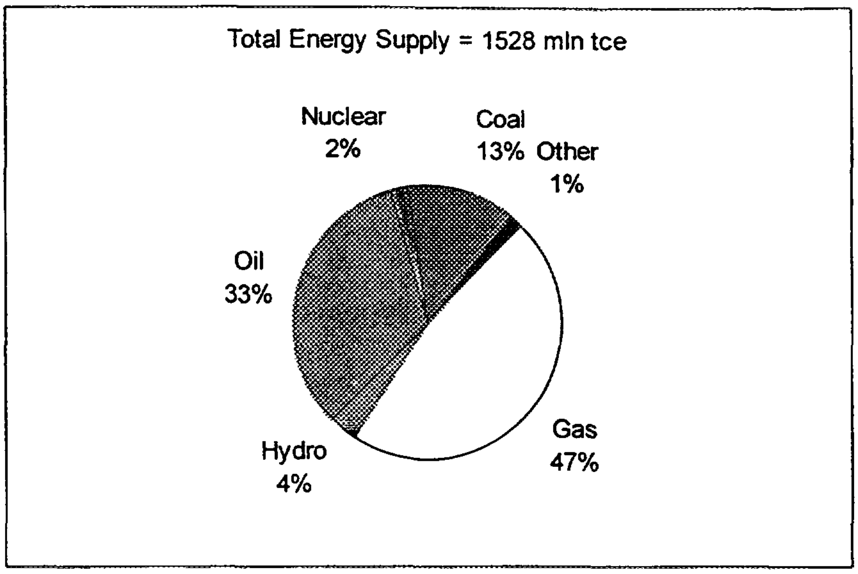

Figure 1.2. Share of the different energy sources in the total production of energy

1.3. Electricity Sector

Generally, the Russian electricity system consist of three large parts (see Figure 1.3):

- Unified Electricity System. This complex and well developed system is part of the large integrated electricity system of the former Soviet Union. As it is shown in Fig. 1.4, this system is the major contributor to the national electricity production. It consists of six large regional systems which are in turn composed of local electricity networks, usually one per administrative province. The large regional systems and their respective share in the capacity of the Interconnected Electricity System are the following:

  ⇒ Central Power Pool ~29%
  ⇒ Middle Volga Power Pool ~10%
  ⇒ Ural Power Pool ~ 23%
  ⇒ Northwest Power Pool ~ 15%
  ⇒ North Caucasus Power Pool ~ 5%
  ⇒ Siberia Power Pool ~18%

- The VOSTOK Regional System. This system covers a large part of the Russian Far East and operates separately from the main grid since only minor energy exchanges with the integrated system exist.

- Isolated Local Electricity Systems. These rather small systems are situated in remote regions where communication with the rest of the country is difficult. They are, however, very important for the respective regions and keep expanding to meet the local need. There are plans for interconnecting these systems to the main grid in the future.

National Electricity Supply System:

1. **Unified Electricity System (UES);**
2. **VOSTOK Regional Electricity System;**
3. **Isolated Local Electricity Systems.**

1. Unified Electricity System (UES):

- Covers the European part of Russia and a large part of Siberia;
- Consists of 6 large Regional Electricity Systems that include 63 Local Electricity Systems;
- Generated 1022 TWh in 1991 which represented 95.6% of the total electricity generation.

2. VOSTOK Regional Electricity System:

- Covers the Far East part of Russia;
- Consists of 4 Local Electricity Systems;
- Generated 45.2 TWh in 1991 which represented 4.2% of the total electricity generation.

3. Isolated Local Electricity Systems:

- Situated in various parts of Russia: in the North, Siberia, Far East;
- Include 5 Local Electricity Systems;
- Generated 1.3 TWh in 1991 which represented 0.1% of the total electricity generation.

Fig. 1.3. Structure of the Russian Electricity Supply System.

The main statistics of electricity generation in Russia are presented in Table 1.4 which also shows the generation by source. The consumption of electricity by the different sectors of the Russian economy is presented in Table 1.5. Some other important statistics concerning electricity generation and consumption are shown in Tables 1.6 and 1.7.

Table 1.4. Electricity Generation in Russia [1, 2, 5, 6] [TWh]

Year	Total Generation	By Source		
		Fossil Fuel Plants	Hydro Plants	Nuclear Plants
1980	805	622	129	54
1981	836	638	134	65
1982	863	670	122	70
1983	898	686	133	80
1984	940	698	151	91
1985	962	703	160	99
1986	1001	732	164	105
1987	1047	764	162	120
1988	1066	779	161	126
1989	1077	789	160	128
1990	1082	797	167	118
1991	1068	780	168	120
1992	1011	718	172	120
1993	937	644	174	119

Table 1.5. Electricity consumption[6, 7] [TWh]

Sectors	1990	1991	1992	1993
- Industry	553.7	531.5	484.8	470.3
- Construction	18.8	16.8	16.3	16.2
- Transportation	103.8	96.7	86.8	85.5
- Agriculture	67.3	73.2	74.8	74.1
- Communal Services (urban)	144.7	150.1	147.5	156.0
- Communal Services (rural)	29.1	30.2	29.7	31.4
- Power Plant House Loads	72.4	71.5	67.6	66.6
- Network Losses	84.2	85.7	86.3	83.4
Total	1074.0	1055.7	993.8	983.5

Table 1.6. Per Capita Electricity Generation and Consumption in Russia[1, 2]

Year	Population (million)	Per Capita Generation (MWh/cap)	Per Capita Consumption (MWh/cap)
1985	143.8	6.7	-
1986	145.1	6.9	-
1987	146.3	7.1	-
1988	147.4	7.2	-
1989	148.0	7.3	-
1990	148.5	7.3	7.2
1991	148.7	7.2	7.1
1992	148.6	6.8	6.7
1993	148.1	6.7	6.6

Table 1.7. Installed generation capacity by source [GW(e)]

Source	1990	1992	1994
Hydro	41	41	41.1
Nuclear	20	20	21.2
Fossil	135	135	115.2
Total	196	196	177.5

2. ENPEP STUDIES CONDUCTED IN RUSSIA AND EXPERIENCE GAINED

2.1. Introduction

The interest of Russia in ENPEP comes from the will to use the well-established and sound methodology for energy planning provided by ENPEP. The existence of numerous ENPEP studies carried out by various national organizations as well as by the International Atomic Energy Agency (IAEA) and Argonne National Laboratory (ANL), confirms the valuable quality of this tool. Since Russia is a country in economic transition moving from a centrally planned economy to a market economy, modifications of the methodology and procedure for energy planning are necessary. The possibility to use ENPEP for this purpose seemed to be worth investigating.

One of the reasons for using ENPEP has been prompted by the regional dimension of the energy problems in Russia which is a large country with regions that can be compared with some countries in size and in the magnitude of the problems. Energy planning at the regional level becomes an essential part of the decision making process in the country. Some of the ENPEP characteristics, e.g., use on personal computers, modular structure, availability at no charge, render it an interesting, reliable and appropriate tool for long-term energy and electricity planning at the regional level. Its use could contribute to improve the quality of regional energy studies and to facilitate the incorporation of regional elements into the national energy policy.

The second objective of the studies was to perform a detailed analysis and obtain reliable results on the important issue regarding the future role of nuclear power in Russia. The development and distribution of ENPEP are supported by the IAEA and ANL which have been using these tools for many years in the issues of nuclear power planning. In order to take advantage of this experience, the participation of Russian experts in ENPEP activities was considered as highly relevant for identifying new strategies for the development of the nuclear sector in the country.

ENPEP was released to Russia in 1992. Since then, the package has been distributed to several interested planning organization within the country. In addition, some energy planning studies with different scopes and objectives have already been conducted using ENPEP. These studies are reviewed in the following section.

2.2. Far East Regional ENPEP Study

The first Russian ENPEP study was carried out by a team of Russian experts[1] who participated in the Interregional Training Course on "Integrated Energy and Electricity Planning for Nuclear Power Development with Emphasis on the ENPEP Package" held at ANL, from 14 September to 6 November 1992. The main objective of this course was to train the participants in the use of ENPEP. Therefore, national teams of experts were required to conduct a case study based on the situation of their country, as a pre-requisite for receiving the ENPEP package for national use, at the end of the course.

The main objective of the Russian team at the course was to get a clear understanding of the ENPEP approach and to obtain training in its use. Emphasis of the study was put on the applicability of the tool to a large-scale regional energy planning in Russia, and on identifying its qualities. Therefore, the study focused on the Far-East region of Russia which has an area of 1.442 million km^2 and a population of 5.936 million inhabitants. This region is divided into four administrative units, namely the Amur province (364,000 km^2), the Khabarovsk territory (825,000 km^2), the Primorsky territory (166,000 km^2), and the Sakhalin province (87,000 km^2). The region has been selected as a separate entity since it has an integrated electricity generating system and most of the primary energy resources consumed by the region are of local origin.

The ENPEP study investigated the regional energy system and its contradictory situation, namely: on one hand, the region is potentially rich in primary energy resources and is one of the richest areas in Russia in this respect; on the other hand, the region is highly dependent on imports of fossil fuels. The study was performed in the following steps:

- Modelling of the overall regional energy balance;
- Projections of the major economic and energy parameters;
- Construction and investigation of several scenarios for developing the system.

The following analyses have been conducted:

- Analysis of the present development trends of the energy system with due attention to the energy related issues;
- Assessment of the regional impacts of exploiting potential gas/oil resources (off-shore extraction of oil/gas near the Sakhalin Island);
- Assessment of the role of nuclear power;
- Sensitivity analysis for the results.

The principal findings of the study for the Far-East energy system include the following:

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[1] The team of Russian experts included:
- Mr. Alexander SHIBANOV - the ENPEP liaison officer in Russia and Head of the Strategic Planning Department, Main Computing Center of the Ministry of Fuel and Energy of the Russian Federation;
- Mr. Vladimir UREZCHENKO - Associate Professor, Moscow Physics and Engineering Institute.
- Mr. Sergey KONONOV - Researcher, RRC "Kurchatov Institute", Moscow.

1. Depletion of domestic energy resources and accordingly increase of imports represent a serious problem for the regional energy system. If no additional domestic energy sources are identified, the share of energy imports might increase (see Figs. 2.1 and 2.2) leading to a significant increase of energy prices. For instance, if the existing trends in extraction costs and import prices continue, the resulting energy prices may increase significantly (Fig. 2.3) reaching levels 1.5 higher compared to 1991.

2. To reduce the importance of the problem mentioned above, new gas/oil fields near the Sakhalin Island could be exploited. If this can be done at reasonable costs, the development of the energy system could become much less expensive, and even a decrease in the price of energy in real terms might be possible. (One of the typical scenarios with the inclusion of the Sakhalin oil/gas in the system is illustrated in Figs. 2.4 to 2.6).

3. The development of new oil resources should be combined with an increase of the capacity of the refineries. Otherwise the refinery might become a key constraint for the development of the energy system.

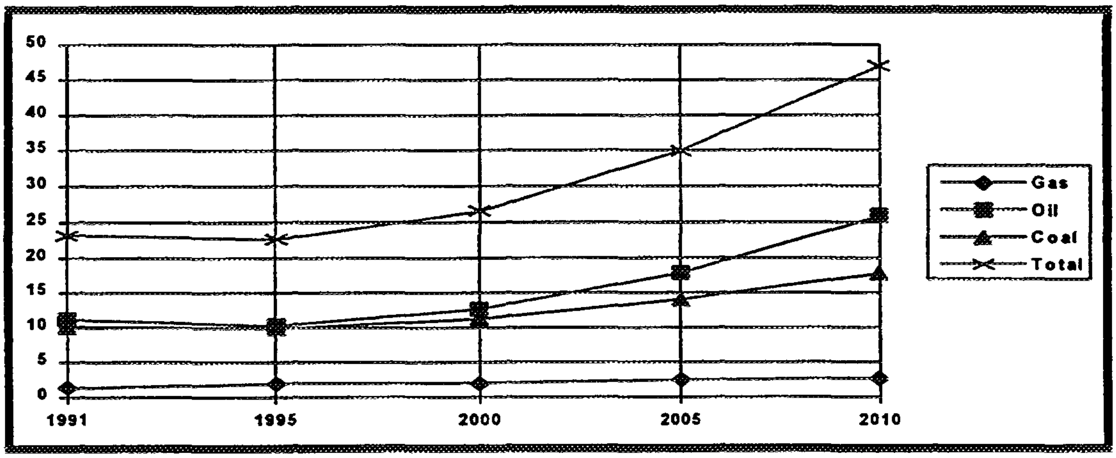

Fig. 2.1. Development of the Energy Supply Structure (million toe)

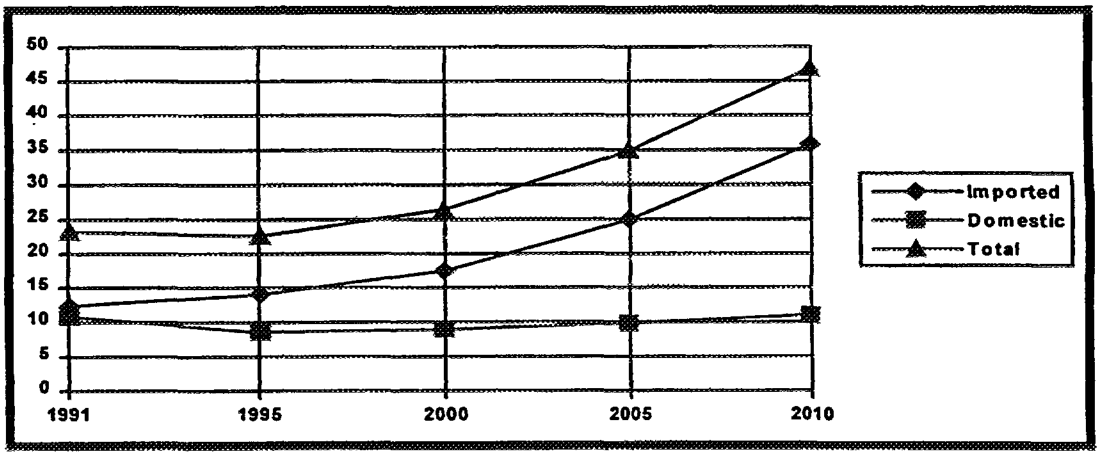

Fig. 2.2. Imported/Domestic Energy Supply (million toe)

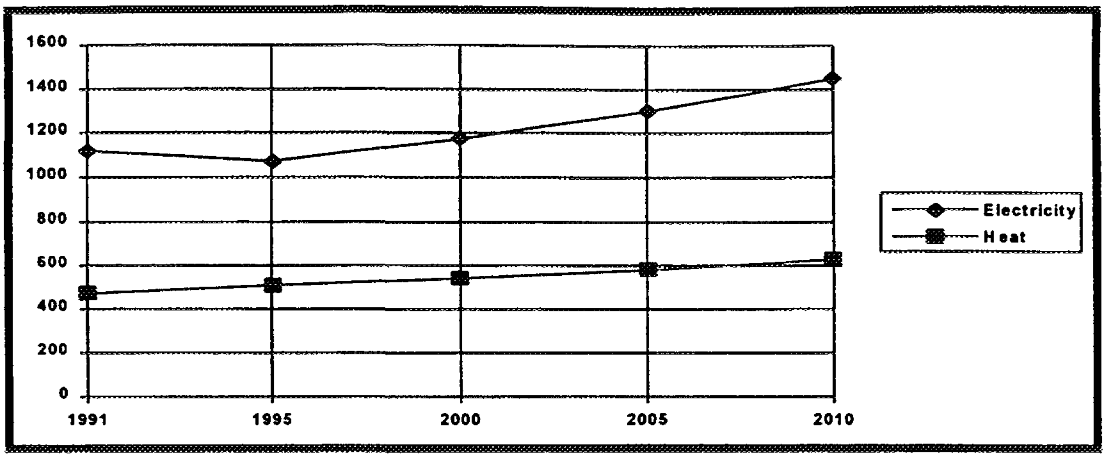

Fig. 2.3. Forecasted Trends of Energy Prices (rubles/toe)

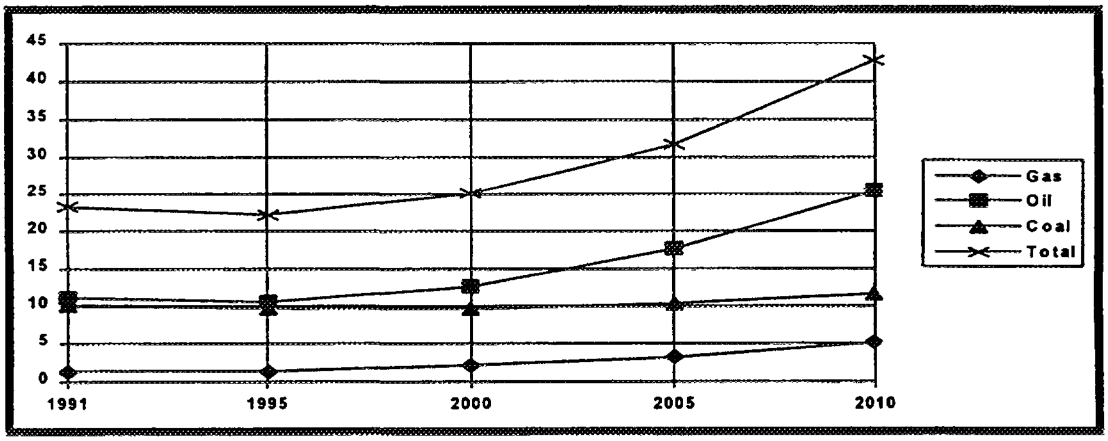

Fig. 2.4. Development of the Energy Supply Structure with the Sakhalin Gas/Oil (million toe)

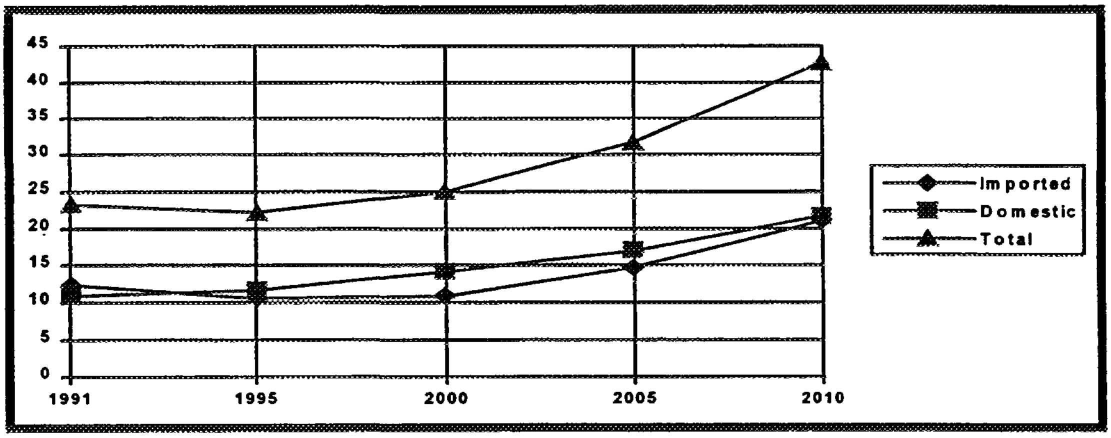

Fig. 2.5. Imported/Domestic Energy Supply for the Energy System with the Sakhalin Gas/Oil (million toe)

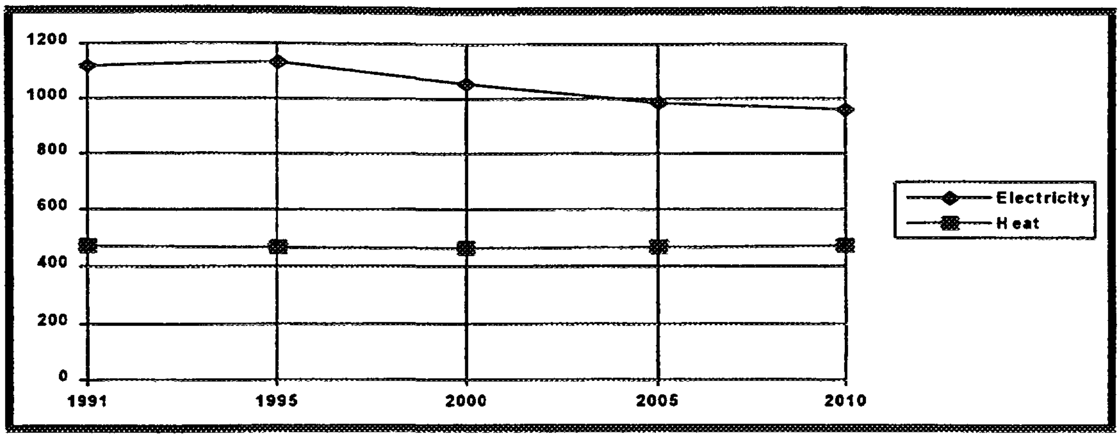

Fig. 2.6. Trends in Energy Prices for the Energy System with the Sakhalin Gas/Oil (rubles/toe)

4. The energy analysis was conducted on the basis of data of 1991. Basic economic data on energy resources and technologies originate from the time of the centrally planned economy. To ensure the applicability of the study results to the new economic situation, reconsideration of the cost structure is necessary. However, such reconsideration has its limits, since it is not possible to carry out a detailed macro-economic investigation only for the purpose of an energy planning study.

The usefulness of ENPEP for large-scale regional energy planning in Russia was proven through this study. Especially important was the opportunity to easily integrate into the energy analysis such factors as the prognoses of macro-economic changes in the region and the expected trends in domestic and imported energy sources. The final report of the study[1] was translated into the Russian language and made available to interested organizations in Russia. As a result, some new regional studies have been launched. One of them is described in the following section.

2.3. St.-Petersburg Regional ENPEP Study

The second ENPEP study was conducted at the Institute of Nuclear Reactors, Russian Research Centre "Kurchatov Institute", Moscow, with Mr. Yu.F. Chernilin, Head of the Department of Nuclear Power Economics and Planning, acting as Head of the Project, and Mr. V.P. Pakhomov, Head of the Department of Hydrogen Power Engineering, acting as Project Coordinator.

The object of the study was the electricity system of St.-Petersburg and the near-by Leningradskaya province in the North-West part of Russia. It occupies about 86,000 km^2, with a total population of 6.7 million inhabitants, of which 5.0 million live in St.-Petersburg. The

[1] S.L. Kononov, A.V. Shibanov, V.M. Urezchenko. Final Report on the Russian Team Study. ANL/IAEA Interregional Training Course on Integrated Energy and Electricity Planning for Nuclear Power Development with Emphasis on the ENPEP Package, Argonne National Laboratory, Argonne, Illinois, USA, 14 September-6 November 1992.

population density is high in this region which also has well developed industries and good prospects for industrial development. As far as the energy system is concerned, the region has one of the most developed energy systems in Russia. In addition to covering the regional electricity demand, it supplies electricity to the neighbouring provinces (Pskov and Novgorod provinces, Karelia) and to Finland.

An important feature of the regional energy system is the role of nuclear energy. As it is illustrated in Fig. 2.7, the share of nuclear electricity, which is generated at the Leningradskaya nuclear power plant[1], is around 40% of the total electricity generation in the region. However, the plant will be decommissioned in the early 2000's. Retirement of several fossil fuel units is also expected. Besides, since the energy demand may also increase, a strategy for replacement and further development of the regional energy system needs to be identified. This problem was brought up by the regional authorities. Therefore, the regional energy commission, supported by several regional institutions, initiated an energy planning study on the formulation of the energy needs and policies.

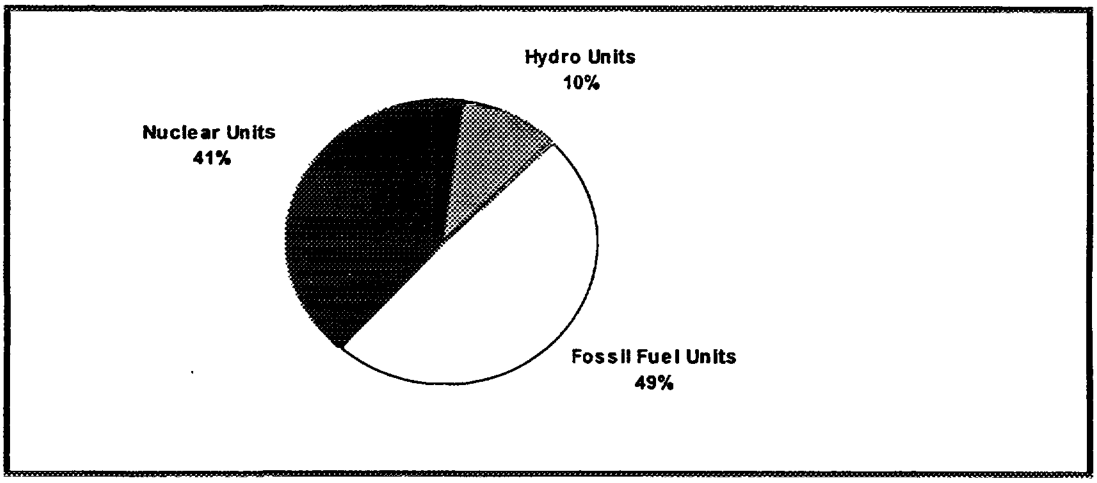

Fig. 2.7. Structure of Electricity Generation in St.-Petersburg Region

However, some drawbacks were identified in the study due to practices applicable to centrally planned economies. Therefore, the "Kurchatov Institute" was requested to launch the same study but using the ENPEP model.

The major issue of this ENPEP study was to investigate alternatives for the replacement of the Leningradskaya nuclear power plant scheduled for retirement. Therefore, projections of prices for competing energy resources available in the region were made; the characteristics of the existing and future technologies were analyzed and inputted into the corresponding database of ENPEP (modules PLANTDATA and BALANCE were used). Finally, the market simulation technique of the BALANCE module of ENPEP was applied to determine the most probable development of the energy market.

The key element of the study was the use of price projections of fossil and nuclear fuels for developing the electricity generation system. This element of the energy analysis that was

[1] The Leningradskaya plant consists of 4 RBMK (LWGR) units of 1000 MW(e) installed capacity each.

completely absent in the regional analysis that had been previously conducted. With ENPEP, escalation of prices of the major energy sources (oil, gas, coal, nuclear fuel) was assumed. As a result, the BALANCE module of ENPEP came up with the forecast of the composition of the energy system. The most important findings of the study are illustrated in Fig. 2.8.

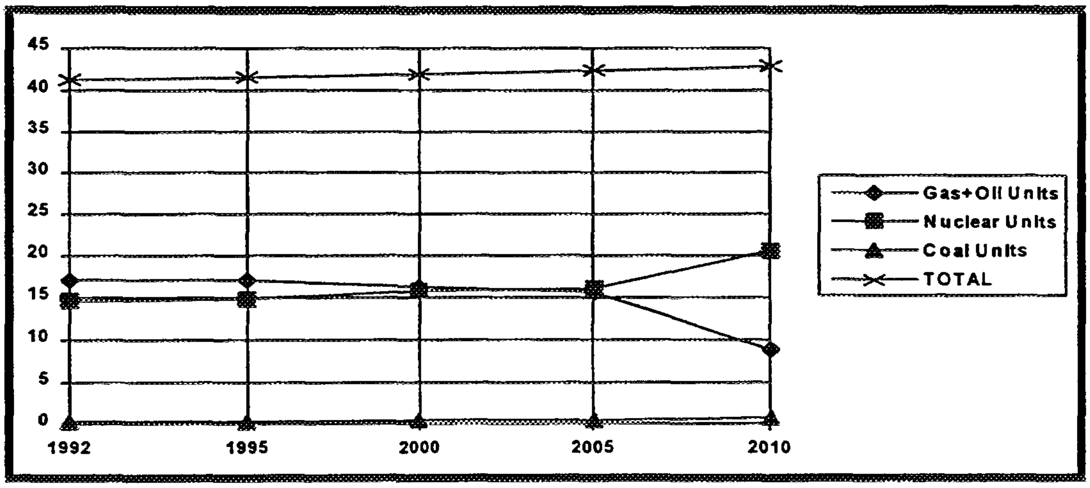

Fig. 2.8. Development of the Structure of Electricity Generation of the St.-Petersburg Region, TWh/a

As it is illustrated in Fig. 2.8, there is a change in the structure of electricity supply. Because of the projected high growth of fossil fuel prices, the optimum share of fossil fueled units will decline in the future. Some switch from gas to coal is also noticeable. However, the nuclear option remains the most economically viable choice for the region. From an economic viewpoint, nuclear energy is more than competitive in the region. There remains the problem of decision makers on how to deal with the issue of social acceptance of nuclear energy and to what extent this issue should influence the decisions to be taken.

On the basis of this study, some suggestions on the development of the regional energy system were formulated and given to the relevant regional authorities as part of the final report of the study[1]. Although the whole analysis was rather preliminary, such suggestions might be useful in the process of formulating the regional energy policy.

2.4. WASP Study for the Central Region of Russia

2.4.1. Background

This section briefly describes a WASP application for Russia. The present study was conducted by a team of Russian experts at the Interregional Training Course on Electric System

[1] Yu.F. Chernilin, V.P. Pakhomov, E.F. Zakharova, I.P. Ilyukhin, S.L. Kononov. Elaboration of the Strategy of Development for the Energy System of the St.-Petersburg's Region with the Use of the ENPEP Package. Report of RRC "Kurchatov Institute", No. 38-191, 1993.

Expansion Planning held at ANL, from 20 September to 12 November 1993[1].

The objectives of the WASP study were the following:

1. To analyse the optimal expansion of the electric system at the regional level,
2. To compare the results of the study with the approaches and outcomes of the current Russian electricity programme in respect to the development of the regional energy system; and if possible, to determine the major sources of differences.
3. To assess the possible role of nuclear energy in the region under study.
4. To identify typical problems that may be important for future WASP applications in Russia.
5. To formulate relevant recommendations for potential users of WASP in the country.

The object of the study was the central region of Russia. This is a large region (about 40 million inhabitants) which is situated in the center of the European part of Russia, and includes Moscow. This region is very industrialized and, as far as the electricity system is concerned, has a large and well developed supply system with an installed capacity of about 50 GWe, representing 1/4 of the total capacity in Russia. The supply system is controlled by a single organization, the so-called Central Power Pool. Plans for the development of the regional electricity system are included in the Russian electricity programme.

2.4.2. Approach to Modeling the Power System

The main analytical tool for the study was the WASP model. The training course during which the study was performed was based on the PC version of WASP known as the ELECTRIC module of ENPEP. The WASP version used during the course was a further enhancement developed recently by the IAEA. This new version, called WASP-III Plus, offers new possibilities for the user. One of the objectives of the training course was to get familiar with these new features for more comprehensive analysis of electricity systems.

For the WASP analysis, one should note the complexity of the power system under study, as Figure 2.9 illustrates. Almost 100 types of plants can be distinguished and they differ in their characteristics.

- The existing units differ, first of all, in their installed capacity. There is a very large range of unit capacities ranging from less than 5 MWe up to 1200 MWe (The 1200 MWe gas fired unit is the largest in the region and in Russia).
- Each plant represents a quite unique mixture of different units. Plants with identical units practically do not exist in the system.

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[1] The Russian team included the following experts:

- Mr. Vladimir S. Kagramanyan - Head of Laboratory of Fuel Cycle Economics, Institute of Physics and Power Engineering, Obninsk, Kaluga Region.
- Mr. Sergey L. Kononov - Senior Researcher, Russian Research Centre "Kurchatov Institute", Moscow.
- Mr. Alexander V. Shibanov - Head of the Department of Innovative Technologies, Main Computing Centre of the Ministry of Fuel and Energy of the Russian Federation, Moscow.

- Plants and units in the actual system also differ by the type of fuel used. The regional electricity system uses gas, fuel oil and several coal types, either of regional origin or imported. In total, there are more than 10 different fuel types in the system, which imposed the need to make some fuel aggregations for the WASP application.
- Units in the system also differ in respect to their technical condition. A large part of the equipment is rather out-of-date. Older units might need to be replaced by new ones or rehabilitated to extend their lifetime. Such activities, which are already in progress or are planned for the near future, should be taken into account when defining the data for WASP.
- Another characteristic of the present energy system is the large share of co-generation units. As it is shown in Fig. 2.9, the installed capacity of co-generation units amounts to 40% of the total installed capacity. Although WASP does not have the means to represent the co-generation process explicitly, there are some ways to simulate co-generation indirectly.

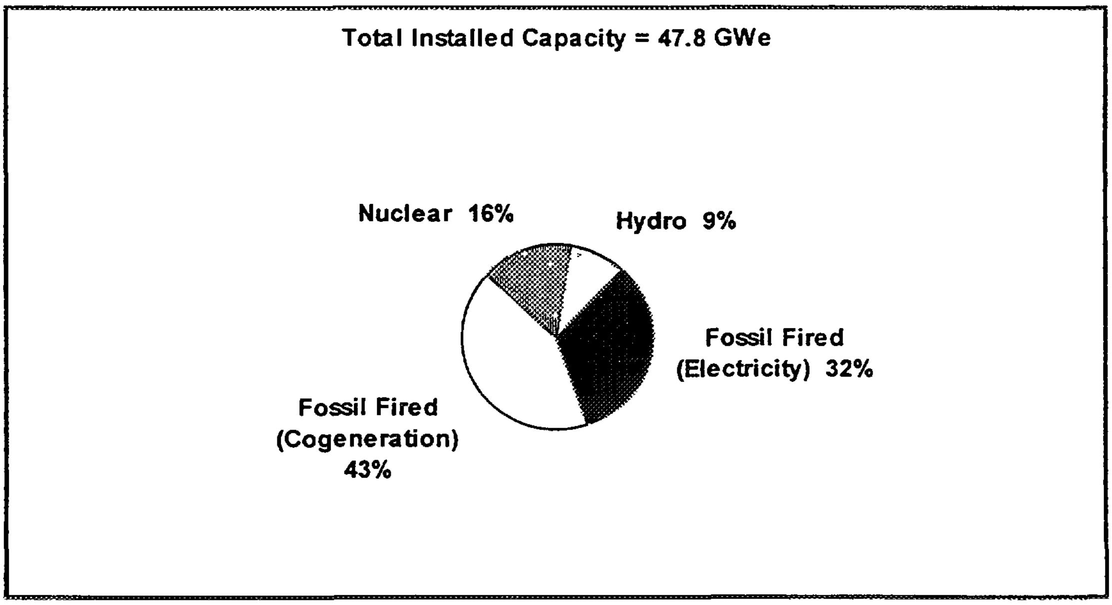

Fig. 2.9. Structure of the Regional Electricity System in 1991

The main problems for modeling the system with WASP are the following:

i) The actual variety of power generating units must be restructured into a scheme suitable for WASP.
ii) Fuel aggregations need to be introduced.
iii) Plausible schedules for unit retirements as well as committed additions to the system capacity must be included into the model.
iv) Since the share of co-generation units is rather large, this type of facility should be represented in the expansion plan, and the accuracy of this representation should be verified.

The following solutions for these problems have been used in the study.

i) Problem of Unit/Plant Aggregation

The key question is how to represent the actual diversity of units in WASP. There are plants of various types in the system: fossil fired units for generation and co-generation, nuclear units, hydro plants. Each plant is unique since plants with a combination of identical units are seldom.

To describe such system in WASP, similar units are grouped into a fictitious plant which is then representative of the identical units. Some accuracy is lost in this process, but it is a reasonable way of reducing the dimension of the problem. Consequently, all power generating units are split into four major groups:

- Fossil fired condensing units;
- Fossil fired cogeneration units;
- Nuclear units;
- Hydro power units.

Except for hydro, each group consists of a number of fictitious plants composed of units similar in respect to their capacity and to the fuel used. For example, fossil fired condensing units consist of the following groups:

K-1200 / Gas. This group includes the single existing 1200 MWe gas fired unit. As it is indicated in Table 2.1, this unit is located at Kostromskaya Power Plant in the Kostroma province. K-1200 stands for the K-1200-240 type of turbine.

K-800 / Gas. This group includes two units of the K-800-240 type. Both units are located at the Ryazanskaya plant in the Ryazan province.

Other sub-groups are presented in Table 2.1.

ii) Problem of Fuel Aggregation

The next important issue is the level of fuel aggregation. The actual system uses gas imported from West Siberia, fuel oil (either imported or refined in the region) and several types of coal. To model this complex system of fuel supply the following types of fuel have been introduced in WASP:

Two types of coal: Coal type 1 is the aggregated coal including all coals used in the actual system. In addition, a special category of coal for new plants has been introduced as a convenient way to calculate what additions in coal consumption can be expected in the future.

Three types of gas: Similarly, several categories of gas were created with the same objective: gas for existing combustion plants; gas for gas turbines; and gas for new combustion plants. In reality, gas and coal fired units use a small quantity of fuel oil for technical reasons. Since WASP does not allow to define a plant with two fuel types, the corresponding consumption of fuel oil is implicitly included into the relevant gas and oil categories. The resulting error is not significant as the consumption of fuel oil in the system is only about 10% of the total consumption of fossil fuels. This simplification should however be noted.

Table 2.1. Base Year Configuration of the Existing (Fixed) System for Fossil Fired Condensing Units

Plant Abbr.	Plant (Equipment) Type	Number of Units	Plant Name (Location)	Installed Capacity:		Unit Characteristics	
				MW(e)	% of Total	Installed Capacity MW(e)	Average Fuel Consumption gce/kWh
KG0F	K-1200 / Gas	1	1.Kostromskaya PP (Kostroma) - 1	1200	7.9	1200	312.2
KG1F	K-800 / Gas	2	1.Ryazanskaya PP (Ryuzanh) - 2	1600	10.5	800	323.5
KC3F	K-300 / Coal	7	1.Ryazanskaya PP (Ryuzanh) - 4 .Cherepetskaya PP (Tula) - 3	2100	13.8	300	371.0
KG3F	K-300 / Gas	22	1.Konakovskaya PP (Tverh) - 8 2.Kostromskaya PP (Kostroma) - 8 3.Kashirskaya PP (Moscow) - 6	6600	43.3	300	324.6
KC4F	K200 / Coal	3	1.Cherepovetskaya PP (Vologda) - 3	600	3.9	200	393.5
KG4F	K200 / Gas	7	1.Shaturskaya PP (Moscow) - 5 2.Schekinskaya PP (Tula) - 2	1415	9.3	205	381.9
KC5F	K150 / Coal	4	1.Cherepetskaya PP (Tula) - 4	600	3.9	150	404.8
KG6F	Other / Gas	10[1)]	...	440	2.9	44	376.9
KG7F	K-325 / Gas	0[2)]	...	0	0	325	320.0
GTUF	GT100 / Oil	7	1.GRES-3 PP (Moscow) - 4 2.Ivanovskaya PP (Ivanovo) - 3	700	4.6	100	572.6
	TOTAL	63	-	15255	100	-	-

Notes:

1) The number of units is fictitious and was introduced to diminish the dimension of the problem; the actual number of units is much greater.
2) No facility exists in this group at the beginning of the study period; however, there are some committed additions in the future.

One type of fuel oil: Only one category of fuel oil is introduced. Actually, only fuel oil for gas turbines is assumed to be in this category. As mentioned above, the use of fuel oil in other facilities is implicitly included into the relevant gas and coal categories.

Three types of nuclear fuel: There are three types of nuclear reactors in the system: two types of Pressurized Water Reactors, and one type of Light Water Graphite Reactors or RBMK in Russian (Chernobyl type reactor). Separate categories of nuclear fuels have been introduced since the fuel for these reactors differs significantly in terms of enrichment and, consequently, in cost.

The fuel disaggregation applied is more or less detailed. The possibility to use up to ten fuel types is a new feature of WASP introduced in the latest version WASP-III Plus. This new feature is a useful enhancement for modeling complex energy systems such as the one under consideration.

iii) Problem of Modeling the Planned Additions/Retirements

To model the differences in technical condition of the units, a plausible schedule of planned retirements was developed. Furthermore, some fixed additions to the power system were introduced to represent the processes of retrofitting and the start of operation of the units that are almost completed and that should consequently not to be included in the system optimization. The co-generation part of the power system is also considered as fixed (decided) and thus excluded from the optimization process.

iv) Problem of Modeling Co-generation

Another important issue that required a special approach for the WASP study was co-generation. Co-generation is an important feature of the Russian energy sector in general and, specifically of the regional system under consideration. Unfortunately, WASP does not consider the process of combined heat and electricity generation. This is, actually, one of the major constraints for WASP applications in the country. However, simulation of co-generation is possible in WASP. The following approach has been applied in this study:

1. Like usual condensing units, co-generation units have been grouped according to the unit capacity and fuel type as described above.

2. Each type of co-generation unit is described by the same type of WASP data as for the condensing units. However, only the shares of fuel and cost allocated for electricity generation are taken into consideration. These shares are determined according to the so-called "physical" method officially accepted in the country.

3. In some periods, co-generation units operate like the condensing ones. This usually happens in summer when the heat demand drops. In this case, the characteristics of the co-generation units differ from those of the normal co-generation regime. Most important is that the specific fuel consumption is higher. To model this effect, some co-generation plants have been split into two fictitious plants - one for modeling the condensing regime and the second for modeling the co-generation regime. All the parameters of the plants have been calculated to ensure that the energy outputs of these units are close to the figures available for the base year (1991).

4. The development of the co-generation system cannot be modeled as part of the WASP optimization procedure because this development is driven by the heat demand. The only possibility to account for the part of the electricity demand taken by co-generation units is to define the co-generation part of the energy system as a sub-system with a predetermined plan of development. This plan was taken from the current Russian energy programme. The plan assumes a growth in the co-generation which might be actually the case actually the case.

As a result of this approach, the share of co-generation in the system and its development are simulated and, accordingly, the share of the electricity demand to be covered by co-generation units is determined and excluded from the total demand. This allows to carry out the WASP optimization process for only condensing power generation facilities, in accordance with the requirements of the WASP model. However, the exclusion of co-generation from the optimization is, objectively, a significant drawback which calls for a detailed separate analysis.

2.4.3. Development and Implications of the Optimal Expansion Plan

The first outcome of the optimization procedure is the determination of the optimal expansion plan under the most plausible (or least arbitrary) assumptions on the values of key parameters. This reference expansion plan serves two major functions:

1. It allows for the analysis of the optimal solution. Such issues as the optimal technology mix, fuel substitution trends, electric system reliability and others can be thoroughly investigated.
2. The reference optimal expansion plan is the base for the sensitivity analysis which is to provide a feeling of the impacts of uncertainties on the plan.

When developing the reference expansion plan several important assumptions have been used. The first assumption is the price system used. As it was mentioned, the prices of 1991 are used throughout the whole study. It includes fuel prices that existed in 1991. An important point here is that in 1992 the country began the transition to the market economy. This process was accompanied by rapid changes in the price system, including prices of energy resources. For the sake of data consistency, these changes were disregarded during the development of the reference optimal expansion plan and no price escalation factors from the 1991 reference values were accounted for in the reference optimal solution.

In addition to this simplification, no technical or fuel constraints are imposed upon the system. The system can select whichever technology from all the candidates described above and in any quantity.

This is quite a straightforward approach to the reference plan and, accordingly, the plan must be straightforward and easy to interpret. All possible complications have been left for the sensitivity analysis.

The detailed characteristics of the optimal expansion plan are given in the Final Report of the study[1]. Actually, this reference optimal expansion plan turned out to be quite simple and easy to interpret. As the prices of fuels are constant and there are no limitations on technologies or fuel availability, the key driving parameter of the plan is the ratio of fuel prices. The assumed ratio of the gas to coal prices is in this case 0.84 (gas is 15% cheaper) and, consequently, the program has to include only gas fired power plants into the optimal solution.

[1] V.S. Kagramanyan, S.L. Kononov, A.V. Shibanov. Final Report on the Russian Team Study. ANL/IAEA Interregional Training Course on Electric Systems Expansion Planning. Argonne National Laboratory, Argonne, Illinois, USA, 20 September - 12 November 1993.

Of course, the program did that. As one can see in the illustration of the expansion plan in Fig. 2.10, only additions of gas fired facilities from the variable system are included in the plan. Accordingly, the share of gas in the system grows substantially.

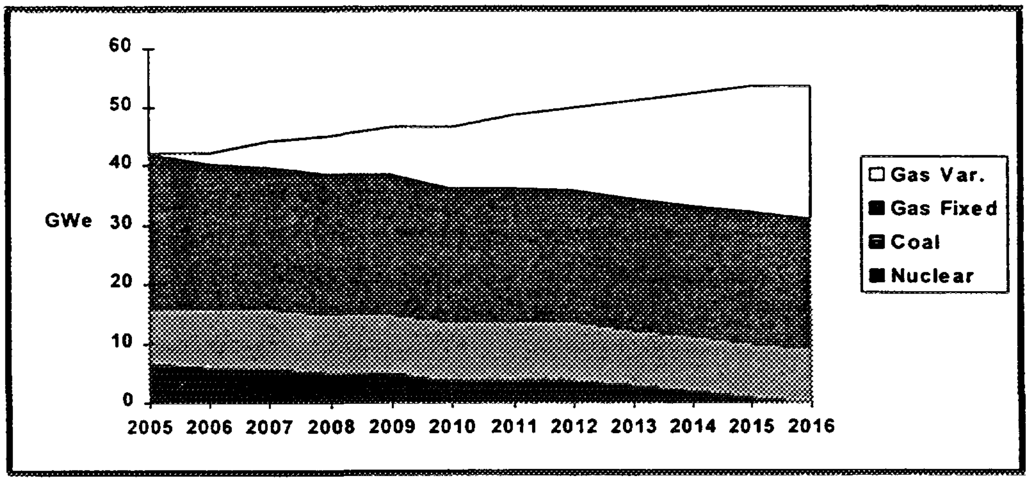

Fig. 2.10. The Structure of the Reference Optimal Capacity Expansion Plan

Actually, the situation is a little more complex. There are five competing gas technologies in the system: two conventional units of different capacity, two types of combined cycle units and gas turbines. They have different status of development and, accordingly, they were allowed to begin entering the system at different times. A more detailed outlook of the optimal evolution of the system looks as shown in Fig. 2.11.

This is the outlook of the optimal solution for the system under consideration. This solution is quite straightforward and easy to interpret but, due to its simplicity, it may be not too realistic. To establish where and how the reality may influence the results the sensitivity analysis was applied for the system.

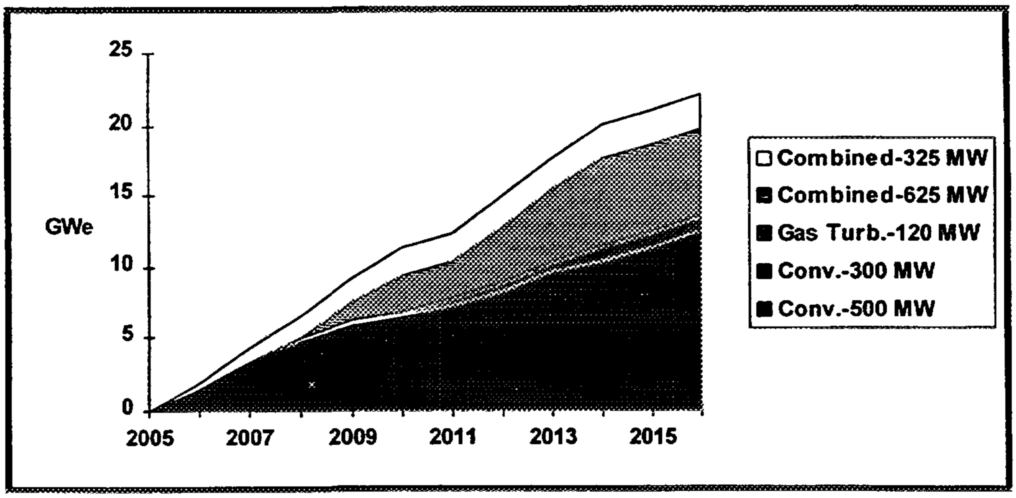

Fig. 2.11. Optimal Structure of Variable System

2.4.4. Sensitivity Analysis

- *Sensitivity to Gas Availability*

What is wrong about the given simple expansion plan is, first of all, that the program selects as much gas as it wants. This may be not realistic for at least two reasons. To begin with, there may be not enough gas available for this purpose. In addition, there may be technological constraints (the industry may not be able to produce so many gas fired units of such a large size).

The first sensitivity case aimed at assessing the impact of such constraints on the optimal solution. To make such an assessment the shares of gas fired technologies were fixed at lower levels than in the optimum. These levels were roughly set corresponding to the probable availability of gas. The result, shown in Fig. 2.12, indicates that some coal fired units are included in the new optimal solution. Of course, the value of the objective function increased in this case - this is the cost of the gas unavailability.

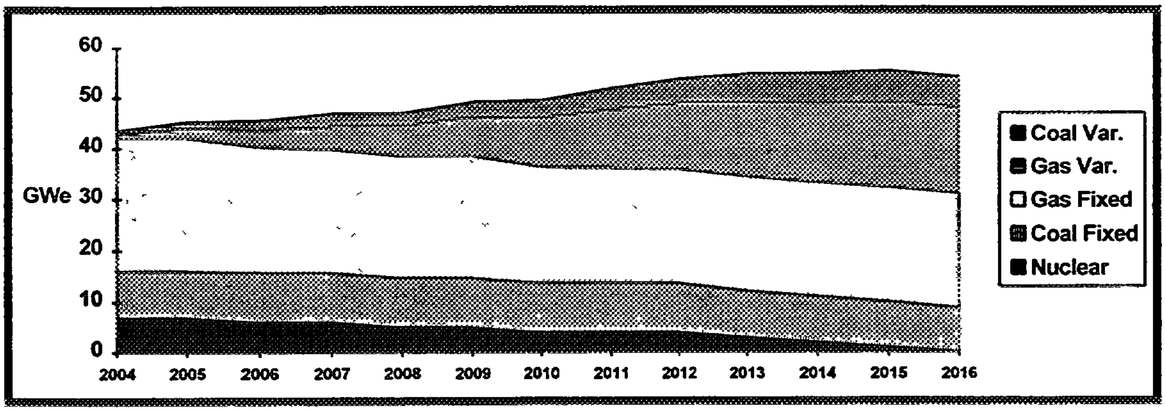

Fig. 2.12. System Sensitivity to Gas Availability

- *Sensitivity to Gas/Coal Price Ratio*

With the transition to the market economy the prices of energy resources are gradually taken out of the state direct control. In due course it may allow for real market prices on energy resources to get established. This may change the existing structure of prices and, consequently, influence the optimal configuration of the electricity system.

In addition, the prices of energy resources may change in the future as the result of growing extraction costs. Although Russia is potentially rich in energy resources, most of the available deposits are to a large extent exhausted. Keeping the level of extraction constant or increasing it can lead to a growth in fuel prices, with different rates of growth for different fuels.

To assess the possible consequences of the escalation of fuel prices, a case has been calculated with a escalation rate of 2% for gas and constant price of coal. The resulting change in the optimum structure of the system is shown in Fig. 2.13. As it is illustrated in this figure, the price escalation can change the system configuration. In this particular case, the system begins to select coal fired candidates instead of gas fired technologies. However, this result was obtained by allowing coal power plants to be the only competitor to gas. However, in reality, there is another technology that can compete with gas, namely nuclear power.

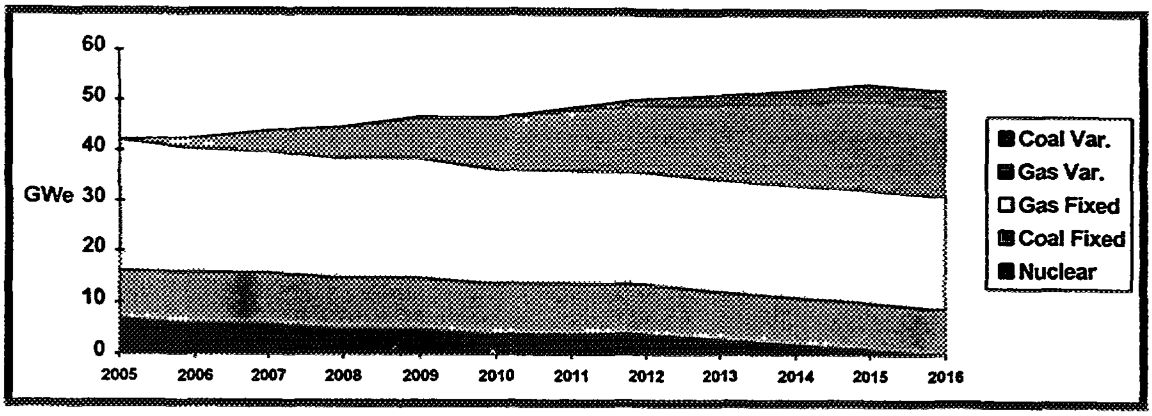

Fig. 2.13. System Sensitivity to Gas Price Escalation

- *Sensitivity to the Availability of Nuclear Power*

Currently, the share of nuclear power in the region is 16% of the total installed capacity. Until recently, the development of nuclear power was considered as the major road for the electricity system. However, after the Chernobyl accident, the plans for nuclear power were reconsidered. Several constructions were canceled and only fossil fired plants are considered as candidates for expansion in the future.

Still, the trend away from nuclear energy has also brought some problems. One of them is fuel supply. As the growth in fuel demand due to the cancellation of some nuclear projects was not expected in the past, difficulties appeared both in increasing the extraction levels and in the fuel transportation from Siberia to the European part of Russia. These difficulties already result in occasional fuel shortages. If the demand for fossil fuels grows further, the problem may become more serious. In addition, there are growing environmental concerns about the expansion of the use of fossil fuels, especially coal.

At the same time, the development of nuclear power has essential advantages, provided that nuclear safety is ensured. The country has its own technological and fuel base for further nuclear power development, as well as qualified personnel available.

Actually, as the difficulties in relying on fossil fuels are being realized by the local authorities, the attitude towards nuclear power is changing. Although it is too early to forecast some substantial growth, nuclear power remains a viable choice, especially for the European part of Russia, including the Central Region which is under consideration in this study. That is why the role of nuclear power is among the sensitivities to be investigated.

For this sensitivity study, it was assumed that there is a 2% escalation in the cost of gas and only nuclear units can compete with the gas fired units. The result (see Fig. 2.14) is that nuclear power is added to the system in 2006 and its penetration into the electricity sector continues thereafter (at the end of the planning period there are six 1000 MWe nuclear units in the system). This clearly shows to what extent the prognoses of the fuel price escalation are vital for decisions to be taken concerning the energy sector.

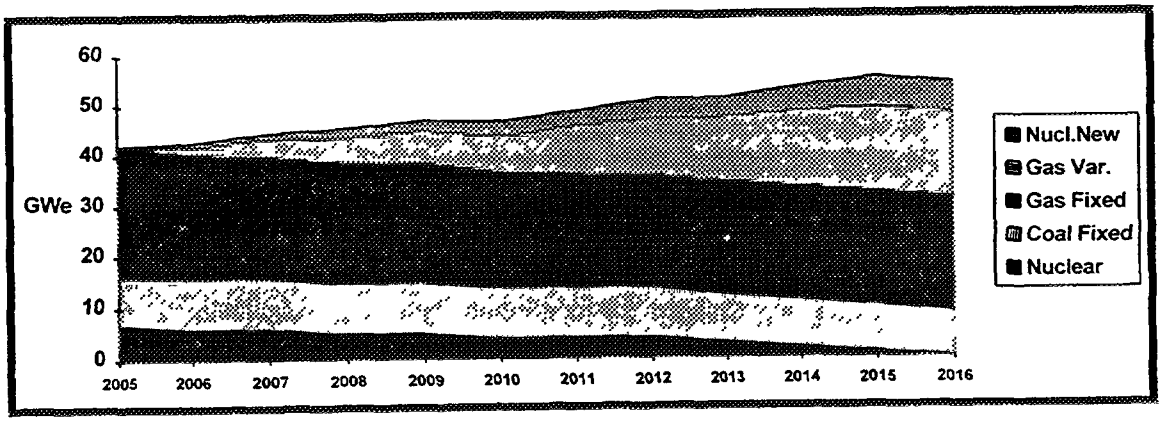

Fig 2.14. System Sensitivity to the Availability of Nuclear Power

2.4.5. Results and Conclusions

One can summarize the outcomes of the WASP Study as follows:

1. The study conducted has shown that the WASP model allows for the simulation of complex electricity systems on a sound methodological basis. This was shown by the example of the WASP application for the regional electricity system of the Central Region of Russia (Central Power Pool).
2. Although WASP is a one-product model, due attention was given to the representation of co-generation processes in the study. An approach for representing co-generation was applied and tested.
3. The major outcome of the WASP model - the optimal expansion plan for the regional electricity system was determined and thoroughly analyzed; the sensitivity of this plan to a number of the most critical uncertainties was calculated.

On the basis of the study some recommendations have been developed:

1. The major outcome of the WASP application for the region is that the price projections for fossil fuels is the key driving parameter for the system development. The elaboration of such prognoses both at the regional and national levels is an urgent task.
2. Among the strategies investigated, the development based on gas was found to be the most economically attractive for the region. However, this result was found under a set of assumptions, with the price structure of 1991 being the most important of them. The change in fuel price hypotheses can essentially change the optimal strategy of development.

3. The determination of the optimal expansion plan with the WASP model is a very serious planning exercise. To ensure that the efforts in developing the optimal plan are not useless it is important to have a relevant information database in the country that could help the planners keep the planning process moving and develop consistent and sound approaches, including further application of WASP.

Concerning future applications of WASP in Russia, it was noted that the WASP model seems to be a powerful and useful tool for the energy analysis. It allows to determine and analyze the optimal strategy of development for a power generating system on a sound methodological basis. However, applications of WASP in the country should take into account the following circumstances:

- WASP offers some possibilities for a dis-aggregated consideration of an energy system. However, these possibilities are rather limited as compared with the specific Russian conditions. This is why it is more promising to apply WASP for the problems of regional scale than for the analysis of the country as a whole.
- WASP considers electricity as the only product of generation; heat is not accounted for in the WASP model directly. So, the co-generation part of the electricity generation must be considered outside the model and then results must be transferred to WASP.
- For those Russian regions where the share of hydro is high, the use of WASP should be complemented by the use of other models considering hydro energy in a more accurate manner than in WASP.

3. SOME SUGGESTIONS ON FURTHER APPLICATIONS OF ENPEP IN RUSSIA

As discussed previously, experience of ENPEP applications in Russia has been accumulated. The BALANCE model was applied for Far East and St.-Petersburg regions. The ELECTRIC (WASP-III Plus) model was used for the analysis of the optimal expansion of the Center Power Pool electric system. These studies have proven that the ENPEP package is appropriate for Russia at the regional level.

Further ENPEP applications in Russia will focus on the following areas:

- Application of ENPEP at the national level. Plans are underway to use the BALANCE model for the whole Russian energy sector.
- Up to now, ENPEP was used only by research institutes such as the RRC "Kurchatov Institute" (Moscow) or the SSC IPPE (Obninsk). The next step will be to have energy companies use this tool.
- For some reasons the IMPACTS model is not applicable to Russia. Great hopes are on the DECADES tools for environmental studies.
- The ENPEP applications in Russia have shown the advantages of this software package. However, further developments of the model are recommended, in particular, the introduction of a more user-friendly interface.

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DEVELOPMENT OF A REGIONAL CAPACITY EXPANSION PLAN IN THE RUSSIAN FEDERATION

Application of the WASP Model

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Abstract

The Wien Automatic System Planning Package (WASP) is used for the development of optimal capacity expansion plans in Russia. The object of the WASP study is the Central power pool, which is the largest power pool in Russia and has an essential share of nuclear power in electricity generation. The objective of the study is to assess the long-term competitiveness of nuclear power in the region. The major features of the power system analysed with WASP are the following: 1) four types of electricity generators are considered: condensing fossil fuel plants, cogeneration fossil fuel plants, nuclear power plants and hydraulic plants; 2) nine fuel categories are considered: gas/fuel oil fuel, several types of coal and several nuclear fuels; 3) escalation of capital, operation and maintenance, and fuel costs as a result of economic transition is explicitly modeled. Under these assumptions, a regional optimal capacity expansion plan is developed that showed the following: (a) Until 2004 there is no need for new electricity generation capacities due to the drop in demand in the 90s, certain lifetime margin of existing capacities, committed additions of co-generators and planned refurbishment/repowering measures; (b) The structure of the optimal capacity mix confirms that nuclear power can retain its role as one of the major electricity generation sources in the region. The most important factor with a positive effect upon the competitiveness of nuclear power plants is the projected escalation of the prices of fossil fuels; (c) The application of WASP has proved that the model can serve as a valuable planning tool at the power pool level in Russia.

1. INTRODUCTION AND BACKGROUND

During the current period of economic transition in Russia, the elaboration of a sound capacity expansion strategy for the power sector is an important requirement due to the long-term character of development in this sector and the large financial investments required. It is especially important for the nuclear component of the power sector which is one of the major electricity sources in Russia but is undergoing a deep crisis because of the general economic crisis and as a consequence of the Chernobyl accident.

In the process of developing such a strategy, it is highly desirable to utilize a sound methodology allowing to properly incorporate the related technical, economic, and environmental issues into the capacity expansion plan and thus provide sound information to decision-makers. In this respect, the use of energy planning tools supported and distributed by the International Atomic Energy Agency (IAEA) that are widely used for energy planning purposes in many countries can become a valuable input to the process of the preparation of the strategy and, as a complement to other national studies, can provide important information for making decisions on further development of nuclear power in Russia.

This report highlights some of the activities undertaken in the course of a two-year research project aimed at the assessment of the long-term role of nuclear power in Russia with the use of IAEA's planning models. The project is undertaken under a research contract with the International Atomic Energy Agency, IAEA Contract No.7710/RB, with Mr. Yu.F. Chernilin, Head, Department of Nuclear Power Economics and Planning of the Institute of Nuclear Reactors of the Russian Research Centre "Kurchatov Institute", acting as the Chief Scientific Investigator. This is part of the country studies in the framework of the inter-agency joint project on data bases and methodologies for comparative assessment of different energy sources for electricity generation (DECADES) initiated by the IAEA.

Several IAEA planning tools were applied in the course of the project. They included some modules of the ENPEP[1] package, the Wien Automatic Planning Package[2] (WASP) being one of them, and the DECADES[3] database system. However, this report concentrates only on the application of the WASP model, which was the most important part of the project. The latest version of WASP (WASP-III Plus[4]) was used.

As the object of the WASP application, a power pool serving a large territory in the center of Russia is selected. This power pool, which is called the Central Power Pool (CPP), is the largest component of the integrated power system of Russia that includes seven such pools. The installed capacity of the CPP is around 50 GW or about 1/4 of the total electricity generation capacity in Russia. Most of the electric load is concentrated in the region itself; the share of power exports is only about 5% of the load. The objective of the WASP study was to implement an analysis of the whole regional power system for assessing the long-term competitiveness of nuclear power in the region.

The region covered by the CPP has an area of approximately 2 million km^2 (about 12% of Russia), while the population (about 50 million) amounts to 1/3 of the total population of the country (the location of the region is illustrated in Fig. 1). This is an industrial region, the share of industry in the total gross product of the region being about 60%.

2. APPROACH TO MODELING THE POWER SYSTEM

In 1993, the installed capacity of the Central Power Pool was about 56 GW [5]. There are more than 80 power plants in the system. They include condensing and cogeneration plants using fossil fuels, nuclear power plants and hydraulic plants including one pumped-storage plant near the town of Zagorsk in the Moscow province (Fig. 2). The dominating energy source for electricity generation is natural gas, but as illustrated in Fig. 2, nuclear power is an essential part of the system. In 1993, nuclear power plants produced 23.9% of the total electricity generated in the pool [6]. To successfully model this system with WASP the following issues have been considered in the study.

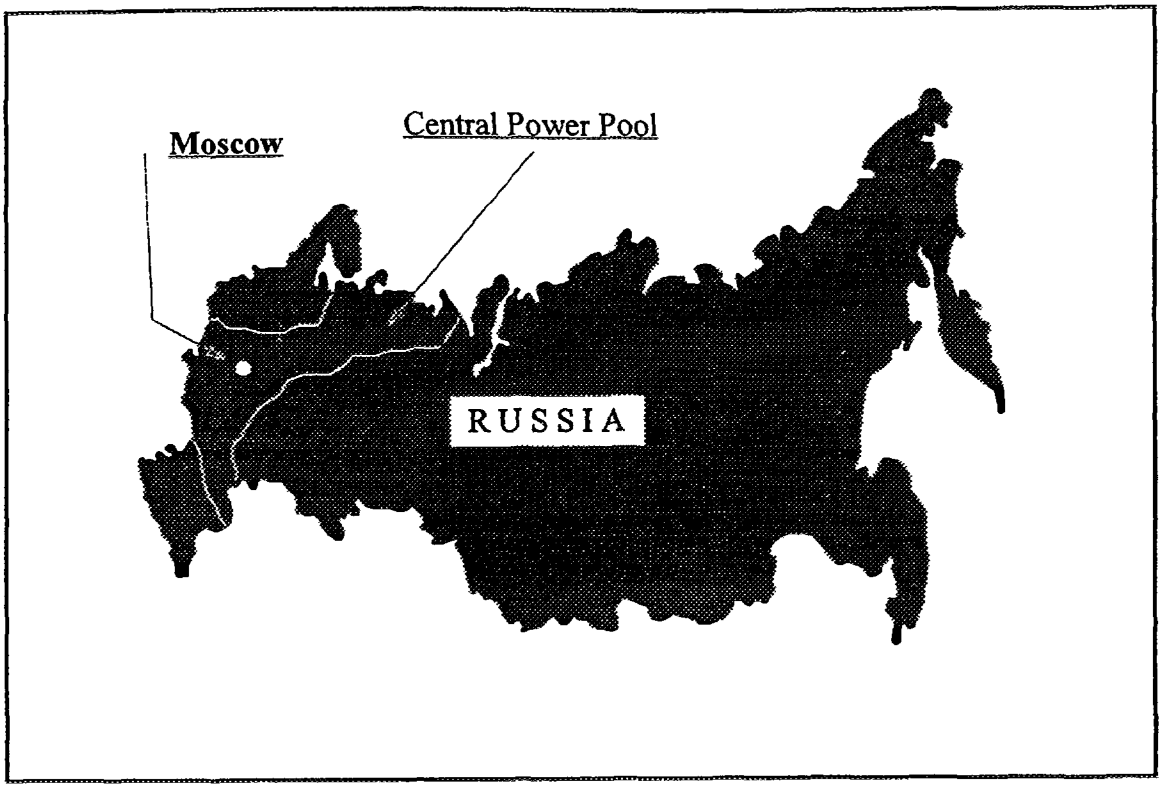


Fig. 1. Location of the Territory of the Central Power Pool

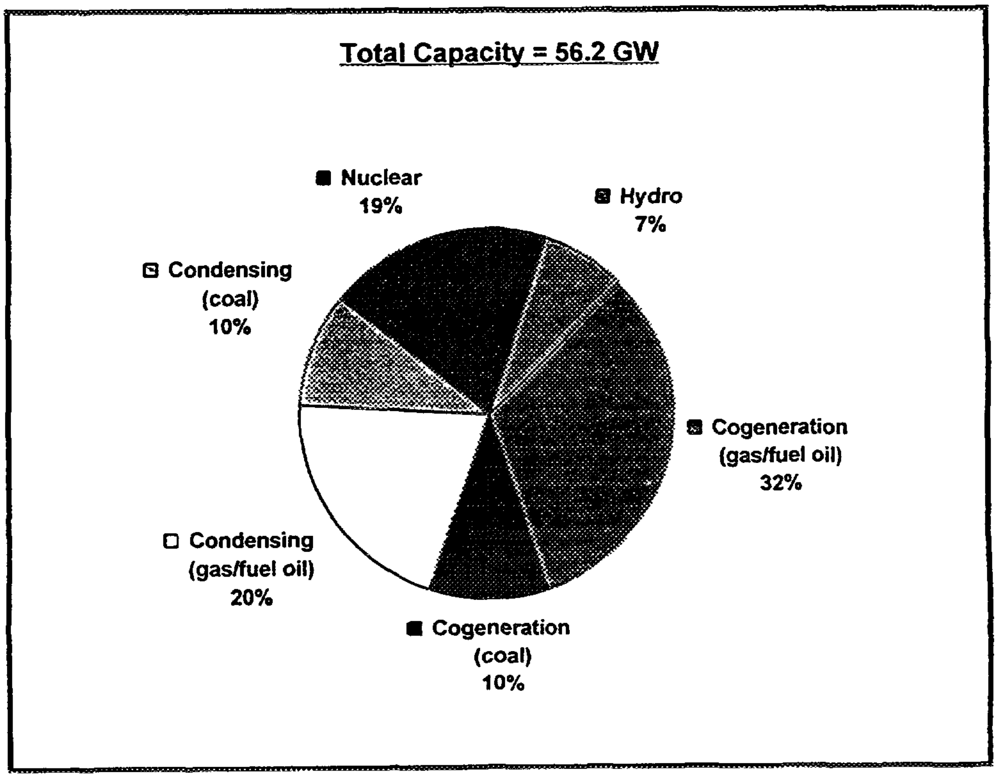


Fig. 2. Breakdown of Capacities by Type and Fuel (1993 Data)

1) Representation of unit diversity

There are plants of various types in the system: fossil fired units for generation and cogeneration, nuclear units, hydro plants. Within each of these categories, there are units widely differing in size (capacity), heat rate and other technical and economic parameters. To describe this system in the WASP format, groups of identical units are selected from all actual plants and combined into some representative groups of equivalent plants that could be also called "fictitious plants".

Each fictitious plant includes the units that 1) are identical or close in parameters (unit type, capacity, technical characteristics) and 2) use the same fuel. As a result, all power generating units are split into four groups as shown in Tables I to IV: condensing fossil fuel plants (Table I); cogeneration fossil fuel plants (Table II); nuclear power plants (Table III) and hydroelectric powei plants (Table IV).

Table I. Representation of Condensing Fossil Fuel Plants

WASP Name	Type of Unit and Fuel Used	Number of Units	Available Capacity		Representative Characteristics (1990-1991)	
			MWe	% of total	Heat Rate, gce/kWh	Capacity Factor, %
KG0F	K-1200 (gas/fuel oil)	1	1200	7	314.1	75.5
KG1F	K-800 (gas/fuel oil)	2	1600	9	323.5	73.5
KG3F	K-300 (gas/fuel oil)	19	5700	33	325.9	68.9
MGDF	MGD-310 (gas)	1	310	2	323.5	68.9
KG4F	K200 (gas/fuel oil)	9	1880	11	346.4	64.8
GTUF	GTU100 (gas turbine fuel)	7	778	5	572.6	6.7
TOTAL	Total for Plants on Gas/Fuel Oil	39	11468	67	-	-
KC3F	K-300 (Kuznetsky Coal)	6	1800	10	369.3	62.5
KM3F	K-300 (Moscow Coal)	4	1120	7	366.2	57.9
KM4F	K-200 (Moscow Coal)	3	600	3	411.2	53.5
KI4F	K200 (Intinsky Coal)	6	1230	7	377.6	63.8
KC5F	K150 (Kuznetsky Coal)	4	525	3	404.8	75.2
KL6F	Other (Local Coals)	-	418	2	406.7	57.6
TOTAL	Total for Plants on Solid Fuels	-	5693	33	-	-
TOTAL	Total for All Condensing Plants	-	17161	100	-	-

Table II. Representation of Cogeneration Fossil Fuel Plants

WASP Name	Type of Unit and Fuel Used	Number of Units	Available Capacity		Representative Characteristics (assessment)	
			MWe	% of total	Heat Rate, gce/kWh	Capacity Factor, %
TG__	Gas-Fired Cogeneration Plants	-	18302	76	240 (el.) 470 (el.+heat)	70
TÑ__	Cogeneration Plants on Kuznetsk Coal	-	2300	9	255 (el.) 505 (el.+heat)	65
TL__	Cogeneration Plants on Other Coals	-	3600	15	265 (el.) 515 (el.+heat)	65
TOTAL	All Plants	-	24186	100	-	-

Table III. Representation of Nuclear Power Plants

WASP Name	Type of Unit	Number of Units	Available Capacity		Representative Characteristics (1991-1993)	
			MWe	% of total	Heat Rate gce/kWh	Capacity Factor, %
RBMK	RBMK-1000	7	7000	65	425.2	71.3
V320	VVER-1000	3	3000	27	382.8	67.2
V230	VVER-440	2	834	8	419.4	62.6
TOTAL	All NPPs	12	10834	100	-	-

Table IV. Representation of Hydraulic Power Plants

Name in WASP	Unit Location (Plant Denomination and Location in Russia)	River	Installed Capacity MWe	Available Capacity		Representative Characteristics (1991)	
				MWe	% of total	Available Generation TWh/year	Capacity Factor,%
NIZH	Nizhegorodskaya HPP (Nizhny Novgorod)	Volga	520	485	11	2.123	46.6
RYBU	Rybinskaya HPP (Yaroslavl province) + Uglichskaya HPP (Yaroslavl province)	Volga	440	370	9	1.823	47.3
VOLZ	Volzhskaya NPP-1(22) (Volgograd)	Volga	2541	2426	57	12.950	58.2
ZAG0	Zagorskaya PSP (Moscow province)	-	800	774	18	0.672	9.6
AGGR	Other (Small) Plants	-	187	187	4.2	0.158	9.6
	TOTAL	-	4488	4242	100	-	-

To model differences in the technical condition of the units, some plausible schedule of planned retirements is developed on the basis of the current equipment status and retirement plans [7,9]. Furthermore, some fixed additions to the power system are included to represent the processes of refurbishment/repowering of existing units and the starting of operation of the units that are almost completed and thus are not subject to the system optimization [7,9]. The cogeneration part of the power system is also modeled as fixed and thus excluded from optimization (see below).

2) Representation of fuel diversity

The Russian power sector and, specifically, the Central Power Pool uses a large number of energy fuels. They include natural gas, fuel oil, several types of coal differing in physical characteristics and costs and several nuclear fuels. Especially diverse is the supply of coal. In addition to coals from the main national deposits such as the Kuznetsk basin and the Kansk-Achinsk basin, there are significant amounts of coal from regional deposits such as the Moscow basin and the Pechora basin, as well as a number of coals produced and consumed locally. Another important feature is that fuel oil is used almost exclusively as a second fuel (for technical reasons such as boiler start-up and as a reserve fuel). Thus, there are no plants using fuel oil as the dominant fuel.

Taking into account these considerations, for modeling purposes the fuels consumed in the Central Power Pool are broken down into several representative categories. The principle of disaggregation is to explicitly represent the types of coal that are mostly used and to combine the types less frequently used into some fictitious categories. Also, it is decided to combine natural gas and fuel oil into one fuel denominated as "Gas/Fuel Oil". (Currently, the share of fuel oil in this fuel is of the order of 10% and it is expected to further decline in the future.) For nuclear fuels, explicit representation of the most typical types is used because of the importance of nuclear power in the region and the emphasis on nuclear power in the study. The resulting fuel breakdown and some representative parameters of the fuels are shown in Tables V to VII.

Table V. Characteristics of the Fossil Fuels Used [8]

WASP No.	Fuel and its Denomination in WASP	Contents of, wt% of fuel			Low Heating Value		
		Ash	C	S	MJ/kg	kcal/kg	CE[a]
0	Gas/Fuel Oil (GM):						
	natural gas[b]	-	75.0	-	34.4	8224	1.17
	fuel oil[c]	0.13	84.7	3.0	39.9	9536	1.36
2	Kuznetsk Coal (KUZN)[d]	14.7	68.4	0.3	25.8	6160	0.88
3	Moscow Coal (MOSC)	28.0	39.6	3.0	10.4	2490	0.36
4	Intinsk Coal (INTA)	25.7	53.8	2.7	18.3	4370	0.62
5	Kansk-Achinsk Coal (K-AC)[e]	6.8	50.3	0.2	15.7	3740	0.53

[a] CE=Coal Equivalent defined as the heat content of the fuel divided by 7000 kcal/kg.
[b] Gas from the Tyumen region is taken as representative.
[c] Fuel Oil M-100 from the Moscow Refinery is taken as representative.
[d] Coal of the CC type is taken as representative.
[e] Borodinsky Coal is taken as representative.

Table VI. Characteristics of the Nuclear Fuels Used [9]

WASP No.	NPP Type and Fuel Denomination in WASP	Fuel Type	Enrichment, wt% of U-235	Average Burnup, GW·day/t of U
8	RBMK-1000 (NUCR)	UO_2	2.4	21
7	VVER-440 and NP-500 (NUCV)	UO_2	3.5	29 (VVER-440) 40 (NP-500)
9	VVER-1000 and NP-1000 (NUCN)	UO_2	4.4	40 (VVER-1000) 43 (NP-1000)

Table VII. Reference Cost Parameters of Fuels (end of 1994) [5]

WASP No.	Fuel and its Denomination in WASP	Cost in Physical Units	Cost in Energy Units, $/tce	Cost in WASP Units, ¢/mln kcal
0	Gas/Fuel Oil (GM):	35.1 $/1000 m³	30	429
2	Kuznetsk Coal (KUZN)	20.2 $/t	23	329
3	Moscow Coal (MOSC)	5.4 $/t	15	214
4	Intinsk Coal (INTA)	14.3 $/t	23	329
5	Kansk-Achinsk Coal (K-AC)	11.1 $/t	21	300
6	Local Coals (CLOC)	-	15	329
8	RBMK-1000 (NUCR)	3.8 mills/kWh	8.94	128
7	VVER-440	3.7 mills/kWh	8.82	126
	NP-500 (NUCV)	2.4 mills/kWh	6.50	93
9	VVER-1000	3.2 mills/kWh	8.36	119
	NP-1000 (NUCN)	2.8 mills/kWh	7.86	112

3. Modeling a large share of co-generation

Co-generation plants provide about 40% of the total electricity generation in the CPP. However, WASP does not have the means of representing the process of cogeneration explicitly. Instead, there are some indirect ways to simulate cogeneration. The following approach is applied in this study:

- Similar to usual condensing units, the co-generation units are grouped according to the unit capacity and fuel type as described above.
- Each co-generation unit is described in WASP data format exactly as the condensing units are. To reflect in the WASP results the actual fuel consumption of the plant for generation of both electricity and heat, the heat rate entered as WASP input includes the consumption of fuel for heat generation. Similarly, in order to show in the WASP results the total plant expenditures, all capital and O&M costs incorporate the expenditures associated with heat generation at the plant.
- The development of the co-generation system cannot be modeled as part of the WASP optimization procedure because this development is driven by the heat

demand and heat generation is not included in WASP. The only possibility to account for the part of the electricity demand taken by cogeneration units is to define the cogeneration part of the energy system as a sub-system with some predetermined plan of development. This plan was taken from the current plans of developing co-generation capacities [5,7].

As a result of this approach, the share of co-generation in the system and its development are simulated and, accordingly, the share of the electricity demand to be covered by cogeneration units is determined and excluded from the total demand. This allows to carry out the WASP optimization process for only condensing units, in accordance with the requirements of the WASP model. However, the exclusion of cogeneration from optimization is a significant drawback which calls for a detailed separate analysis.

4) Definition of expansion candidates

Generally, there is a large number of electricity generation technologies that can be considered as expansion candidates. They include gas-fired units (both traditional and combined-cycle units); coal fired units using various coals (Kuznetsk and Kansk-Achinsk coals are the predominant ones) and various technologies of combustion (pulverized coal units, fluidized bed combustion units); nuclear units of various design. Among the latter, two evolutionary projects are considered as most promising for the future: the NP-500 and the NP-1000 nuclear power plants. The list of potential expansion candidates and their major technical parameters are given in Table VIII. One can notice that hydrolectric power plants are not included in the list of candidates. The reason is that such projects are scarce and they need to be considered specifically for each project. The most promising of them are included into the future generation system as fixed (committed) capacities.

Table VIII. Technical Parameters of Expansion Candidates

WASP Name	Type of Unit & Fuel Used	Fuel Number in WASP	Operating Capacity (MWe)		Heat Rates (gross) gce/kWh (kcal/kWh)		Reliability Parameters	
			Minimum	Maximum	At minimum power	At maximum power	Forced Outage Rate, %	Planned Outages days/year
VGAS	K-300 [10] (gas/fuel oil)	0	200	300	329 (2303)	315 (2205)	5.6	40
VKAN	K-500/Pulverized [9] (Kansk-Achinsk coal)	5	430	500	329 (2303)	325 (2275)	6.6	46
VKUZ	K-300/Pulverized [9] (Kuznetsk coal)	2	260	300	329 (2303)	325 (2275)	6.6	46
VCLK	K-320 / AFBC [11] (Kuznetsk coal)	2	260	320	329 (2303)	325 (2275)	6.6	46
VN05	NP-500 [9,12] (nuclear fuel)	7	615	635	350 (2450)	350 (2450)	3.0	60
VN10	NP-1000 [9,11,12] (nuclear fuel)	9	1070	1100	335 (2345)	335 (2345)	3.0	60
VCCG	CC-360 [5,11] (gas/fuel oil)	0	250	360	266 (1862)	253 (1771)	5.6	40
VGTU	GTU-150 [7,vol.4] (gas turbine fuel)	0	150	150	411 (3080)	411 (3080)	2.2	21

5) Definition of basic economic parameters

The basic economic parameters of the expansion candidates are given in Table IX. There are two values for each economic parameter: one for 1994 (i.e., today) and the other one for 2010. It is assumed that capital and operational costs will escalate as a result of the market transition process, reaching by 2010 the level close to that in the developed countries. The specific assumptions about the escalation rates for capital costs are taken from the studies in support of the Joint U.S.-Russian Energy Alternatives Study [5], except for the projection of the costs of nuclear units in 2010. The latter is assessed in accordance with the data in [13]. (As projected in [5], specific capital costs for Russian nuclear units are assumed 10% lower than those of the U.S. nuclear units). As it can be assessed from the data in Table IX, the annual escalation rates for capital and operational costs are: for gas-fired units and gas turbines- about 2.5%/year; for coal-fired units - 3.4%/year; for nuclear units - 3.8%/year for NP-500 and 3.7%/year for NP-1000.

Table IX. Economic Parameters of Expansion Candidates (1994/2010)

WASP Name	Type of Unit & Fuel Used	Base Construction Cost (BCC) $/kWe (gross)	Interest During Construction*) (IDC), % of BCC	Total Construction Cost (BCC+IDC), $/kWe (gross)	Operation & Maintenance Costs	
					Fixed $ / kWe-month ($ / kWe-year)	Variable $ / MWh
VGAS	K-300 (gas/fuel oil)	550 -------- 820	29.9 -------- 29.9	715 -------- 1065	1.70 (20.4) -------- 2.53 (30.3)	-
VKAN	K-500 Pulverised (Kansk-Achinsk coal)	752 -------- 1286	29.9 -------- 29.9	977 -------- 1671	2.57 (30.8) -------- 4.39 (52.7)	-
VKUZ	K-300 / Pulverized (Kuznetsk coal)	816 -------- 1398	29.9 -------- 29.9	1061 -------- 1815	2.79 (33.5) -------- 4.78 (57.3)	-
VCLK	K-320 / AFBC (Kuznetsk coal)	964 -------- 1432	29.9 -------- 29.9	1253 -------- 1861	2.98 (35.7) -------- 4.42 (53.0)	3.86 -------- 5.73
VN05	NP-500 (nuclear fuel)	793 -------- 1565	38.5 -------- 38.5	1098 -------- 2167	5.93 (71.1) -------- 8.73 (104.8)	-
VN10	NP-1000 (nuclear fuel)	714 -------- 1299	38.5 -------- 38.5	988 -------- 1799	4.23 (50.8) -------- 6.47 (77.6)	-
VCCG	CC-360 (gas/fuel oil)	599 -------- 903	22.4 -------- 22.4	733 -------- 1105	2.40 (28.8) -------- 3.61 (43.3)	-
VGTU	GTU-150 (gas turbine fuel)	530 -------- 790	12.2 -------- 12.2	595 -------- 886	1.55 (18.6) -------- 2.30 (27.7)	-

*) Calculated at the discount rate of 12%.

6) Definition of fuel cost escalation factors

In addition to the escalation of capital and operational costs, the escalation of fuel prices to the world market level is also part of the consequences of the transition to the market economy. The scenario of fuel price escalation is taken from [5]. The resulting forecast of fuel prices in 2010 (end of the escalation period) is given in Table X.

One can note the differences in the fuel cost escalation rates: gas/fuel oil - about 7.5%/year; coals - 7.0%/ year; nuclear fuels - 4.3%/year. Lower rates for nuclear fuel need to be emphasized. This is one of the potential sources of the economic competitiveness of nuclear power in the future.

Table X. Reference Cost Parameters of Fuels (forecast for 2010) [5,9]

WASP No.	Fuel and its Denomination in WASP	Cost in Physical Units	Cost in Energy Units, \$/tce	Cost in WASP Units, ¢/mln kcal
0	Gas/Fuel Oil (GM)	111 \$/1000 m^3	95	1357
2	Kuznetsk Coal (KUZN)	60 \$/t	68	971
7	Nuclear Fuel for VVER-440 and NP-500 (NUCV)	7.3 mills/kWh (VVER-440) 4.8 mills/kWh (NP-500)	17.4 (VVER-440) 13.0 (NP-500)	249 (VVER-440) 186 (NP-500)
9	Nuclear Fuel for VVER-1000 and NP-1000 (NUCN)	6.3 mills/kWh (VVER-1000) 5.5 mills/kWh (NP-1000)	16.5 (VVER-1000) 15.4 (NP-1000)	236 (VVER-1000) 220 (NP-1000)

7) Economic screening of the candidates

As shown, the candidates differ in the technical and economic characteristics. Before starting the optimization procedure, it is reasonable to compare the candidates in order to identify better technologies and thus reduce the dimension of the optimization procedure. The usual method of screening curves is used for such comparison (Figs. 3 and 4).

As one can see from this illustration, the economic competitiveness of the candidates changes with time as the result of the assumed escalation for capital, operational and fuel costs. The most important change is that, due to accelerated escalation of fuel costs, the technologies most efficient in fuel consumption will gain in economic terms. Such technologies are the combined-cycle units and nuclear units of the NP-1000 design. Thus, the system that heavily relies on natural gas in the conditions of 1994 indicates a trend to some combined gas-nuclear composition in the conditions of 2010. Coal-fired technologies do not appear attractive due to both high capital costs and high fuel costs.

The results of economic screening of the expansion candidates allow to roughly assess the structure of the optimal capacity expansion plan. However, the correct plan can only be found with the full optimization at the system level which would allow to take into account such essential factors as the form of the load curves, the schedule of planned retirements, operation of co-generators and hydraulic plants, etc.

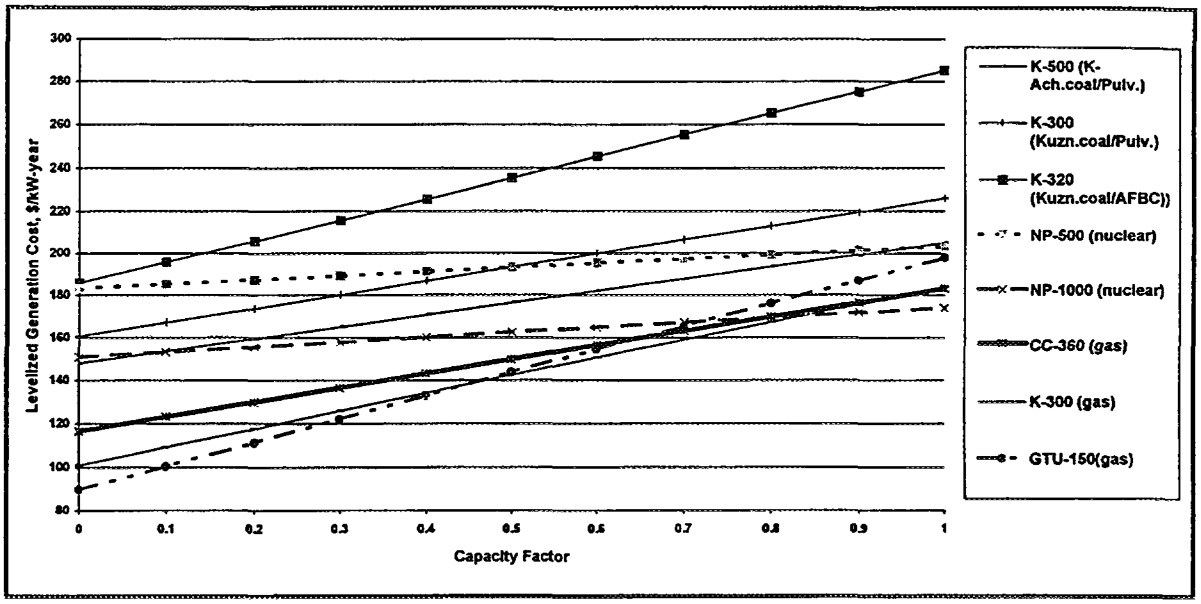


Fig. 3. Screening Curves Comparison of Candidates for 1994

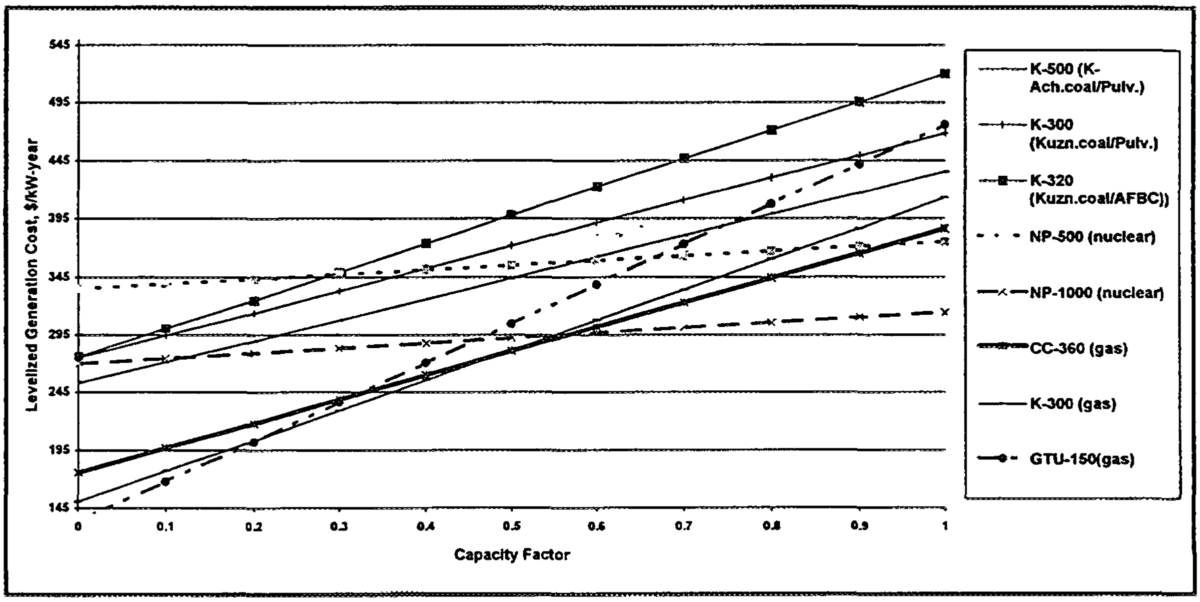


Fig. 4. Screening Curves Comparison of Candidates for 2010

3. RESULTS OF THE WASP APPLICATION

3.1. Optimal Capacity Expansion Plan: Structure and ImplicationS

The structure of the optimal capacity expansion plan developed with WASP-III Plus is shown in Figs. 5 and 6. Figure 5 illustrates the structure of the whole generation system including existing capacities (both cogeneration and condensing units), committed additions of new units, and the new condensing capacities determined as the result of the WASP optimization procedure. Figure 6 includes only newly constructed units, i.e., the condensing electricity generators selected by WASP for construction. Thus, it is in Fig. 6 that one can see the structure of the optimal solution. One can note the following characteristic features of the found optimal capacity expansion plan:

- Until 2004 there is no need for new electricity generation capacities due to the drop in demand in the 90s, certain lifetime margin of existing capacities, predetermined inputs of co-generators and planned refurbishment/repowering measures.
- For the system as a whole (Fig. 5), there are no drastic changes over the study period. The shares of gas-fired and hydraulic plants slightly increase, while the share of nuclear and coal units slightly decrease. At the same time, the detailed structure of the variable, i.e., optimized part of the system does show some essential changes.
- The optimal solution includes four types of electricity generation: combined-cycle units, conventional gas-fired units, nuclear units and gas-turbines.
- As was shown with the screening curve analysis, at the beginning of the planning period (1994) gas-fired technologies are the best economically. This is a natural result of rather low gas prices at that time. However, as gas and coal become more and more expensive reflecting accelerated escalation of fossil fuel prices, nuclear power becomes competitive and nuclear units start to enter the optimal solution. As a result, it is the nuclear unit that enters the system first when new capacities are required (2004). At the end of the study period (2015) there are two nuclear units in the system. The remaining part of the new capacities are mostly gas-fired units, combined-cycle units being predominant. This is a consequence of the ability of gas-fired units to serve half-peak and peak loads while nuclear units are competitive only when working as base load. The latter effect is accentuated by the modeled changes in the load curves, i.e., by the unevenness of the load growing with time.
- There are no additions of new coal-fired units in the optimal solution, the reason being too high capital costs (see the screening curves for coal in Figs. 3 and 4).
- To some extent, the high share of new gas-fired units in the system can be explained by the fact that their relatively low capacity (about 300 MWe) allows them to fit better the rather small annual capacity additions required by the system as compared to the 1000 MWe nuclear units.

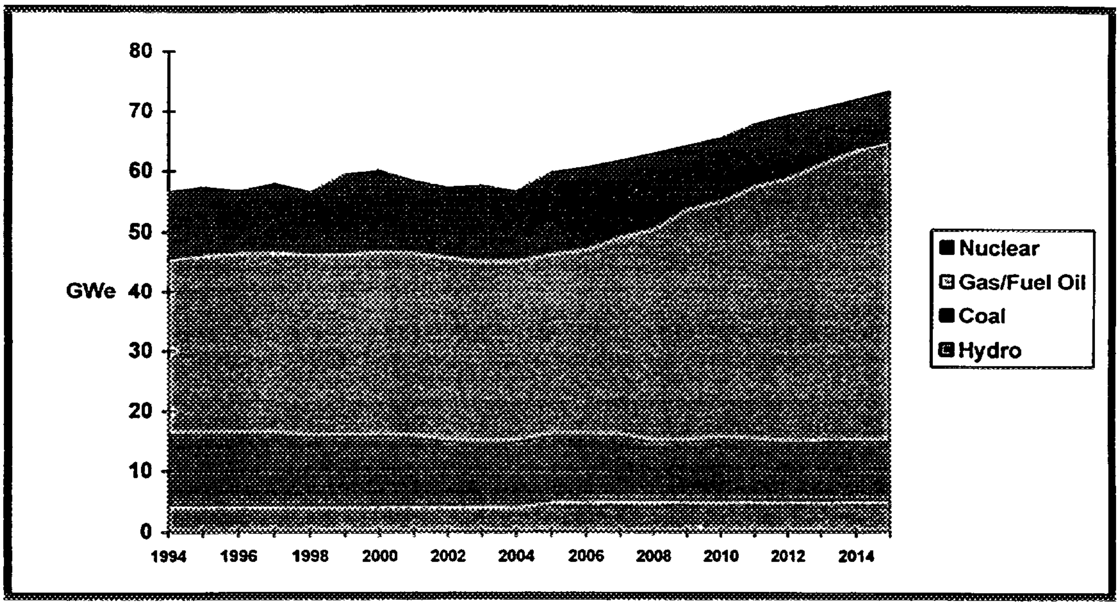


Fig. 5. Structure of the Optimal Capacity Expansion Plan

In general, the composition of the optimal solution confirms the conclusion that could be also drawn from the screening curve analysis: while at low prices of fossil fuels the competitiveness of nuclear power might be questioned, the accelerated escalation of these prices to the world market level increases the economic advantage of nuclear power and as a result, nuclear units become part of the optimal capacity expansion plan. This allows to assert that nuclear power should retain its current important role in the considered regional power system.

3.2. Sensitivity Analysis

Due to the general economic and social instability in Russia, a large number of the key parameters used in the study are highly uncertain. Thus, a sensitivity analysis is required in order to assess the impact of various uncertainties on the optimal composition of the system. In the course of this analysis, all sensitivities are conditionally broken down into four groups:

- Sensitivities to demand uncertainties (e.g., to higher/lower demand growth rates);
- Sensitivities to economic uncertainties (e.g., to the value of the discount rate);
- Sensitivities to social uncertainties (e.g., to the acceptance of nuclear power);
- Sensitivities to system uncertainties (e.g., to the value of the reserve margin).

At present, the sensitivity analysis is not yet complete. However, some representative results have been already obtained and they are illustrated in Figs. 7 and 8. In respect to the long-term role of nuclear power, these results show the following:

- Under the low demand scenario, nuclear units are added to the optimal solution much later than in the reference case - in 2009 as compared with 2004 for the reference case. However, the share of nuclear units in the total capacity commencing operation after 2009 is much higher than in the reference case.

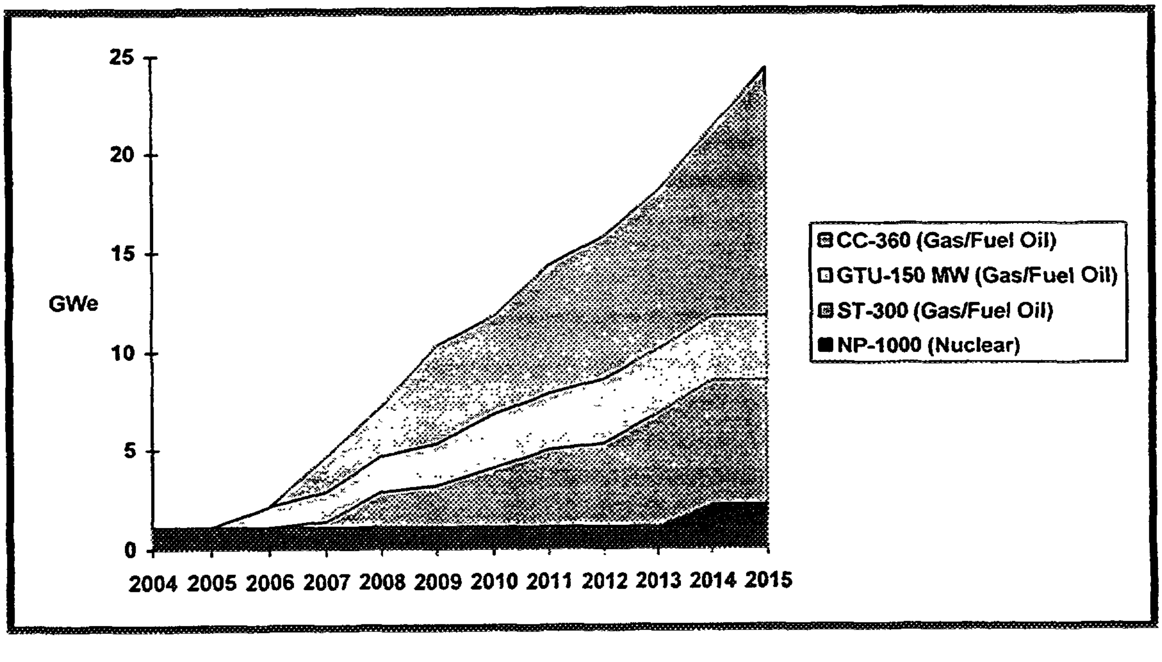
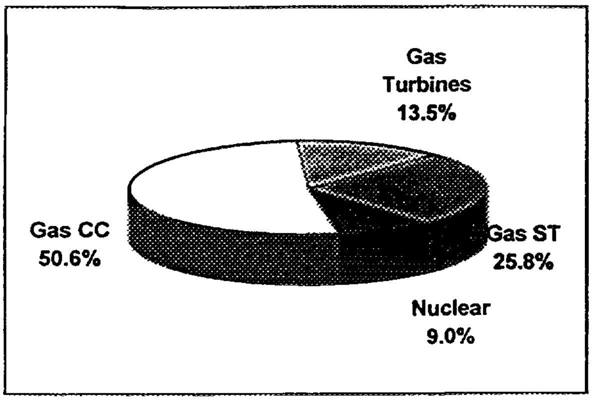
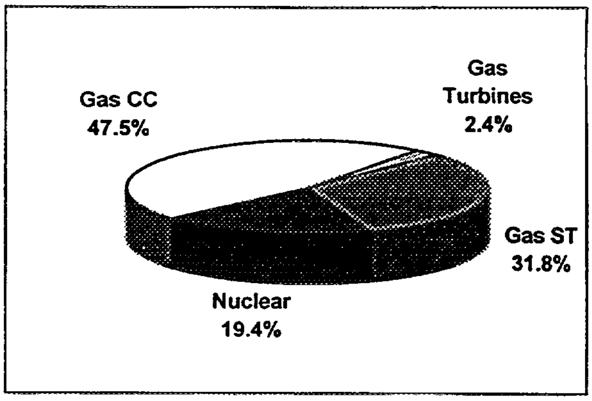


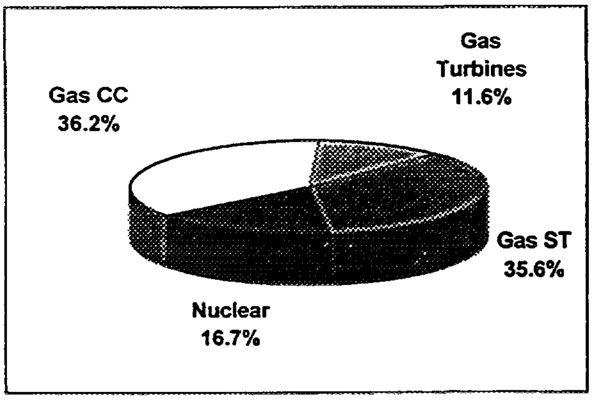
Fig. 6. Composition of the Variable System (Inputs of New Capacities)



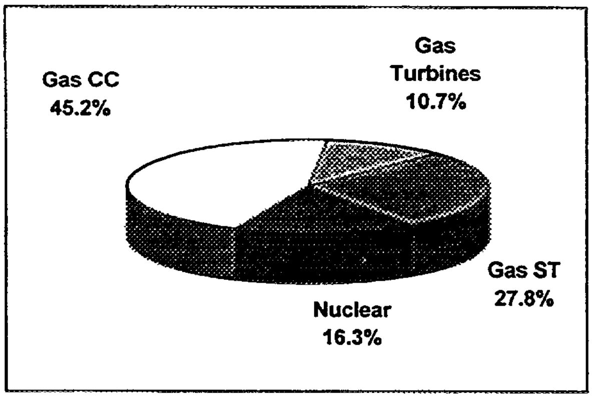
a) The Reference Case



b) The Low Demand Case



c) The High Demand Case



d) The Higher Reserve Margin Case

Fig. 7. Comparison of the Structure of New Capacities for the Reference Case and Sensitivity Cases (in per cent of the total installed capacity of new units added to the system by 2015)

The reason for this is obvious: the deficit of electricity appears later in the low demand case, but it is exactly in that period (2005-2010) that the escalation of fossil fuel prices makes nuclear power preferable. Thus, in a way, nuclear power appears more attractive under the low demand scenario that under the average demand scenario.

- Under the high demand scenario, the share of nuclear units in the variable system is lower than in the low demand case. However, in absolute terms the share of nuclear power is higher: by 2015, there should be five (5) new 1000 MWe nuclear units as compared with only two such units in the reference case. Thus, the high demand scenario also includes nuclear power as part of the optimal solution.

- Currently, the possibility of increasing the normative value of the reserve margin in the Russian power pools is under consideration. In particular, for the Central Power Pool it has been suggested to change the reserve margin from 12% to 18%. Under such assumption, both the number of new nuclear units and their share in new capacities increase: from two new nuclear units by 2015 in the reference case to four units in the relevant sensitivity case.

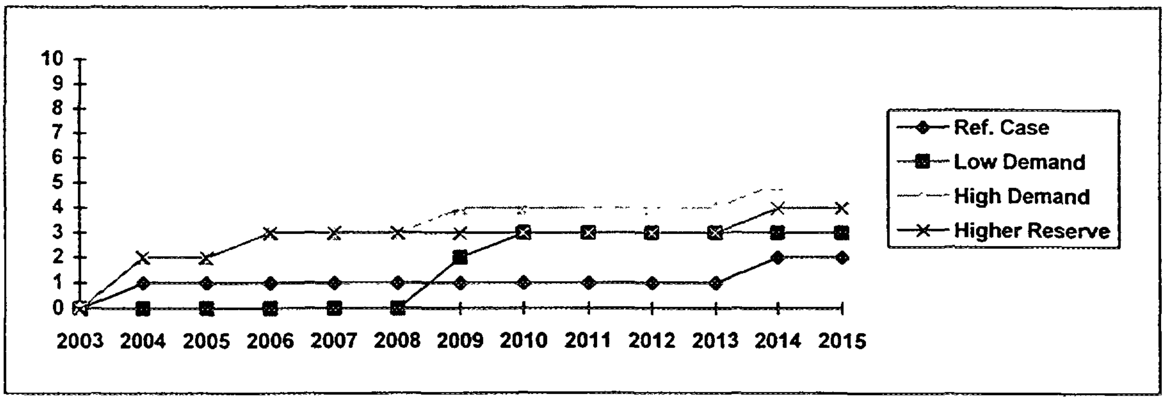


Fig. 8. Comparison of the Number of New Nuclear Units for the Reference Case and Sensitivity Cases

Thus, the sensitivity analysis has confirmed so far that nuclear power has some potential of competitiveness in the system notwithstanding variations in the projected load and some other factors. Moreover, some changes in the parameters assumed for the reference case results in a significantly higher share of nuclear power in the system than in the reference case.

3.3. Environmental Impacts

In view of environmental impacts, the following emissions of the power system are currently being assessed: ash, SO_2, NO_X, CO, CO_2. For these calculations, the methodology and the database of the IMPACTS module of the ENPEP package [1] are used (the emission database of the IMPACTS module incorporates U.S. data taken mostly from [14]. Due to the use of U.S. data, this should be regarded as a very preliminary assessment. Nevertheless, it will give an idea of the magnitude of the environmental impacts and thus provide a basis for further analyses. The results of the environmental impact analysis are expected to be ready late in fall of 1995 and they will be fully documented in the final report of the project to be issued in December 1995.

4. CONCLUSIONS

One can summarize the outcomes of the WASP study as follows:

- The WASP application for the regional electricity system of the Central Region of Russia (Central Power Pool) has shown that the WASP model allows for the simulation of complex electricity systems on a sound methodological basis.

- Although WASP is a one-product (electricity) model, some representation of the cogeneration processes is possible. Still, problems related to the role of cogeneration in the system have to be analyzed outside the WASP model.

- The major outcome of the WASP model - the optimal expansion plan for the regional electricity system - is prepared and analyzed; and the most important sensitivities to a number of critical uncertainties are calculated.

The following conclusions can be drawn from the results of the study:

1. Until 2004 there is no need for new electricity generation capacities due to the drop in demand in the 90s, certain lifetime margin of existing capacities, predetermined inputs of co-generators and planned refurbishment/repowering measures.

2. The study confirmed that in the conditions of the economy in transition the projection of cost escalation factors is the key driving parameter for the system development. This relates to all costs: capital, operation and maintenance, and fuel costs. The elaboration of such projections with adequate consistency at both the regional and the national levels is an urgent task.

3. Among the strategies investigated, the development based on gas-fired technologies is found to be economically attractive for the region. However, when taking into account the possibility of accelerated price escalation for fossil fuels, the structure of the optimal capacity mix confirms that nuclear power is fairly competitive in the long-term perspective and should retain its role as one of the major electricity generation sources in the region.

In addition, one can make the following remarks concerning the applicability of the IAEA's WASP to the analysis of the Russian power system.

- The new, enhanced version of WASP (WASP-III Plus) has been an important step forward in the development of the program. Although the enhancements have been mostly technical, some of them, e.g., the possibility of considering 10 types of fuel instead of 4, are necessary for a realistic representation of such complex systems as the Russian one.

- The absence of modeling cogeneration remains a drawback of the WASP model. This drawback is essential for the Russian power pools with their high share of cogeneration units.

- At present, WASP calculates the structure of the optimal solution and some system costs. However, WASP does not calculate the cost of generated electricity as a function of time for the system as a whole and in a unit-by-unit representation. This would be a very useful enhancement of the model.

- The study has confirmed that WASP can be successfully used for regional applications in Russia. However, the role of interconnections is rather high in some of the Russia's power pools, as well as for the national system as a whole. In such cases, planning tools capable of modeling electric interconnections should be used instead of, or in combination with the WASP model.

ACKNOWLEDGMENTS

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OPTIMAL DEVELOPMENT PATH FOR THE SLOVENIAN ELECTRICAL POWER SYSTEM USING THE WASP AND ELBIVIM MODELS

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Abstract

The paper summarises the results of the WASP study conducted for Slovenia. A thorough analysis shows that the model is applicable to the Slovenian power system. Parallel operation with the domestic ELBIVIM model is nevertheless recommended in order to extract the maximum benefits from both models.

1. INTRODUCTION

The paper presents results of a study performed in May 1995 at the "Milan Vidmar" Electric Power Research Institute [1]. The aim of the study was to determine the applicability of the WASP model to the Slovenian electric power system (EPS). The abbreviated name of the study WSVN stands for WASP SLOVENIA.

2. APPLICATION CHARACTERISTICS

For the calculation of the electricity consumption from 1995 to 2020, the higher scenario [2], the so-called GZ-PE scenario, was taken into consideration in order to have a wider range for possible additions to the system. Figure 1 shows the peak load of this scenario. The growth rate of the peak load ranges between 0.6% and 0.9% over the study period.

Although the IAEA recommends to divide each year into four seasons as a compromise between the computation time of the WASP program and the accuracy of the results concerning the simulation of the system operation, the present analysis was done on a monthly basis. This allowed a direct comparison of the results with those of previous studies that were based on the use of domestic computer models.

Based on the consumption for 1986, twelve (12) typical monthly electric load diagrams were determined and represented with 24 load steps of equal widths (hours). The year 1986 has been chosen as a reference year because of its relative stability. It is believed that in the near future the shapes of the load diagrams will tend to match those of 1986.

Figure 2 presents the Load Duration Curve (LDC) for January 1986, while Figure 3 shows the peak power ratios corresponding to each month (as a ratio of the annual peak load).

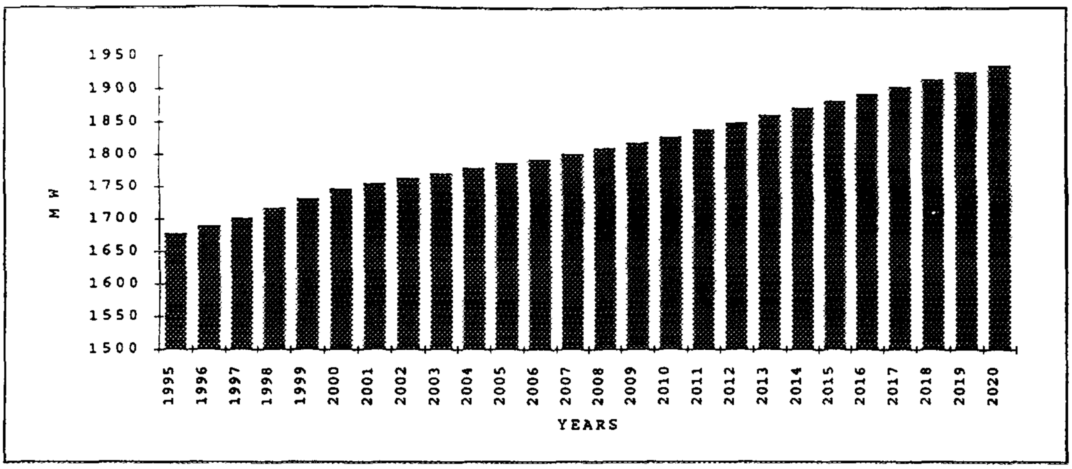

Figure 1. Peak load Projections (GZ-PE Scenario)

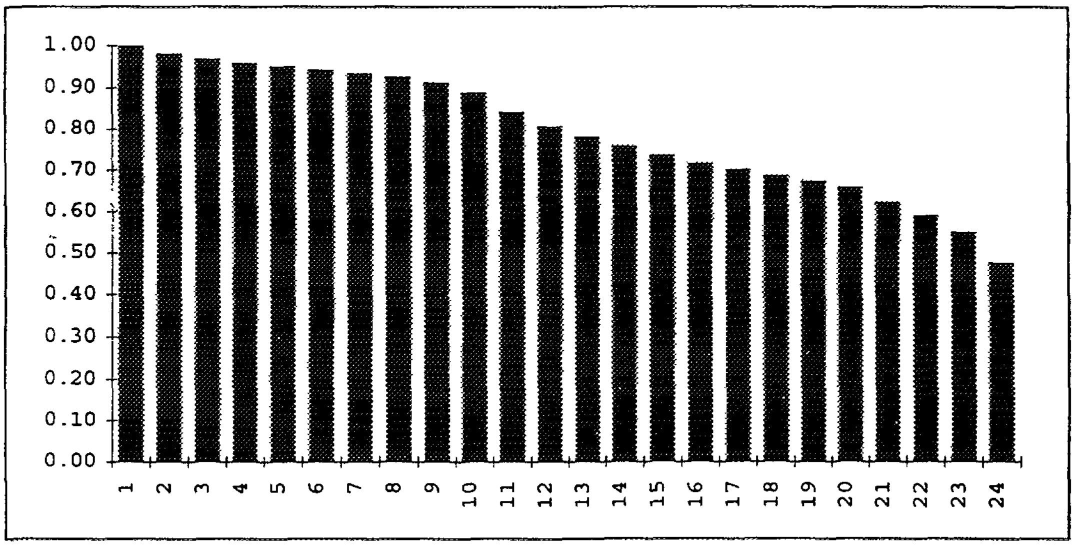

Figure 2. Normalised LDC for January

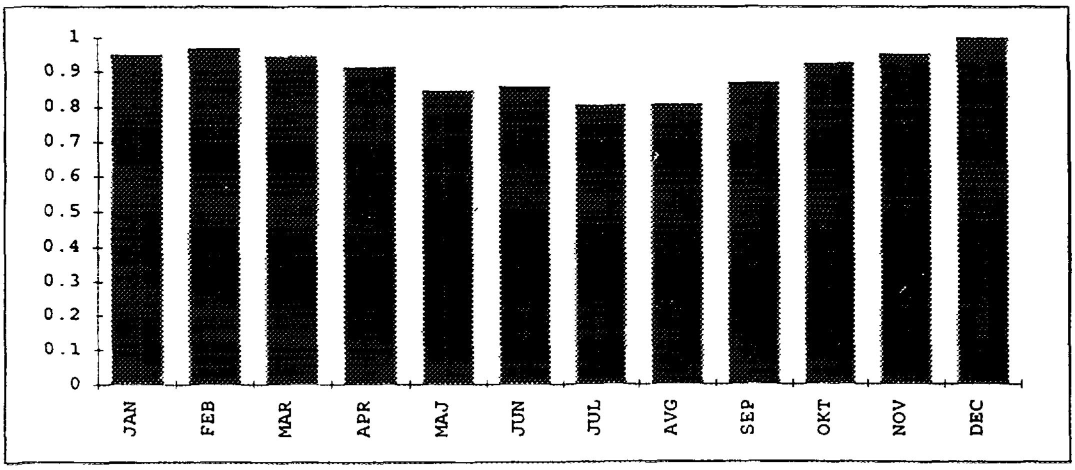

Figure 3. Monthly peak demand in 1986

3. HYDRO POWER PLANTS (HPPs)

For the calculation of the possible capacity generation by hydroelectric power plants, the domestic ELBIVIM model was used due to the following two main reasons:

- the assessment of the possible generation is performed in detail by the ELBIVIM model and takes into consideration the specific conditions of operation of the Slovenian HPPs (various hydro profiles of the main rivers, limitations of basin oscillations, special operating regimes for the lower power plants in the chain, etc.)

- the use of the domestic model allows a partial automatisation of the importation of data from ELBIVIM to WASP. Therefore, the possible capacity generation was drawn from ELBIVIM and inputted into the FORTRAN program called ELBWAS. This program was used to convert the data into the format required by WASP .

The hydroeletric power plants considered in the present study have been taken from [3].

Hydrological Conditions

The ELBIVIM model was also used for determining the hydrological conditions. In the model, the hydrological year is defined with cumulative probabilities. The probabilities of occurrence of the five hydrological years in the ELBIVIM model are 5%, 20%, 50%, 80% and 95%, respectively (in ELBIVIM the corresponding years are named very wet, wet, average, dry and very dry).

In WASP, the sum of the probabilities of the individual hydrological conditions must add up to 100%, meaning that they are defined with the so called "probability density". This is the reason why the probabilities of the five hydrological conditions in the present WASP study had to be set at 5%, 15%, 30%, 30% and 20%. This is one of the main differences with respect to ELBIVIM where each hydrology is treated independently. Table 1 shows the available hydro generation for the various hydrological conditions used in WASP (HC1, HC2, HC3, HC4, and HC5) and for each year in which the hydroelectric power plant sub-system changes in composition.

Table 1: Available HPP generation (GWh)

Year	Installed	HC1	HC2	HC3	HC4	HC5	PRET
	Capacity	0.05	0.15	0.30	0.30	0.20	aver.
1995	695	4343	3891	3370	3240	2668	3317
1998	799	4827	4257	3669	3494	2888	3606
2000	911	5216	4592	3922	3800	3070	3880
2002	950	5429	4766	4069	3966	3163	4029
2004	991	5651	4951	4224	4141	3257	4186
2006	1020	5832	5106	4354	4283	3342	4317
2011	1044	5894	5153	4393	4333	3365	4358
2015	1077	5987	5233	4463	4368	3406	4414
2020	1098	6010	5245	4486	4356	3408	4421

4. THERMAL POWER PLANTS (TPPs)

Eight types of fuel were defined: NUCL (nuclear fuel), LIGN (Sostanj lignite), RJAV (Trbovlje brown coal), UPR1 (imported coal - 18.4 MJ/kg), UPR2 (imported coal - 27.1 MJ/kg), NAFT (liquid fuel), PLIN (natural gas), UVEL (imported electricity).

4.1. Existing system and firmly scheduled changes in the composition

The selection and characteristics of the thermal power plants have been done according to [3]. Foreseen changes in the composition of the system were also considered, including: environmental rehabilitation of unit TES4 of the Sostanj TPP in 1998; closing down of the TES1, TES2 and TES3 units in 2005 and of the TES4 unit in 2014; construction of a new TES6 unit in 2015; replacement of the steam generators of Krsko in 1998; retirement of the gas power plants of Brestanica and Trbovlje in 2009 and 2005, respectively; replacement of boilers 1 and 2 at TE-TO Ljubljana (combined heat and power plant) in 2005.

Since it will not be possible to construct any thermal power plant in Slovenia before 1998, the requirements for electrical energy and power might be covered by contracting the stand-by power from the UCPTE system: 275 MW in 1995 and 1996, 225 MW in 1997 and 125 MW in 1998.

4.2. Variable System

The variable system includes the following units:

- gas turbine GT1 (70 MW);
- gas turbine GT2 (150 MW);
- gas steam power plant GS2 (210 MW);
- gas steam power plant GS3 (350 MW); and
- thermal power plant TET3 (200 MW).

Owing to specific problems that might occur related to the calculation of the generation by hydroelectric power plants in cascade and to enforce comparability of the results with [2], hydro power plants are not included as expansion candidates.

5. CONFIGURATION SET-UP

The reserve margin in the critical period [1] to be satisfied by alternative system configurations was set in the range between 10% and 45%. The critical period was calculated with regard to the hydrological condition HC5 which corresponds to a very dry hydrological year in the ELBIVIM model.

The reliability constraint (Loss of load probability - LOLP) to be satisfied by the expansion configurations was evaluated between 20 and 40 hours annually similarly to other studies performed in this field in the past years in Slovenia.

6. PROBABILISTIC SIMULATION

The WASP model simulates the operation of every configuration that is generated by the program according to the constraints described in the previous chapter. By means of probabilistic simulation and based on the characteristics of the system load and of the plants included in the particular configuration, WASP will carry out production costing analysis. The idea is to determine the generation of each power plant under the given load duration curve. The most important information required for this purpose is the loading order of the thermal power plants. WASP also permits calculation of this loading order based on a user-determined economical local order.

Since some units have characteristics that cannot be covered only with variable costs, an adaptation of the unit's loading order was made.

- The co-generation power plant, TE-TO Ljubljana, occupies the first place.
- The second case of deviation from the economic loading order corresponds to a unit of the Trbovlje TET 2. According to its variable costs it should be ranked above all the Šoštanj units. This would mean a decrease of the power generated and a frequent tripping of the unit which is impossible for this type of plant.

Therefore, the plant loading order was adopted as shown in Table 2. The UE unit represents the contracts for stand-by power from UCPTE.

Table 2: Unit Loading Order

11.	UE
10.	PEB, PET
9.	PT 1, PT 2
8.	TES 3, TES 2, TES 1
7.	PPEB 2
6.	TET 2, TET 3
5.	TES 5
4.	TES 4, TES 6
3.	NEK, NEK-rep.
2.	TOL 2, FBC 2
1.	TOL 3, HCEA

The next important parameter that affects the loading order is the criterion of sufficient spinning reserve (SPNRES) in the system. This was set at the level of 3 x $(Pload)^{1/2}$. The main part of the spinning reserve is assured by large units of Šoštanj (TES 4, TES 5 and TES 6); gas turbines contribute to 40% of P_{max} whereas the remaining units are set at 10% of P_{max}.

Table 3 shows the average generation for the reference year 1995 on the basis of the parameters determined for the probabilistic simulation. The resulting value of the LOLP index is 10.8 hours per year (at the level of 275 MW of the stand-by power contracted from UCPTE!). Finally, the amount of energy not served (ENS) represents 0.9 GWh.

Table 3: Generation in 1995 (GWh)

PRET	3317.4
TES 2	187.5
TES 3	274.9
TES 4E	1753.5
TES 5	1659.3
TET 2	468.8
PET	124.2
PEB	213
NEK	2209.5
TOL 2	205.9
TOL 3	185.8
UE 1	18.7
UE 2	4.2
UE 3	2.8
UE 4	3.9
UE 5	88.2
THERMAL	7400.2
TOTAL	10717.6

7. OPTIMAL DEVELOPMENT OF THE EPS WITHOUT CONSTRAINTS ON THE CONSTRUCTION OF SPECIFIC PLANTS

Besides the plant performance characteristics and other simulation parameters that were specified in the previous paragraphs, economic parameters are also of great importance in the calculation of the optimal path.

- A discount rate of 8%/p.a. was selected for cost comparison of the alternative expansion strategies. The same value (8%) was used to determine the interest during construction (IDC) portion of the investment cost of new plants.
- The unserved energy associated to each configuration was penalized using a unitary cost of 2 US$/KWh.
- It is assumed that the construction period is 2 years for gas turbines and 3 years for TET3 and combined cycle plants.

The optimal development path (named WSVN-1) selected by the model suggests the following construction schedule:

- GS2 in 1998;
- GS3 in 2005; and
- GT1 in 2013.

Figure 4 shows the system reserve (RES), the value of the reliability (LOLP) index and the energy not served (ENS) for each year of the study period. In this figures, reserve margins are expressed as percentage (%), LOLP in hours per year, and ENS in 100 MWh. Figure 5 shows the capital investment necessary for the construction of the power plants considered by the optimal solution.

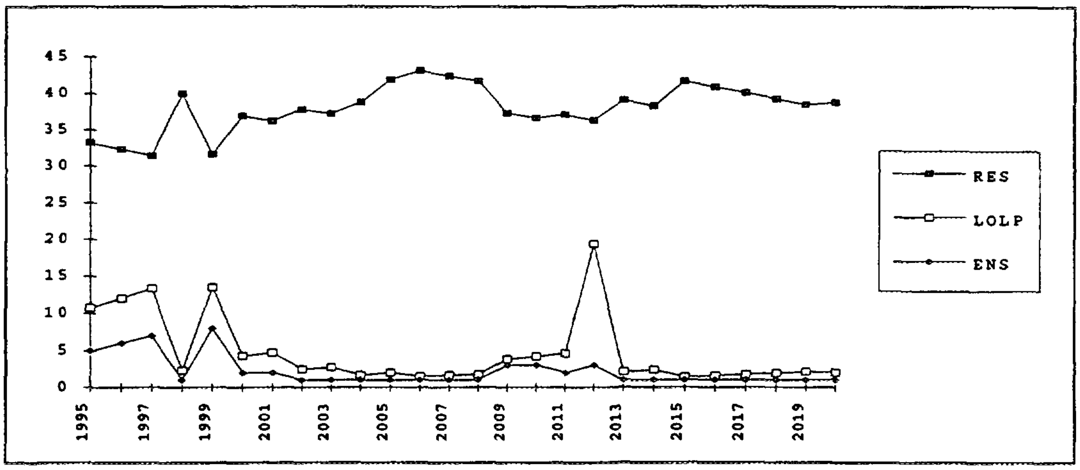

Figure 4. Some of the indicators

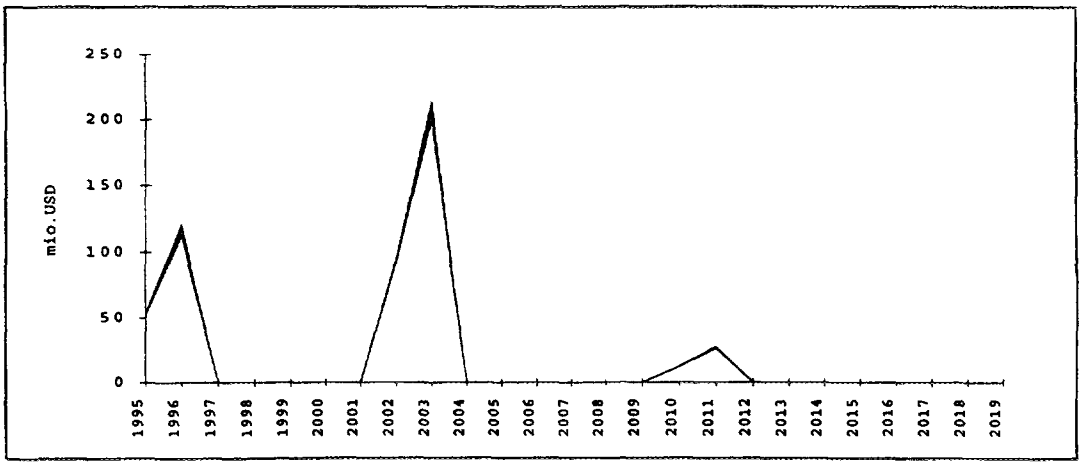

Figure 5. Investment cost

The net present value of the total cost of expansion (i.e. the value of the WASP Objective Function) of the optimal solution would amount to 4.246 billion US$ in 1995.

8. OPTIMAL DEVELOPMENT WITH SCHEDULED CONSTRUCTION OF TET 3

The optimal expansion plan for the system discussed above does not include the construction of TET 3. Therefore a second WASP analysis (named WSVN-2) was performed considering the addition of TET 3 as a firm commitment: the unit is added in year 2005 which corresponds to the year of retirement of TET 2. In this case, the optimal development path selected by the model suggests the following expansion plan:

- GS2 in 1998;
- (another) GS2 in 2005; and
- TET3 in 2005.

The net present value of the total cost of expansion is of 4.354 milliards US$ which corresponds to 108 millions US$ more compared to the previous case (WSVN-1).

9. COMPARISON OF THE MODELS

When setting up hydrological data for the study performed with the WASP model, the available generation by hydro power plants were taken from the results of the ELBIVIM model. For thermal power plants, the study was also considerably adapted to the domestic model. Although the approach and theoretical background of the WASP and ELBIVIM models are quite different, the results of the two models are very similar.

Table 4 shows the relations between four solutions: WSVN-1, WSVN-2, GZ-DV and GZ-ZP. The last two solutions are given by the domestic ELBIVIM model in [2].

The solutions for the WSVN-1 and GZ-ZP cases are comparable. The same is also valid for the solution of the WSVN-2 and GZ-DV cases. These solutions are very similar but not identical since WASP cannot take into account a gradual construction of gas-steam power plants.

In relation to the total number of plants, the solutions in any year of the study period match quite well. For example looking at the total installed capacity, one can note that in year 2020 the solution for WSVN-1 (1xGT1, 1xGS2, 1xGS3) is equivalent to the WSVN-2 solution (2xGS2, 1xTET3) and that for GZ-DV (4xGT1, 1xGT2, 1xTET3) since their total added capacity is very similar. Only the solution GZ-ZP (1xGT1, 2xGT2, 1xGS2) is lower in installed capacity by approximately 1xGT1 which results from the possibility of higher LOLP factors during the last years of the study in the analysis performed with the ELBIVIM model.

Table 4: Comparison of solutions of the two models

Year	WASP						ELBIVIM					
	WSVN-1			WSVN-2			GZ-ZP			GZ-DV		
	GT1	GS2	GS3	GT1	GS2	TET3	GT1	GT2	GS2	GT1	GT2	TET3
1995	0	0	0	0	0	0	0	0	0	0	0	0
1996	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
1997												
1998		1			1		2			2		
1999		↓			↓		↓	1			1	
2000								↓			↓	
2001												
2002												
2003												
2004												
2005			1		2	1	0	2	1	3		1
2006			↓		↓	↓		↓	↓	↓		↓
2007												
2008												
2009							1			4		
2010							↓			↓		
2011												
2012												
2013	1											
2014	↓											
2015												
2016												
2017												
2018												
2019												
2020	1	1	1	0	2	1	1	2	1	4	1	1

Note: The table does not contain repetitions.

10. CONCLUSIONS

The WASP model is in a way complementary to the domestic ELBIVIM model and suitable for long term studies for the Slovenian EPS.

Compared with the ELBIVIM model, it has however some deficiencies due to its method of calculation [1]. The same applies to the ELBIVIM model which has some deficiencies compared with the WASP model.

Nevertheless, the WASP model offers a wide range of possibilities for planning long term developments of the Slovenian EPS, provided that verification of results from the two models is made.

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INTEGRATED RESOURCE PLANNING FOR THE RATIONAL USE OF ENERGY IN SLOVENIA

Overview of analysis with discussion of the role of WASP

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Abstract

Integrated resource planning (IRP) for the rational use of energy in Slovenia is presented in this paper. The main objective of the analysis is the improvement of the overall energy efficiency in Slovenia. Emphasis of the IRP analysis is given on: 1) comparison of demand and supply options and 2) embedding of the planning procedure into a structured analysis procedure to make the planning process more transparent. The Wien Automatic System Planning package (WASP) will be used in the modeling framework for determining the optimal expansion plan for different demand patterns.

This paper provides an overview of the IRP project for Slovenia[1]. The paper consists of three sections. The first section aims at giving an insight on the motivations for the analysis; the second section describes the case studies in structured analysis steps. The role of WASP is discussed in the third part.

1. OUTLINE AND OBJECTIVES

The objective of the Integrated resource planning (IRP) for the rational use of energy in Slovenia is to provide decision support to the energy policy of Slovenia in view of the major challenge being faced by the country, namely the improvement of its overall energy efficiency.

IRP is the planning process that aims at an optimal allocation of all resources to provide a given energy service. IRP is an extension of the more traditional approach of expansion planning of the energy supply sector. The energy system is enlarged beyond the level of final energy delivered to the user, to include energy transformations on the users' premises and processes which provide useful results of energy use, namely energy services.

In the present study, IRP is considered from the national perspective. The IRP approach is applied to the energy supply and use of Slovenia. Two main sectors of energy use are considered in detail: the industry sector and the households sector. The objective of IRP in this case is to provide a policy framework in such a way that the different agents, which supply and

[1] The overview is based on texts from different authors used as part of the project documentation. Selection and discussion of the role of WASP is prepared by the author.
Integrated resource planning for the rational energy use in Slovenia is an ongoing project. Phase I is financed by the Ministry of Economic Affairs of the Republic of Slovenia and carried out by the following institutions: Jozef Stefan Institute, Energy Efficiency centre, Faculty of Mechanical Engineering of Ljubljana, Milan Vidmar Electroinstitute, and Institute of Ecology.

consume energy, minimize the required economic efforts of the whole energy system. The IRP process, which involves also a structured approach for solving the problem, will identify proper ways and means to implement the policy measures.

The proposed project is in line with the strategic orientation given in the National Strategy of Efficient Energy Use and Supply of Slovenia which stresses in particular the need to promote the rational use of energy by tapping the energy conservation potential and enhancing demand side policies.[2]

The area of concern of this analysis is the energy use and supply in Slovenia, with specific consideration of the efficiency of energy use. Characteristic of the current agenda of decision making is a broad scope of the definition of the problem. An energy strategy is concerned with both energy supply and energy use. Also, the concerns are not only those of economic efficiency and security of supply, but also health, environmental, risk, and social impacts.

The problem is defined on the national level from a general perspective as requested by the Parliament or the Government.

In Slovenia, the most recent round of the comprehensive decision making at the national level started with the preparation of an energy strategy that was requested by the Parliament in 1993. The current strategic document, referred to by the Parliament as the "Resolution on the strategy of efficient use and supply of energy for Slovenia", identifies the possible domains for improvements in both energy supply and use, and the possible directions for a dynamic harmonization of this sector of the society.

The Resolution describes the area of concerns with the following text:

"Due to concerns over increased energy intensity, due to extent of adverse effects on the environment and the necessity to diminish the vulnerability caused by energy dependency, the implementation of the proposed resolution on the strategy can significantly contribute to the affirmation of Slovenia as an energy efficient state, where the supply of energy and the efficient use are sources of stability, reflection of a determination for an efficient, environmentally compatible development and a consequence of the expectations of the people for a better standard of living."

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2 In 1994, real growth of GDP was estimated to be around 5% (1% in 1993), and the increase of industrial production above 6% GDP per capita amounts to approximately 6.900 US$/capita at current exchange rates It can be expected that the recovery will continue in the next two years with expected real growth rates of 4% to 5%.
The energy sector plays a particularly important role in the economic transformation process. Energy intensity (GDP/primary energy) is about three times higher in Slovenia compared to countries of the European Union In 1992, the energy intensity was 184 toe/mECU in the European Union compared to 565 toe/mECU in Slovenia.
Saving measures which are cost-effective even at the present low energy prices are estimated to amount to some 10% in the industry sector and to some 30% in the building sector in terms of final energy (with a 25% p.a discount rate) With an expected price increase in the forthcoming years and under consideration of more realistic discount rates, the cost-effective potential will even increase
The energy sector contributes to an important extent to the environmental degradation in Slovenia Based on figures from 1993, the greatest share in SO_2 emissions comes from electricity generation representing 81 % of all emissions Also, electricity production contributes by 27 % to NOx emissions and its share in CO_2 amounts to 47% followed only by transport On the per capita basis, the comparison of emissions between Slovenia and countries of the European Union gives the following results
Slovenia (European Union) SO_2 91 3 (34 0) kg/cap NOx 28 4 (32 5) kg/cap CO_2 6 3 (8 7) t/cap

2. CASE STUDIES: INDUSTRY AND HOUSEHOLDS SECTORS

The two case studies carried out in the framework of the IRP project are described in the following paragraphs.

Quantification of the problem. Energy use in Slovenia is considerably higher than in West European countries. In comparison to countries of the European Union (EU), the energy intensity is approximately three times higher in Slovenia. In 1992, the total energy intensity was 184 toe/mECU in the EU compared to 565 toe/mECU in Slovenia.

The definition of the problem is based mainly on the draft document on the energy strategy of the Government of Slovenia after discussion with the Parliament. The current version of the document is being analysed in order to define the objectives (directives for expected developments and improvements) and the goals (level of accomplishment).

Scenarios. Two scenarios were adopted: a "PLUS" and a "MINUS" scenario. Short term projections (up to year 2000) of possible developments were available from governmental economic development studies. The long range (up to year 2020) scenarios adopted have been used in other energy studies. For the world-market energy prices no firm linkage with the domestic development scenarios is foreseen.

Strategies. Energy strategies consist of sets of policy measures. The measures proposed in the strategy document of the Government were listed and grouped. For the demand side, the "Energy Conservation Strategy for Slovenia" study is a more relevant source for strategy measures. In this study, measures were quantitatively analysed according to their impact on the energy use. Energy audits constitute further sources on strategy measures. Some additional measures were defined by the IRP project team.

Table 1 summarises the strategies selected. Three strategies were proposed for both case studies, industry and households: a *business as usual*, a *moderate efficiency driven* and an *intensive efficiency driven* strategy.

Data. Relevant public data bases available in Slovenia were reviewed in order to supplement the data on energy supply which are used for the energy balances of Slovenia, with more specific data on energy use. Detailed data bases on energy use by the industrial sector are maintained by the Statistical Office of Slovenia. The content of data bases on the industrial consumption was evaluated and access to synthetic data was secured. For the planned analysis of energy consumption patterns, the relevant population and building census were identified and acquired. Results of the household consumption survey were evaluated for modelling energy use by the household sector.

Model. Conceptually, the model consists of the following parts: households, industry (i.e. manufacturing), local energy supply and large scale energy supply. Other energy uses (services and transport) are at the present not modelled but data will be used from standard energy planning studies. A schematic presentation is given in Figure 1. This presentation does not reflect the actual state of the model but is only illustrative.

Analysis. The full analysis of the problem includes:

- Calculation of the economic optimum for each scenario and strategy, namely:

  - total cost, including cost structure;
  - cash flow;
  - energy flows and energy balances;
  - emissions of main pollutants;
  - resource consumption;
  - employment.

- Sensitivity analyses to variations of the main influencing parameters and constraints.

Table 1

Industry - Scenario table for three strategies related to three different intensive energy efficiency programs

	Scenarios	"MINUS"			"PLUS"		
	Real income	2.2 % p.a.			5.5 % p.a.		
	Average increase of industrial VA: *(1995-2000)* *(2001-2020)*	2.4 % p.a. 1.9 % p.a.			5.2 % p.a. 3.8 % p.a.		
GROUP OF MEASURES	*Strategies*	"0"	MODERATE improvement of energy efficiency	INTENSIVE	"0"	MODERATE improvement of energy efficiency	INTENSIVE
a	*Information and promotion programs*	base case	yes	yes	base case	yes	yes
b	*Technical regulation, standards and agreements*	base case	yes	yes	base case	yes	yes
c	*Management regulations, standards and incentive programs*	-	yes	yes	-	yes	yes
d	*Financial incentives for energy efficient investment*	-	moderate	intensive	-	moderate	intensive
e	*CHP and energy networks*	-	moderate	intensive	-	moderate	intensive
f	*Employ all technical options for efficient use of energy, domestic energy and renewable energy*	-	moderate	intensive	-	moderate	intensive
g	*Steel industry arc furnaces*	base case	moderate	intensive	base case	moderate	intensive
h	*Paper industry*	base case	moderate	intensive	base case	moderate	intensive
i	*Energy pricing, measurement and tariffs*	-	yes	yes	-	yes	yes
j	*Emission tax of x SIT*	no	no	yes	no	no	yes
k	*Energy tax of y SIT*	no	no	yes	no	no	yes

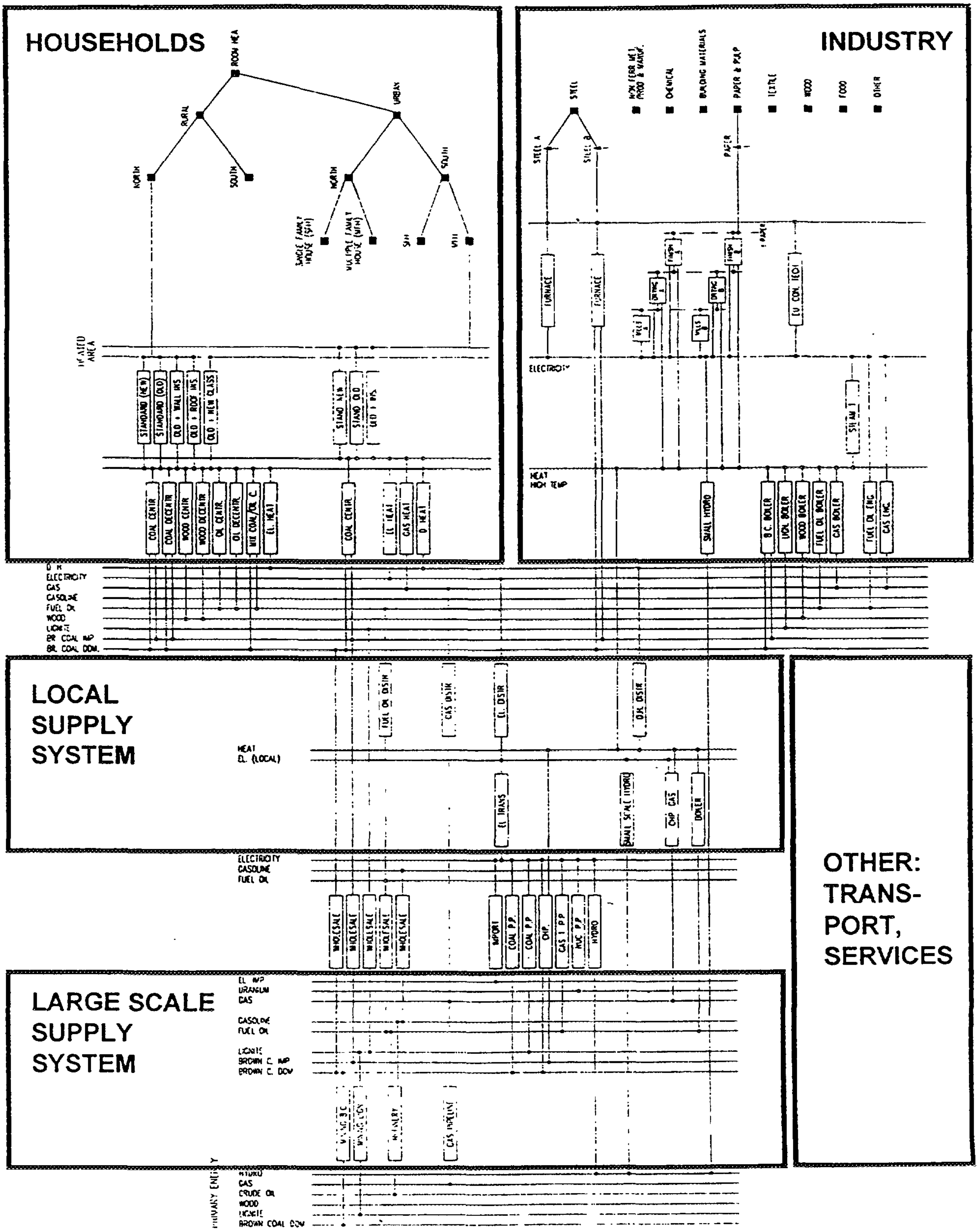

Figure 1. Reference Energy System and Subsystem

Policy recommendations. At an early stage of the project, policy recommendations will be drafted on the basis of the problem analysis and development of the Scenario Table. The recommendations will be reviewed at each of the three phases of the project. For policy recommendations, robust and multicriterial conclusions based on the Scenario Table analysis will be proposed.

Implementation and Monitoring Program. Following the policy decisions, the project should be extended to the policy implementation phase. The project extension should include monitoring of the results achieved by the chosen strategies.

3. MODELLING FRAMEWORK

In the procedure of integrated resource planning, supply and demand should be analyzed in an integrated approach. For demand side, the screening simulation model called PLANET is envisaged. WASP will be used for the optimization of the generation expansion plan (see Figure 2).

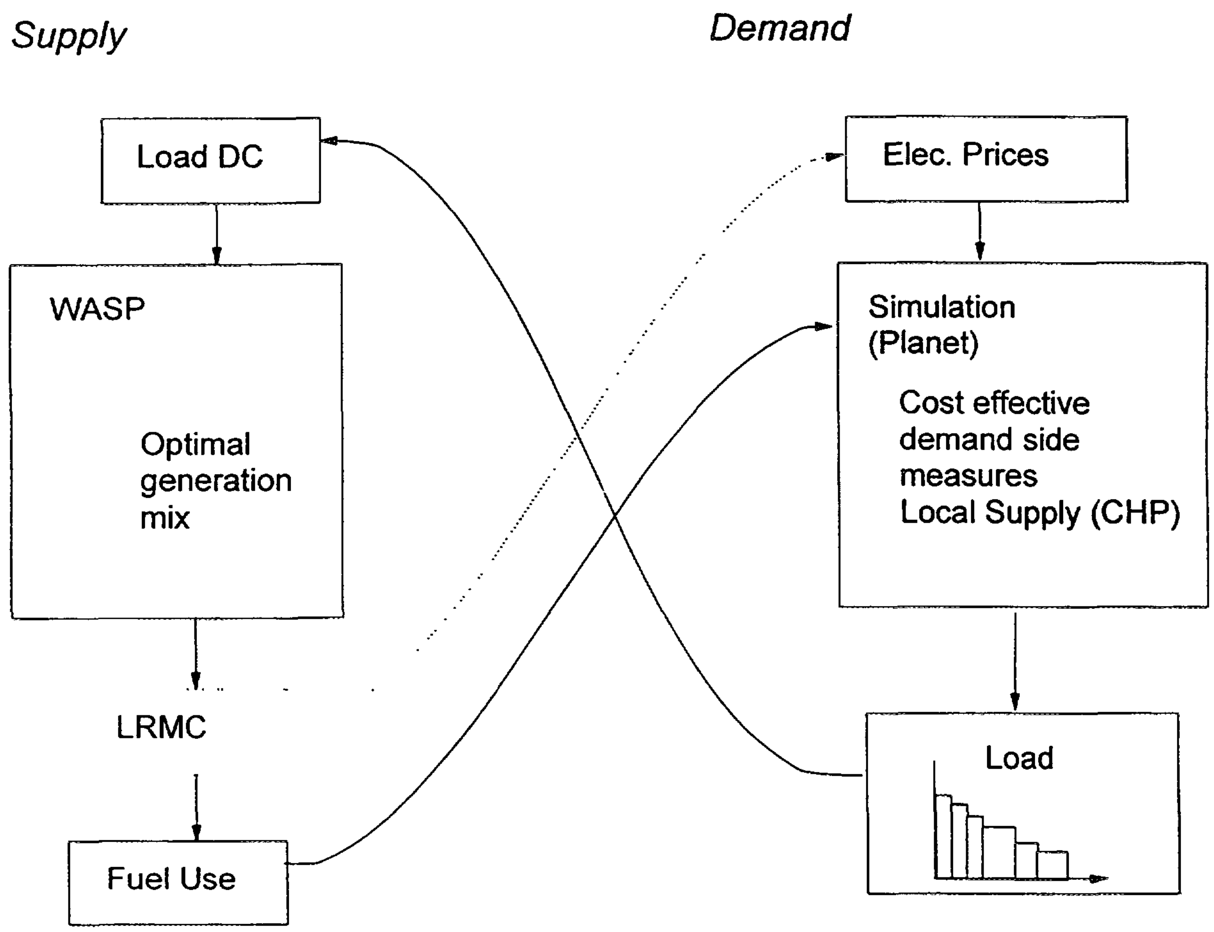

Figure 2. Interlinks between WASP and the demand simulation model

The three interlinks between the demand and supply models are at the following levels: (a) load diagram modelling, (b) long run marginal costs of electricity, and (c) local supply systems.

The two models (PLANET, WASP) will be connected by exchanging inputs and outputs as follows: in the demand model, the electricity demand will be represented with six different load steps representing different tariff periods, plus peak load.

This tariff structure has been in use in Slovenia for electricity sales from qualified producers since September 1995. In addition, three seasons are introduced for the household sector and other groups.

A study of the impact of demand side measures on the load diagram is described in [Renar 93], the expansion planning being analyzed by the ELBIVIM model. Qualified, existing and potential producers will be modelled inside the demand model as long as they are not dispatchable (a capacity ceiling of 220 MWe for district heating purposes is planned). Long run marginal costs can be applied as input in the demand model for assessment of the cost effectiveness of measures. In addition, fuel consumption data is required as an input for integrated balance model.

Results of the demand and supply analyses will require an additional estimation of the financial, environmental and social impacts of the options.

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SYSTEM INTERCONNECTION STUDIES USING WASP

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Abstract

The aim of this paper is to describe the application of WASP as a modelling tool for determining the development of two electric systems with interconnections. A case study has been carried out to determine the possibilities of transfer of baseload energy between Turkey and a neighboring country. The objective of this case study is to determine the amount of energy that can be transferred, variations of Loss of Load Probability (LOLP) and unserved energy, and the cost of additional generation with interconnection.

The break-even cost will be determined to obtain the minimum charge rate at which TEAS (Turkish Electricity Generation-Transmission Corp.) needs to sell the energy in order to recover the costs. The minimum charge rate for both capacity and energy will be estimated without considering extra capacity additions, except for the ones needed by the Turkish system alone.

1. INTRODUCTION

WASP (Wien Automatic System Package) is a modelling tool designed to determine the least cost electrical energy generation system expansion plan and to analyse system development by considering technical and economic constraints. WASP does not aim at carrying out the complete analysis required for electric system expansion studies. For an extensive planning study, some other analytical tools must be used to complement the pure economic analysis carried out by means of WASP (e.g. models to analyse the expansion of the transmission system, financial planning models, etc.).

Experience has been gained from the use of WASP for analysing the existing electric system and system expansion studies for planning purposes. WASP is essentially a model for an integrated power system; however, it is possible to use the model for interconnection studies between two or more electric systems.

The present case study has been carried out to determine the changes in annual generation of the existing units, generation costs (Fuel and O&M) and system reliability as a result of the electrical interconnection between Turkey and a neighboring country. The aim is to evaluate the energy that can be sold by Turkey. Investigations on the behavior of the Turkish Electric System are the focus of this paper. Results of the case study will be compared to the official Reference Case of Turkey's long-term electricity generation expansion plan.

The power system considered in the WASP analysis, in terms of the power plant characteristics refers only to the Turkish Electric System data, mainly because of difficulties in obtaining system data for other countries.

2. BENEFITS OF ELECTRICAL INTERCONNECTIONS

The interconnection between two or more electrical grids provides mutual assistance in real time in the short-, medium- and long-terms between the electric power systems. However, on the negative side, it could propagate power system disturbances over far greater geographical areas.

Fundamental advantages of the interconnection are the following:

- Reduction of the installed reserve of generation capacity for the same level of reliability;
- Reduction of the spinning reserve in generation for the same level of security;
- Economies of scale in the generating system, since the larger size of the grid allows to accept higher rating units having lower specific investment costs and lower operating costs;
- Reduction of the peak load of the interconnected system through the diversity of the peak periods in each subsystem,
- Improvement of the units' maintenance schedules, leading to savings in investment and running costs,
- Contribution to the more rational use of energy.

3. LOAD SYSTEM MODIFICATION

Before explaining the case study carried out with interconnection between two electric systems, first it is necessary to reflect the capacity of the interconnection line on the system load. In other words, the system load (electricity demand) should be increased by the capacity of the interconnection line. This will account for the capability of exporting electrical energy from the Turkish system.

The capacity of the interconnection line between Turkey and the neighboring country has been assumed as 400 MW from the year 1997 to the year 2002, and 800 MW after 2003. Assuming that power and energy will be sold during off-peak hours (three hours per day have been considered as peaking hours) which is 7665 hours in a year, the system load has been increased by 400 MW between 1997 and 2002 and by 800 MW after 2003 for each hour, except three hours per day. Based on this increment, a new demand file has been established and a new load system has been defined for use as the LOADSY input file for WASP.

In order to define new system load while keeping the peak load unchanged, load and duration magnitudes have been calculated from LDC points of the LOADSY data file, the capacity of the interconnection line added to the load values for the duration of 7665 hours (approximately) and then, the LDC points have been evaluated again. At the end of the process the load duration curve increased by the amount of the interconnection line capacity during off-peak hours of the period. The original and increased load duration curves of the fourth period for years 1997 and 2003 are shown in Figs. 1 and 2.

Figure 1

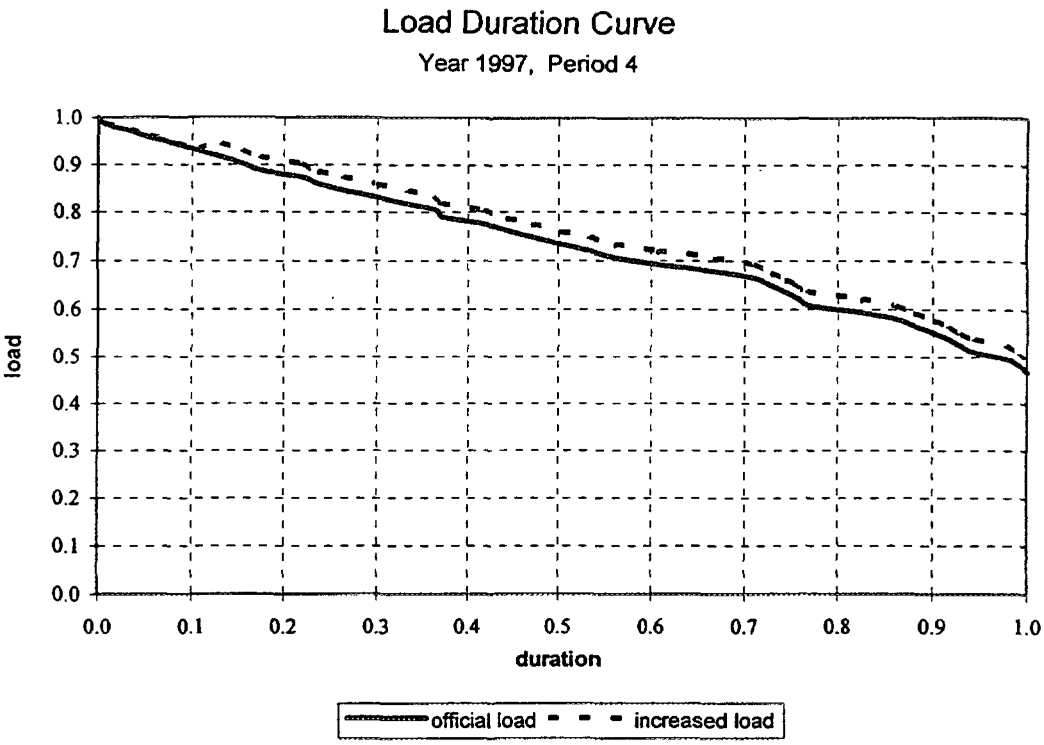
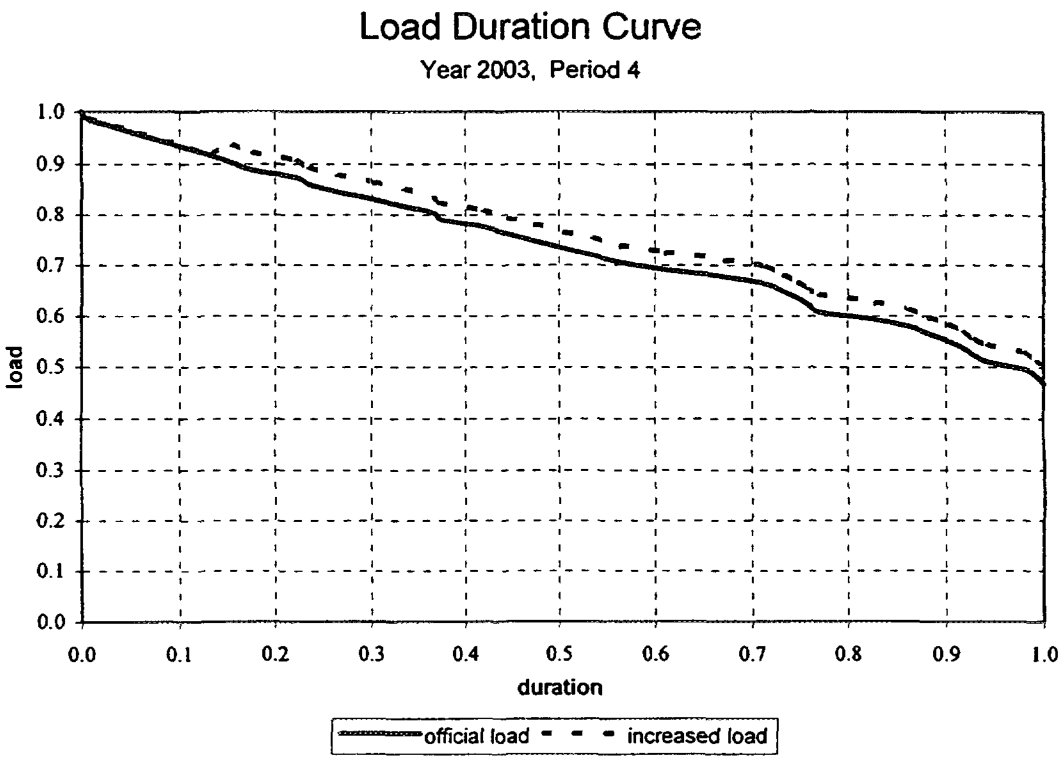


Figure 2



Here it is very important to explain briefly the method of changing the load of the system. This process has been done manually by using Turkey's official System Load data. Load magnitude and duration points of the original LOADSY file have been converted to load magnitudes and duration and then the load magnitude has been increased by the appropriate amount for the above-mentioned years. However, to adjust exactly the load for a duration of 7665 hours per year is too difficult from the existing official system load data. For this study the capacity of interconnection line has been added to the load magnitude corresponding to the nearest value for off-peak duration. For this reason, the energy demand of the system could not be increased exactly. Consequently, the WASP results may deviate from the reality with respect to the values of the system generation.

4. ASSUMPTIONS

The objective is to compare the results of the interconnection case study with the official electricity generation expansion plan of Turkey. It is essential to determine the amount of energy that can be sold by Turkey without changing the reference case system configuration. In other words Turkey will not construct any new power plant for interconnection purposes. So the peak load should not be increased during peaking hours as mentioned in Section 1, but the system load must be increased by the amount of the capacity of the interconnection line during off-peak hours, that is 87.5% of the total period duration.

The reserve margin of the reference case study (min. 40%, max. 60%) has been kept the same for this study. However, in order to supply the energy demand without changing the system configuration, the Loss of Load Probability (LOLP) is not limited for the year 1997. Consequently, the LOLP in this year exceeds the reference case criterion (3%). Similarly, the Unserved Energy increases for this case study (see Table 2).

As there will be no new generation unit investment, the construction costs will remain as in the reference case. New optimization will not be allowed, but the result of the reference case will be simulated in order to determine the system operation results under the new assumptions of the system load.

5. SOFTWARE USED FOR THE STUDY

The main tool used in the study is the WASP model. As mentioned above, no new generation unit investment has been permitted and all data have been kept as in Turkey's official reference case in order to compare results on the same basis.

QUATTRO PRO Version 4.0 has been used as an auxiliary tool to increase the Turkish system load by the capacity of the interconnection line between Turkey and other neighboring electric system for the commissioning years as described in Section 2.

To extract operational values from WASP results, a complementary Program Package WPP (WASP Post-processing Programs) has been used. This is a package of eight separate programs developed in FORTRAN 77 by staff from the Research Planning and Coordination

Department Generation Planning Group of TEAS (Turkish Electricity Generation-Transmission Corporation. These have been integrated by a QuickBASIC program.

These programs derive results from the outputs of the DYNPRO and MERSIM modules of WASP and some new manually established data files in order to produce useful tables for decision makers. These include:

1) Annual generating unit addition by plants and demand-supply balance,
2) Annual capacity addition and yearly capacity development,
3) Annual fuel costs and fuel consumptions of plants,
4) Annual fixed O&M costs of the plants,
5) Annual variable O&M costs of the plants,
6) Annual total running costs of the plants and the system,
7) Annual generation amounts of the plants,
8) Annual capacity factors of the plants.

6. CASE STUDY FOR INTERCONNECTION

As discussed in the previous sections, it is possible to use WASP for interconnection studies between two or more electric power systems. This paper discusses such an application, specifically for a case study that aimed at determining changes in the system operation results when considering the interconnection between two electric systems.

The case study has been carried out to calculate the system operation results with interconnection in order to determine the amount of energy that Turkey can sell to other power system (INT1 CASE). In this case, the capacity of the interconnection line is being thought as additional energy demand that can be sold by Turkey to the other electric system, and the corresponding load amount represented by the capacity of the interconnection line is added to the LOADSY data file for 87.5% of the period duration for appropriate years.

By defining new system load, simulation runs with WASP (INT1 CASE) have been carried out without optimizing the reference configuration (with no new generation unit investment) by using the same data as in the official reference case (REF CASE). The results show an increase of the energy produced (which can be sold), fuel cost, variable O&M cost. Further, a considerable increase occurs in the amount of unserved energy and LOLP as compared to the official reference case. (Table 1)

For the evaluation of the energy that can be sold by Turkey, increasing the demand by the amount of the line capacity is enough. By executing WASP simulation runs with the increased system load, the generation of some power plants increases from the values in the Reference Case. This additional energy is the energy that can be sold to the other electric system.

Table 1
SYSTEM OPERATION COST

REF CASE

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
FUEL (m$)	1,311 45	1 455 75	1,619 82	1,805 66	1,907 94	1,998 56	2,119 23	2 232 75	2,334 65	2,452 84	2 693 48	2 967 60	3 167 26	3 407 41	3 707 28
FIXED O&M (m$)	311 39	330 16	386 97	436 22	468 79	510 24	541 40	583 66	619 48	727 36	813 85	905 74	1,044 77	1,132 90	1,197 84
VAR O&M (m$)	52 94	56 05	63 48	65 26	77 83	84 86	88 80	96 97	100 83	110 37	127 39	146 15	155 27	169 05	186 45
TOTAL (m$)	1,675 78	1 841 96	2,070 27	2,307 04	2,464 56	2,593 65	2,749 43	2,913 38	3,054 96	3,290 57	3,634 72	4,019 49	4,367 30	4,709 36	5,091 57
ENERGY (GWh)	94,593 30	102 470 90	111,022 70	120,267 30	130,290 70	140,809 70	151,676 30	163,380 30	175,991 50	189,568 90	203,598 80	218,742 70	236,028 00	252,540 50	271,365 60
TOTAL COST (m$)	1,693 24	1 861 40	2,089 70	2,324 29	2,473 45	2,614 96	2,774 47	2,939 36	3,085 90	3,322 57	3,667 37	4,053 49	4,398 41	4,745 31	5,174 59

TOT COST/ENERGY (*)	1 790	1 817	1 882	1 933	1 898	1 857	1 829	1 799	1 753	1 753	1 801	1 853	1 871	1 879	1 907
TOTAL/ENERGY (*)	1 772	1 798	1 865	1 918	1 884	1 842	1 813	1 783	1 736	1 736	1 785	1 838	1 858	1 865	1 876

INT1 CASE

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
FUEL (m$)	1 311 45	1 578 74	1 735 66	1 922 85	2,032 57	2,069 93	2 195 26	2,378 84	2,500 56	2 623 92	2 826 55	3 105 43	3,316 14	3,569 15	3 872 26
FIXED O&M (m$)	311 39	330 16	386 97	436 22	468 79	510 24	541 40	583 66	619 48	727 36	813 86	905 74	1,044 77	1,132 90	1,197 84
VAR O&M (m$)	52 94	58 59	66 23	68 27	81 33	86 97	91 14	100 68	105 90	117 05	132 33	151 21	162 65	178 42	197 88
TOTAL (m$)	1,675 78	1,967 49	2,188 86	2,427 34	2,582 69	2,667 14	2,827 80	3,063 18	3,225 93	3,468 33	3,772 73	4,162 38	4,523 56	4,880 47	5 267 98
ENERGY (GWh)	94,593 30	105,422 30	114,405.30	123,931.80	134,256 40	143,690 00	154,777.70	168,941.10	181,979 05	196,019 20	209,450 00	225,032 40	241,789 40	259,805 80	279,162 48
TOTAL COST (m$)	1,693 24	1,986 92	2,208 23	2,444 67	2,601 50	2,688 70	2,852 94	3,089 39	3,257 06	3 500 36	3,805 80	4,196 86	4,556 09	4,916 81	5,351 45

TOT COST/ENERGY (*)	1 790	1 885	1 930	1 973	1 938	1 871	1 843	1 829	1 790	1 786	1 817	1 865	1 884	1 892	1 917
TOTAL/ENERGY (*)	1 772	1 866	1 913	1 969	1 924	1 856	1 827	1 813	1 773	1 769	1 801	1.850	1 871	1 879	1 887

DIFFERENCE (INT1 - REF)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
FUEL (m$)		122 99	115 84	117 29	124 63	71 38	76 03	146 09	165 90	171 08	133 07	137 83	148 88	161 74	164 98
FIXED O&M (m$)							-				-	-	-		
VAR O&M (m$)		2 64	2 75	3 01	3 50	2 11	2 34	3 71	5 07	6 68	4 94	5 06	7 38	9 37	11 43
TOTAL (m$)		125 53	118 59	120 30	128 13	73 49	78 37	149 80	170 97	177 76	138 01	142 89	156 26	171 11	176 41
ENERGY (GWh)		2 951 40	3,382 60	3 664 50	3,965 70	2,880 30	3,101 40	5 560 80	5,987 55	6 450 30	5 851 20	6,289 70	6,761 40	7,265 30	7 806 88
TOTAL COST (m$)		125 52	118 53	120 38	128 05	73 74	78 47	150 03	171 16	177 79	138 43	143 37	156 68	171 50	176 86

TOT COST/ENERGY (*)	4 253	3 504	3 285	3 229	2 560	2 530	2 698	2 869	2 756	2 386	2 279	2 317	2 361	2 265
TOTAL/ENERGY (*)	4 253	3 506	3 283	3 231	2 551	2 527	2 694	2 856	2 756	2 359	2 272	2 311	2 356	2 260

(*) TOT COST/ENER is obtained by the use of WPP, while TOTAL/ENERGY is the result from WASP Both values are expressed in cents/kWh

First, the increase of generation should be taken into account. Since there is no constraint on LOLP, the generating system supplies the demand without taking into account system reliability but within the defined reserve margins. The result shows that Turkey can sell energy almost at the full capacity of the interconnection line. The amount of energy that could be sold to neighboring systems could be higher than the simple capacity of the transmission line, when taking into consideration the potential mismatch of the actual system load as a result of the problems associated to the load system data discussed in Section 2. In parallel with the energy increase the system unit generation cost increases. While the fixed O&M costs remain unchanged as compared to the Reference Case, fuel costs and variable O&M costs of generating units are higher.

When the results of this case are compared to the Reference Case, it is seen that this additional energy is produced by more expensive generating units in the Turkish electric system. This results in system generation costs higher than in the Reference Case. By using the differences of total system generation and associated costs of this case and those for the Reference Case, the unit generation cost of energy to be sold by Turkey can be determined.

Another important point is the change in LOLP and unserved energy. This case study shows that the system reliability index (LOLP) exceeds Turkey's Reference Case limits in the year 1997 that is the starting year of the interconnection between Turkey and the neighboring systems. In other words, Turkey can supply additional energy up to the capacity of the interconnection line but with a higher risk of energy shortage in 1997. In other years, the LOLP also increases but it remains within the accepted limits of the Turkish official Reference Case. (Table 2)

Another important result is the difference between Annual Project Generation (APG)[1] and expected generation from each power plant. The results of the study show that hydro, natural gas, domestic lignite (except CAYIRHAN with FGD) power plants operate almost at the level of project generation without interconnection. The additional energy to be sold is produced by expensive power plants in the Turkish system. (Table 3)

7. CONCLUSIONS AND RECOMMENDATION

It has been aimed to describe the use of WASP for determining the possibility of Turkey to sell electrical energy to a neighboring country's electric system through an interconnection. For the case study, the system load of Turkey has been increased by the amount of capacity of the interconnection line during 21 hours per day, three hours per day being assumed as peaking hours.

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[1] APG = (1-FOR) * (1-MAINTD/365) * CAPA*8760

where;

APG	:	Annual Project Generation Capacity (MWh)
FOR	:	Forced Outage Rate (%)
MAINTD	:	Maintenance day (days)
CAPA	:	Capacity (MW)

Because of the difficulties in obtaining information related to the characteristics of the power system of any other neighboring country intended to be connected with the Turkish electric system, the case study has been carried out by using only Turkish electric generation system data.

The study determined the amount and the cost of electricity that Turkey can sell to other electric systems. The amount of energy is found by running WASP with the increased system load as mentioned above without optimization (it means no new generation unit investment is allowed) but by simulating Turkey's Official Generation Expansion Plan with the modified system load. This run results in larger electricity generation than in the official Reference Case. The difference is the energy that can be sold by Turkey.

To determine the cost of this additional energy, the value of the generations, fuel costs, fixed and variable operation costs of the power plants are evaluated by using the WASP Post-processing Programs (WPP) mentioned in Section 4. From the additional generation amount associated costs, the unit cost of additional energy can be calculated.

The system reliability should be considered together with the cost and amount of energy that can be sold. In the case study, in the year 1997, the LOLP of the program exceeds Turkey's official limit.

To prevent the energy shortage risk in year 1997, the start up of the interconnection line can be postponed 1 year or, eventually, a new generation unit can be commissioned for addition to the Turkey's existing system. By adding a new generating unit, the reliability of the Turkish system would increase not only for 1997 but also for all preceding years. However, commissioning of a new generating unit would cause higher unit generation costs, because the construction, fuel and operation costs of the additional unit should be considered, and a new WASP optimization would have to be carried out.

Table 2
SYSTEM COSTS AND RELIABILITY INDICES

	YEAR	COST m$	LOLP %	LOLP DAYS	ENS HC1	ENS HC2	ENS HC3
REFERENCE CASE	1996	1,693,241	0.8512	3.11	9.9	0.4	327.8
	1997	1,861,400	1.4252	5.20	22.9	0.8	696.9
	1998	2,089,703	1.3840	5.05	24.3	0.9	288.2
	1999	2,324,288	1.8963	6.92	43.5	2.4	369.5
	2000	2,473,452	2.2736	8.30	56.8	2.1	560.3
	2001	2,614,959	1.6660	6.08	36.5	1.1	403.3
	2002	2,774,466	1.6972	6.20	38.3	0.9	920.5
	2003	2,939,356	1.7982	6.56	43.6	1.1	962.8
	2004	3,085,903	1.8418	6.72	45.6	0.9	1182.0
	2005	3,322,573	2.0366	7.43	56.2	1.3	898.2
	2006	3,667,370	2.2507	8.22	71.5	2.6	658.1
	2007	4,053,492	2.5392	9.27	91.0	4.0	761.4
	2008	4,398,407	2.5612	9.35	99.6	5.0	726.2
	2009	4,745,310	2.4187	8.83	92.2	5.1	724.0
	2010	5,174,588	2.2923	8.37	86.1	5.3	727.1

	YEAR	COST m$	LOLP %	LOLP DAYS	ENS HC1	ENS HC2	ENS HC3
INT1 CASE	1996	1,693,241	0.8512	3.11	9.9	0.4	327.8
	1997	1,986,917	5.2763	19.26	220.2	16.7	1442.1
	1998	2,208,234	1.7472	6.38	55.0	20.3	849.0
	1999	2,444,672	2.3414	8.55	78.1	24.4	781.3
	2000	2,601,497	2.8202	10.29	96.9	26.7	1395.1
	2001	2,688,696	1.8349	6.70	47.6	5.3	784.1
	2002	2,852,941	1.8633	6.80	50.3	5.7	1530.9
	2003	3,089,386	2.0718	7.56	119.4	59.6	2167.9
	2004	3,257,057	2.1370	7.80	127.9	61.3	2480.4
	2005	3,500,359	2.3733	8.66	146.8	70.8	2229.5
	2006	3,805,796	2.6660	9.73	122.5	38.5	1518.9
	2007	4,196,855	3.0210	11.03	143.9	44.3	1438.5
	2008	4,555,093	3.0343	11.08	157.2	48.7	863.3
	2009	4,916,813	2.8550	10.42	154.4	51.6	856.2
	2010	5,351,453	2.7013	9.86	152.6	55.0	860.3

	YEAR	COST m$	LOLP %	LOLP DAYS	ENS HC1	ENS HC2	ENS HC3
DIFFERENCE INT1 CASE - REF CASE	1996	-	0.0000	0.00	0.0	0.0	0.0
	1997	125,517	3.8511	14.06	197.3	15.9	745.2
	1998	118,531	0.3632	1.33	30.7	19.4	560.8
	1999	120,384	0.4451	1.63	34.6	22.0	411.8
	2000	128,045	0.5466	1.99	40.1	24.6	834.8
	2001	73,737	0.1689	0.62	11.1	4.2	380.8
	2002	78,475	0.1661	0.60	12.0	4.8	610.4
	2003	150,030	0.2736	1.00	75.8	58.5	1205.1
	2004	171,154	0.2952	1.08	82.3	60.4	1298.4
	2005	177,786	0.3367	1.23	90.6	69.5	1331.3
	2006	138,426	0.4153	1.51	51.0	35.9	860.8
	2007	143,363	0.4818	1.76	52.9	40.3	677.1
	2008	156,686	0.4731	1.73	57.6	43.7	137.1
	2009	171,503	0.4363	1.59	62.2	46.5	132.2
	2010	176,865	0.4090	1.49	66.5	49.7	133.2

Table 3

ANNUAL PROJECT GENERATION - REF CASE GENERATION

(GWh)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
HYDRO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AFSIN-ELBISTAN	30.8	52.9	152.6	370.2	423.2	604.6	634.8	752.6	1,143.3	817.4	712.1	708.0	851.4	665.7	491.9
SEYITOMER	1.1	1.1	0.9	0.9	0.9	0.9	0.9	0.9	1.2	1.0	1.0	1.2	1.0	1.0	1.0
TUNCBILEK A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TUNCBILEK B	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.6	0.5	0.5	0.5
YATAGAN	1.3	1.5	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Y. CATALAGZI B	127.2	141.3	212.0	558.6	550.0	554.6	541.2	550.5	1,206.0	1,316.9	1,345.5	1,364.3	1,515.0	1,782.8	1,810.9
SOMA A	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOMA B	1.5	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
CAYIRHAN	1,546.1	1,513.1	3,069.9	3,092.5	3,046.6	3,537.1	3,762.7	3,855.0	3,862.9	3,864.0	3,864.7	3,857.8	3,870.2	3,891.6	3,909.3
KANGAL	0.8	2.4	3.5	12.9	20.7	41.2	49.4	65.8	78.3	79.4	79.0	80.6	106.2	85.7	64.4
YENIKOY	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
KEMERKOY	-	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.2	1.2	1.1	1.2	1.2	1.2	1.2
ORHANELI	437.6	426.0	643.5	853.0	876.0	954.6	959.6	966.8	970.2	982.0	1,233.5	1,234.0	1,244.3	1,257.6	1,269.1
AMBARLI-HOPA	3,138.5	2,932.7	3,260.6	3,319.7	3,288.5	3,387.9	3,383.6	3,686.9	4,063.1	4,264.3	4,269.3	4,269.0	4,294.3	4,332.5	4,362.7
ALIAGA	1,256.0	1,250.9	1,252.2	1,247.9	1,244.3	1,250.0	1,249.2	1,248.7	1,248.3	1,248.1	1,247.2	1,243.7	1,244.0	1,245.1	1,246.9
OTHER GT	62.9	62.6	62.7	62.5	62.3	62.6	62.5	62.5	62.5	62.5	62.4	62.3	62.3	62.3	62.4
HAMITABAT	1,721.0	1,837.0	2,410.9	2,997.9	2,897.0	3,849.5	4,082.9	5,264.9	5,647.8	5,690.4	6,182.4	6,564.1	7,243.6	7,350.7	7,438.5
AMBARLI NG	247.7	307.8	567.5	945.8	1,152.1	1,877.2	1,956.9	2,391.0	2,403.6	3,784.2	4,919.9	5,604.7	6,121.8	6,325.8	5,977.4
PREVILIGED CO.	383.1	348.1	386.8	510.7	507.1	526.6	529.9	532.6	534.0	567.2	684.0	683.5	688.5	695.3	701.4
AUTOPRODUCERS	7,656.1	7,450.5	7,835.9	7,839.3	7,985.1	8,359.8	8,363.5	8,363.3	8,370.3	8,368.3	8,355.3	8,339.3	8,351.7	8,380.5	8,402.4
KEMERKOY (6 Month)	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LIGNITE (340 MW	-	-	-	-	1.1	2.4	3.0	4.1	4.6	4.6	5.6	6.6	6.6	7.2	7.1
LIGNITE (300 MW	-	-	-	0.7	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.0	2.0	1.8
LIGNITE (150 MW	-	-	-	-	-	-	-	-	0.3	0.5	0.5	0.9	1.0	1.0	1.0
AMASRA-CATALAGZI	-	-	-	-	-	-	-	-	-	-	-	-	-	1,759.3	6,720.8
IMPORTED COAL	-	-	-	-	-	-	-	-	-	1,659.5	3,256.6	5,052.5	8,836.0	10,296.5	10,472.3
NATURAL GAS	1.4	3.0	5.8	18.6	30.3	77.5	121.4	186.2	238.3	257.6	274.0	309.4	428.5	382.6	300.9
NUCLEAR	-	-	-	-	-	-	-	-	-	3.2	3.2	3.2	4.5	4.5	4.5

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TURKISH EXPERIENCE WITH THE USE OF IAEA PLANNING MODELS

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Abstract

Most of the IAEA planning methodologies for energy and electricity planning have been transferred to Turkey as part of Technical Co-operation projects on the subject matter. The transfer has been supplemented by adequate training to national experts through their participation in the above projects and in the training courses on these models organized by the IAEA. The experience gathered in the use of these models in Turkey is described in this paper, highlighting how the models are imbedded in the country's planning procedure for energy and electricity matters.

1. BACKGROUND INFORMATION

The continental setting of Turkey is described in Asia and the regional setting in Asia Minor. Turkey is a strategically located bridge between Asia and Europe. Occupying the whole of classical Asia Minor (Anatolia) and a small portion of Eastern Thrace in Europe, Turkey has a total area of about 780,000 square km. It is bounded on the north by the Black Sea; on the east by Georgia, by Armenia, by Nahcevan and by Iran; on the south by Iraq, Syria and the Mediterranean sea; and on the west by the Aegean Sea and the Sea of Marmara. In Europe it has frontiers with Greece and Bulgaria.

European Turkey, which comprises 3% of the land area, is separated from Asian Turkey by the Bosphorus, the Sea of Marmara, and The Dardanellas.

According to the last census, which was carried out in 1990, the population of Turkey was determined as 57 million in 1990 and it is estimated to be around 62 million in 1995, further increasing to 67 million in 2000 and 78 million in 2010. During the past decade the population growth averaged about 2.2 percent per year. An annual average growth rate of 1.6 percent is expected during the next 15 years.

Despite a slow migration to urban areas, about 38 percent of the population still live in rural areas. It is assumed that this percentage will be around 27% in 2010. The population density is 79 person per square kilometer. The population is concentrated in the west and along coastal areas. Istanbul, located on the Bosphorus, with a population of 7.3 million inhabitants is the largest city and the center of industry and commerce. Ankara, the capital city situated in the center of Anatolia, has a population of 3.3 million. The other large cities, Izmir, Adana, Bursa have populations of 2.7, 1.9 and 1.6 million respectively. Since the population growth is considered as too high for a developing country, now the Government's policy of encouraging population increase has been superseded by a policy favoring family planning.

Tables 1 to 4 present some statistical information on the principal economic indicators for Turkey, with special reference to the evolution of the Gross Domestic Product and its structure.

Table 1
Gross National Product/ At 1987 Prices (Billion Turkish Lira)

	1988	1989	1990	1991	1992	1993	1994
AGRICULTURE	13627	12562	13452	13420	13942	14112	14057
INDUSTRY	17094	17928	19552	20204	21581	25622	24159
Mining	1353	1468	1443	1493	1500	1484	1601
Manufacturing	14191	14660	16186	16685	17815	21628	19964
Energy	1550	1800	1923	2026	2266	2510	2594
SERVICES	39807	40381	43545	43774	46795	51567	49752
Construction	4907	5205	5141	5187	5494	6119	5992
Trade	14315	14053	15850	15743	17323	19489	18014
Transport&Com.	8616	8959	9981	10034	10832	11787	11541
Public Services	3859	3906	4019	4117	4259	4336	4371
Other Services	8110	8258	8554	8693	8888	9836	9834
GDP AT FACTOR COST	70528	70871	76549	77398	82319	91301	87968
NET FACTOR INCOME FROM ABROAD	-198	849	1013	534	922	1086	412
INDIRECT TAXES-SUB.	5778	5627	7030	6955	7082	5290	3429
GNP AT MARKET PRICES	76108	77347	84592	84887	90323	97677	91809

Table 2
Gross National Product Sectoral Growth Rates (%)

	1988	1989	1990	1991	1992	1993	1994
AGRICULTURE	8.0	-7.8	7.1	-0.2	3.9	1.2	-0.4
INDUSTRY	2.7	4.9	9.1	3.3	6.8	18.7	-5.7
Mining	-0.8	8.5	-1.7	3.5	0.5	-1.1	7.8
Manufacturing	2.1	3.3	10.4	3.1	6.8	21.4	-7.7
Energy	11.7	16.2	6.8	5.3	11.8	10.8	3.3
SERVICES	0.0	1.4	7.8	0.5	6.9	10.2	-3.5
Construction	-5.4	6.1	-1.2	0.9	5.9	11.4	-2.1
Trade	3.2	-1.8	12.8	-0.7	10.0	12.5	-7.6
Transport&Com.	0.6	4.0	11.4	0.5	8.0	8.8	-2.1
Public Services	1.9	1.2	2.9	2.4	3.4	1.8	0.8
Other Services	1.2	1.8	3.6	1.6	2.2	10.7	0.0
GDP AT FACTOR COST	2.7	0.5	8.0	1.1	6.4	10.9	-3.7
NET FACTOR INCOME FROM ABROAD	0.0	0.0	19.3	-47.3	72.7	17.8	-62.0
INDIRECT TAXES-SUBS.	-4.2	-2.6	24.9	-1.1	1.8	-25.3	-35.2
GNP AT MARKET PRICES	1.5	1.6	9.4	0.4	6.4	8.1	-6.0

Table 3
Composition of GDP by Sectors/At Current Prices (%)

	1988	1989	1990	1991	1992	1993	1994
AGRICULTURE	19.3	17.7	17.6	17.3	16.9	15.5	16.0
INDUSTRY	24.3	25.3	25.5	26.1	26.2	28.1	27.5
Mining	1.9	2.1	1.9	1.9	1.8	1.6	1.8
Manufacturing	20.2	20.7	21.1	21.6	21.6	23.7	22.7
Energy	2.2	2.5	2.5	2.6	2.8	2.8	3.0
SERVICES	56.4	57.0	56.9	56.6	56.9	56.4	56.5
Construction	7.0	7.3	6.7	6.7	6.7	6.7	6.8
Trade	20.3	19.8	20.7	20.3	21.0	21.3	20.5
Transport&Com.	12.2	12.6	13.0	13.0	13.2	12.9	13.1
Public Services	5.5	5.5	5.3	5.3	5.2	4.8	5.0
Other Services	11.4	11.8	11.2	11.3	10.8	10.7	11.1
GDP AT FACTOR COST	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4
Average Annual Exchange Rates of Turkish Lira

	US $	DM
1982	164.16	67.56
1983	228.47	89.25
1984	368.66	129.33
1985	524.97	180.84
1986	680.50	315.94
1987	859.97	480.24
1988	1425.87	810.54
1989	2125.02	1132.14
1990	2612.95	1623.89
1991	4181.93	2516.52
1992	6882.59	4428.89
1993	11007.99	6648.83
1994	37481.65	23817.23

As can be seen in Table 3, the share of the Agriculture sector in GDP fell constantly from 19% in 1988 to 16% in 1994, although the agricultural value added steadily increased. The fall, however, is not due to the agricultural sector being neglected but primarily due to the increase in the services sector. The share of the industrial sector in the total GDP which was 24% in 1988 increased to 28% in 1994.

Foreign trade has made great progress in the last decade as a result of increased investment and export incentives, as well as intensified efforts for outward orientation. The level of foreign trade with Middle East and Islamic Countries in particular, reached considerable heights. In addition, during this period, the share of Turkey's foreign trade in world trade increased.

The export which was US$ 11.6 billion in 1989 increased to US$ 17.5 billion in 1994. About 60% of the exports goes to OECD countries, 20% to Islamic countries, 5% to Eastern European countries. Of the total exports, 92% correspond to manufacturing industries, 6% to agriculture and 2% to mining products. The major exporting industrial sub-sectors are textiles, iron and steel industries.

On the other hand the imports grew with much higher growth rates in the same period (1989-1994), from US$ 15.8 billion in 1989 to US$ 23 billion in 1994. About 65% of the imports come from OECD countries, 15% from Islamic countries, 6% from Eastern European countries. Of the imports, 83% are for manufacturing industries, 15% mining and 2% agricultural products. The major imported products are machinery, crude oil, chemicals, petrochemicals, iron and steel products.

2. CURRENT ENERGY SITUATION IN THE COUNTRY

Turkey is not a rich country in regard to primary energy endowments. The primary energy demand of the country has been met through imports of crude oil, oil products, natural gas and hard coal.

Turkey's energy consumption has increased faster than production, so self-sufficiency in the energy supply has also declined. The primary energy production was 26.9 MTOE (million tons of oil equivalent) in 1994, i.e., 45% of the total primary energy supply (TPES) was met by indigenous production. The components of primary production in 1994 were: 45% coal, 15% oil and natural gas, 10% hydro, 30% non commercial and other renewable energy sources.

The total primary energy supplied was 59.5 MTOE in 1994. Although the dependence on oil has been reduced since 1980's, oil is still the major energy source with the biggest share of TPES (46%). Oil represented 73% of the total energy imports (Table 5). Natural gas started penetrating the energy market in the late 1980's and its consumption is increasing rapidly since. Natural gas consumption increased from 68 mcm (million cubic meters) in 1985 to 5400 mcm in 1994, of which 5300 mcm were imported, representing 8.3% of TPES. Oil and gas contributed by 53% to the Total Final Consumption (TCF), while the share of other fuels was 18% for coal and coal products, 11% for electricity and the rest for non commercial and renewable sources.

The primary energy production is expected to increase to 60 MTOE in 2010 with an average annual growth rate of 5.1% between the years 1994-2010. In the same period the total primary energy supply is expected to increase to 156 MTOE in 2010 with an average annual growth rate of 6.2%. Domestic energy production will represent only 38% of the total in the year 2010. As in the past, the difference between local production and the energy requirement would be met by imports.

Electricity demand will increase from 78 TWh in 1994 to 272 TWh in 2010. The total installed capacity has reached 21 GW at the end of 1994. The plants which have been operating or were under construction in 1994 will cover the demand for electricity up to the year 1997. In order to meet demand after this year, a long term programme was prepared by using the WASP model. According to the outcome of this model, the installed capacity will reach about 60 GW in 2010. Of the total generation, 36% would be produced by coal fired power plants, 18% by gas fired power plants and 39% by hydro plants in 1994. The shares in the total production are expected to be 43%, 23%, 29% in 2010 respectively. Because of its low calorific value most of the lignite production will be used in power plants. In order to protect the environment, all new lignite plants will be installed with FGD (flue gas desulphurization) units and there is a programme to install FGD units in existing plants which are polluting their surroundings.

Table 5
Energy Production and Consumption in 1994

Total Primary Energy Supply	59.5 MTOE
Primary Energy Production	26.9 MTOE
PEP %	45%

Structure of the Primary Production

Coal	45%
Oil and gas	15%
Hydro	10%
Non Commercial & Other	30%

Structure of Total Final Consumption

Oil and gas	53%
Coal & Coal Prod.	18%
Electricity	11%
Non Commercial & Other	18%

2.1 PLANNING PROCEDURE AND ORGANIZATION

2.1.1 Principal Organizations for Economic and Energy Planning and Their Interactions

The Ministry of Energy and Natural Resources (ETKB) is the main body of the Turkish energy sector, which directly reports to the Prime Ministry and was originally established in 1963 with the following objectives;

- to determine and implement national energy policy goals,
- to provide coordination between the Ministry's dependent and related institutions and other public and private entities,
- to prepare and/or control plans and programmes within the framework of a defined energy policy and
- to ensure the implementation of the plans and programmes.

All exploration, development, production and distribution activities for energy and natural resources are supervised and controlled by the Ministry.

The dependent and related institutions of the ETKB can be classified into three groups; the petroleum, solid fuels and electricity related entities. The "dependent units", the Mineral Exploration and Research Directorate, Electrical Power Resources Survey and Development Administration, and Petroleum Affairs are essentially research/survey oriented. General Managers of these bodies report to the Assistant Under Secretaries. The "related units" are State Economic Enterprises (KIT) a part of the public sector which are producers in the energy sector. The dependent and related units are briefly described below.

Dependent Units

1) **General Directorate of Petroleum Affairs (PI):** Within the framework of the Turkish petroleum law, the main activities of this organization are to give permission to Turkish and foreign companies for exploration, production and refining of oil; setting of product pricing; organization of Liquified Petroleum Gas (LPG) marketing; preparation of accounts related to the Fuel Price Stabilization Fund, Exploration Fund, etc.

2) **Mineral Exploration and Research Directorate (MTA):**MTA, established in 1935, is the oldest and the most important organization responsible for systematic investigation and research on all kinds of mineral resources.

3) **Electrical Power Resources Survey and Development Administration (EIE):** EIE supports and supplements activities of the State Hydraulic Works (DSI), concentrating especially on research for small hydro plants implementation. The EIE is also involved in foundation and map investigation and surveys with the aim of identifying the power potential of water resources and of preparing dam and hydropower projects. All kinds of studies related to research, development programme, etc., on new and renewable energies, and studies on energy conservation, are being carried out by this administration.

Related Units and Other Entities

1) **Turkish Electricity Generation Transmission Corporation (TEAS)**: TEAS is responsible for preparing and implementing the general electricity expansion plans and programmes for the national grid and power stations of the country; for construction of thermal power plants, and for establishing and operating electricity generation and transmission facilities. On the other hand there exists relatively small private power utilities and auto-producers belonging to both private and state utilities which contribute by only 8% to the total electricity generation.

2) **Turkish Electricity Distribution corporation (TEDAS):** TEDAS is responsible for distribution planning activities, electricity distribution and trade.

3) **Turkish Coal Enterprises (TKI):** TKI, established in 1957, is responsible for mining, marketing and trading lignite and asphaltite in the country. Private companies also produce about 4 million tons of lignite per year and make their own distribution.

4) Turkish Hard Coal Authority (TTK): TTK carries out exploration, exploitation and marketing of domestic hard coal. It operates the coal mines of the country which produce 4 million tons of bituminous coal every year.

5) Turkish Petroleum Corporation (TPAO): TPAO is responsible for exploiting, drilling, producing and refining petroleum in the country. TPAO owns more than three quarters of the refinery capacity. The Turkish Petroleum Office Inc. (Petrol Ofisi) was delegated with the responsibility of distributing petroleum and petroleum products.

6) Petroleum Pipeline Corporation (BOTAS): BOTAS is the main agency for installation and operation of oil and gas pipelines throughout the country. It is also authorized to sign and execute the contracts for natural gas imports, prepare plans and programmes for utilization of this gas in various sectors and distribution of the gas to various cities and consumer sectors.

7) Turkish Petroleum Refineries Corporation (TUPRAS): TUPRAS's main field of activity is processing crude oil for the purpose of meeting country's requirement for petroleum products, importing petroleum products required to cover country's domestic needs. There is also one private (foreign) refinery active in the energy sector, ATAS, which holds 13% of the total refinery capacity.

8) State Hydraulic Works (DSI): DSI was established in 1953 to plan, design and construct works for flood protection, irrigation, drainage water supply and waste water disposal purposes. It is also responsible for determination of the hydraulic potential, preparing feasibility studies, making decisions for ranking dams and hydroelectric projects, constructions of dams and hydroelectric stations. Upon completion of the construction of hydroelectric stations, they are handed over to TEAS for the operation.

9) Turkish Atomic Energy Authority (TAEK): TAEK, a research organization, is responsible for preparing and implementing the nuclear energy plans and programs for the country. TAEK, in co-operation with several universities, concentrates on uranium and thorium exploration, extraction refinement and conversion and nuclear fuel cycle and safety.

The Ministry of Environment has the sole responsibility for planning, implementing and coordinating all environmental issues in the energy field to ensure sound environment in close cooperation with the other Ministries and all related institutions.

General energy policy is the responsibility of the Ministry of Energy and Natural Resources (ETKB). The State Planning Organization (DPT) is responsible for overall economic planning and thus there is a close linkage between the two organizations. Recommendations for budget and policy priorities are made by ETKB but the DPT has the final authority. The DPT works closely with the Office of the Prime Ministry.

2.1.2 Planning Procedure, Analytical Tools Used and Frequency of Planning Exercise:

The analysis of future energy needs corresponding to the sets of socioeconomic development scenarios for Turkey is carried out by using a simulation model called MAED (Model for Analysis of Energy Demand) and the investigation of the optimal electric generation system expansion program with a model called WASP (Wien Automatic System Planning Package). Both models were developed by the IAEA and transferred to Turkey in 1985 within the framework of the co-operation effort between the Agency and the Government of Turkey.

The Ministry of Energy and Natural Resources is responsible for preparing and implementing the analysis of future energy and electricity demand and TEAS (Turkish Electricity Generation and Transmission Corporation) is responsible for preparing and implementing the studies related to determination of the electric power demand and of the optimal electric system expansion programs. Since 1989, another model named VALORAGUA (A Model for the Optimal Management of a Hydro Thermal Electric Power System) has been used for electricity generation planning studies in conjunction with WASP Model.

MAED - Model for Analysis of the Energy Demand

The computer model MAED is a simulation model for evaluation of the medium and long-term demand for energy in a country. The model includes modules to convert annual electricity demand to hourly consumption, i.e., to the power demand on the grid. In this way, the MAED results can be used to study the optimization of the electric generation system.

MAED is designed to reflect structural changes affecting energy demand by means of a detailed analysis of the social, economic and technical system. This approach takes account of: - demographic development (population growth, human settlements, etc.); - changing social needs of the individuals; - industrial policy of the country; - policy with regard to transport and other matters as well as technical progress.

The model is also designed to reflect trends in the potential market for each final energy form, electricity, coal, gas, oil, solar energy, etc.

The following sequence of operations is undertaken: Analysis of the structure of the country's final energy consumption, identification of the social, economic and technical factors influencing final demand, specification of the functional links between energy consumption and resulting factors, construction of scenarios of socioeconomic and technical development, and finally evaluation of the energy consumption corresponding to each scenario.

WASP - Model for Electricity Generation System Expansion Analysis:

The optimization analysis of the expansion of the electricity generation system is carried out using the WASP model.

The WASP model is designed to find the optimal expansion plan for a power generating system which will meet the forecasted electricity demand over the planning horizon while satisfying certain user-specified constraints. The economic criteria for comparing alternative expansion plans of the system is represented by the total costs of the plan, including investment costs of the power plants added by the plan, total operating costs (fuel and operation and maintenance costs) of the resulting system, plus the cost of the energy not served. All costs are expressed in present worth value at a reference data chosen by the user and based on a discount rate also specified by the user. The constraints that can be taken into consideration are the reliability of the system, in terms of the reliability index called Loss-of-Load-Probability (LOLP) and the reserve margins (% of the demand), and the schedule of plant addition.

The basic input data for the WASP model includes the following items:

- System load characteristics (annual peak demand, seasonal peak demands and the load duration curves for each period into which the year is subdivided).
- Characteristics of all generating plants considered in the study (i.e. operating levels, heat rates, plant unavailability, etc., for thermal plants and the seasonal characteristics of hydroelectric power stations).
- Operating costs (fuel and operation and maintenance costs) for all generating units.
- Loading order of the plants.
- Investment costs (construction cost including interest during construction and fuel inventory cost) for the generating plants used as expansion candidates.
- Other economic information such as discount rate and escalation rate and the unit cost of each kWh of unserved energy.
- Constraints to be used in the exercise including the required limit of LOLP, reserve margins and schedule of plant additions.

VALORAGUA - A Model for the Optimal Management of Hydro Thermal Electric Power System:

The objective of the VALORAGUA model, which was developed by the Electricidade de Portugal (EDP), is to take into consideration the technical, physical and operational constraints that affect the generation of the system and the random conditions (water inflows of hydroelectric power plants, power demand, availability of the generation system) to determine the most economic operational policies of a system.

The VALORAGUA model was conceived to minimize the operation cost for a given configuration of an electric power system. These costs are the sum of the operation costs of thermal power plants, the cost of imported energy and the cost of energy not served, minus the benefits from exports and sales to special consumers.

Basic inputs of the VALORAGUA model are the following:

- power demand, load duration curve,
- thermal power plants: installed capacity, availability at each load step, average operating cost, maintenance duration,
- hydroelectric power plants: from the standpoint of reservoir parameters, the maximum and minimum reservoir volume, storage capacities, volume level curves from the stand point of the hydroelectric power plants, the definition of cascades, the minimum tail water level, the volume of turbine water, maximum flow capacity, head loss, turbine/generator efficiency,
- monthly tributary inflows (maximum 30 years),
- the capacities of the transmission lines, lines operating voltages, etc.

The results provided by the model include the following:

- the generation of the thermal and hydroelectric generation sub-systems together with the marginal operating costs, and the total generation;

- the operation of the reservoirs of hydroelectric power plants: the volume of water that spills and that is used in turbines, the water levels of the reservoirs,
- the operation of hydroelectric power plants: the amount of power that can be drawn from the power plants at each step of the load curve, the benefits derived from the electrical energy generated during each time period,
- the operational results of thermal power plants: the amount of power that can be drawn from the power plants at each load step of the load curve, the benefits of the electrical energy that was generated during the time period.

BALANCE Model:

The purpose of the BALANCE module of the ENPEP package is to project energy supply and demand balances for any study period.

The BALANCE module processes a representative network of all energy production, conversion, transport, distribution, and utilization activities in a country or region, as well as the flows of energy and fuels among those activities. Nodes of the network represent energy activities or processes such as refining, while the links of the network represent energy fuel flows and associated costs among those specific activities.

The balances are constructed based on the relative economics of the alternative sources of supply and technology needed to meet the final demand, subject to the constraints that may exist on processing capacity and government regulations affecting energy uses and prices.

The following information is necessary to describe the energy sector for BALANCE:

- Energy network,
- Base-year supply and demand balance,
- Reserves, capacities, and costs of productions,
- Energy processing efficiencies, capacities, and capital and operating costs,
- Electric sector data, such as load duration curves,
- Demand projections for the study period,
- Import fuel price projections.

BALANCE uses this description of the energy sector and the demand projections to balance energy supply and demand using the equilibrium approach. BALANCE computes annual energy flows and energy prices for all energy activities (each link of the energy network). BALANCE is not an optimization model, but instead simulates and describes energy market choices that are made by producers and consumers.

This module was introduced in Turkey by IAEA in 1993 and since then, studies have been carried out to develop the efficient use of the module. However many problems have been faced both in collecting data and application of the module.

The equivalent unit used in BALANCE does not match Turkey's practice of using TOE (Ton of Oil Equivalent) in all energy statistics and planning studies. The MAED model also uses TOE units. BALANCE uses BOE (Barrel of Oil Equivalent) as the energy unit for calculating purposes. This implies that it is necessary to convert all the input data of BALANCE to BOE and all the outcome of the module to the equivalent unit used in Turkey

(TOE) manually every time. This is time consuming and increases the work load of Turkey's planners[1]. Consequently, it is suggested to modify the BALANCE module in order to allow the use of the TOE as unit instead of BOE.

Turkey case study (BALANCE) has been run by selecting a 18 year-period (1993-2010) and taking 1993 as a base year. But some difficulties are faced in the interpretation of the outcome of the module because Turkey users are not familiar with BOE.

The Turkish energy network is dimensioned as follows (see Figs. 1 and 2):

• depletable resources nodes	17
• renewable resources nodes	3
• decision/allocation nodes	23
• conversion nodes	5
• multiple output nodes	1
• stockpile nodes	6
• demand nodes	42
• price regulation nodes	6

Some of the assumptions used in the study include the following:

- the reserves of the resources are unlimited,
- transportation of the resources and products, except for electricity, is neglected,
- the distance factor is neglected in the cost calculation (the spatial distribution effect of resources is neglected),
- the prices of resources do not change overtime,
- total and individual capacities of the conversion process facilities are unlimited,
- the efficiency of nuclear, coke and natural gas conversion process facilities is 100%,
- all refineries (5 refineries) of the country are represented as one refinery with approximately 235 million BOE per year capacity,
- the refinery profit factor is taken as 4%,
- different demand projections (taken from output of the MAED module) are used for describing the sectors' demand growth rate,
- in the case of refinery products (diesel, gasoline, LPG, kerosene, residual oil, heating oil), excess production will be either exported or stockpiled,
- the planning period was selected 18 years (1993-2010) and 1993 was taken as the base year in all calculation.

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[1] For example, the amount of domestic natural gas is 182 TOE in 1993. It is then necessary to multiply this value by 7 (conversion factor between BOE and TOE) in order to prepare the data for use in the BALANCE module. Viceversa, in order to incorporate the BALANCE results into the reports normally prepared in Turkey, it would be necessary to divide these results by 7. Obviously, this is time consuming. On the other hand, while these values are being converted (from TOE to BOE or vice versa) the probability of error is very high.

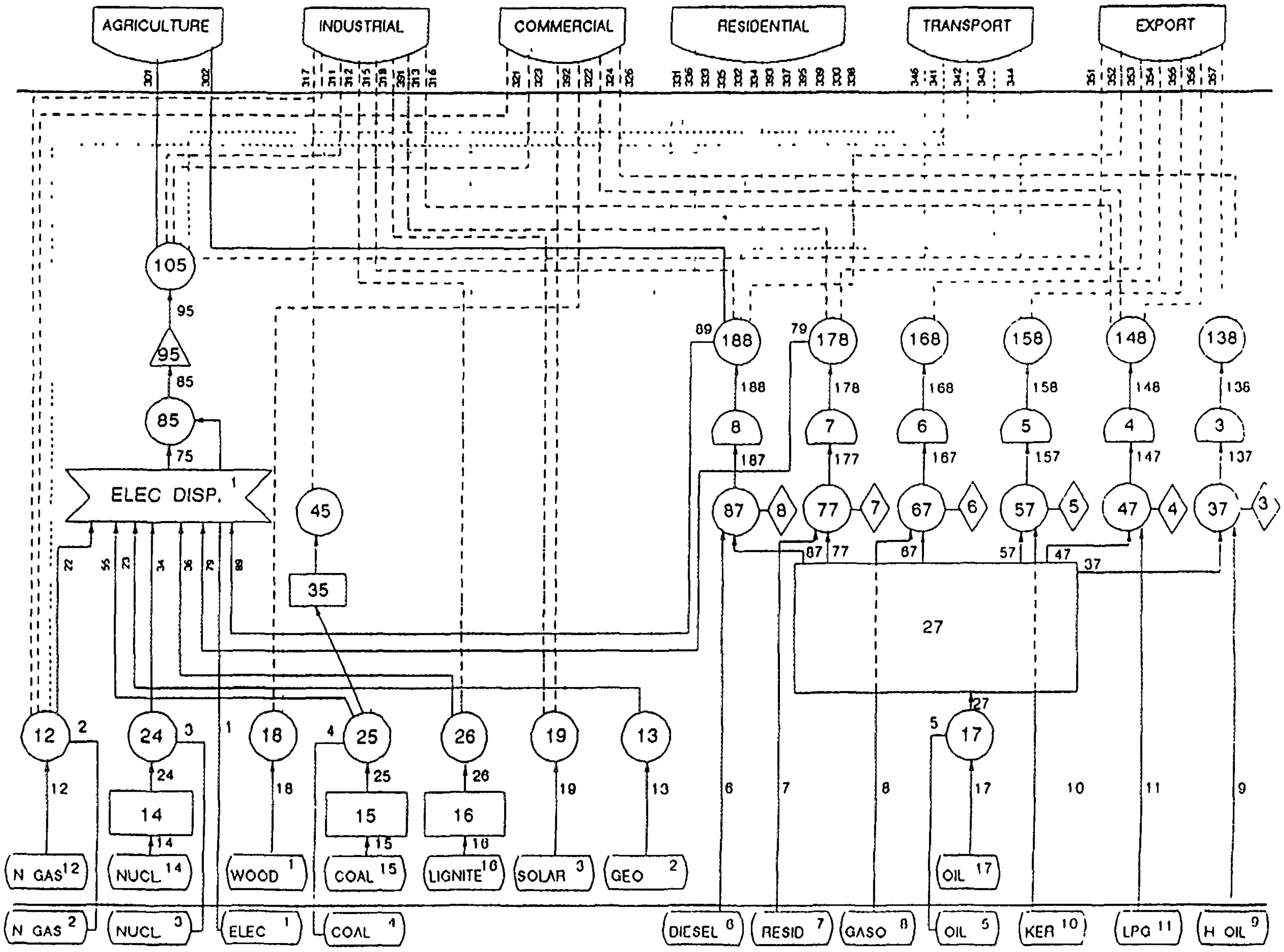


Figure 1: Energy Network

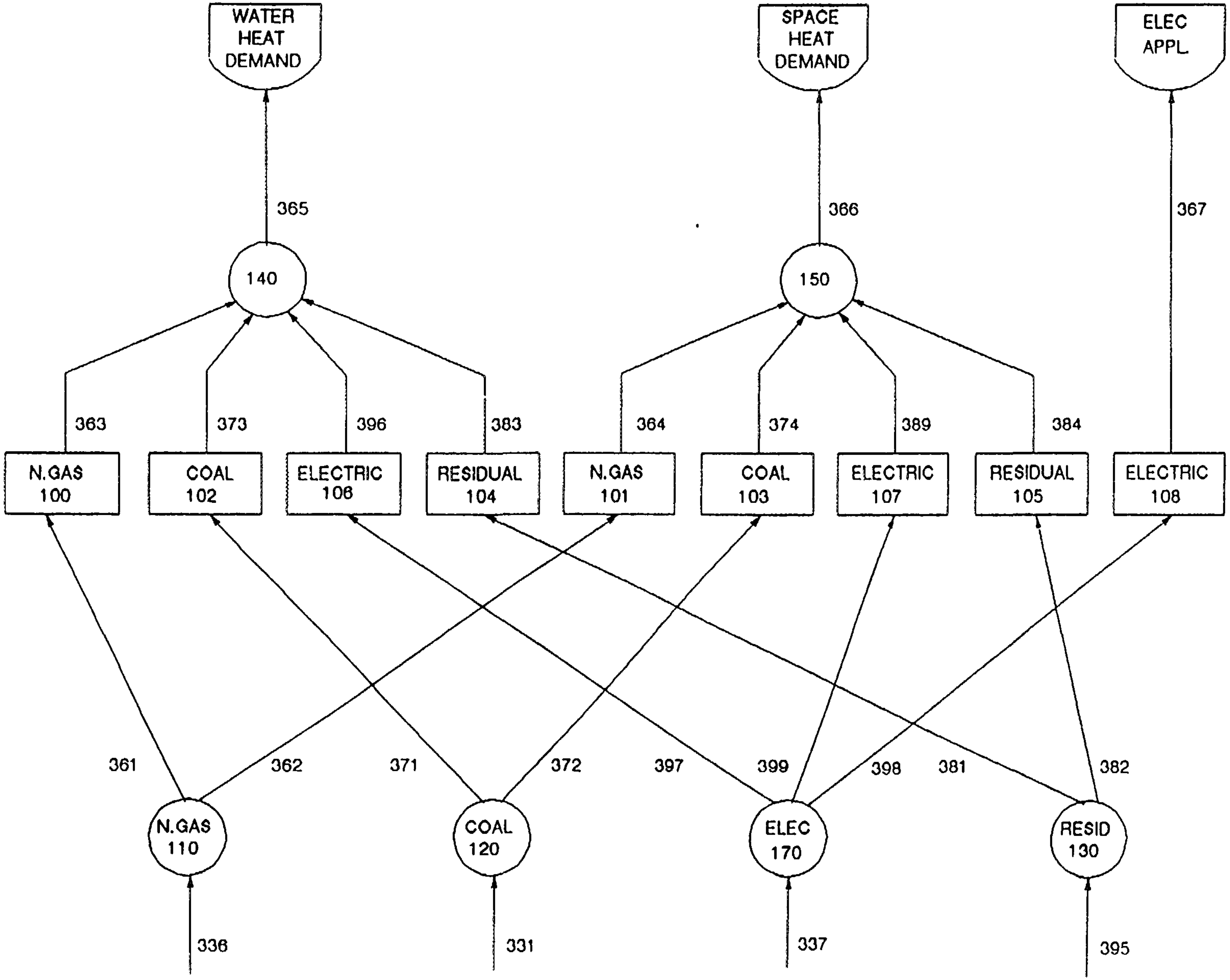


Figure 2: Residential Sub-Network

Depletable Resource and Import Fuel Process Data:

The supply curve data was taken from the country data and statistics from the International Energy Agency (IEA). The base year quantities for the resources and oil products were taken from ETKB Statistics (Ministry of Energy and Natural Resources). The annual capacities of resources were considered to be limited. No price change was considered in the study.

Renewable Resource Process Data:

Wood, solar and geothermal resources were described as renewable resources. Waste and wood were described by the same step function whereby waste, without any price, was represented in the first step, while wood was represented with some price in the second step. The base year quantities were taken from ETKB's reports.

Decision/allocation Node Data:

Base-year split were obtained from the reports prepared by ETKB. The premium multiplier, price sensitivity and lag parameters were selected with a heuristic approach. In the supply of refinery products such as oil, LPG, kerosene, residual oil and gas provided from domestic resources have priority. Natural gas and hard coal have priority in space heating.

Conversion Process Data:

No data on total capacity investment and O&M costs were available. Therefore, the total capital investment and O&M costs were taken as 0. The capacity of individual plants was assumed to be unlimited.

Demand Process Data and Energy Demand Growth Data:

Five demand growth rate projection sets were used for the study, one set being used for one or more sectors (0, 1%, 10%, 6%, 8%). These growth rates were taken from the MAED results.

Multiple Output (Refinery) Process Data:

Output ratios of refinery products (gasoline, LPG, heating oil, diesel, residual oil and kerosene) were obtained from the reports prepared by ETKB. Capacities of individual units were taken from the Turkish Petroleum Activities report.

Stockpile Data:

The following energy resources were assumed to have stockpiles:

- gasoline,
- LPG,
- heating oil,
- diesel,
- residual,
- kerosene

Price Regulation Process Data:

Since the refinery products have different selling price in the country, the price multiplier was calculated using Turkey's reference prices. No price addition was considered.

Electric Sector Data:

Base year production values were taken from the last WASP run performed by TEAS. Reserve margin was accepted as 15%. The Snyder Method was selected as the load duration curve approximation method. The value of the interest rate was selected as 10%. Other information was imported from the ELECTRIC module of ENPEP.

Results and Discussion:

Energy production using various domestic fuels during the planning period increases from 165 BOE/year to 360 BOE/year. Lignite resources have a major role in the Turkish energy production and there is a significant increase in the quantity used for energy production.

The most important energy resource for electricity generation will be hydro. Based on the latest long term generation expansion study carried out by means of the WASP-III model, lignite will have an important share in electricity generation. Since new hard coal units (both domestic and imported) will be commissioned after year 2005 there will be a sharp increase in consumption of this fuel type after that year. The first nuclear power plant would be on line in 2005. Consumption of oil in the electric sector will decrease during the planning period.

In the year 1995, energy demand will be expected to be around 445 million BOE/year (see Fig. 3). Approximately a 100% increase will be expected in the total energy demand by 2010. The industry sector will have the biggest share of this total.

The share of the residential sector in the total energy demand is around 22%, which means approximately 86 million BOE/year, 92 million BOE/year and 111 million BOE/year in the years 1995, 2000, 2010 respectively (Table 6). In 1994, oil consumption in the residential sector had the highest share. Although this consumption will increase very slowly as compared to other energy types, its share will still be the highest in this sector in the year 2010.

Table 6

SECTORAL ENERGY DEMAND FROM BALANCE

(Million BOE)

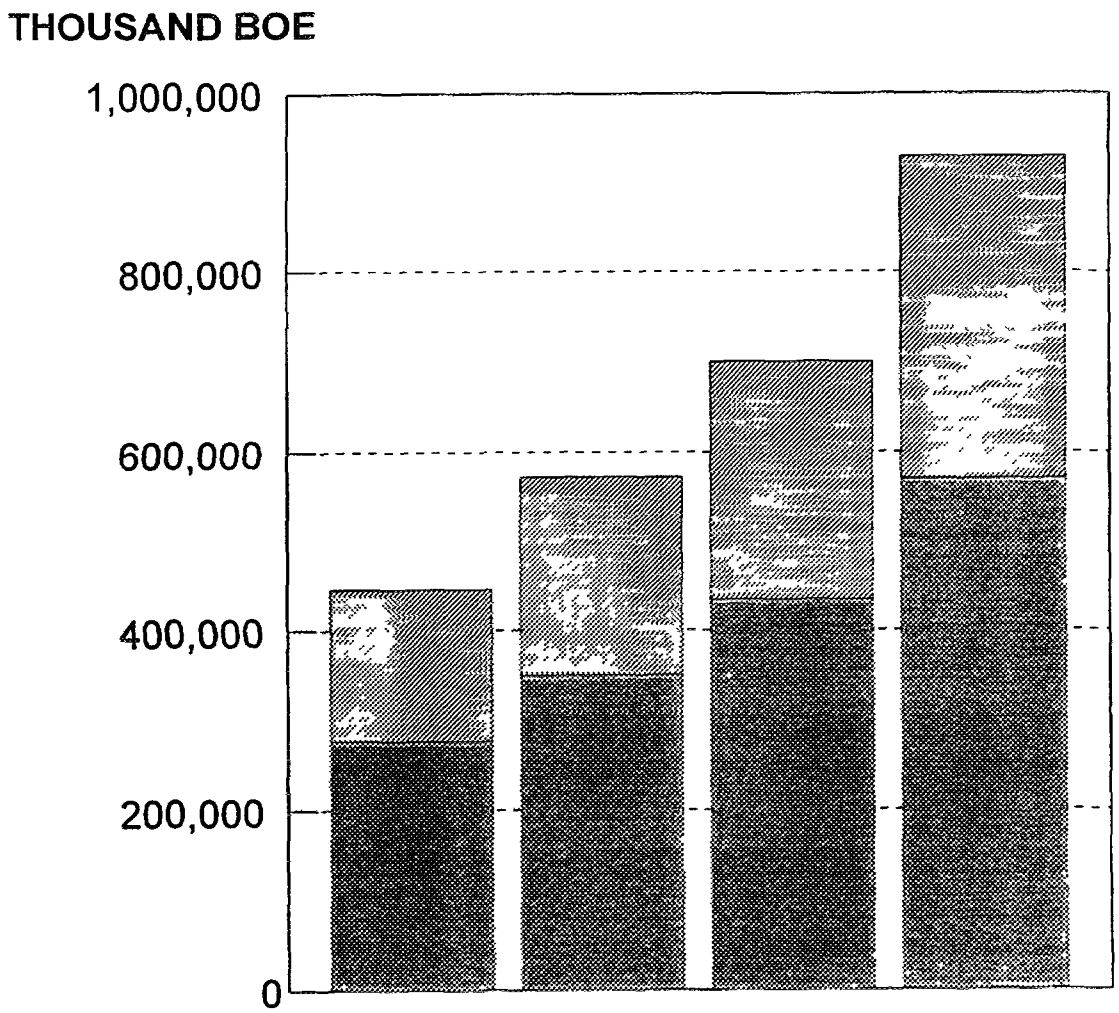
Sector	1995	2000	2010
Agriculture	18	24	44
Industry	118	157	296
Residential	86	92	111
Commercial	44	50	62
Trasportation	72	87	134
TOTAL	338	410	647

Regarding fuel imports for energy production, the quantity of the imported resources such as crude oil, residual oil, natural gas and coal tend to increase during the planning period with crude oil representing the major imported energy resource. The quantity of other imported resources, that are used to produce energy, are constant and insignificant during the period.

The results obtained from the application of the BALANCE Module to Turkish energy system are summarized in some graphs. Energy production using various domestic fuels during the planning period is shown in Figure 4. As can be seen in the figure, lignite has a major role in the Turkish energy production and there is a significant increase in the quantity to be used in the future. Wood and waste is the second major domestic resource although the amount concerned is constant over the study period. Although oil has a significant market share at the beginning of the period, it can be noted from the figure that oil share will notably decrease until the end of the period. Also, a slight increase in domestic hard coal consumption can be seen from the figure.

Electricity generation by the various primary resources during the planning period is shown in Figure 6, which indicates that the most important energy resource for electricity generation during the planning period will be hydroelectricity. Based on the model results, it can be expected that lignite will have an important share in the total electricity generation.

On the other hand, the results of the model indicate that the first nuclear power plant can be commissioned in the Turkish interconnected system after year 2005. Based on the model predictions, it is expected that the share of nuclear plants in electricity generation will increase.

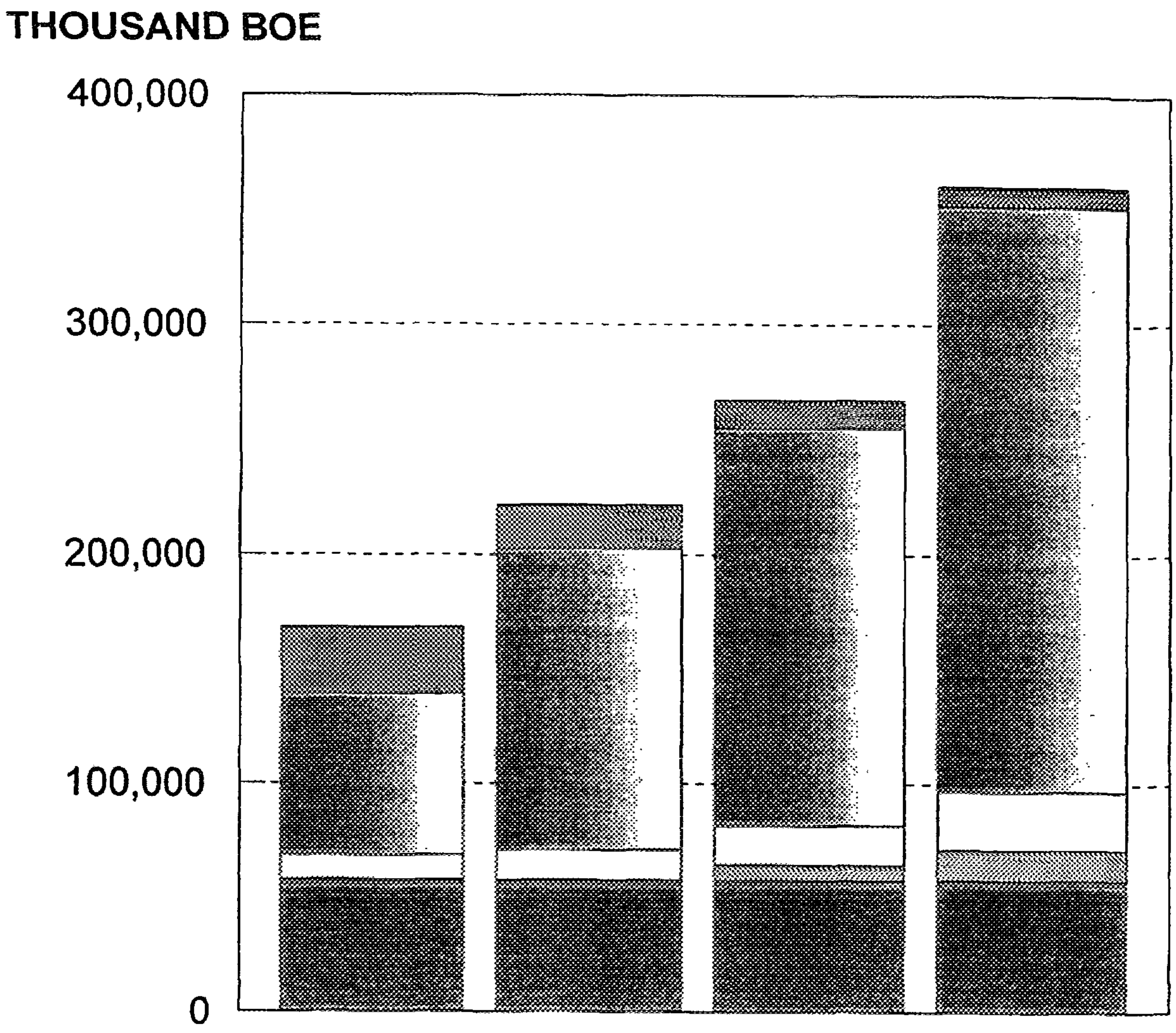


	1995	2000	2005	2010
IMPORTED ENERGY	277,402	350,202	432,813	569,370
DOMESTIC ENERGY	167,977	221,511	267,331	360,416

FIGURE 3

IMPORTED ENERGY AND DOMESTIC

ENERGY PRODUCTION

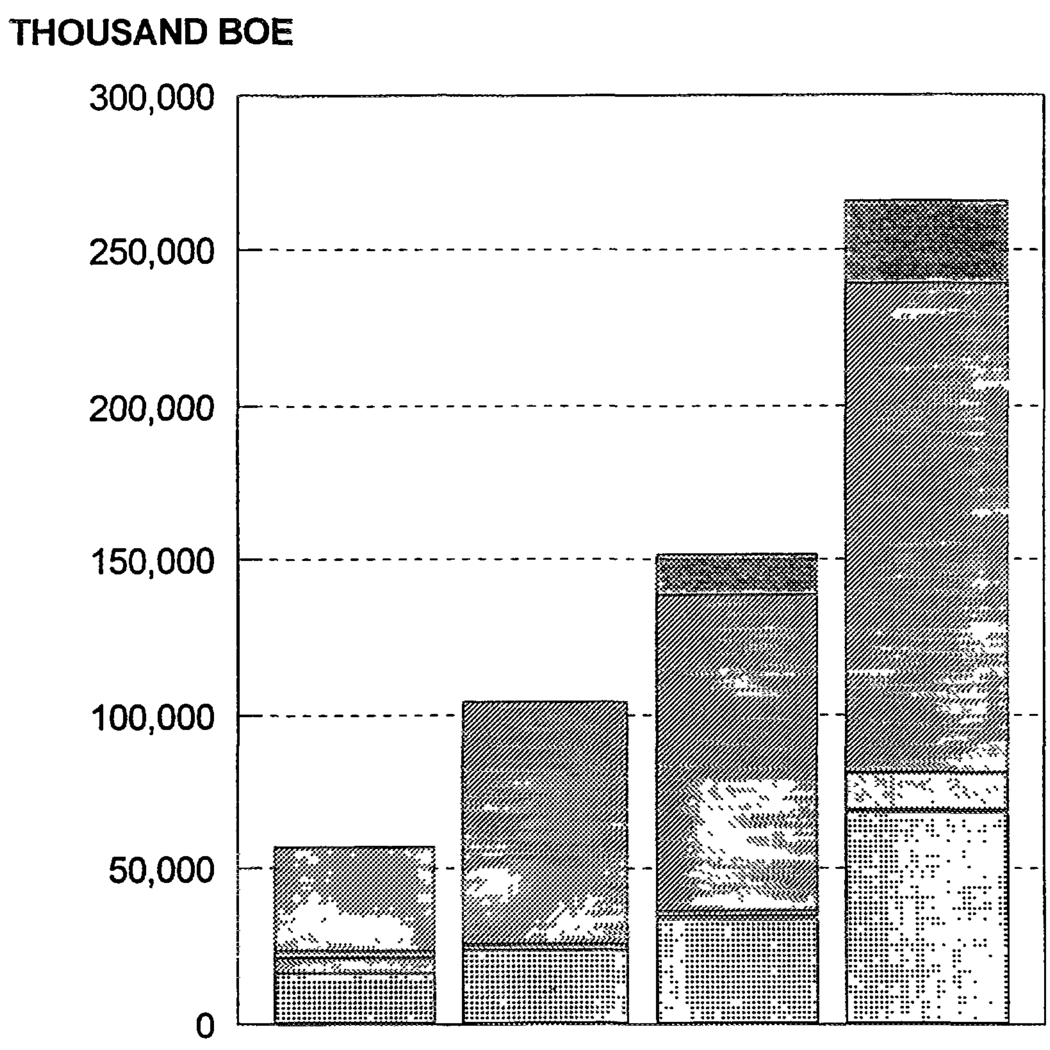


	1995	2000	2005	2010
WOOD	55,615	55,615	55,615	55,615
N.GAS	1,500	1,500	1,500	1,500
GEO	745	745	745	745
NUCLEAR	–	–	6,708	13,416
H.COAL	10,872	13,449	17,692	25,608
LIGNITE	70,184	131,444	172,696	255,009
OIL	28,753	18,300	11,675	7,435
SOLAR	308	458	700	1,088

FIGURE 4

DOMESTIC ENERGY PRODUCTION

BY FUEL

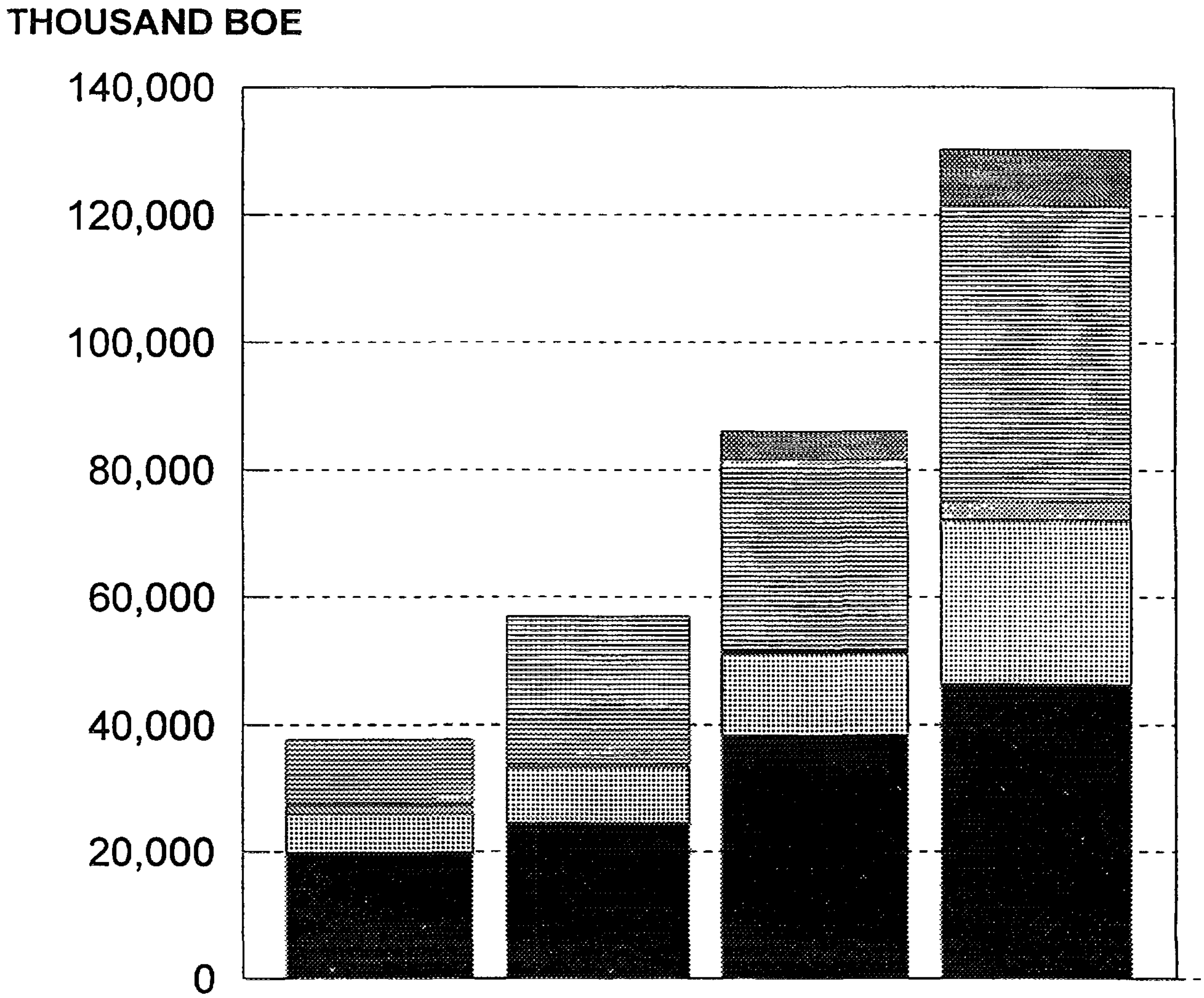


	1995	2000	2005	2010
GEO	535	535	535	535
N.GAS	16,020	23,355	33,012	67,449
RESIDUAL	5,025	1,583	1,163	947
H.COAL	2,155	554	1,610	12,146
LIGNITE	33,323	78,364	101,984	157,990
NUCLEAR	--	--	13,416	26,833

FIGURE 5

THERMAL ENERGY REQUIREMENT

BY FUEL TYPE



	1995	2000	2005	2010
HYDRO	19,757	24,388	38,318	46,164
GEO	51	51	51	51
N.GAS	6,133	8,942	12,639	25,825
RESIDUAL	1,466	462	340	276
H.COAL	491	126	367	2,768
LIGNITE	9,760	22,951	29,869	46,273
NUCLEAR	--	--	4,402	8,804

FIGURE 6

ELECTRICITY GENERATION

BY FUEL FUEL TYPE

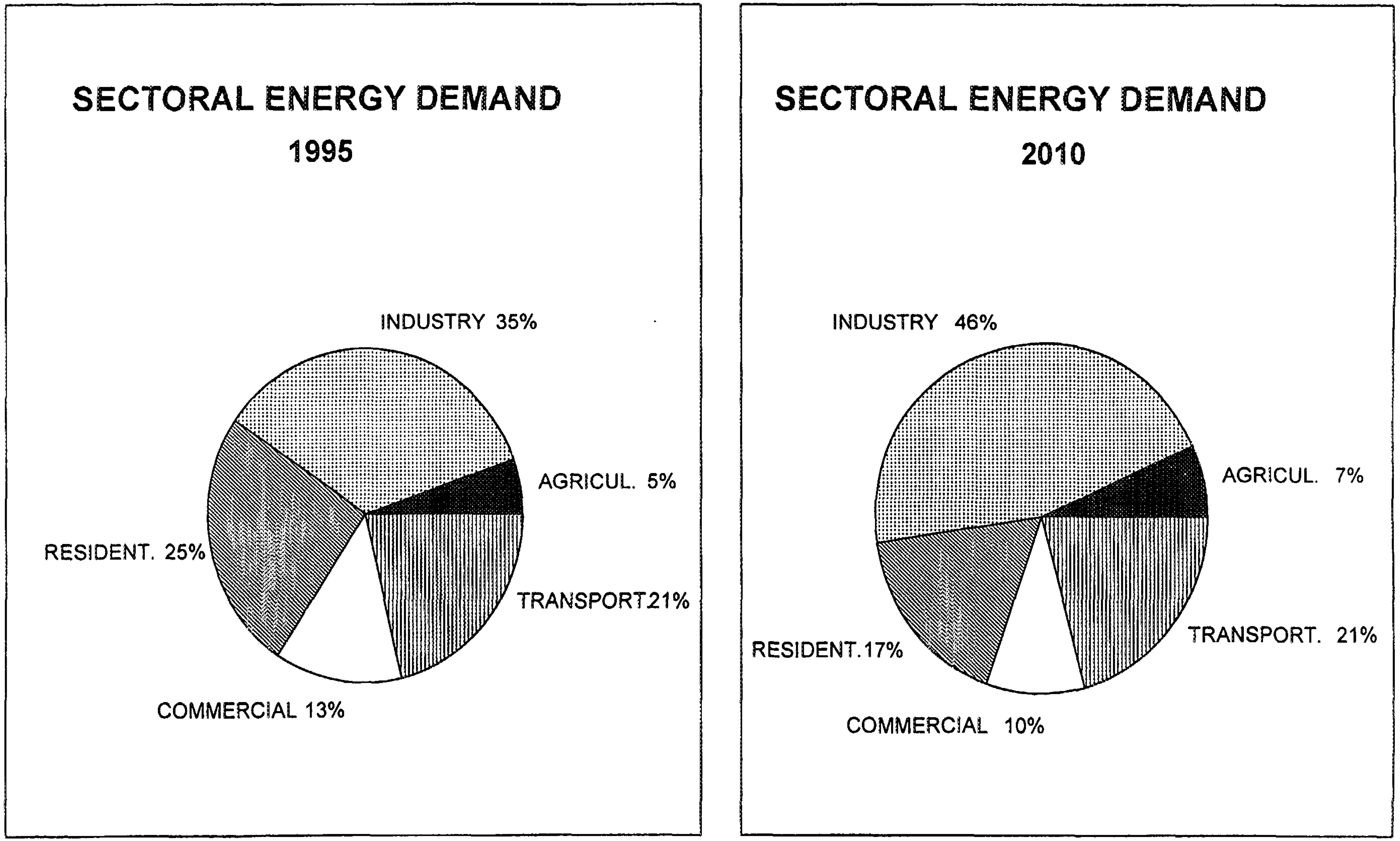

SECTORAL ENERGY DEMAND
1995
INDUSTRY 35%
AGRICUL. 5%
TRANSPORT 21%
COMMERCIAL 13%
RESIDENT. 25%
SECTORAL ENERGY DEMAND
2010
INDUSTRY 46%
AGRICUL. 7%
TRANSPORT. 21%
COMMERCIAL 10%
RESIDENT. 17%

FIGURE 7

XA9745313

DEVELOPMENT OF THE UKRAINIAN POWER SECTOR TAKING INTO ACCOUNT THE ENVIRONMENTAL IMPACT OF POWER FACILITIES

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Abstract

This paper concentrates on the following problems:

- evaluation of total environmental impacts from all kinds of power plants on the whole territory of Ukraine,
- evaluation of environmental impacts in selected regions due to uneven power facilities distribution.

Analysis of the environmental situation in Ukraine was conducted using the IMPACTS module of the ENPEP package with account to the Ukrainian energy requirements in perspective. Some recommendations concerning the development of power facilities and reduction of air emissions are also given.

1. BACKGROUND INFORMATION

1.1. Geography and Location

Ukraine is situated in the center of Europe. The country occupies 603,700 square kilometers. The climate is warm and rainy. The average winter temperature is between -3 °C and -7 °C and the average summer temperature is approximately +20 °C to +25 °C.

1.2. Population

The total population is 52.2 million and the population density is 85.2 persons per square kilometer, with 68% of the people living in cities and towns and 32% in rural areas. Table 1 shows the growth rate of population in Ukraine over the period 1989-1994.

Table 1

POPULATION (millions)

	1989	1990	1991	1992	1993	1994
Total population	51.7	51.9	52.1	52.2	52.1	52.1
Urban population	34.6	35.1	35.3	35.4	35.4	35.4
Rural population	17.1	16.8	16.8	16.8	16.7	16.7
Growth rate, %	0.4	0.4	0.4	0.2	-0.2	0

1.3. Economic Situation

The economic situation of the country has declined over the latest years as the result of market reforms. The economic evolution can be expressed in terms of its Gross National Product (GNP). The changes in the composition of GNP over the period 1985-1993 are shown in Table 2.

Table 2

STRUCTURE OF GROSS NATIONAL PRODUCT (%)

Sector	1985	1990	1991	1992	1993
Industry	102.7	99.3	95.2	93.6	92.6
Agriculture	99.0	96.3	86.8	91.7	100.9
Building	97.0	99.5	91.8	74.7	60.8
Transport	100.4	94.8	89.3	88.5	80.1
Other	102.9	111.5	90.3	82.0	64.5
Total	102.1	97.6	92.5	89.8	90.6

1.4. Electricity Sector

The fuels used for electricity generation in Ukraine include gas, mazut and coal. In the last years the share of natural gas, mazut, and coal decreased by 4%, 38% and 15% respectively. The country was forced to buy some quantities of oil as well as natural gas abroad, in order to run the existing power plants.

The production of the domestic fuel resources is shown in Table 3.

Table 3

PRODUCTION OF DOMESTIC ENERGY RESOURCES

	1985	1990	1991	1992	1993	1994
Oil (million t)	5.8	5.3	4.9	4.5	4.2	3.6
Gas (billion m^3)	112.5	127.6	111.2	109.6	95.5	81.2
Coal (million t)	189	164.8	135.6	133.7	115.7	98.3
Mazut (million t)	17.9	19.1	18.6	15.74	13.98	11.9
Electric energy (billion kW*h)	272	298.5	278.7	252.5	227.4	201

It should be mentioned that seven new deposits of natural gas have been commissioned recently. The estimated volume of the gas stocks is 34 billion m^3. According to this, it is expected that, the share of gas in the total fuel consumption for power plants will increase in the future. However, it should be noted that a significant part in the demand for gas is met by imported gas. The consumption of energy resources for electricity generation in Ukraine is shown in Fig. 1.

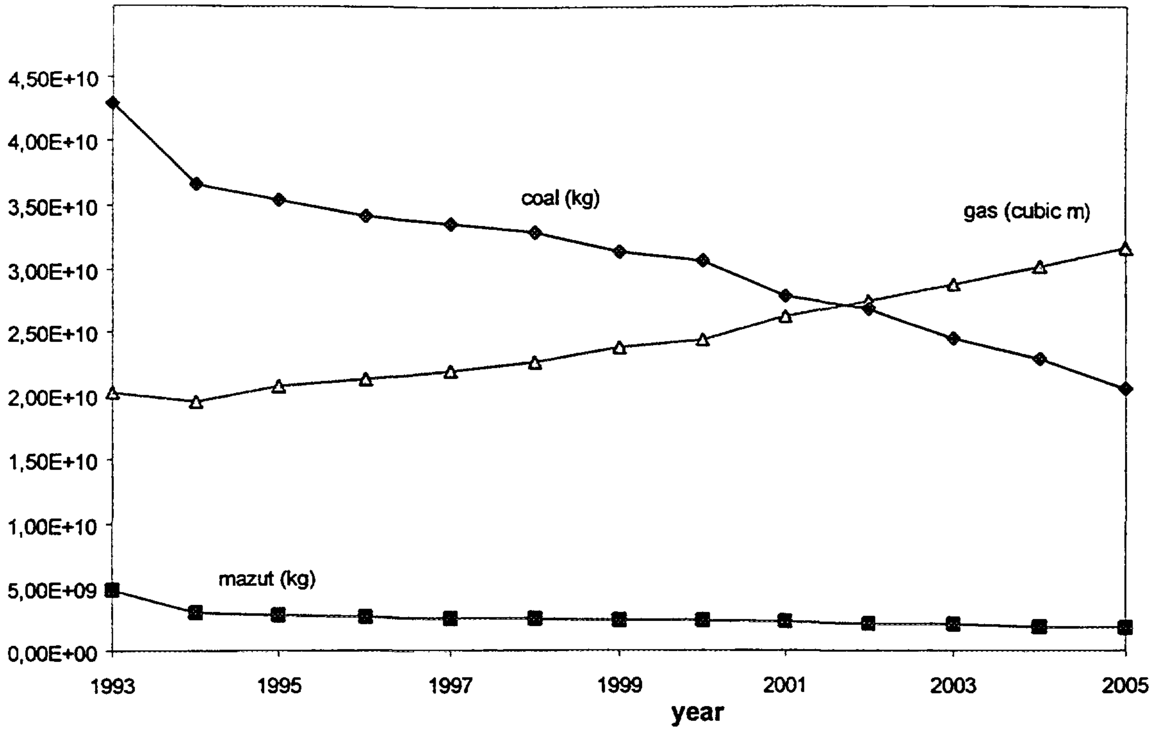

Fig. 1. Consumption of energy resources for electricity generation

Historical data on electricity generation (billion kW*h) in Ukraine are shown in Table 4.

Table 4

ELECTRIC POWER OUTPUT (billion kW*h)

	1985	1990	1991	1992	1993	1994
Thermal power stations and Hydroelectric stations	218.7	222.3	203.6	178.7	152.2	132
Nuclear power stations	53.3	76.2	75.1	73.8	75.2	69
Total	272	298.5	278.7	252.5	227.4	201

The forecast of electricity generation (billion kW*h) in Ukraine for the period 1995-2005 is displayed in Fig. 2.

The installed capacity of thermal, hydroelectric, and nuclear power stations in Ukraine is shown in Fig. 3. As can be seen from this figure, the shares of thermal power stations, hydroelectric stations and nuclear power stations in the overall capacity are about 24.8%, 9.2% and 66% respectively.

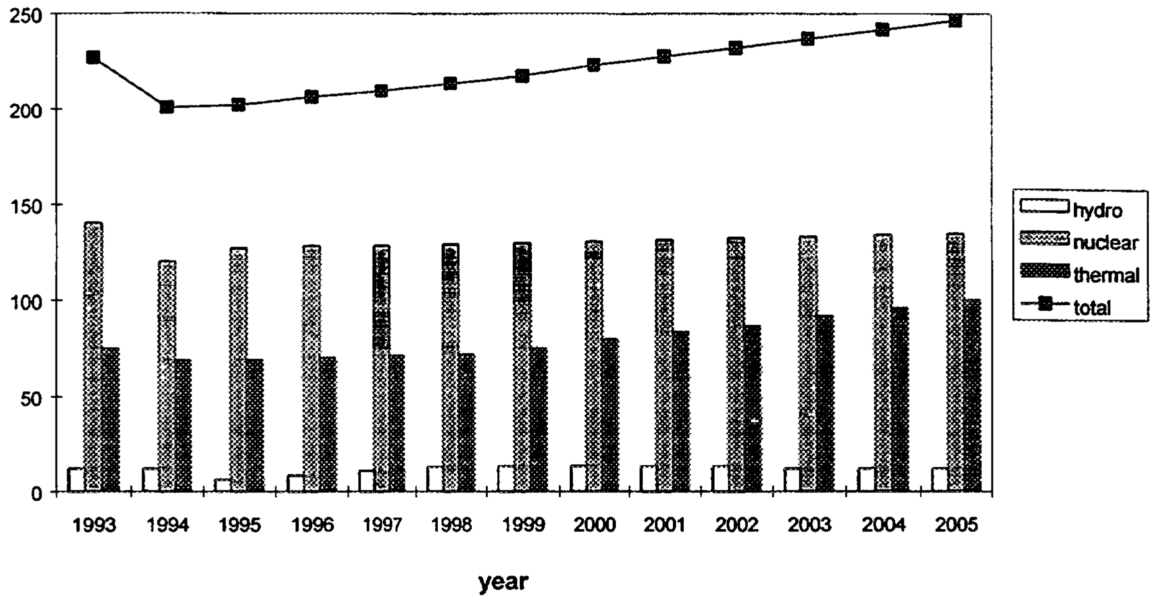

*Fig 2. Forecast of electricity generation (billion kW*h)*

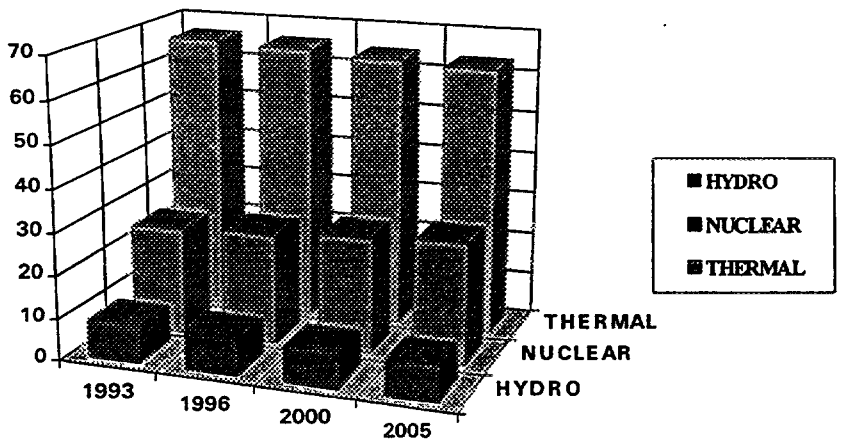

Fig. 3. Generating capacities (%)

Domestic fuel resources (coal, oil, gas) are not sufficient to meet the total energy demand. Therefore, nuclear power is an important source of electricity generation. It should be noted, however, that there are some constraints on nuclear electricity. In the frame of the present study, no nuclear power development is considered after the year 2000. In addition, the share of hydroelectric power plants will remain insignificant. As a result, gas will maintain a predominant role as a fuel for power plants over the entire study period.

The number of units and generating capacity output of the various nuclear power reactors in operation and under construction in Ukraine are summarized in Table 5.

Table 5
NUCLEAR POWER REACTORS IN OPERATION OR UNDER CONSTRUCTION

NPP	In operation		Under construction	
	N of units	Total MW(e)	N of units	Total MW(e)
Rovno	3	1766	1	1000
Zaporozhie	5	4750	1	1000
Khmelnitsky	1	950	1	1000
Chernobyl	3	2367	-	-
South-Ukrainian	3	2850	-	-

The main problems of the Ukrainian power system are the following:
- nearly 50% of energy resources for power plants are imported from abroad (90% from Russia);
- around 45% to 90% of the equipment of the thermal power stations have practically exhausted their lifetime;
- the strategy of advancing the nuclear power programme was not realized;
- deterioration of the environmental situation in regions with thermal and hydroelectric power plants.

Basic actions for solving these problems are as follows:
- projects for reconstruction of outdated facilities;
- construction of facilities using new technology;
- using process developments;
- purchasing foreign equipment for construction of new power plants.

2. ANALYSIS CONDUCTED

2.1. Nature of the problem:

- Development and planning for new power facilities and for commissioning of power plants taking into account the environmental impacts of the power sector.
- Evaluation of the environmental situation with account to the Ukrainian energy requirements in perspective.

2.2. Proposed solutions to overcome the problem

The solution of the problem focuses on the comparison of the environmental impacts of different power plants parameters (air pollutant, water pollutant, solid waste) and economic parameters of facilities.

Advantages of development on any variety of the plants will be given to the plants with the lowest environmental burdens and with the minimum maintenance cost.

2.3. Approach and Cases Considered

The problem is solved by two steps:

- **Case 1**: so called "fast" calculation of environmental impacts using the databases installed in the IMPACTS module of ENPEP.
- **Case 2**: calculation of environmental impacts using the data for actual facilities.

The approach used in Case 1 consists of the following points:

1. Inputting the energy system configuration.
2. Selecting the environmental coefficients from the databases.
3. Assigning the facilities to geographical regions.
4. Imposing environmental regulations.
5. Computing environmental residuals.
6. Analysing the results.

To simplify ther discussion of the analysis conducted by means of the IMPACTS module of ENPEP, the following list of abbreviations has been accepted:

- For energy facilities:
  - ECD- power plants using coal as a fuel;
  - EOW- energy facilities using mazut as a fuel;
  - EGW- power plants consuming gas;
- For control devices:
  - PPR- particulates precipitator;
  - WET- limestone scrubber;
  - LNO- low NO_X burner.

2.3.1. Inputting the energy system configuration

There are 3 types of energy facilities that are included in the analysis, namely: ECD, EOW, EGW. These are illustrated below.

This aggregation is conventional and is used only for the approximated calculation in Case 1.

2.3.2. Selecting the environmental coefficients from the databases

The generic energy and generic facility from the IMPACTS database which were the closest to the actual facility under study were assigned to the actual energy facility. The process is illustrated in Fig. 4.

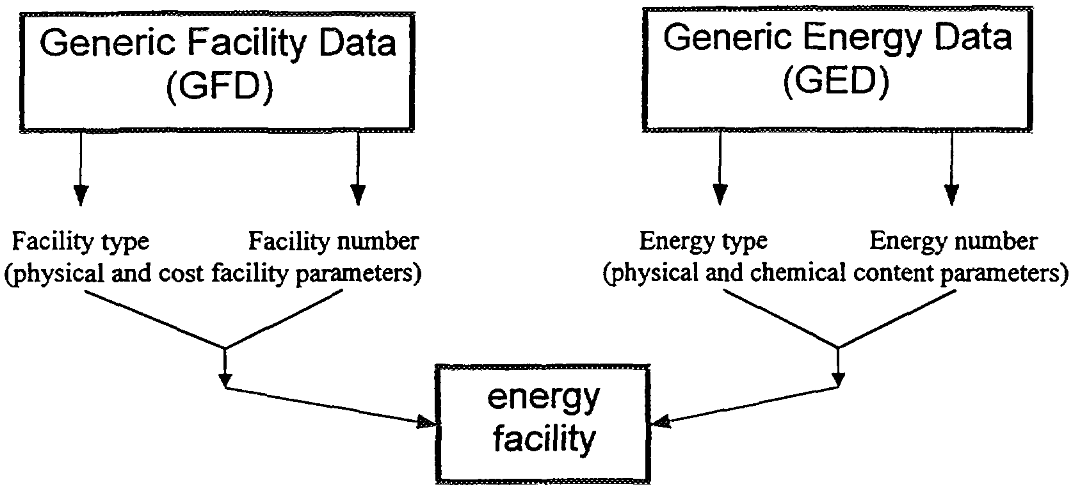

Fig. 4. Selection of characteristics of the energy facilities

2.3.3. Assigning the facilities to geographical regions.

The geographical distribution of the facilities was defined by dividing the whole territory of Ukraine into the following eight regions: *Donbass* region; *Dnepr* region; *Kiev* region; *Vinnitca* region; *Kharkov* region; *Lvov* region; *Odessa* region, and *Krim* region.

Each region has three types of facilities (ECD, EOW, EGW), with the exception of the Odessa region for which only two facility types (EOW, EGW) were assigned.

2.3.4. Imposing environmental regulations

For each of the impacts considered, environmental controls in the various forms of regulations were applied to reduce the environmental discharges. In this case study only air pollution were considered and two forms of regulations were imposed. These are: emission limits and required control devices.

2.3.5. Computing the environmental residuals

Uncontrolled and controlled air emissions have been calculated. Two cases were considered: one without any emission control and the other with some emission regulations imposed.

2.3.6. Analysing the results

Total Uncontrolled Air Emissions in Ukraine

The results of the analysis in terms of the total uncontrolled air emissions are very illustrative of the problems faced by Ukraine's energy system. As a result of decreasing coal consumption for Ukrainian power plants the total emissions of particulates in Ukraine declines for the whole study period.

On the other hand, the total SO_2 emissions sharply decrease in the first year and then gradually decline up to the horizon of the study. This is a direct consequence of the assumed fuel consumption prognoses.

The character of NO_X emission reflects the change in the gas consumption for Ukrainian electricity generation. There is the decline of the emission in the first year due to the decrease of gas consumption for power plants. Then, as the gas consumption grows, the emissions gradually increases.

Regional Distribution of Uncontrolled Air Emission in Ukraine

The regional distribution of the uncontrolled air emissions for Case 1 is shown in Figures 5 to 7.

According to the amount of air emissions (as shown in Figs. 5, 6, 7) all assumed regions can be arranged in the following order: Donbass, Dnepr, Lvov, Kiev, Kharkov, Vinnitca, Krim, Odessa.

For all regions, except the Odessa region, the character of the change for all kinds of emissions remains the same for the total uncontrolled air emission in Ukraine. Regarding the Odessa region, particulates emission increases after the year 1994 but the share of this emission is insignificant. This result reflects the fuel consumption in the Odessa region.

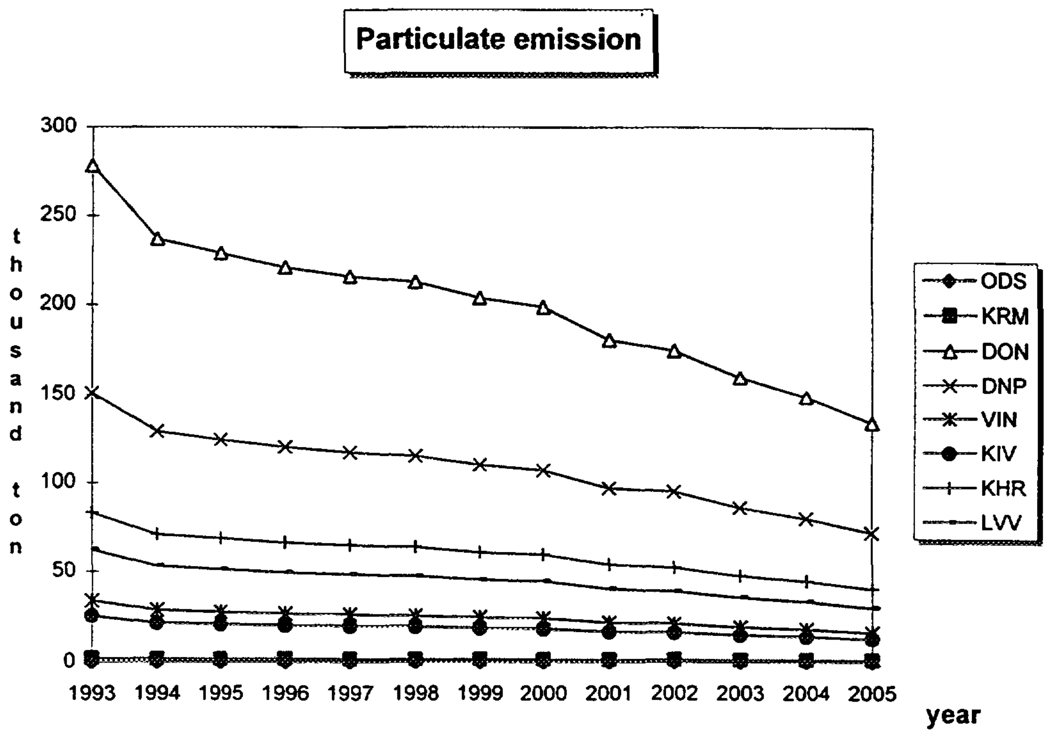

Fig. 5. Regional Distribution of Uncontrolled Particulate Emission in Ukraine

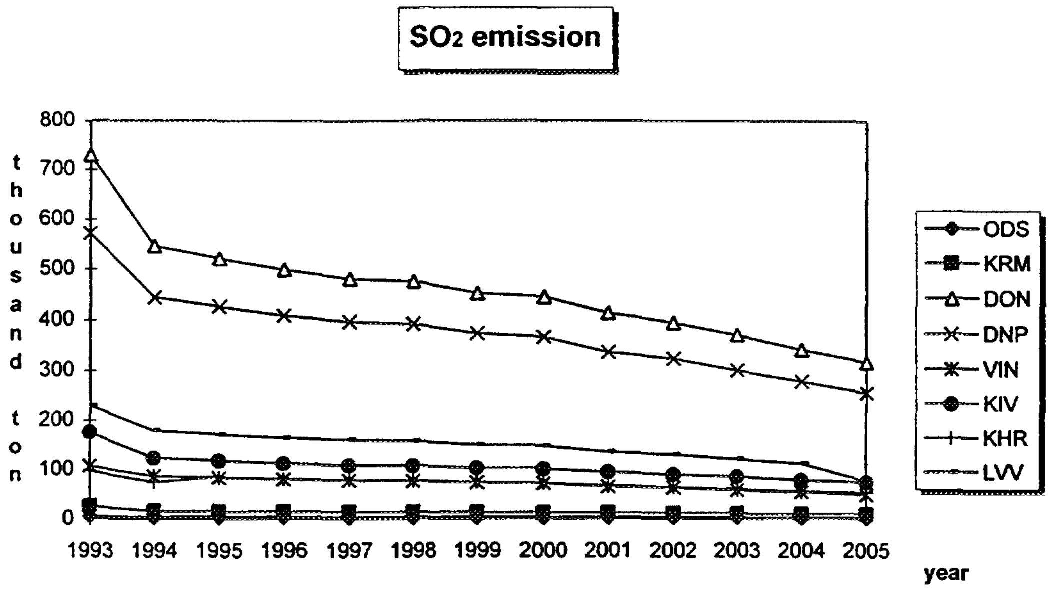

Fig. 6. Regional Distribution of Uncontrolled SO_2 Emission in Ukraine

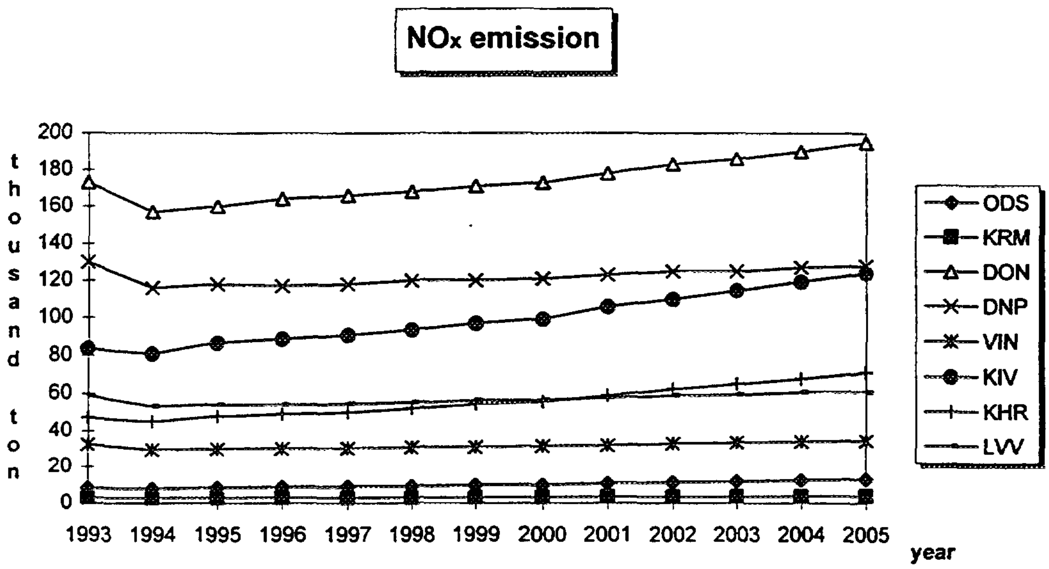

Fig. 7. Regional Distribution of Uncontrolled NO_X Emission in Ukraine

Uncontrolled Emissions in All Regions by Facility Type

Uncontrolled Emissions by Facility Type have also been calculated for each region. Taking as an example the DNEPR region, all forms of uncontrolled air emissions for facilities type ECD and EOW decrease over the entire study period. But for facility type EGW these emissions increase. These results reflect the assumed evolution of the fuel consumption.

Total Uncontrolled and Controlled Air Emissions in Ukraine

The above results illustrate the need to introduce emission control. It is supposed that the installation of control devices is made first in the regions with high air emission. Such regions are Donbass, Dnepr, Lvov, Vinnitca. For ECD facilities, WET and PPR devices are imposed. WET devices are applied for EOW facilities. LNO devices are installed on EGW facilities.

Following the installation of these facilities the air emissions in Ukraine reduce nearly to pollution standards.

Regional Distribution of Uncontrolled and Controlled Air Emissions in Ukraine

The comparison of the regional distribution of uncontrolled and controlled emissions for the DNR region shows that for significant reduction of NO_X emissions using LNO devices only for EGW facilities is not sufficient. Apparently, other types of control devices or additional forms of regulation should be applied. This problem will be considered in further case studies.

4. CONCLUSIONS

1. The main reasons for conducting the case study described above were the following:

    - to learn the IMPACTS module methodology and the technique for modeling various environmental aspects of energy generation,
    - to obtain a preliminary evaluation of the environmental impacts situation in Ukraine as soon as possible,
    - to conduct further analysis for the actual power facilities, based on the experience gained through the conduct of the present study.

2. The model of energy system chosen in this case is very simplified but gives satisfactory results for evaluation of the environmental situation in Ukraine.

3. The total amount of uncontrolled air emissions in Ukraine is much higher than the accepted pollution standards (4-7 times higher). The largest part of the total emissions is for SO_2 emission, followed by particulates emission. The next largest value is NO_X emission. However, after the year 1996, NO_X emissions will be higher than particulates emissions.

4. For all regions, except the Odessa region, the character of emissions is similar for the entire territory of Ukraine, i.e. particulates and SO_2 emissions decrease, NO_X emission increases.

5. The maximum of the emissions corresponds to facilities type ECD, followed by facilities type EOW and type EGW.

6. According to the assumed forecasts, the future increase in electricity demand will be met mainly by gas. As a result, the total amount of air emissions in Ukraine will not increase.

7. For further reduction of the current environmental burdens in Ukraine various forms of regulations must be applied. The forms of these regulations are different for each facility type and depend on the region considered.

5. RECOMMENDATIONS

As a result of the analysis conducted, the following recommendations can be made for improving Ukraine's environmental situation:

1. For a significant reduction of air emissions in Ukraine, the various types of control devices must be applied first in the regions with the largest emissions. Such regions are DONBASS, DNEPR, then LVOV, KIEV.

2. The following control devices are recommended for various types of facilities:
   - PPR and WET devices - for power plants using mainly coal as a fuel.
   - WET devices - for facilities where mazut is the principal fuel consumed,
   - LNO devices - for power plants consuming gas.

3. Taking into account the environmental impacts of the power sector, development of energy facilities using gas as a fuel is more preferable than the one based on other types of fuel.

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