

MAED: MODEL FOR ANALYSIS OF THE ENERGY DEMAND

1. INTRODUCTION

Since its creation and as part of its mandate concerning the promotion of the peaceful uses of nuclear energy, the International Atomic Energy Agency (IAEA) has been involved in the execution of the so-called Nuclear Power Planning Studies. The principal objectives of such studies are in general, the determination of the optimal schedule of power plant additions to meet the future demand for electricity in a given country (or a world region), and in particular, an estimation of the role that nuclear power may play in meeting this demand.

For this analysis, the IAEA developed the WASP computer program (Wien Automatic System Planning Package) and a related methodology. The WASP program is designed to find the economically optimal generation expansion policy for an electric power system within certain constraints specified by the user.

The experience gained in the use of WASP for the execution of the studies above mentioned led to the development of improved versions, namely WASP-II, WASP-III, and WASP-IV, which may be released by the IAEA to interested Member States under special arrangements.

Although the WASP methodology has been recognized as suitable for carrying out Nuclear Power Planning Studies, some criticisms have been raised to these studies, specially concerning the projections of electricity demand used in each case. In fact, part of the main input data required for the execution of a WASP study corresponds to the future projections of the electricity demand in terms of both, electric energy and power requirements.

Following the recommendations of several experts in energy planning, the IAEA has developed a methodology for determining the energy demand based on a scenario approach: The MAED Model (Model for Analysis of the Energy Demand). MAED is applied by the Agency in conjunction with the WASP code for carrying out Energy and Nuclear Power Planning Studies (ENPP) for its Member States.

The general approach to the MAED methodology was developed by Messrs. B. Chateau & B. Lapillonne (MEDEE: Modele d'Evolution de la Demande d'Energie) of the Institut Economique et Juridique de l'Energie (IEJE) of the University of Grenoble, France. In fact, MAED is closely related to a simplified version of this methodology, known as MEDEE-2 that was adapted by B. Lapillonne to the needs of the International Institute for Applied Systems Analysis (IIASA, Laxemburg, Austria) for carrying out studies on global energy assessment.

While respecting the general structure of MEDEE-2, important modifications were introduced in MAED by IAEA staff members. They concern: the parameters required to be specified as input data; the equations used for calculating energy demand of some sectors; and the printed output produced by the programs.

More important, MAED includes some additional modules which may be used to convert first, the total annual electricity demand into the hourly electricity consumption expressed in terms of the load imposed on the electric power generating system in each hour of the year, and then into the so-

called load duration curve of the power system, which is only a convenient representation of the load for the purpose of analysing the expansion of the system. This permits using the MAED results directly as input data to the WASP computer program.

2. MAED METHODOLOGY

MAED is a simulation model for evaluating the energy demand implications (in the medium and long term) of a scenario describing a hypothesized evolution of the economic activities and of the lifestyle of the population.

Under its apparent complexity, MAED is a rather simple model relating the energy demand to the set of social, economic and technological factors that influence this demand. The energy demand is disaggregated into a large number of end-use categories; each one corresponding to a given service or to the production of a certain good. The nature and level of the demand for goods and services are a function of several types of choice: socio-political (for example the dwelling surface per inhabitant, type and amount of electrical appliances to be used in households); socio-economic (priority in development of certain industries or economic sectors, the country's policy for public transportation); purely economic (for example the influence of changing fuel prices); or solely technological (such as the evolution of the efficiencies of certain types of equipment, market penetration of new technologies or energy forms, etc.)

MAED relates systematically the specific energy demand for producing the various goods and services identified in the model to the corresponding social, economic and technological factors that affect this demand. All independent determining factors, i.e. the "scenario", which constitute in a certain way the driving force of the model, are exogenously introduced.

The knowledge of these determining factors permits the systematic evaluation of the various categories of energy demand of each economic sector considered. Grouping these individual energy demands in a homogeneous manner permits the calculation of the total energy demand of the country or region under consideration.

Special attention is given to the calculation of the demand of electricity which is not only performed annually as for all other energy forms, but also on an hourly basis in terms of the electric power demand of the various consumers in each hour of the year. This in turn, permits the determination of the input data on the electric load imposed to the generating system as required by the WASP model.

3. ORGANIZATION OF MAED

MAED is composed of the following modules and associated data files. The number assigned to each module indicates the proper sequence of their execution:

- **Module 1** (Energy Demand Calculations), processes information describing the social, economic, and technological scenario of development and calculates the total energy demand for the desired years. The breakdown of this demand by energy form and by economic sector

considered is also provided as part of the results of the analysis. This module creates a file (FT12: "LOADSCEN") to be used later by Module 2.

- **Module 2** (Hourly Electric Power Demand), uses the total annual demand of electricity for each sector (contained in file "LOADSCEN") to determine the total electric power demand for each hour of the year or, in other words, the hourly electric load which is imposed on the power system under consideration. During its execution, this module creates a file (FT13: "LOADYEAR") to be used by Module 3.
- **Module 3** (Electric Load Duration Curve), uses the hourly loads (contained in file "LOADYEAR") to produce the Load Duration Curve of the power system as required for the execution of a WASP study. Two output files are created by this module during execution. The first one, file (FT14: "LOADWASP") contains the WASP input data, and the second (FT15: "LOADPLOT") contains the same information but presented in a different format as required for plotting the load duration curve.
- **Module 4** (Load Modulation Coefficients) is an auxiliary module that may be used to analyse the past evolution of the coefficients describing the variation of the hourly electric loads based on load curves determined from statistical data. An additional input file, i.e. "LOADCHRO", with the chronological electric power demand hour-by-hour for past years of statistics, is required for executing this module. This module creates no output file.

3.1. Module 1: Energy Demand

The energy demand is calculated by MAED as a function of a scenario of possible development. This scenario is sub-divided into two sub-scenarios:

- One is related to the socio-economic system and describes the fundamental characteristics of the social and economic evolution of the country;
- The second is related to the technological factors that should be taken into account in the calculation of energy demand, for example the efficiency of each alternative energy form and its penetration into its potential markets.

Two major subroutines are used by module 1 to perform the main calculations: A macroeconomic subroutine (MACRO) determines the level of activity of each economic sector considered; and another subroutine (DEMAND) calculates the total energy demand for each end-use category aggregating the economic sectors into three main "energy consumer" sectors: Household/Service Sector; Industry/Agriculture Sector, and Transportation Sector. The combination of these two subroutines provides a systematic accounting framework for evaluating the effect on the energy demand of any change of economic nature or in the standard of living of the population.

When various energy forms, i.e. electricity, fossil fuels, etc., are competing for a given end-use category of energy demand, this demand is calculated, first in terms of useful energy and then

converted into final energy, taking into account the penetration, into the given market and the efficiency of each alternative energy source, both specified as scenario parameters.

In the model, the demand for fossil fuels is not discerned in terms of coal, gas or oil, because this largely depends on the possibilities of supply and relative prices of these fuels, aspects that are out of the scope of the analysis carried out by the use of MAED. The substitution of fossil fuels by alternative "new" energy forms (i.e., solar, district heat, etc.) is nevertheless estimated, due to the importance of the structural changes in energy demand that these energy forms may produce in the future. Since these substitutions will be essentially determined by political decisions, they are to be taken into account at the stage of formulating and writing the scenarios of development.

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

For each end-use category, the energy demand (useful or final) is related to a set of socio-economic and technological determining factors (macroeconomic parameters, physical quantities, etc.) whose evolution with time will determine the energy demand projections.

3.2. Module 2: Hourly Electric Power Demand

This module is used to convert the global annual electricity demand (in terms of energy) of each economic sector considered to the demand broken down on an hourly basis, i.e. to the power demand or electric load imposed on the electric power system by the sector being considered. For simplification, module 2 of MAED considers two major aggregated sectors: Household/Service sector and Industry/Transport sector.

These calculations are performed using the various "modulation factors" which characterize changes in the electricity consumption of each particular hour with respect to the average consumption. In order to determine the electric load of a sector in a given hour, day, and week of the year, from the total annual electricity demand of the sector, the program takes into account:

- (a) the trend of the average growth rate of the electricity demand during the year;
- (b) the changes in the level of electricity consumption owing to the various seasons of the year (this variation may be reflected on a monthly or weekly basis, depending on the available information);
- (c) the changes in the level of electricity consumption owing to the type of day being considered (i.e. working day, weekends, special holidays, etc.);
- (d) Finally, the hourly variation of electricity consumption during the given type of day considered.

The electric load of a given sector in a certain hour, day and week is characterized by one modulation coefficient for each of the above time variations. The multiplication of all these coefficients by the average electricity demand of the sector permits obtaining the power demand of the sector (i.e., the electric load imposed on the generating system by this sector) in the hour considered. Furthermore, the modulation coefficients are known for each hour of the year, execution of the

above procedure in a sequential manner permits the calculation of the 8760 values of the electric load for each sector.

After all the hourly electric loads for each sector have been determined, the aggregation of the loads for the same hour produces the hourly values of the total electric load imposed on the power system in the year considered. The representation of these values consecutively on a graph (time vs. load) produces the so-called hourly load curve of the electric power system.

It should be noted that the modulation coefficients previously mentioned can only be obtained from statistical analysis based on past operating experience for the power system under consideration. Various statistical studies of this nature have concluded that for a given sector, these coefficients show very little variation from one year to another (except when certain economic activities aggregated into the sector experience a notably rapid development). In fact, the power systems load curve of a given country is more influenced by the relative contribution of each economic sector to the total electricity demand. A lesser influence on the system load curve is accorded to variations of the various modulation coefficients (i.e. daily, seasonal, hourly) of each individual sector with the years.

3.3. Module 3: Load Duration Curve

This module is used to transform the hourly load curve of the power system into a different format, as it is required by the WASP program. For this purpose, the program uses the 8760 values of power demand imposed on the grid (calculated by module 2) in the year and classifies them in a decreasing order. The time duration of all power demands having the same level of magnitude are added up and finally, each load magnitude and its respective accumulated time duration are normalized: load magnitudes with respect to the maximum load of the year and time durations with respect to 8760.

Plotting these relative values of load magnitude versus their respective load duration in a graph permits the representation of the so-called "normalized" annual load duration curve (L.D.C.) of the electric power system.

For WASP analysis, it is usually convenient to divide the year into an equal number of periods. Thus, based on the specified number of periods, module 3 determines each period to be used later on by WASP.

3.4. Module 4: Load Modulation Coefficients

This module is considered an auxiliary tool for MAED. It may be used for determining the various load modulation coefficients (trend, seasonal, daily and hourly) characterizing the total system power demand in a given year. Execution of this module for several years of past experience for the system under consideration may be very useful in the analysis of the power demand characteristics of the system and of their variations with the years.