AN ADAPTIVE AND ITERATIVE APPROACH TO DYNAMIC MODELLING OF BICRITERION OPTIMIZATION IN POWER SYSTEMS EXPANSION DECISIONS

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ABSTRACT

In this study,power systems expansion decisions are modelled using Bicriterion Linear Programming techniques. The model consists of: energy and power demand forecasts, production capacity, build-up rate, nuclear, hydro (both base and peak), fossil and fuel energy constraints in an adaptive process of 5-yr. increments for a 25-yr. planning horizon.

The model, as applied to the Turkish Power System, contains 40 decision variables and 45 constraints. Efficient (nondominated) solutions are obtained at each iteration with respect to the economic cost objective and one of the following objectives: pollution, space occupied or risk involved.

The aim of this study is to derive a framework for the power systems expansion decisions based on trade-off functions between pairs of objectives.

A particular combination of objective functions and changes in some parameters result in different scenarios.

A fast algorithm developed by Kızıltan [8], is adapted and used as a subroutine in order to obtain the preliminary solutions to the problem.

According to the adaptive nature of the study, the overall solutions are grouped together to form decision alternatives and to show the trade-offs between the objectives.

Special effort was expended on the generation of the computer programs so that minimum handling of data for a particular scenario is achieved together with a self explanatory output design.

ÖZET

Bu çalışmada İki Amaçlı Doğrusal Programlama Tekniği kullanılarak güç sistemlerinde genişleme kararları modellenmiştir. Model, enerji ve güç talep tahminleri, üretim kapasitesi, kapasite artış oranı, nükleer, hidro (baraj ve türbin) ve fosil enerji kısıtlarını içeren uyarlamalı bir yöntem olup 5'er yıllık artışlı 25 yıllık planlama dönemini kapsamaktadır.

Türkiye güç sistemine uygulandığı haliyle model 40 karar değişkeni ve 45 kısıttan meydana gelmektedir. Her dürüm (iterasyon) sonunda ekonomik maliyet muhakkak göz önüne alınmak suretiyle, çevre kirliliği, kapsanan alan ve risk amaçlarından biri esas alınarak çalıştırılan model için baskın çözümler elde edilmiştir.

Bu çalışmanın amacı, amaç fonksiyonları arası, ödünleşim işlevlerine (trade-off functions) dayalı olarak güç sistemlerini genişletme kararları için bir çatı meydana getirmektir.

Amaç fonksiyonlarının çeşitli kombinasyonları ve bazı parametrelerdeki değişiklikler farklı senaryoları oluşturmaktadır.

Kızıltan [8] tarafından geliştirilen hızlı algoritma uyarlanarak problemin ilk etaptaki sonuçlarını elde etmek için bir alt-program olarak kullanılmıştır.

Çalışmanın uyarlamalı niteliğine göre, sonuçta bütün çözümler, karar alternatiflerini belirlemek ve amaçlar arası ödünleşimi göstermek üzere gruplandırılmıştır.

Veri kolaylığı açısından bilgisayar programlarının hazırlanmasında özel çaba gösterilmiş olup belirli bir senaryo için kendi kendini açıklayan bir çıktı deseni elde edilmektedir.

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CHAPTER I
INTRODUCTION

I.I. NATURE OF THE STUDY

Due to the emergence of new dimensions in energy systems analysis in general and in electrical systems planning in particular, the decision making process in electrical power system investments has become much more complex in comparison with that of several years ago.

One of the new dimensions is the widespread interest in a clean environment. The production of electric power is one of the major sources of environmental pollution. The main residuals produced by fossil-fuel-burning steam plants contribute to pollution of the air through the emission of sulphur oxides, nitrogen oxides, carbon oxides, and hydrocarbons.

Another new dimension is the concern over nuclear technology. The sudden increase in energy prices and the threat of future energy shortages have activated interest in nuclear technology which in turn has led to a new set of environmental problems, since nuclear plant operation involves the release of radioactivity.

Therefore, the basic objective of economic efficiency subject to certain technical considerations has to be reviewed. Presented in this study is one possible approach that attempts to accommodate several objectives in power systems expansion decisions.

The procedure is based on generating relevant decision alternatives through the use of a bicriterion linear programming technique. The model has been applied to the Turkish electricity system for the objectives of minimizing:

i) economic cost,
ii) pollution,
iii) space occupied
and iv) risk involved.

I.2. METHODS OF PRODUCING ELECTRICITY

As the electric power industry has expanded, the composition of primary energy used to produce electricity has changed in character.Hydroelectric power, conventional steam-electric power and nuclear power are considered in this study.

I.2.1. HYDROELECTRIC POWER

Hydroelectric generation uses water flows powering turbines that turn electric generators. Hydro facilities are particularly useful as peak-load generators because of their ability to start quickly and make rapid changes in output. Other advantages are low operating and maintenance expenses, no fuel costs, and long life. On the other hand the investment costs per kilowatt for hydroelectric power plants are higher than for steam-electric facilities although low operating costs help to offset the large initial outlay.

I.2.2. CONVENTIONAL STEAM-ELECTRIC POWER

Steam-electric power plants burn fossil-fuels in the form of oil,natural gas or coal to convert water to high pressure steam used in turbines which power electric generators.

I.2.3. NUCLEAR POWER

Nuclear power plants are similar to fossil-fueled plants in that heat is used to convert water to high pressure steam, which powers turbines and electric generators. The difference is that, rather than using oil, coal, or natural gas to produce the heat, nuclear energy is employed.

I.3. ENVIRONMENTAL EFFECTS OF ELECTRIC POWER PRODUCTION

Various methods of producing electric power have different environmental effects. Aside from the problems of their financing tremendous amounts of capital equipment, these effects should also be considered in power systems expansion decisions.

I.3.1. HYDROELECTRIC POWER

Hydro plants produce no air pollution, water pollution, radioactivity, or solid wastes. The primary environmental effect of a hydro facility generally is the flooding of possibly valuable and scenic land areas. Also, since most hydroelectric generating plants are not close to the main centers of electrical consumption, many kilometers of high-voltage power lines are required for transmission. However, many of the fossil-fuel plants are near points where fossil-fuel is available, rather than where the power is delivered, so this problem is not necessarily unique of hydro plants.

On the other hand, to offset, at least partially, the harmful effects on the environment of hydro facilities, some environmental improvements also take place after construction of a dam such as providing flood control.

I.3.2. CONVENTIONAL STEAM-ELECTRIC POWER

Fossil-fuel-fired steam-electric power plants pollute both the air and the water. The problems have been compounded by the fact that, due to economies of scale, utilities have continued to build larger generating units; and, in many cases, they have placed the units close together or in the same region.

The most obvious residuals emitted from fossil-fuel plants are those which pollute the air. The burning of fossil-fuels results in the emission of hydro-carbons, nitrogen oxides, sulfur oxides, carbon monoxide and dioxide, and particulate matter. Coal burning plants are the greatest polluters. Sulfur oxides also attack physical objects whereas particulate matter has damaging effects on health, vegetation, and materials. Another important point is that the combustion of fossil-fuels has accelerated the generation of carbon dioxide which may have significant climatic effects.

Another type of pollution caused by fossil-fuel steam plants is thermal pollution. A primary requirement of a steam-electric plant is that it should be sited near a source of water that is sufficient in size to provide adequate cooling for waste heat. The primary problems caused by waste heat are in further use of the water and in the effect of heat on aquatic life. As water becomes warmer, there is an increase in biochemical processes and a reduction in the ability of the water to hold dissolved gases, especially oxygen.

I.3.3. NUCLEAR POWER

Nuclear power plants produce no air pollution, but radiation and the disposal of radioactive wastes have presented serious environmental problems. In addition, water thermal pollution exists on an even larger scale than fossil-fuel plants. Nuclear plants emit more waste heat into water than comparably sized fossil-fuel plants.

Many environmentalists contend that the principal hazards of nuclear steam-electric plants are the constant release of radioactive residuals, the disposal of radioactive wastes and the possibility of a loss-of coolant accident. While there is no apparent danger of a conventional atomic explosion in a nuclear power plant, a break in the cooling system could cause such intense heat from the fuel rods that the reactor core would melt to the bottom of the reactor vessel which might turn the water into high pressure steam and result in an explosion, sending large amounts of radioactivity outside the plant and the results could be of catastrophic proportions.

I.3.4. SPACE OCCUPATION AND AESTHETIC CONSIDERATIONS

Power generation affects the environment not only through its fuel needs and pollution products but also by requiring land to help generate and transport electricity. By far the largest land users are hydroelectric dams which create reservoirs occupying up to several hundred square kilometers, and transmission lines, whose rights-of-way for the nation as a whole take up a large area. Coal plants too, consume large areas. Within each site, they require coal shipping and handling facilities, sufficient storage for ashes as they come out of the plant, and large stacks to disperse ait pollutants. Many power plants are installing also cooling towers if sufficient water is not available to handle thermal discharges.

As electric generating plants expand in size and move away from major load centers, high voltage transmission lines and their supporting towers become even more familiar sights since underground transmission lines are not feasible with today's technology.

The importance of the new dimensions such as pollution, space occupied and risk involved in electrical power system investments is worth greater elaboration. Interested readers may refer to Kavrakoğlu [3] and Kızıltan [6] for further information. Scott's [12] survey on pollution in the electric power industry is also related to the same subject.

CHAPTER II

MULTIOBJECTIVE DECISIONS

II.1. INTRODUCTION

Decision making is inherently more complex when there is more than one objective since the computation and evaluation of alternatives become more difficult with the number of objectives. Another reason for this complexity is the fact that the preferences must be articulated in order to consolidate different choice criteria. A posteriori articulation of preferences; i.e. choosing the desirable alternative after all relevant solutions have been generated is used in this study. For this purpose, the bicriterion algorithm developed by Kızıltan [8] is adapted and used as a subroutine in order to obtain the preliminary solutions to the problem. In this chapter, the solution procedure will be explained briefly. More information and the theory can be found in [8].

II.2. THE SOLUTION PROCEDURE OF BICRITERION LINEAR PROGRAMMING

The algorithm presented here for bicriterion linear programming is developed by Kızıltan [8] and generates either all efficient extreme points or a subset of such efficient points corresponding to a decision maker's specified space of objective weights. The computational requirements of the algorithm are quite low; in fact only a series of divisions and comparisons are needed for the determination of adjacent efficient extreme points. The mechanics of the algorithm is given by the flow diagram in Figure II.1.

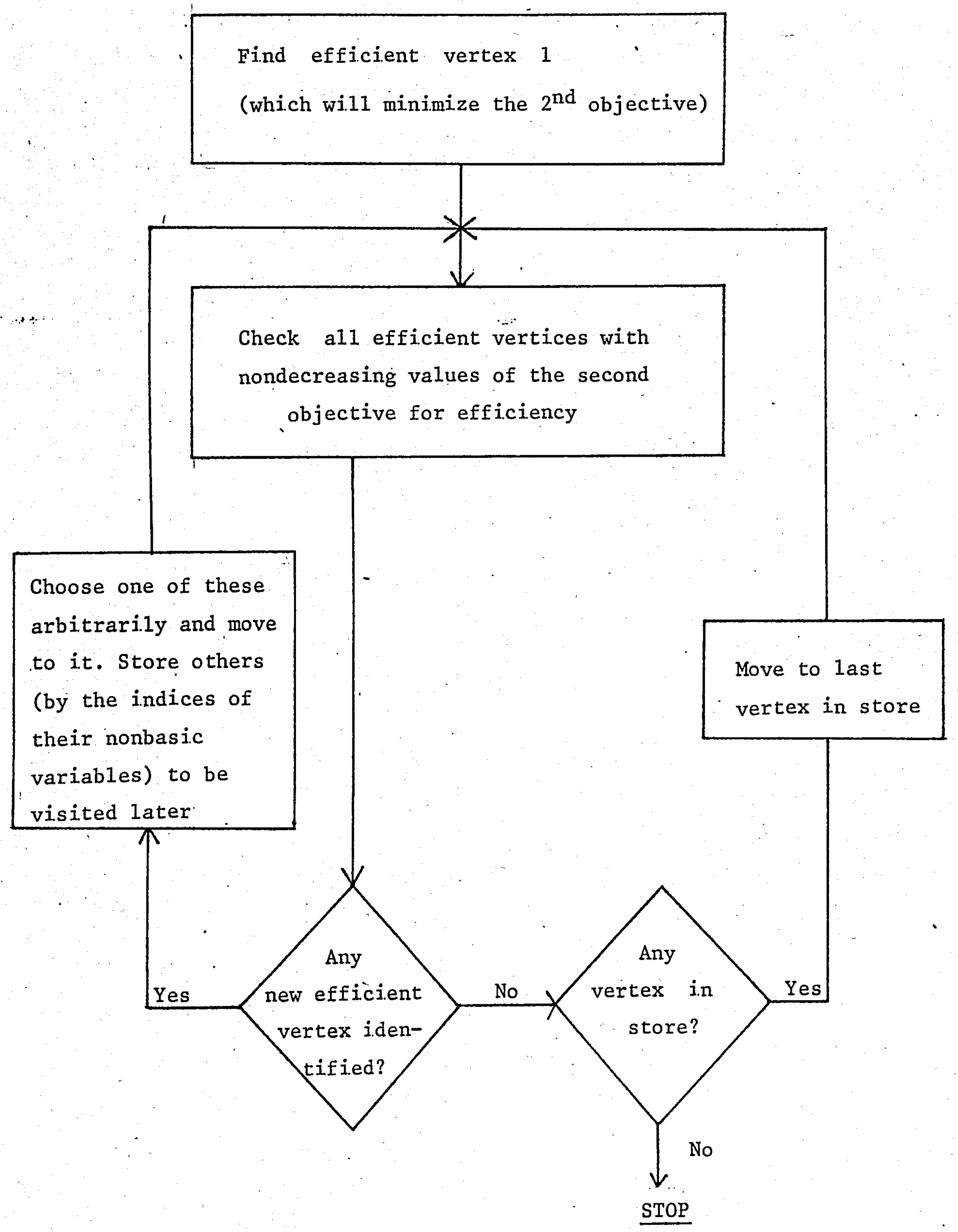


Figure II.1. The Flowchart of The Algorithm [6]

In Kızıltan's study some relevant results of multiobjective linear programming are reviewed and the implications for bicriterion problems are discussed. Then a new algorithm for bicriterion linear programming which requires only a series of divisions and comparisons for determination of adjacent efficient extreme points is developed.

The multiobjective linear programming problem is formulated as

$$\max_{x \varepsilon X} \; C^{o}x$$

$$X = \{x \mid Ax \leqq b, \quad >0\}$$

where the rows of the pxn matrix C^{o} represent the different objective functions, A is an mxn matrix and x and b are n and m dimensional vectors respectively as in any standard linear programming problem; and maximization refers to determination of efficient solutions.

Here an efficient solution is defined as follows:

Definition: A solution $x^{o} \varepsilon X$ is said to be efficient if and only if there doesn't exist $x \varepsilon X$ such that $C^{o}x \geq C^{o}x^{o}$ and $C^{o}x \neq C^{o}x^{o}$.

For any basic feasible solution x^{o} there is an associated basis B and reduced cost matrix C. By renumbering variables as necessary, partitioning A and C^{o}, we have $C = C^{o}_{B}\, B^{-1}N - C^{o}_{N}$ where the subscript B denotes basic and subscript N denotes nonbasic. A well-known result of multiobjective linear programming is the following:

Theorem 1. A point $x^{o} \varepsilon X$ is efficient if and only if there exists $\lambda > 0$ such that x^{o} is optimal for

$$\max_{x \varepsilon X} \; \lambda^{T} C^{o} x \qquad (P_{\lambda})$$

This theorem implies the following result:

Theorem 2. A given solution $x^{o} \varepsilon X$ is efficient if and only if there exists an associated efficient basis.

A basis is said to be efficient if and only if there exists $\lambda>0$ such that $\lambda^T C \geqq 0$.

For the special case of bicriterion linear problems, it is observed that the nonbasic variable set of any efficient basis can be partitioned into component subsets. Based on this partitioning a necessary and sufficient condition for a given basis to be efficient is stated. Next, a necessary and sufficient condition for checking the efficiency of adjacent bases is given.

Theorem 3. Given an efficient basic solution, the basic solution obtained by introducing x_j into basis is an adjacent efficient basic solution if and only if either

$$\text{i)}\quad C_{1j}/C_{2j} = \min_{q\varepsilon Q} C_{1q}/C_{2q}$$

or

$$\text{ii)}\quad C_{1j}/C_{2j} = \max_{k\varepsilon R} C_{1k}/C_{2k}$$

or iii) $j\varepsilon T$

where

$$Q = \{j\varepsilon N \mid C_{1j} < 0, \quad C_{2j} > 0\}$$

$$R = \{j\varepsilon N \mid C_{1j} > 0, \quad C_{2j} < 0\}$$

$$T = \{j\varepsilon N \mid C_{1j} = C_{2j} = 0\}$$

and N is the index set of nonbasic variables.

Finally, a given efficient basic solution is the optimal solution to P_λ for any λ satisfying,

$$-\lambda_2/\lambda_1 \;\varepsilon\; [\max_{k\varepsilon R} C_{1k}/C_{2k},\ \min_{q\varepsilon Q} C_{1q}/C_{2q}]$$

or

$$\lambda_2/\lambda_1 \;\varepsilon\; [\max_{q\varepsilon Q} - C_{1q}/C_{2q},\ \min_{k\varepsilon R} - C_{1k}/C_{2k}] \qquad (R_\lambda)$$

The bicriterion algorithm is based on these results and the connectedness of the set of efficient bases, and proceeds as follows:

Initially the second objective is maximized. If it is the unique solution then an efficient basis is at hand. Otherwise an efficient basic solution is selected from the alternative basic solutions maximizing the second objective. Next the nonbasic variable(s) x_j, $j \varepsilon Q$ satisfying the condition i) of Theorem 3 and x_j, $j \varepsilon T$, if any, are determined. Next x_j is entered into basis provided that this basis is not already visited. If there are ties for the entering variable, corresponding bases are stored to be visited later. When no new efficient basis can be identified, the algorithm stops.

In the case that there are ties for the entering variable alternative efficient solutions that is efficient solutions giving the same objective vector exist. If this is not the case, then the algorithm starts by maximizing the second objective and moves to the basic solution maximizing the first objective and stops. Since the convex combination of any two adjacent efficient basic solutions give the efficient edges then the set of all efficient solutions consisting of a set of efficient edges are obtained.

The intuitive reasoning behind the algorithm is that given an efficient point, in order to move to an adjacent efficient point, one should move in a direction where the rate of decrease of the second objective is a minimum while the rate of increase of the first objective is maximum.

The operation of the algorithm can be explained with a single numerical example:

Suppose the problem is formulated in bicriterion linear programming with two nonnegative variables:

Example Problem

$$\max\ Z_1 = 7x_1 - x_2$$

$$\max\ Z_2 = 3x_1 + 5x_2$$

$$\text{s.t.}\qquad x_1 \le 4$$

$$2x_2 \le 12$$

$$3x_1+2x_2 \le 18$$

$$x_1, x_2 \ge 0$$

The simplex tableau for the initial efficient basic solution is given as follows:

		x_1	x_2	S_1	S_2	S_3
S_1	2	0	0	1	1/3	-1/3
x_2	6	0	1	0	1/2	0
x_1	2	1	0	0	-1/3	1/3
Z_2	36	0	0	0	3/2	1
Z_1	8	0	0	0	-17/6	7/3
					↑	

Here $Q=\{S_2\}$ and since Q has a single element $C_{1S_2}/C_{2S_2} = \min_{q \in Q} C_{1q}/C_{2q}$ and S_2 is the entering variable.

Proceeding in this fashion we obtain the following set of efficient basic solutions:

		x_1	x_2	S_1	S_2	S_3
S_2	6	0	0	3	1	-1
x_2	3	0	1	-3/2	0	1/2
x_1	4	1	0	1	0	0
Z_2	27	0	0	-9/2	0	5/2
Z_1	25	0	0	17/2	0	-1/2 ↑

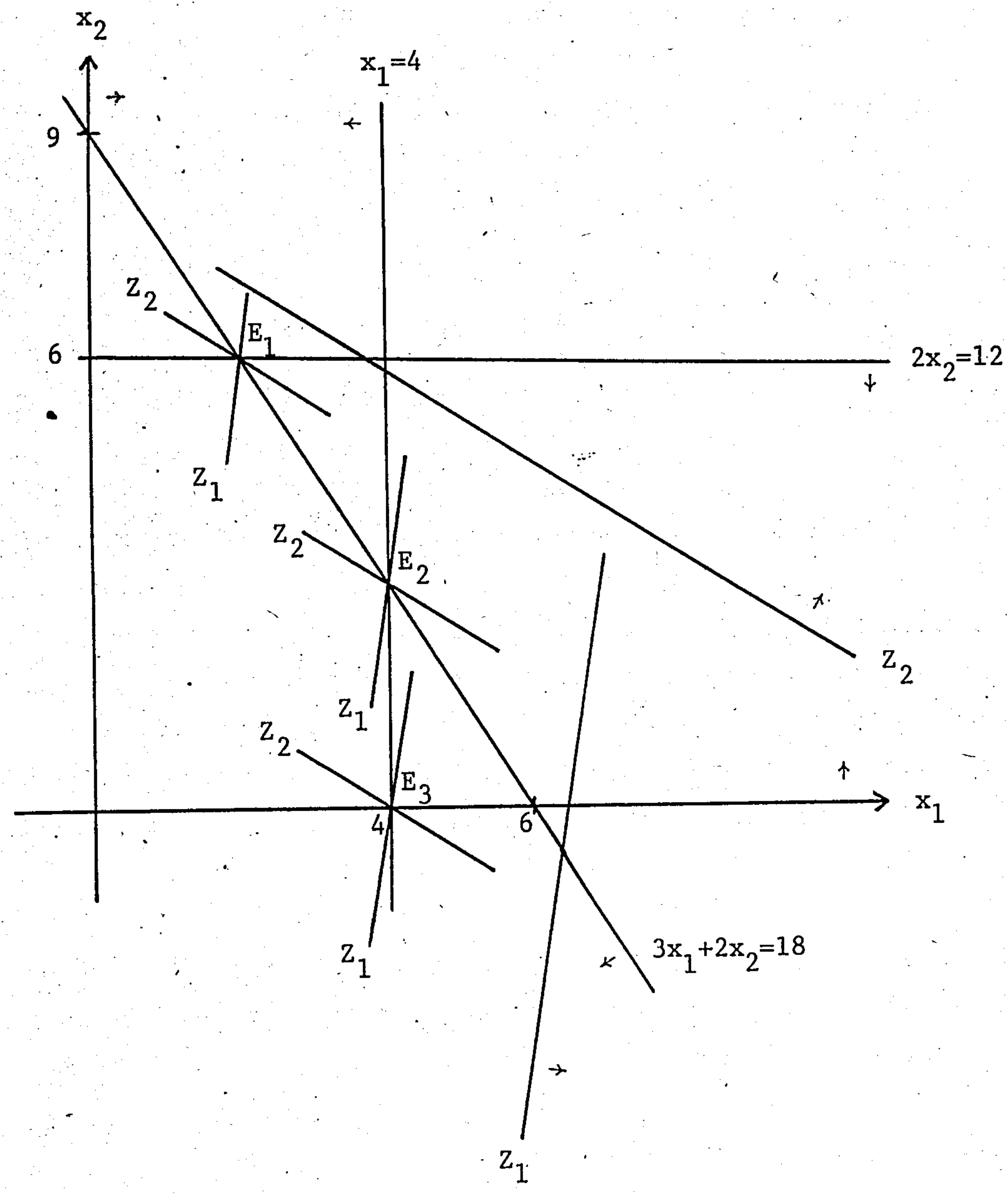
		x_1	x_2	S_1	S_2	S_3
S_2	12	0	2	0	1	0
S_3	6	0	2	-3	0	1
x_1	4	1	0	1	0	0
Z_2	12	0	-5	3	0	0
Z_1	28	0	1	7	0	0

Summarizing the efficient basic solution set is the following:

$$\{(Z_1, Z_2; x_1, x_2, S_1, S_2, S_3)\} =$$

$$\{(8, 36; 2, 6, 2, 0, 0), (25, 27; 4, 3, 0, 6, 0), (28, 12; 4, 0, 0, 12, 6)\}$$

The same solution set can be represented by graphical solution:



E_1: (2,6) with $Z_1=8$, $Z_2=36$
E_2: (4,3) with $Z_1=25$, $Z_2=27$
E_3: (4,0) with $Z_1=28$, $Z_2=12$

E_1 is the efficient point at which the second objective function (Z_2) is maximized; then the second efficient point will be in the direction that as maximum increase occurs in the first objective, at the same time the minimum decrease in the second objective which is the case for point E_2. Then E_3 is found next by the same logic.

The main concern in this study was generation of efficient extreme points or a relevant subset of them corresponding to a decision maker's specified preference region. The algorithm developed by Kızıltan [8] , enumerates all efficient extreme points or only those efficient extreme points satisfying the interval limits on the objective weights, if these are specified and outputs a range for the values W1, W2 for those efficient points.

II.3. MULTIPLE CRITERIA DECISION MAKING (MCDM'

The objective of multicriteria analysis, as stated before, is the study of decision problems in which several points of view must be taken into consideration. In general there will be contradictions between the different points of view considered, in such a way that an action A might be better than an action B on one criterion, and worse on another. The usual approach then, to the modeling of the decision maker's behavior is based upon a concept called utility theory, where the net attractiveness of any alternative is measured by a utility function u, as stated in [11].

Depending on the assumptions about the specificability of the utility function of the decision maker, the multiple Criteria Decision Making Problem can be approached by the analyst in three different ways, [13].

1. Although u is unknown at first, it can be made explicit in its totality, i.e. as a veritable model of decision maker's preference structure. This approach can be studied by Multiattribute Utility-Theory (MAUT).

2. Although the function u is assumed to be unknown and implicit, it can be made partially explicit by way of man-machine interactive dialogue. The decision maker is able to provide information on properties of u, partial trade-offs and simple preference statements. This methodology is known as interactive programming.

3. The third assumption is that a function u is unknown and implicit, it cannot be made explicit or revealed; it is usually assumed to be a monotone, nondecreasing and concave function. Then the task is to identify a set of nondominated solutions (or alternatives).

Some observations are made in the following, for the decision maker and his role in MCDM with respect to the above approaches:

1. The decision maker is actively involved in the assessment of his preference function, often independently of a given decision problem. Once the function is assessed it is used to select an appropriate solution, replacing the decision maker himself.

2. The decision maker is actively participating both in the assessment of his preferences and in the process of decision-making itself.

3. The decision maker is dominant and his decision making role is unaffected. The decision problems are no longer solved by replacing the decision maker by a mathematical model, but by helping the decision maker to obtain his solution by describing his preferences. In this case, he is aided by being presented with nondominated solutions only. These can be obtained without the decision maker's participation in the procedure. His final decision is thus almost entirely independent of the analyst.

MCDM is a large developing research subject within itself. So only a brief review of the main concepts behind each of the above mentioned basic approaches will be given in this section, so the interested readers can find the detailed theory on MAUT in [2], [11], [13], [16].

Multiattribute Utility Theory (MAUT)

The main assumption underlying MAUT is that a utility function u can be actually assessed. Utility does not reflect the decision maker's phychological intensity of preference, but, it is designed to provide a model consistent with his choice behavior, and thus to be useful in predicting future outcomes of choice. Since it is quite difficult to assess the utility function directly, in a global way, it is attempted to decompose u into its basic independent components. The role of the scientist is to determine this function.

Interactive Method

Utility function is defined on the values of individual objectives which are assumed to be explicitly known; on the other hand u is assumed to be only implicitly known.An interactive method is a procedure consisting of an alternation of stages of calculation and discussion. The calculation stage allows the scientist to select an action to offer to the decision maker during the discussion stage. The discussion stage then allows the decision maker to consider the scientist's proposition, and provide information about his preferences. This additional information is to be introduced into the model in the next calculation stage. In some cases the decision maker is required only to provide answers to certain yes or no questions on feasible trade-offs presented him.

Nondominated Solutions

The theory used in the thesis is mainly based on this approach and can be further developed using this concept in the existence of the decision maker.

If the set of all nondominated solutions is denoted by N, it should be known that nondominated solutions do not provide any insight into the process of decision-making itself, rather, N represents a useful generalization of utility-based solution concepts under the conditions of minimum information. Even though knowing set N is helpful in reaching an acceptable decision, it might not solve the problem of choice, since the set of nondominated solutions (the size of N) may be quite large. Basically, a single nondominated solution must be selected as "the solution" of a given problem. If one can effectively reduce the size of N to a very few points (or to a small subset), then such a choice will be made easily. Successive reductions of N, through interactive incorporation of additional information of the decision maker are used in several methodologies.

One approach can be stated as partial decisioning. As the number of alternatives to be compared increases, there is a tendency toward partial decisioning and reduction of the number of alternatives of the part of a decision maker. The decision maker may express the properties of his ideal solution that he is looking for among the components of the set N. Then discarding some "obviously" inferior alternatives he will obtain a smaller set now. The sequential screening and comparisons will lead to obvious changes in the number and the nature of alternatives comprising the available set. Then a single alternative which is ideal or probably the closest one to ideal will have been selected.

CHAPTER III
DYNAMIC MODELLING OF THE POWER SYSTEMS EXPANSION PROBLEM: AN ADAPTIVE APPROACH

III.I. MODELLING THE POWER SYSTEMS EXPANSION PROBLEM

The electrical power system expansion problem poses considerable difficulties even when only a single objective is considered. In an actual system, there are a variety of power plants with different fixed and variable costs, availability factors, capacities, etc. On the demand side, the load is subject to large changes at different seasons, months, days and even hours of the day, in addition to stochastic events that may alter this demand. Furthermore, the expansion program must be taken together with the operating program of all power plants in order to avoid suboptimal decisions.

In view of the size and complexity of the system, and given that there may be considerable uncertainties in various elements, it would be almost impossible to consider all aspects of the system within a single model.

The model given below is a modified version of the model which had been applied to the electrical system in Turkey by Kavrakoğlu [4] .

5 types of power plants are analyzed: nuclear, hydro-base (dam+turbine), hydro-peak (turbine only), coal and fuel-oil. All technical and financial aspects are expressed as linear relations for five 5-year periods, thus resulting in a 25-year planning horizon. Four objectives are considered significant: economics, pollution, space occupied, and risk involved. While other factors such as employment, opportunities, etc. may also play

a role, only these four objectives mentioned above are considered to have deciding influences Economics will always be a determinant in any investment decision. Pollution and space occupied are taken as the two important dimensions of environmental impact and the risk involved implies the potential damage which is the combination of the probability of an accident and the extent of damage that such an accident would cause.

These four objectives can be expressed generally as:

cost: $$Z_1 = \sum_{t=1}^{5} \left(\frac{1}{1+r}\right)^{5t-2} \left\{ \sum_{i=1}^{5} \alpha_i P_{it} + 5 \left[\alpha_i' E_{it} + \mu U_t\right] \right\}$$

pollution: $$Z_2 = \sum_{t=1}^{5} \sum_{i=1}^{5} \gamma_i E_{it}$$

space occupied: $$Z_3 = \sum_{t=1}^{5} \sum_{i=1}^{5} \beta_i P_{it}$$

risk involved: $$Z_4 = \sum_{t=1}^{5} \sum_{i=1}^{5} \delta_i P_{it}$$

where

P_{it} : Additional capacity for i type power plant during period t.

E_{it} : Energy generated per year by i type power plant during period t.

U_t : Unsatisfied energy demand during period t.

α_i : Unit cost of installed power for i type power plant.

α_i' : Unit cost of energy generated for i type power plant.

γ_i : Pollution coefficient for i type power plant.

β_i : Space occupied coefficient for i type power plant.

δ_i : Risk coefficient for i type power plant.

μ : Unit cost of unsatisfied energy demand.

r : Discount factor compounded annually.

$\left(\frac{1}{1+r}\right)^{5t-2}$: Discount factor for a 5-year period (discounting is done from the mid year for each period)

The constraints of the model are:

. Energy Demand : Energy generated plus unsatisfied demand must be greater than or equal to the energy demand.

$$\sum_{i=1}^{5} E_{it} + U_t \geq ED_t \qquad t=1,5$$

where ED_t is the energy demand per year during period t.

. Power Demand : Power demand must be satisfied at all times.

$$\sum_{j=0}^{t} \sum_{i=1}^{5} P_{ij} \geq PD_t \qquad t=1,5$$

where PD_t is the power demand during period t and P_{i0} is the existing capacity for i type power plant.

.. Production Capacity : Amount of energy that can be generated at time t can not exceed the power capacity at that time multiplied by the maximum load factor (f_i) of the respective power plant types.

$$E_{it} \leq C_i f_i \sum_{j=0}^{t-1} P_{ij} \qquad j=1,5 \quad t=1,5$$

where energy production is lagged by one time period (5 years) with respect to implementation of a new-project. C_i is the conversion factor including reserve margin.

. Build-up Rate : The amount of new capacity added for each type of power plant is limited by the development of technical capacity through the coefficient K_i.

$$P_{it} \leq K_i \sum_{j=0}^{t-1} P_{ij} \qquad i=1,5 \qquad t=1,5$$

. Hydro-Peak Limitation : Existing hydro-peak power is restricted by the existing hydro-base power at any time through the coefficient h.

$$\sum_{j=0}^{t} P_{3t} \leq h \sum_{j=0}^{t} P_{2t} \qquad t=1,5$$

where $\sum_{j=0}^{t} P_{2t}$ and $\sum_{j=0}^{t} P_{3t}$ denote Hydro-base and Hydro-peak powers respectively.

III.2. THE ADAPTIVE APPROACH

The modelling of the power system expansion problem discussed earlier in this chapter requires the forecast of energy demand for each period. Once the values of ED_i are set, there is no possibility to change them throughout the planning horizon of 25-years. But energy demand during a period is a function of various factors. Two important factors that determine the energy demand level are the price of the electricity supplied and the Gross National Product (GNP) of the country. On the other hand, GNP during a period is also a function of the energy consumption of the country. Therefore the first period solutions obtained from this procedure will affect the energy demand of later periods since the cost of electricity generated during the first period is a function of the alternative choosen to generate the required energy. The problem is the same for other periods.

Therefore, a periodic review of the system at the end of each period is required so that the necessary adjustments can be made.

The adaptive procedure described below overcomes this problem, and from that point of view it is superior to other approaches. Another desirable feature of the adaptive approach is the fact that it eliminates the end-effects. Since energy production is lagged by one time period (5 years) with respect to the implementation of a new project and the period right after the planning horizon is not considered, there may be no need for additional capacities at the fifth period, a very unrealistic situation. The adaptive approach overcomes the problem since the total planning horizon is enlarged and the relevant planning horizon is less than this total planning horizon.

III.3. THE ADAPTIVE SOLUTION PROCEDURE

The adaptive solution procedure employed is depicted in Figure III.1.

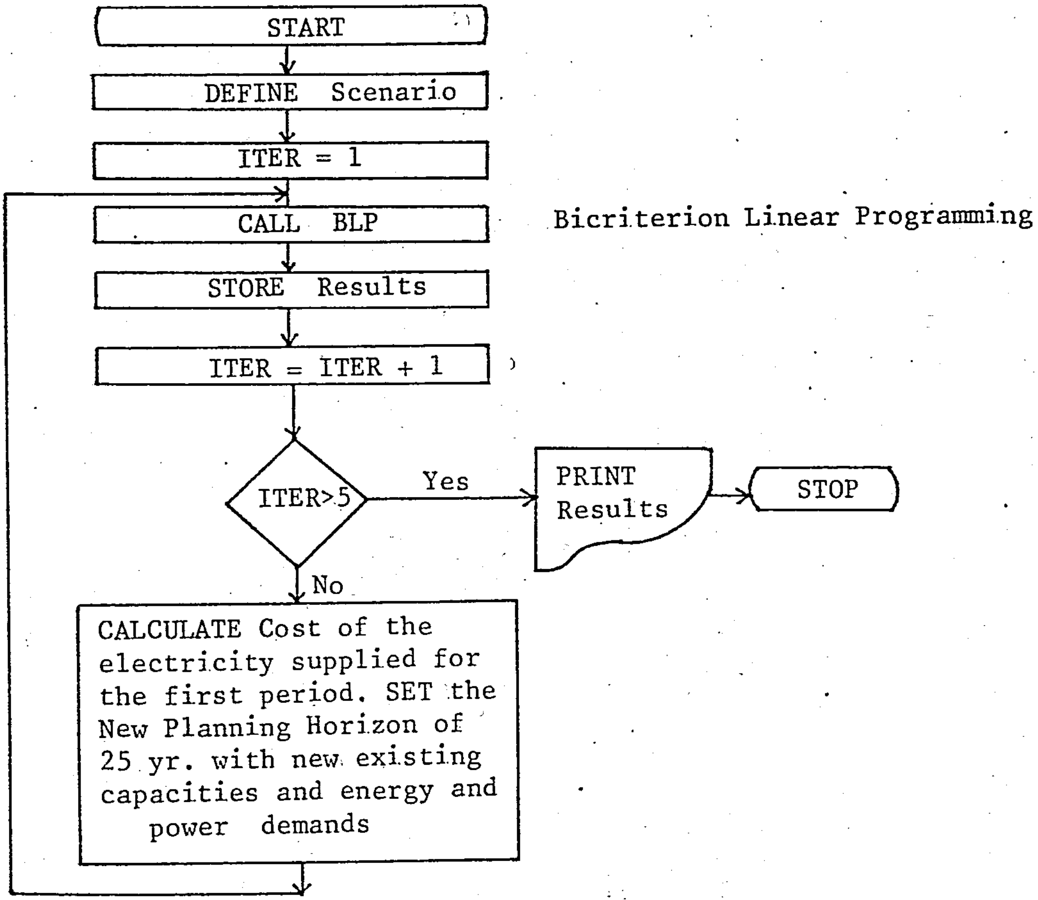


Figure III.1. The Adaptive Solution Procedure

The beginning year is taken as 1982. Then, according to Figure III.1, for 5 iterations, the planning horizon changes as in Figure III.2. The set of results consisting of the solutions for the first periods at each iteration constitutes the aggregate results for the 25-year relevant planning horizon.

1.Iteration	1982- 1986	1987- 1991	1992- 1996	1997- 2001	2002- 2006				
2.Iteration		1987- 1991	1992- 1996	1997- 2001	2002- 2006	2007 2011			
3.Iteration			1992- 1996	1997- 2001	2002- 2006	2007- 2011	2012- 2016		
4.Iteration				1997- 2001	2002- 2006	2007 2011	2012- 2016	2017- 2021	
5.Iteration					2002- 2006	2007- 2011	2012- 2016	2017- 2021	2022- 2026

Figure III.2. The Planning Horizon at Each Iteration

The objectives are taken two at a time with the economics objective always being present and the trade-offs between objective pairs are observed. Bicriterion analysis provides conceptual ease for the decision maker,in selecting his preferences, in that efficient solutions can be represented graphically in an easy manner and can be interpreted and analyzed more readily.

In other words, in real life applications the bicriterion linear programming is expected to generate (efficiently) a subset of nondominated solutions and then the decision maker is expected to state (explicitely or implicitely) his preferences among that subset of efficient points (The efficient point most preferred by the decision maker will then generate the input parameters to the next 5-year period bicriterion linear programming). This process will continue until all five 5-year periods are considered. One of the most important advantages of this procedure is to give a flexibility to the decision maker to review his value judgements and to reassess his preferences at the end of each iteration considering the new economic, environmental and social conditions indicated by the efficient solutions generated so far.

However working with an actual decision maker and obtaining his real preferences was beyond the scope of this study. Consequently the approach adopted was to try to simulate a decision maker. This, in itself, is no easy task either and requires careful and extensive consideration of the several factors entering into the decision-making process. Although a detailed model of the preference system of a decision maker could be developed, a much simpler approach which was considered to be adequate for the purposes of this study was taken. A weight ratio W1/W2 which indicates the relative importance given to the two objectives by the decision maker is specified and at each iteration only the efficient solution corresponding to that weight ratio is generated. Although in this case the capacity of the algorithm is not utilized as it should be, either by developing a model simulating the decision maker, or by interacting with an actual decision maker the capacity of the model developed can be used fully.

The algorithm used requires a range for the weight of the second objective function in order to generate the efficient extreme point(s) valid for that range. If this range is specified as (0,1), then all of the efficient extreme points will be generated. In order to satisfy the input requirements of the algorithm, the necessary range (a_1, a_2) is calculated from $r = \frac{W1}{W2}$ as follows:

$$W1 + W2 = 1$$

$$\frac{W1}{W2} = r \rightarrow W1 = rW2$$

From these two equations it can be found;

$$rW2 + W2 = 1$$

$$W2(r+1) = 1$$

$$W2 = \frac{1}{r+1}$$

$$a_1 = \frac{1}{r+1} - 0.01$$

$$a_2 = \frac{1}{r+1} + 0.01$$

So if we choose $\frac{W1}{W2}$ as 3, then

$$a_1 = \frac{1}{3+1} - 0.01 \rightarrow a_1 = 0.24$$

$$a_2 = \frac{1}{3+1} + 0.01 \rightarrow a_2 = 0.26$$

is obtained and a_1 and a_2 are used as the range for which the algorithm works.

If a large range is specified for the weight ratios initially, all efficient extreme points whose weight ratios are falling in that range will be generated at the end of the first iteration. The necessary adaptations (i.e. energy-power demand forecasts, initial power capacity adjustments, etc.) will take place for each solution set of efficient extreme points; and the next iteration, bicriterion linear programming will start for each of them. After the completion of the fifth iteration, there will be too many solution branches which will most probably cause a complexity for the decision maker.

III.3.1. SCENARIO SPECIFICATIONS

The main aim of this study was to derive a framework for the power systems expansion decisions based on trade-off functions between pairs of objectives. Therefore which two objectives out of the four objectives are considered is the first specification of the scenario, and is denoted by S_1. The second specification, denoted by S_2, is an expression of the implicit utility function of the decision maker. After all efficient solutions are generated, the decision maker(s) will choose one of these in line with his (their) implicit utility function. However, since cooperation with the decision maker was not possible within the scope of this study, the relative importance given to the two objectives was considered in the form of the objective weight ratio, W1/W2. The third one, S_3, is the desired profit margin which will be added to the unit cost of the energy supplied in order to determine the unit price of electricity. Finally, the income elasticity, S_4, used in forecasting demand, is also taken as a scenario specification since different income elasticity values are tested. Therefore, (S_1, S_2, S_3, S_4) define a specific scenario.

III.3.2. SUBROUTINE BLP (BICRITERION LINEAR PROGRAMMING)

Subroutine BLP enumerates either all efficient extreme points or any desired subset of such points of the problem. However only the efficient extreme point for which the range of objective weights as defined in section II.2. , with (R_λ) is returned back as the solution of the problem. Except this modification, the solution procedure is the same as the one explained in Chapter II.

III.3.3. SUBROUTINE UPDATE

Given a specific value for W1/W2, Subroutine BLP returns a solution subject to the constraints whose RHS vector (b-vector) has to be changed for energy and power demand entries. At the end of each iteration the energy and power demands have to be recalculated for the new planning horizon. Subroutine UPDATE is used to achieve this function.

In order to facilitate data handling, at each iteration the initial set of data is read from the same logical unit. The FORTRAN statement REWIND n, where n is the number of the logical unit is used for this purpose. Then, depending on the iteration counter, the necessary updates take-place. These updates are related to:

i) 1st period nuclear power assignment

ii) Initialization of new beginning capacities

iii) Energy demand

iv) Unsatisfied Energy demand, and

v) Power demand.

Energy demand, unsatisfied energy demand, and power demand calculations and updates will be discussed in detail in the following sections. 1st period nuclear power assignment is carried on for the first period of the first iteration since an existing capacity of zero for nuclear power plant type would lead to zero additional capacity for the next periods and iterations due to the constraint

$$P_{11} \leq K_1 P_{10} \quad \text{where}$$

P_{11} is the additional nuclear capacity at the first period,
K_1 is the build-up rate for nuclear power plants, and
P_{10} is the existing nuclear capacity at the beginning of the planning horizon. Since

$$P_{1t} \leq K_1 \sum_{j=0}^{t-1} P_{1j} \quad \text{for} \quad t=2,3,4,5,$$

there would be no possibility for an additional nuclear power plant capacity. Therefore the constraint

$$P_{11} \leq K_1 P_{10} \quad \text{where} \quad P_{10}=0$$

$$P_{11} - K_1 P_{10} \leq 0 \quad \text{is changed to}$$

$$P_{11} - K_1 P_{10} = 1 \quad \text{only for the first iteration.}$$

Initialization of the new beginning capacities for each iteration is carried on by simple FORTRAN statements depending on the value of the iteration counter. Therefore, for the second, third, fourth and fifth iterations the following assignments are included:

$$P_{i0} = P_{i0} + P_{i1} \quad \text{for } i \text{ type power plant.}$$

where P_{i0} at the left side of the equality sign is the existing capacity of the i type power plant at the beginning of the n^{th} iteration, P_{i0} at the right side of the equality sign is the existing capacity of the i type power plant at the beginning of $(n-1)^{st}$ iteration, and P_{i1} is the additional capacity of the i type power plant at the first period of the $(n-1)^{st}$ iteration.

III.3.4. COST AND PRICE OF ELECTRICITY SUPPLY

Energy demand is a function of various factors including the price of the electricity as a major variable. Therefore, before going on with the energy demand calculations for new planning horizons, the price of the electricity has to be estimated. Subroutine UPDATE calculates the new price of the electricity for the second, third, fourth and fifth iterations.

Let $PRICE_t$ = Price of the electricity at the t^{th} iteration.

$COST_t$ = Cost of the electricity at the t^{th} iteration.

PROFIT = Profit margin for the electricity supplied (a scenario specification)

then $$PRICE_t = COST_t \times (1+PROFIT) \qquad (1)$$

Furthermore, let

$$COST_t = COSTIN_t + COSTOP_t \qquad (2)$$

where $COSTIN_t$ and $COSTOP_t$ are the investment and operating cost components of $COST_t$ respectively.

EG_{it} = Energy generated yearly by i type power plant at the first period of the t^{th} iteration.

UL_i = Useful (economic) life of i type power plant.

then

$$\text{COSTIN}_t = \frac{\sum_i \frac{\alpha_i}{UL_i}(P_{i0}+P_{i1})_{t-1}}{\sum_i EG_{i,t-1}} \tag{3}$$

and

$$\text{COSTOP}_t = \frac{\sum_i \alpha_i' \, EG_{i,t-1}}{\sum_i EG_{i,t-1}} \tag{4}$$

where α_i and α_i' are the unit investment cost of the i type power plant and unit operating cost of the energy supplied by i type power plant.

Combining (1), (2), (3), (4), we get

$$\text{PRICE}_t = (1+\text{PROFIT}) \left(\frac{\sum_i \frac{\alpha_i}{UL_i}(P_{i0}+P_{i1})_{t-1} + \sum_i \alpha_i' \, EG_{i,t-1}}{\sum_i EG_{i,t-1}} \right) \tag{5}$$

In other words, the cost of the electricity supplied is a weighted average of the cost of the electricity supplied by various power plant types. On the other hand, the cost of the electricity supplied by a specific power plant is the sum of its operating cost per energy unit generated plus the ratio of the yearly depreciation over yearly energy generated by this specific power plant.

III.3.5. ENERGY DEMAND FORECAST

As mentioned earlier energy demand is a function of various factors such as price of the electricity, GNP per capita, population, industrialization, etc.

The use of GNP instead of GNP per capita is a good and widely used approach since it represents also the population and industrialization factors together with GNP per capita factor.

In other words, GNP is a function of GNP per capita, population, and industrialization. Thus, ceteris paribus a change in one of these factors will affect GNP in the same direction.

Starting from this point of view, the following formula is used to estimate energy demands for new planning horizons.

$$ED_t = ED_{t-1} \left(\frac{PRICE_t}{PRICE_{t-1}} \right)^{PR.EL.} \left(\frac{GNP_t}{GNP_{t-1}} \right)^{IN.EL.} \qquad (6)$$

where PR.EL. and IN.EL. are the price and income elasticities respectively.

GNP_t is also calculated as a function of GNP_{t-1} by the following formula

$$GNP_t = (A)\ (GNP_{t-1}) \left(\frac{ED_{t-1}}{ED_{t-2}} \right) \quad 1{,}15 \qquad (7)$$

since, due to the mutual influence, GNP is also a function of the energy demand.

Then combining (6) and (7)

$$ED_t = ED_{t-1} \left(\frac{PRICE_t}{PRICE_{t-1}} \right)^{PR.EL.} \left(A\, \frac{ED_{t-1}}{ED_{t-2}} \right)^{IN.EL.} \qquad (8)$$

is obtained.

In the calculations PR.EL. is taken as -0.4 . A which is a constant is taken as 1.155 and IN.EL. is considered as a scenario specification.

Subroutine UPDATE calculates the price of the electricity supplied and the resulting energy demands for new planning horizons at each iteration and makes the necessary changes in the b vector accordingly.

Since PROFIT (Profit Margin) and IN.EL. (Income Elasticity) are the two of the four scenario specifications, different values for these two parameters can be tested and their influences can be analyzed.

III.3.6. UNSATISFIED ENERGY DEMAND

In the previous section, we have discussed how energy demand is forecasted for new planning horizons. Since we have assumed that the additional capacities will operate one period later, the beginning capacities at each iteration have to satisfy the first period energy demands. However, this is not guarantied. For instance, a sharp decrease in the price of the electricity may highly effect the first period energy demand and existing capacities may not be sufficient to generate the necessary energy. Then an infeasible solution may result. To overcome this situation, unsatisfied energy demand is permitted but a relatively large cost coefficient is assigned in order to hold the unsatisfied energy demand at a minimum level. Then, running different scenarios with different profit margins and income elasticities the point at which the unsatisfied demand vanishes can be found. Since the profit margin, in other words, the price of the electricity is a controllable variable, efficient price policies which won't lend to unsatisfied energy demands will result.

III.3.7. POWER DEMAND FORECAST

Since "Power Demand (PD) must be satisfied at all times" is one of the constraints of the problem, new power demands for new planning horizons have to be estimated. Once the new energy demands are calculated as described, power demand estimates can be obtained accordingly. For this purpose an average load factor of 0.55 is used and power demand (GW) is obtained from energy demand (TWH) by the following formula:

$$ED_t = \frac{8760}{1000} (0.55) PD_t \qquad (9)$$

$$PD_t = \frac{ED_t}{4.818}$$

where 8760 is the number of hours in a year and $\frac{1}{1000}$ is the conversion factor of Tera to Giga.

Subroutine UPDATE calculates and assigns new power demand values to the "b vector" in the same way as it does for the energy demand except that unsatisfied power demand is not permitted.

III.3.8. SUBROUTINE STORE

Due to the adaptive nature of the algorithm, at the end of each iteration the values have to be saved and reinitialization occurs. Subroutine STORE does this function. It is called from the main program at the end of each iteration and the values to be saved are stored in a matrix whose rows represent the iteration number. At the end of the fifth iteration, the matrix contains all the necessary information for the Aggregate Tableau consisting of the first period decisions of each iteration.

III.3.9. SUBROUTINE RWRITE

Once the iterations are terminated, Subroutine RWRITE is called in order to print out the results. The output consists of three pages for each scenario. The first page, as illustrated in Figure III.3, containes the necessary information about the terminology of the variables. The second part of the first page is used to define the specific scenario under consideration. OBJ1, PR.EL. and D.RATE have always the same values of COST MINIMIZATION, -0.4, 8.0 % respectively since they are assumed constant regardless of the scenario. The other four parameters, OBJ2, W1/W2, PROFIT, and IN.EL. define the specific scenario under consideration, and in the figure these are POLLUTION MINIMIZATION 1.0, 20 % and 0.8 respectively.

In the second page, the results of each iteration are printed. The rows constitute the variables and their corresponding values at each iteration are listed columnwise. A cross reference table is used since the variables used in subroutine BLP are in the form of X(1), X(2), X(3),... etc.
The last rows are reserved for the PRICE and Energy Demand (ED) of the iteration under consideration. Figure III.4. illustrates the corresponding output.

```
TERMINOLOGY
-----------

I : POWER PLANT TYPE      1 : NUCLEAR
                          2 : HYDRO-BASE (DAM)
                          3 : HYDRO-PEAK (TURBINE)
                          4 : COAL
                          5 : FUEL

T : TIME PERIOD             1.ITERATION  2.ITERATION  3.ITERATION  4.ITERATION  5.ITERATION

                        1 :  1982-1986    1987-1991    1992-1996    1997-2001    2002-2006
                        2 :  1987-1991    1992-1996    1997-2001    2002-2006    2007-2011
                        3 :  1992-1996    1997-2001    2002-2006    2007-2011    2012-2016
                        4 :  1997-2001    2002-2006    2007-2011    2012-2016    2017-2021
                        5 :  2002-2006    2007-2011    2012-2016    2017-2021    2022-2026

P(I,0) : EXISTING CAPACITY (GW) FOR I TYPE POWER PLANT

P(I,T) : ADDITIONAL CAPACITY (GW) FOR I TYPE POWER PLANT DURING PERIOD T

E(I,T) : ENERGY GENERATED (TWH) PER YEAR BY I TYPE POWER PLANT DURIND PERIOD T

ED(T)  : ENERGY DEMAND (TWH) PER YEAR DURING PERIOD T

PRICE  : PRICE OF THE ENERGY SUPPLIED (TL/KWH)

PROFIT : PROFIT MARGIN FOR THE ENERGY SUPPLIED (%)

IN.EL. : INCOME ELASTICITY

PR.EL. : PRICE ELASTICITY

D.RATE : DISCOUNT FACTOR (%) COMPOUNDED ANNUALLY


SCENARIO SPECIFICATIONS
-----------------------

 OBJ1 : COST MINIMIZATION

 OBJ2 : POLLUTION MINIMIZATION

 (W1/W2) =  1.0

 PROFIT  =  20.0 %

 IN.EL.  =    .8

 PR.EL.  =   -.4

 D.RATE  =   8.0 %
```

Figure III.3. Terminology of the Variables

```
VARIABLE         1.ITER.   2.ITER.   3.ITER.   4.ITER.   5.ITER.
--------         -------   -------   -------   -------   -------

P(1,0)               .00      1.00      2.20      4.84     10.65
P(2,0)              2.00      3.40      5.78      9.83     16.70
P(3,0)               .30       .30       .30       .30       .30
P(4,0)              1.40      2.94      4.50      7.61     11.42
P(5,0)              1.60      1.60      1.60      1.60      1.60

P(1,1)              1.00      1.20      2.64      5.81     12.78
P(2,1)              1.10      2.33      4.05      6.88     11.69
P(3,1)               .00       .00       .00       .00       .00
P(4,1)              1.54      1.56      3.11      3.81      2.08
E(4,1)              7.80     16.39     25.10     42.44     63.68
E(5,1)              5.43      1.10      5.28      5.77      5.82

P(1,2)              1.20      2.64      5.81     12.78     28.11
P(2,2)              2.39      4.05      6.88     11.69     17.88
P(3,2)               .00       .00       .00       .00       .00
P(4,2)              1.30      1.59      1.73       .46       .00
E(4,2)             16.39     25.10     42.44     63.68     75.28
E(5,2)               .15       .00       .00       .00      6.37

P(1,3)              2.64      5.81     12.78     28.11     54.40
P(2,3)              4.05      6.88     11.69     19.88     33.79
P(3,3)               .00       .00       .00       .00       .00
P(4,3)               .33       .14       .00       .00       .00
E(4,3)             23.63     33.94     52.11     66.22     66.14
E(5,3)               .00       .00      2.41      6.37       .00

P(1,4)              5.91     12.78     28.11     49.09     62.93
P(2,4)              6.88     11.69     19.88     33.79     57.45
P(3,4)               .00       .00       .00       .00       .00
P(4,4)               .96       .00       .00       .00       .00
E(4,4)             25.47     34.73     52.11     46.50       .00
E(5,4)              6.37      6.37      6.37      6.37       .00

P(1,5)               .00       .00       .00       .00       .00
P(2,5)               .00       .00       .00       .00       .00
P(3,5)              1.20      1.10       .00       .00       .00
P(4,5)               .00       .00       .00       .00       .00
E(4,5)             30.80     29.26     21.80       .00       .00
E(5,5)              6.37      6.37      6.37       .00       .00


PRICE               5.50      5.41      4.82      5.10      4.87


ED(1)              22.00     36.95     65.75    113.37    191.33
ED(2)              36.00     60.47    107.60    185.51    313.08
ED(3)              59.00     99.10    176.34    304.03    513.11
ED(4)              97.00    162.93    289.91    499.84    843.58
ED(5)             159.00    267.07    475.22    819.33   1382.78
```

Figure III.4. The Results of Each Iteration

```
**********************
*                    *
*  AGGREGATE TABLEAU *        OBJ1 :   4131.17
*                    *
**********************        OBJ2 :   1694.63

                                 1982-1986  1987-1991  1992-1996  1997-2001  2002-2006
                                 ---------  ---------  ---------  ---------  ---------

ENERGY DEMAND (TWH) SATISFIED        22.00      36.95      65.75     113.37     191.33

ENERGY DEMAND (TWH) UNSATISFIED        .00        .00        .00       1.00       9.00

--------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------

NUCLEAR
-------

EXISTING CAPACITY   (GW)               .00       1.00       2.20       4.84      10.65
ADDITIONAL CAPACITY (GW)              1.00       1.20       2.64       5.81      12.78
ENERGY GENERATED    (TWH)              .00       4.57      10.05      22.12      48.66

--------------------------------------------------------------------------------------

HYDRO-BASE
----------

EXISTING CAPACITY   (GW)              2.00       3.40       5.78       9.83      16.70
ADDITIONAL CAPACITY (GW)              1.40       2.38       4.05       6.88      11.69
ENERGY GENERATED    (TWH)             8.76      14.89      25.31      43.03      73.15

--------------------------------------------------------------------------------------

HYDRO-PEAK
----------

EXISTING CAPACITY   (GW)               .30        .30        .30        .30        .30
ADDITIONAL CAPACITY (GW)               .00        .00        .00        .00        .00

--------------------------------------------------------------------------------------

COAL
----

EXISTING CAPACITY   (GW)              1.40       2.94       4.50       7.61      11.42
ADDITIONAL CAPACITY (GW)              1.54       1.56       3.11       3.81       2.08
ENERGY GENERATED    (TWH)             7.80      16.39      25.10      42.44      63.68

--------------------------------------------------------------------------------------

FUEL
----

EXISTING CAPACITY   (GW)              1.60       1.60       1.60       1.60       1.60
ENERGY GENERATED    (TWH)             5.43       1.10       5.28       5.77       5.82

--------------------------------------------------------------------------------------
```

Figure III.5, The Final Aggregate Tablo

Finally, the last page is used to print out the final aggregate tableau and the objective function values of the scenario considered. The output is shown in Figure III.5. Both satisfied and unsatisfied energy demands are printed for each period. Then, for each power plant type, the existing capacity, additional capacity and energy generated are listed accordingly.

CHAPTER IV

APPLICATION OF THE MODEL TO THE TURKISH ELECTRICAL SYSTEM

The model with four objectives is applied to the Turkish electrical system. In order to analyze their consequences, different scenarios are developed. Throughout this chapter, the objectives, constraints, scenario specifications, and results obtained will be discussed in the given order.

The additional features of the program set, subroutine NEWOBJ, which permits the optimization of the cost function only for the first two periods at each iteration, and subroutine ADJUST, which enables the algorithm to modify the (W1/W2) ratio during the execution of a specific scenario will be presented too.

After all efficient solutions are generated, one of them would be chosen by the decision maker according to his implicit utility function, however decision maker's implicit utility function would also change under the new economic and environmental circumtances. Since there is no cooperation with the decision maker in this case, the prespecified objective weight ratio (W1/W2) now will be changed in each iteration if necessary to simulate the changes in a real decision maker's utility function.

IV.I. THE OBJECTIVES OF THE MODEL

As mentioned, there are four objectives to be considered two at a time, the cost objective being always concluded. The other three objectives are risk, pollution and space. All are in the minimization form.

IV.1.1. COST MINIMIZATION OBJECTIVE

$$
\begin{aligned}
\text{Min } C = \sum_{t=1}^{5} \left(\frac{1}{1+r}\right)^{5t-2} \Bigg\{ \sum_{i=1}^{4} \alpha_i P_{it} + 5\Bigg[\alpha_1' \frac{8.76}{1.15} f_1 \sum_{j=0}^{t-1} P_{1j} \\
+ \alpha_2' \frac{8.76}{1.20} f_2 \sum_{j=0}^{t-1} P_{2j} \\
+ \alpha_4' E_{4t} + \alpha_5' E_{5t} + \mu U_t\Bigg] \Bigg\} .
\end{aligned}
$$

where

i : is the power plant type

$i = 1$ nuclear
$i = 2$ hydro base (dam+turbine
$i = 3$ hydro peak (turbine only)
$i = 4$ coal
$i = 5$ fuel

t : is the subscript of the 5 five years periods.

r : is the discount factor compounded annually.

P_{io} : is the existing capacity (GW) of the i type power plant.

P_{it} : is the additional capacity (GW) of the i type power plant during period t.

E_{it} : is the energy generated (TWH) per year by i type power plant during period t.

α_i : is the investment cost (TL/W) of the i type power plant.

α_i' : is the operating cost (TL/KWH) of the energy generated by i type power plant.

f_i : is the load factor of the i type power plant.

μ : is the unit cost of unsatisfied energy demand.

$(\frac{1}{1+r})^{5t-2}$: is used in order to consider the mid-year of each five-year period and r is taken as 8 % compounded annually.

Furthermore,

- It is assumed that energy production is lagged by one time period.

- Energy generated by nuclear and hydro-base power plants are expressed as a function of their existing capacities by the following transformations:

$$E_{1t} = \frac{8.76}{1.15} f_1 \sum_{j=0}^{t-1} P_{1j}$$

$$E_{2t} = \frac{8.76}{1.20} f_2 \sum_{j=0}^{t-1} P_{2j}$$

where 8.76 is the number of hours in a year (8760) divided by the conversion factor (1000) to convert giga to tera.

$\frac{1}{1.15}$ and $\frac{1}{1.20}$ are the reserve margins for the nuclear and hydro power plants as a result of internal effects such as unpredicted break-downs.

- No additional capacity is allowed for fuel type power plant but energy generation from the existing capacity is permitted.

. The values of the parameters* are as follows:

i	α_i TL/W	α'_i TL/KWH	f_i	Useful Life (economic) Years
1 (nuclear)	100	2	0.60	25
2 (hydro-base dam)	70	1	0.60	100
3 (hydro-peak turbine)	20	-	-	20
4 (coal)	60	4	0.70	30
5 (fuel)	-	8	0.50	30

μ = 20 TL/KWH

Table IV.1. The Values of the Parameters Used in Cost Objective Function

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* All the values of parameters are given by Prof.İbrahim Kavrakoğlu, Boğaziçi University.

IV.1.2. RISK, POLLUTION AND SPACE MINIMIZATION OBJECTIVES

Environmental impact and potential damage aspects are not as easily quantified as financial aspects. For Risk (R), Pollution (P), and Space (S) minimization objectives, an ordinal ranking is made [6] . The ranking is given below.

	Cost		Risk	Pollution	Space
	Fixed	Variable			
	α	α'	δ	γ	β
Highest ↑	Nuclear	Coal	Hydro	Coal	Hydro
	Hydro	Nuclear	Nuclear	Nuclear	Coal
Lowest	Coal	Hydro	Coal	Hydro	Nuclear

Table IV.2. The Ranking of Power Plants w.r.t. the Objectives

In the objective function, the additional capacities are given a coefficient for risk and space minimization whereas energy generated is assigned a coefficient for pollution minimization.

However the energy generated is transformed to existing capacity in the pollution objective for nuclear power plants as it is done in the cost minimization objective.

The resulting Risk, Pollution, and Space Minimization objectives are as follows:

$$\text{Min} \quad R = \sum_{t=1}^{5} \delta_1 P_{1t} + \delta_2 P_{2t}$$

$$\text{Min} \quad P = \sum_{t=1}^{5} \gamma_1 P_{1t} + \gamma_4 E_{4t} + \gamma_5 E_{5t}$$

$$\text{Min} \quad S = \sum_{t=1}^{5} \beta_1 P_{1t} + \beta_2 P_{2t} + \beta_4 P_{4t}$$

The values of the parameters are taken as

i	risk δ_i	pollution γ_i	space β_i
1 (nuclear)	8	1	1
2 (hydro)	10	-	10
4 (coal	-	10	2
5 (fuel)	-	5	-

Table IV.3. The Values of the Parameters Used in Risk, Pollution and Space Objective Functions

As regards risk involved, a higher coefficient assigned to hydro plants rather than nuclear plants may appear conterintuitive. However, quite a few dams have failed and in the event of a failure, the number of lives that would be affected is of the same order of magnitude for either type of plant.

As regards to pollution, coal power plants are more objectionable. Few would argue that the radiation or excess heat release of a nuclear power plant affects the environment as much as the chemical pollution caused by the burning of fossil-fuels especially if low quality-high sulphur content coal is considered.

Finally the space occupied by the reservoir of a dam is much more than any other type of plant and the area required by the nuclear power plant is usually less than a coal power plant which has to be considered together with its storage facilities.

In determining the objective coefficients; the investment cost was taken as the sum of power plant and transmission costs. Transmission costs are almost as high as plant costs and may vary significantly depending on the distance that energy transmitted to.

In Turkey, where the hydro potential is rather distant from the main load centers, the largest unit transmission costs are incurred for hydroelectricity. Lowest transmission cost apply for coal power plants while nuclear plants would entail costs of intermediate value.

As it is said above, environmental impact and potential damage aspects are not as easily quantified as financial aspects.

Environmental impact, as defined here, refers to pollution caused by burning of coal, fuel, radioactive emissions from a nuclear power plant; and land covered by the reservoir of a hydroelectric plant, and nuclear and coal plants relatively in small amount. Although these indicators imply different dimensions and necessarily entail a certain subjective evaluation, the ranking given in Table IV.2. may be representative of many analyses.

IV.2. THE CONSTRAINTS OF THE MODEL

There are 45 constraints involving 40 variables in the model. These constraints are:

- Energy Demand : Energy generated plus unsatisfied demand must be greater than or equal to the energy demand (ED).

C01-C05 $$\frac{8.76}{1.15} f_1 \sum_{j=0}^{t-1} P_{1j} + \frac{8.76}{1.20} f_2 \sum_{j=0}^{t-1} P_{2j} + E_{4t} + E_{5t} + U_t \geq ED_t \qquad t=1,5$$

- Power Demand : Power Demand (PD) must be satisfied at all times.

C06-C10 $$\sum_{i=1}^{5} \ell_i P_{i0} + \sum_{j=1}^{t} \sum_{i=1}^{4} \ell_i P_{ij} \geq PD_t \qquad t=1,5$$

where ℓ_i is the reserve margin coefficient and is equal to 0.80 for i=1 (nuclear), 0.85 for i=4 (coal) and 1.00 for $i \neq 1$ and 4.

- Production Capacity : Amount of energy that can be generated at time t cannot exceed the power capacity at that time multiplied by the load factor. This constraint is applied to coal and fuel power plants.

C11-C15 $$E_{4t} \leq \frac{8.76}{1.10} f_4 \sum_{j=0}^{t-1} P_{4j}$$ t=1,5

C16-C20 $$E_{5t} \leq \frac{8.76}{1.10} f_5 P_{50}$$ t=1,5

where $\frac{8.76}{1.10}$ has the same meaning as explained for nuclear and hydro power plant types in Section IV.1.1.

- Build-up Rate : The amount of new capacity added is limited by the development of technical capacity through the coefficient K_i for nuclear hydro and coal power plant types.

C21-C35 $$P_{it} \leq K_i \sum_{j=0}^{t-1} P_{i,j}$$ i=1,2,4 t=1,5

where K_i are taken as

i	K
1 (nuclear)	1.2
2 (hydro-base)	0.7
4 (coal)	1.2

A relatively low K factor for hydro-base type power plant also restricts the hydroelectricity that can be generated by the hydro potential developed up to that time.

- Hydro-Peak Limitation : Existing hydro-peak power is restricted by the existing hydro-base power at any time

C36-C40 $$\sum_{j=0}^{t} P_{3t} \leq 1.5 \sum_{j=0}^{t} P_{2t} \qquad t=1,5$$

- Beginning Capacities (GW)

C41 $P_{10} = 0.0$

C42 $P_{20} = 2.0$

C43 $P_{30} = 0.3$

C44 $P_{40} = 1.4$

C45 $P_{50} = 1.6$

IV.2.1. INITIAL DATA FOR "b VECTOR" AND OTHER SPECIFICATIONS

- At the beginning of the first iteration, energy and power demands are taken as

ED (1) = 22.0 TWH	PD (1) = 4.56 GW
ED (2) = 36.0 TWH	PD (2) = 7.48 GW
ED (3) = 59.0 TWH	PD (3) = 12.28 GW
ED (4) = 97.0 TWH	PD (4) = 20.18 GW
ED (5) = 159.0 TWH	PD (5) = 33.02 GW

- For cost of the electricity calculations ED(0) is taken as 13.4 TWH and price of the electricity at the beginning of the first iteration is taken as 5.50 TL/KWH. A 20 % additional increase in energy prices is assumed starting from the third period.

- Additional nuclear capacity at the first period of the first iteration is assumed to be 1.0 GW.

. The starting calender date is taken as 1982.

. The following cross reference tableau is used for the identification of the variables.

P_{10}	X_1	P_{11}	X_6	P_{12}	X_{12}	P_{13}	X_{18}	P_{14}	X_{24}	P_{15}	X_{30}
P_{20}	X_2	P_{21}	X_7	P_{22}	X_{13}	P_{23}	X_{19}	P_{24}	X_{25}	P_{25}	X_{31}
P_{30}	X_3	P_{31}	X_8	P_{32}	X_{14}	P_{33}	X_{20}	P_{34}	X_{26}	P_{35}	X_{32}
P_{40}	X_4	P_{41}	X_9	P_{42}	X_{15}	P_{43}	X_{21}	P_{44}	X_{27}	P_{45}	X_{33}
P_{50}	X_5										
		E_{41}	X_{10}	E_{42}	X_{16}	E_{43}	X_{22}	E_{44}	X_{28}	E_{45}	X_{34}
		E_{51}	X_{11}	E_{52}	X_{17}	E_{53}	X_{23}	E_{54}	X_{29}	E_{55}	X_{35}
		U_1	X_{36}	U_2	X_{37}	U_3	X_{38}	U_4	X_{39}	U_5	X_{40}

IV.3. FIRST SET OF SOLUTIONS AND OBSERVATIONS

The following 18 scenarios are tested with PROFIT = 20 % and IN.EL.=0.8

Scenario Number	OBJ2	W1/W2
1	RISK	3.0
2	RISK	2.0
3	RISK	1.0
4	RISK	0.5
5	RISK	0.2
6	RISK	0.1
7	POLLUTION	3.0
8	POLLUTION	2.0
9	POLLUTION	1.0
10	POLLUTION	0.5
11	POLLUTION	0.2
12	POLLUTION	0.1
13	SPACE	3.0
14	SPACE	2.0
15	SPACE	1.0
16	SPACE	0.5
17	SPACE	0.2
18	SPACE	0.1

It is found that, regardless of the scenario under consideration, the same results are obtained for $W1/W2 \geq 0.5$. In other words the cost objective is very effective and the efficient points are separated with sharp edges. But for lower values of W1/W2 such as 0.1, 0.2, differentiation of the solutions depending on OBJ2 occurs.

IV.3.1. COST EMPHASIZED SOLUTION

From the financial point of view, the power plants were ranked as Hydro, Nuclear, and Coal as Hydro being the most economic one. Therefore for cost emphasized solution, the following procedure, illustrated through Figure IV.1, should hold roughly at any period.

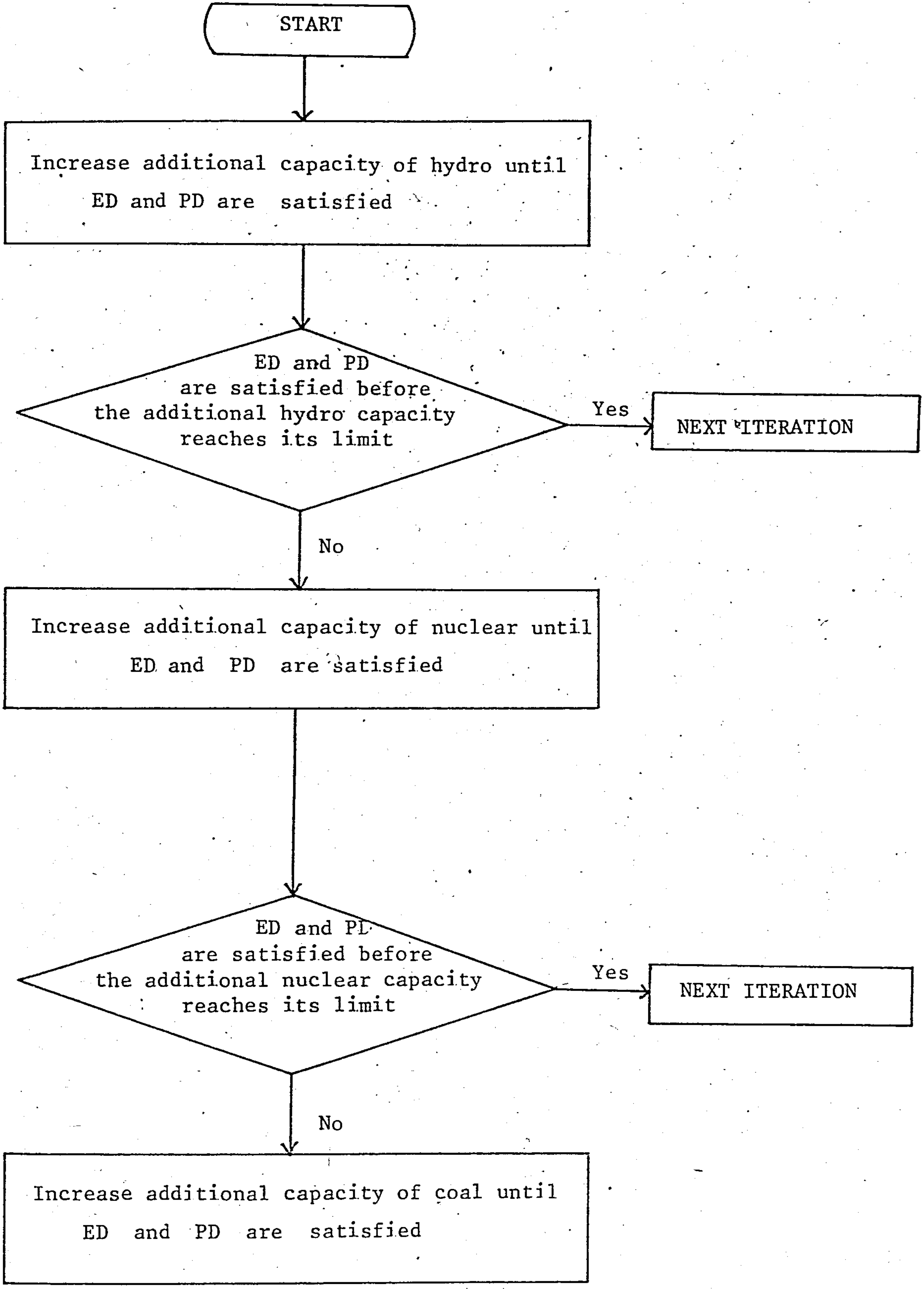

Figure IV.1. The Decision Procedure For Cost Emphasized Solution

Although the optimization of the whole horizon at each iteration may affect the solutions as well as other factors, a similar solution is expected where cost objective is dominant.

The results given in Figure IV.2. are consistent with this approach.Both hydro-base and nuclear are at their maximum levels and the rest of the energy demand is supplied by coal. Furthermore if we have changed the ranking Hydro-Nuclear-Coal to Nuclear-Hydro-Coal, the same results would appear since both Hydro and Nuclear are at their maximum levels.

IV.3.2. POLLUTION EMPHASIZED SOLUTION

The same ranking is still valid for pollution emphasized case and both Hydro and Nuclear are at their maximum levels. The rest of the energy demand is supplied again by coal. However due to the higher price of electricity, energy demand is lower. Therefore, the additional capacity increase for coal is expected to be less than the one in the first case. The results obtained and shown in Figure IV.3. support this view and the total coal power plant capacity is less than half of that previously calculated.

IV.3.3. SPACE EMPHASIZED SOLUTION

In line with the above discussion, when the space occupation is considered, one expects that both nuclear and coal capacities should be used up to their maximum limits and the rest of the energy demand should be supplied by hydro.

But the results obtained are exactly the same as in the first case and seem inconsistant with the above criterion,as can be observed through Figure IV.4. This is partly due to the problem being very constrained so that there is no so many alternatives and also cost and space objectives are not contradictory in this feasible region. Although the overall results given by the aggregate tableau remain the same, the solution set at each iteration shows quite a lot of variation with the 12 scenarios. The overall optimization of the five periods may result in better investments for the second,third,fourth and fifth periods at the expense

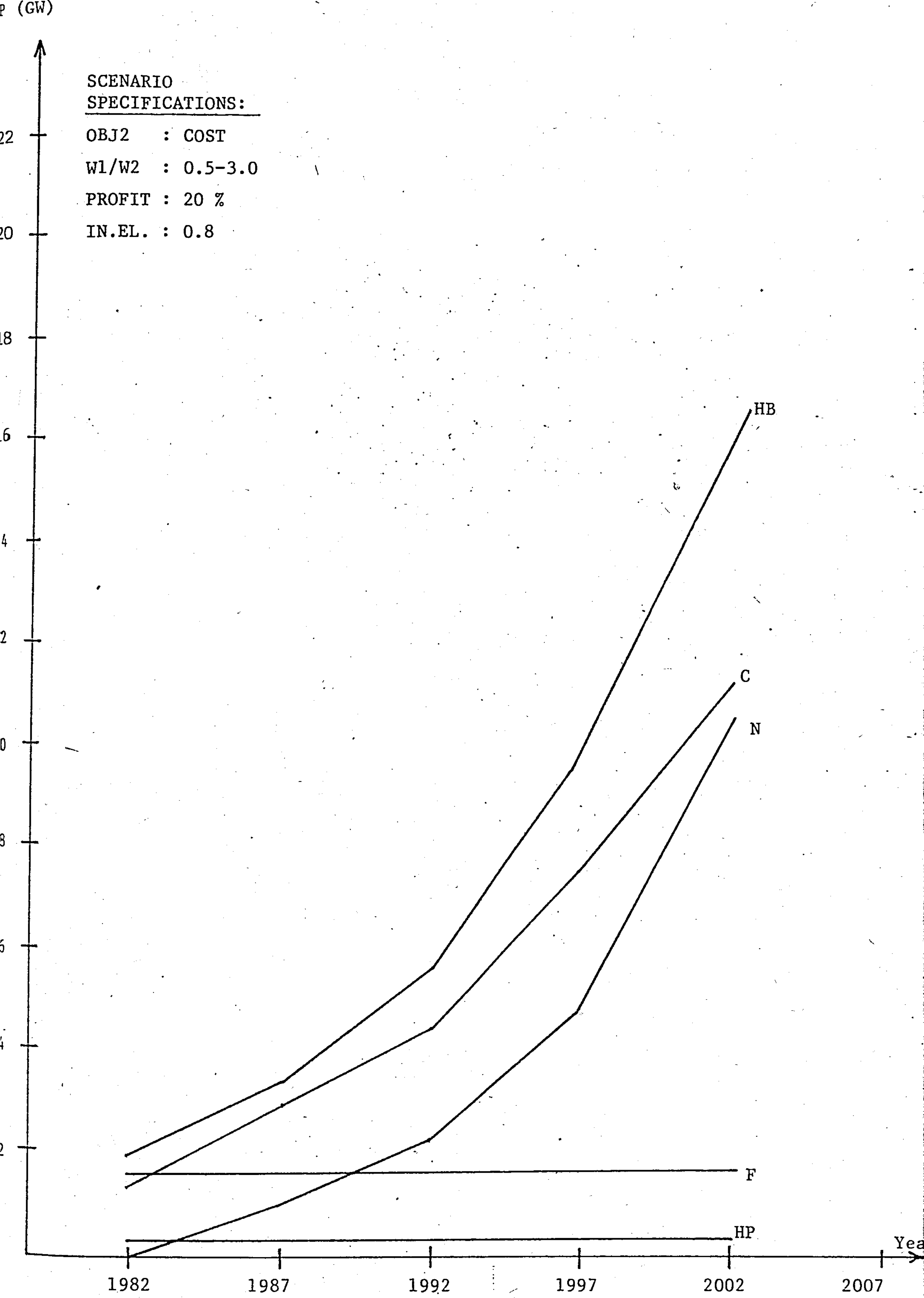

Figure IV.2. The Graphic of Cost Emphasized Solution

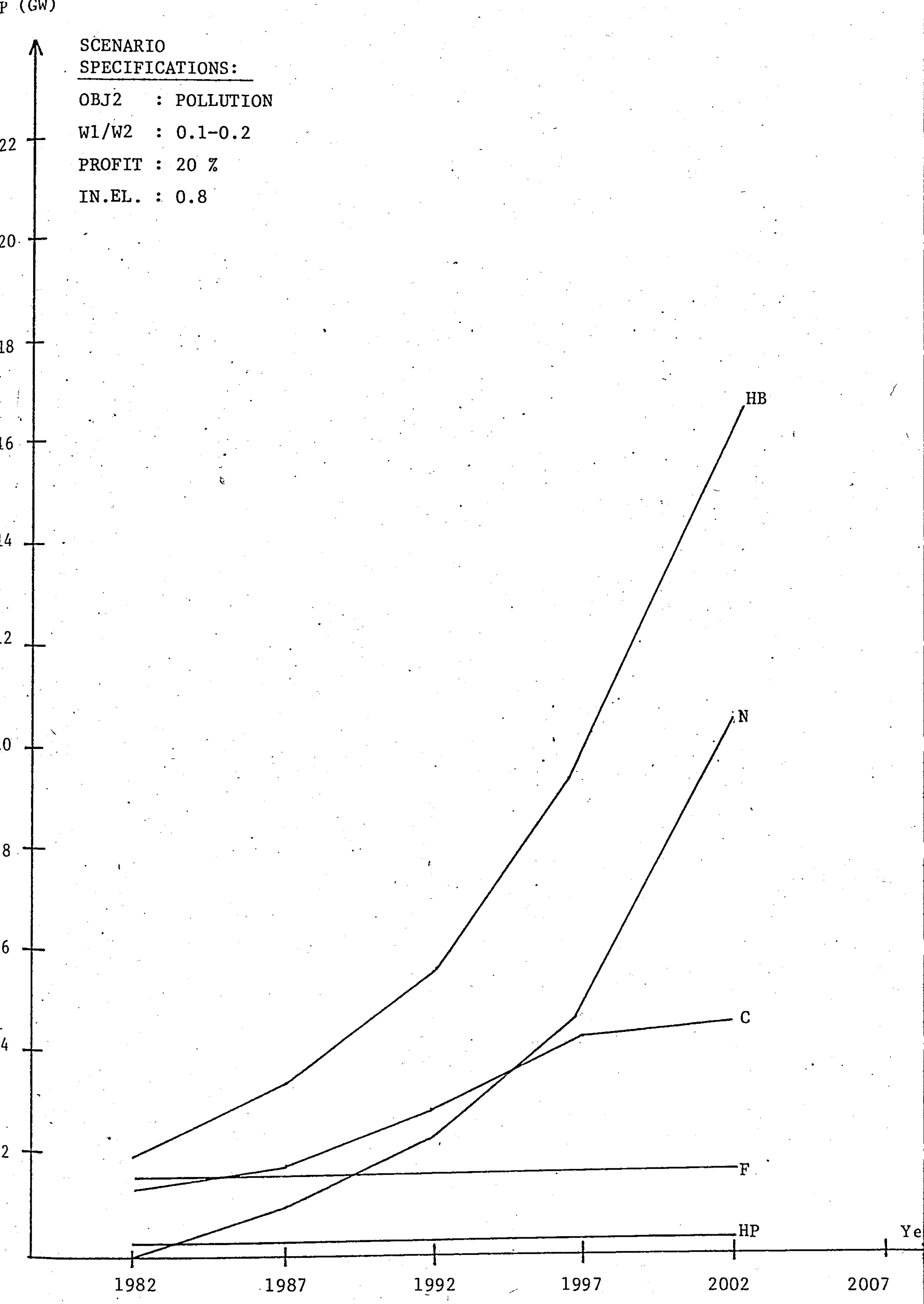

Figure IV.3. The Graphic of Pollution Emphasized Solution

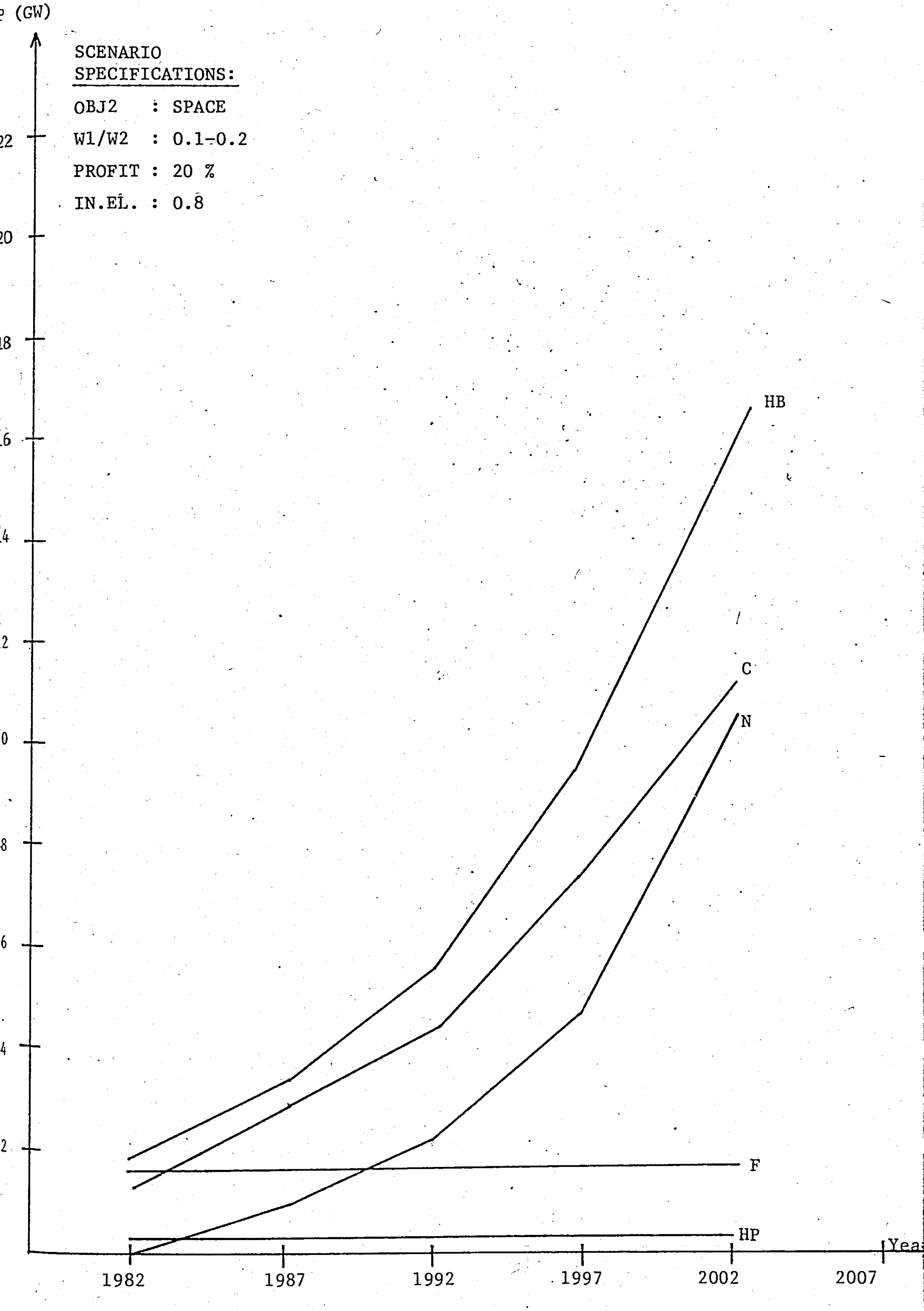

Figure IV.4. The Graphic of Space Emphasized Solution

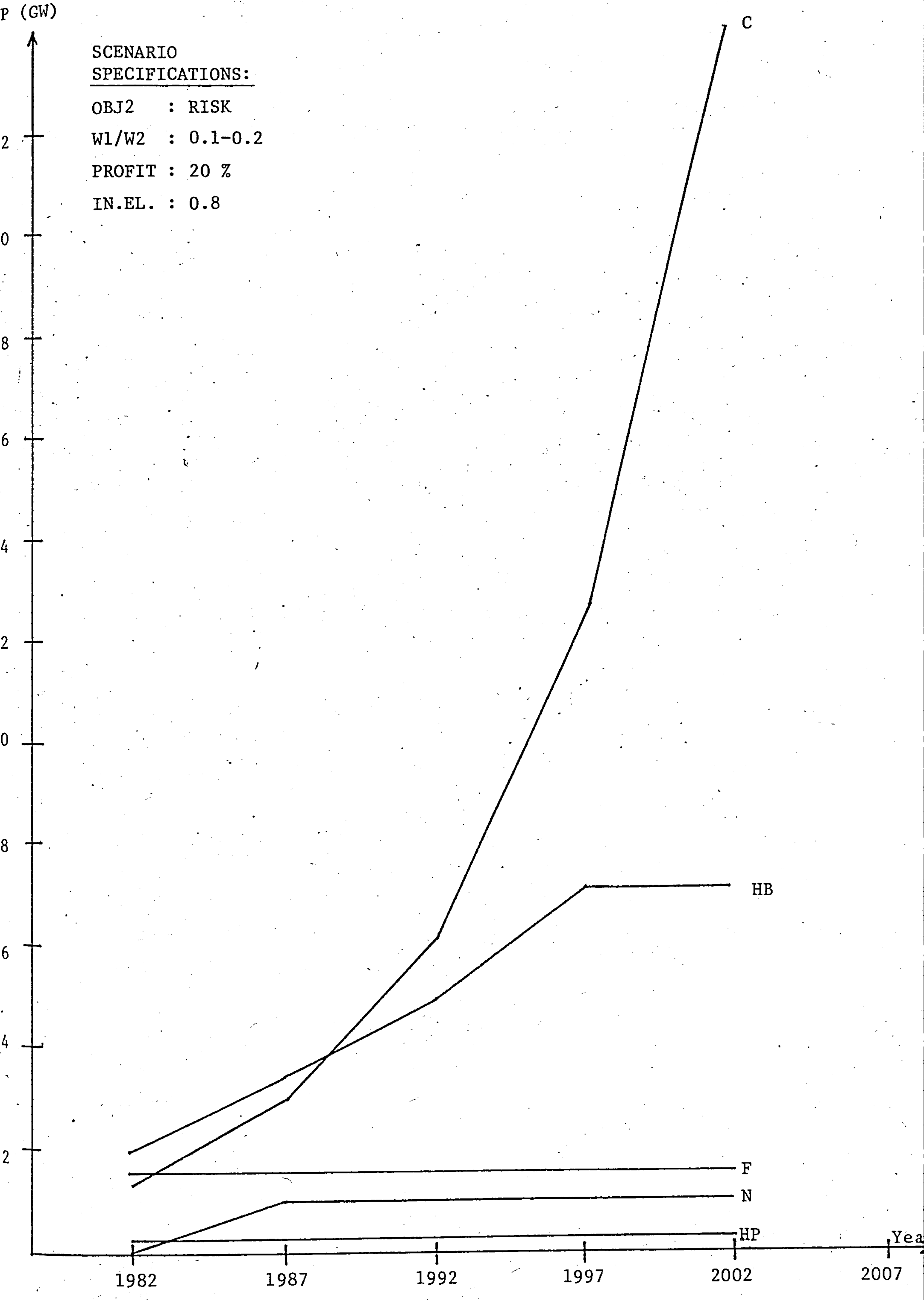

Figure IV.5. The Graphic of Risk Emphasized Solution of the first period. In fact the results are more sensitive to scenario parameters but this can not be observed from the aggregate tableau where only the first periods of each iteration are considered.

So at that point a new feature is added to computer program set: the program NEWOBJ which enables the user to execute the same scenario with the same objective functions and constraints where only the first two periods of each iteration are optimized.

IV.3.4. RISK EMPHASIZED SOLUTION

When risk involved is emphasized, the results are consistent with what should be expected. The riskless alternative shown in Figure IV.5, namely coal power plants are favored. Additional capacity for coal type power plants is used at its maximum level, and the rest of the energy demand is supplied by hydro plants. Since energy demand is satisfied before additional hydro capacity reaches its limit, no additional nuclear capacity is required except 1.0 GW at the first period according to the formulation.

For the moment the following observations can be made according to the results obtained from 18 scenarios already tested. Figure IV.6 summarizes the solutions:

- 1. There are not many alternatives for the first periods, and the number of alternatives increases only for the last periods.
- 2. During the planning horizon, there will be no need for additional hydro-peak capacity.
- 3. Nuclear capacity is either at its minimum or maximum level depending on the scenario specifications. (subroutine ADJUST will permit intermediate values).
- 4. The price of the electricity is decreasing since fuel plants are no longer favoured.
- 5. Energy demand is lowest when pollution objective is emphasized. There is no unsatisfied demand, especially during the last periods.

SCENARIO	PRICE OF THE ELECTRICITY(TL/KWH)					ENERGY DEMAND (TWH / YEAR)										EXISTING CAPACITY as of 2002 (GW)		
	1.P	2.P	3.P	4.P	5.P	1.P		2.P		3.P		4.P		5.P		N+C	TOTAL	N+C / TOTAL
						S	U	S	U	S	U	S	U	S	U			
COST	5.50	5.41	4.82	5.10	4.87	22.0	-	36.95	-	65.75	-	113.37	1.0	191.33	9.0	22.07	40.67	0.54
RISK	5.50	5.41	4.74	5.49	5.43	22.0	-	36.95	-	66.20	-	111.64	-	188.13	3.0	27.30	36.39	0.75
POLLUTION	5.50	5.49	5.52	4.95	4.52	22.0	-	35.73	1.0	57.99	1.0	94.10	6.0	153.29	8.0	15.27	33.87	0.45
SPACE	5.50	5.41	4.82	5.10	4.87	22.0	-	36.95	-	65.75	-	113.37	1.0	191.33	9.0	22.07	40.67	0.54
MEAN	5.50	5.43	5.06	5.16	4.98	22.0		36.64		63.92		108.12		181.02				

Figure IV.6. The Aggregate Results of 18 Scenarios

- 6. The base power (Nuclear + Coal) is approximately % 50 of the total capacity except in the case where RISK objective is favoured.Since coal is the riskless alternative, the base power reaches % 75 of the total capacity for that case.

IV.3.5. ENERGY GENERATED AND ITS PRICE

Figure IV.7. illustrates the total energy generated for each of the four results. Depending on the price of the electricity at each period, energy demand and supply show different increasing patterns. When pollution is emphasized, the level of the prices is relatively high, so energy demand and accordingly energy supply are low. Since the price of electricity is a controllable variable by the use of the profit margin, unsatisfied demand can be eliminated by using higher profit margins, thus increasing the electricity prices. In general the prices are decreasing since we do not favour the fuel plants which have the most expensive operating costs. A policy of keeping the electricity price at its previous level whenever a decrease is observed may be a good policy to eliminate unsatisfied energy demand. According to the results obtained, Figure IV.8. shows the maximum and minimum values of the electricity prices for each period. Without any intervention and regardless of the scenario choosen, the price of the electricity is expected to have a value between the upper and lower curves at each period.

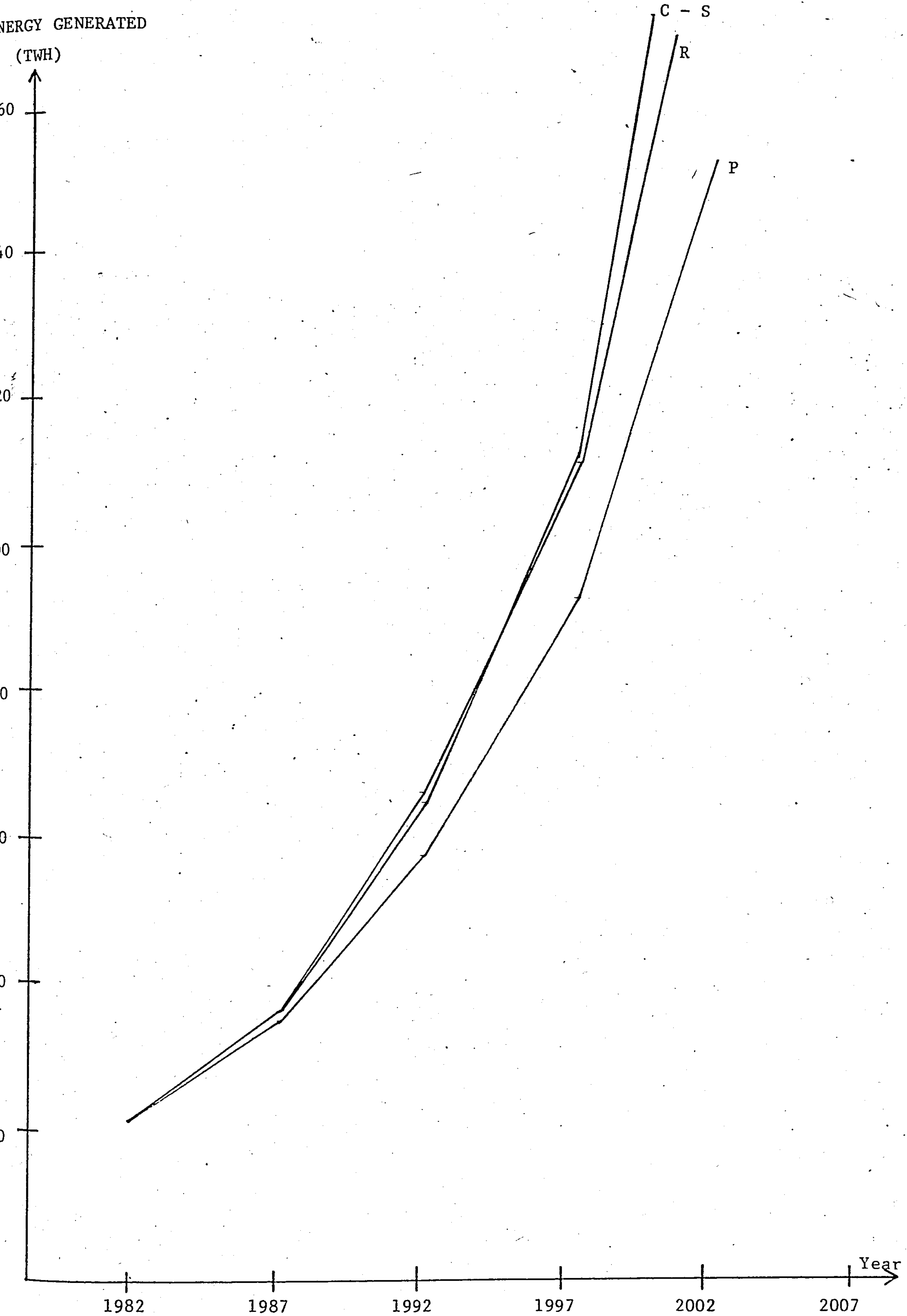

Figure IV.7. The Graphic of Energy Generated for Each of 4 Objectives Emphasized

PRICE OF THE ELECTRICITY SUPPLIED

Upper and Lower Values Curve

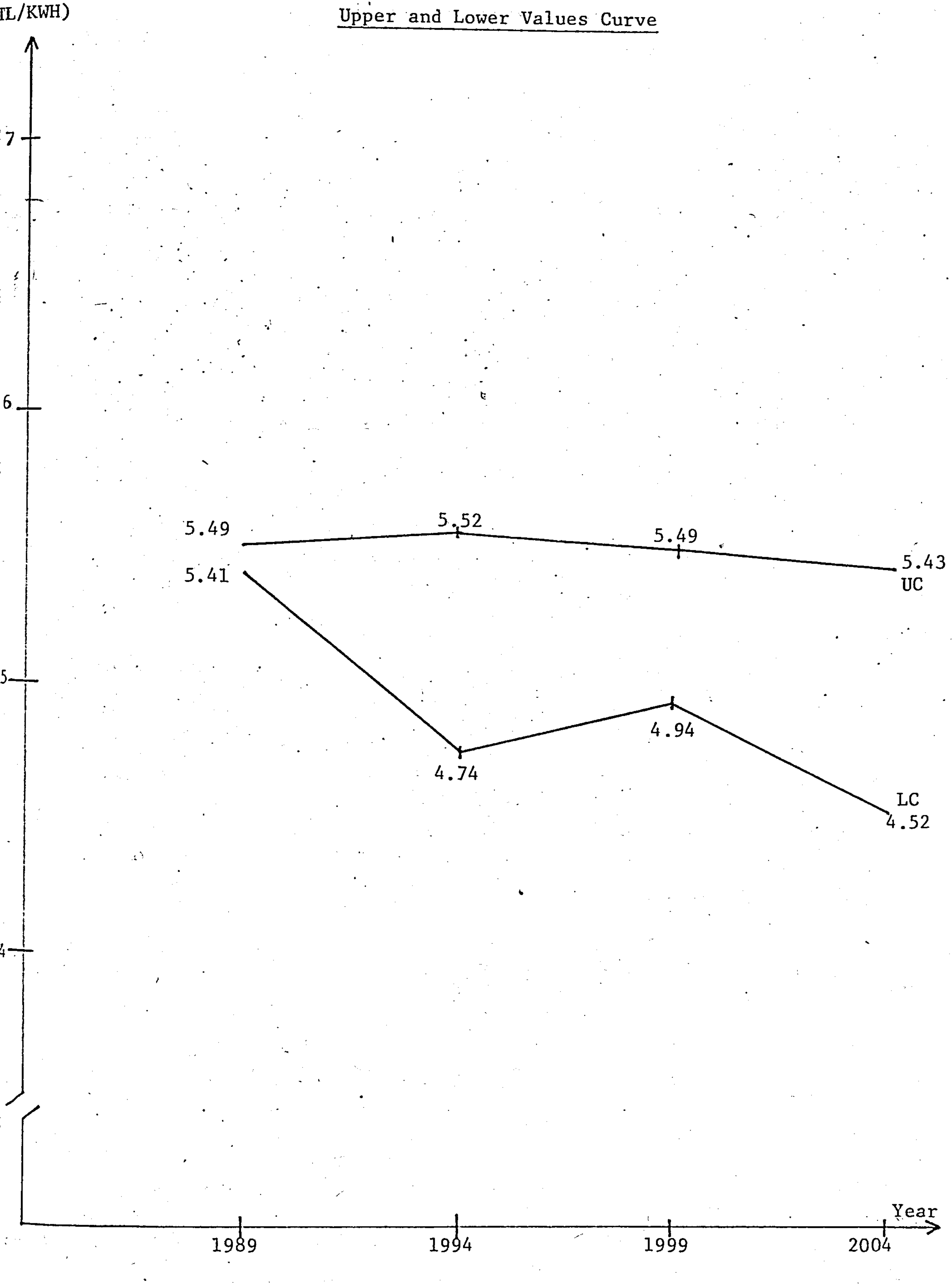

Figure IV.8. The Maximum and the Minimum Levels of the Electricity Prices

IV.4. SECOND SET OF SOLUTIONS: TWO-PERIOD OPTIMIZATION

IV.4.1. SUBROUTINE NEWOBJ

Since the overall optimization of the five periods may result in better investments for the second, third, fourth and fifth periods at the expense of the first period, a new feature is added to the programs in order to optimize only the first two periods subject to the same constraints. Subroutine NEWOBJ is written for this purpose. Once called from the main program, it makes the necessary changes on C-matrix (the term matrix is used in stead of vector since there are two C-vectors according to the bicriterion approach). The idea behind this approach is to point out how much the results in the aggregate tableau are sensitive to the scenario specifications, especially to the W1/W2 ratio.

IV.4.2. RESULTS AND OBSERVATIONS

The following scenarios are tested with PROFIT=20 % and IN.EL.0.8 for two period optimization approach.

Scenario Number	OBJ2	W1/W2
19	RISK	3.0
20	RISK	1.0
21	RISK	0.5
22	RISK	0.2
23	RISK	0.1
24	POLLUTION	3.0
25	POLLUTION	1.0
26	POLLUTION	0.1
27	SPACE	3.0
28	SPACE	1.0
29	SPACE	0.1

It is observed that when risk is considered, differentiation from overall optimization of five periods occurs for $W1/W2 \leq 0.5$ whereas exactly the same results are obtained for pollution minimization and different efficient vertices are found for space minimization regardless W1/W2 ratio. In other words when space minimization objective is considered, the results are sensitive to the weight ratio and when pollution is considered, W1/W2 ratio looses its importance. For risk minimization, the weight ratio is a policy determinant up to a certain level.

Figure IV.9. shows the situation for space minimization case where the results are sensitive to W1/W2 ratio. It can be observed that the hydro power is substituted by coal as the weight ratio decreases, i.e. more importance is given to space minimization objective. On the other hand when risk is considered, as illustrated in Figure IV.10, the decrease in hydro capacity as W1/W2 decreases is due to low energy demand of the scenario because of higher electricity price.

Two other important observations can be derived from the results. First, the substitution of coal and hydro occurs in the last periods. This is also consistent with our previous conclusion which states that we do not have many alternatives in the first periods. The second observation is related to the development of nuclear capacity. Considering the case of overall optimization of five periods and that of two-period optimization, it can be seen that the nuclear additional capacity is either at its minimum or maximum.

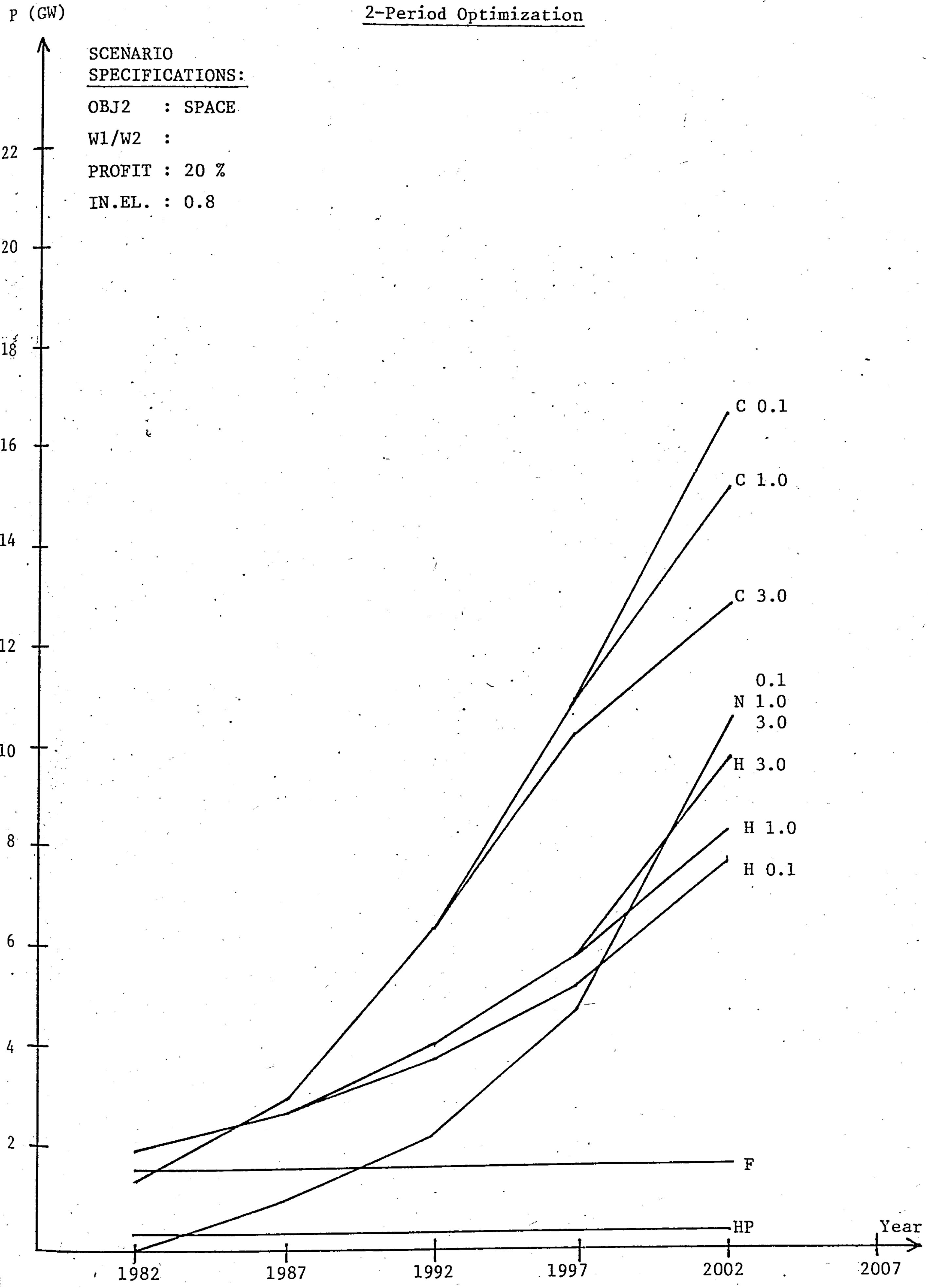

Figure IV.9. The Graphic of Space Minimization for 2-Period Optimization

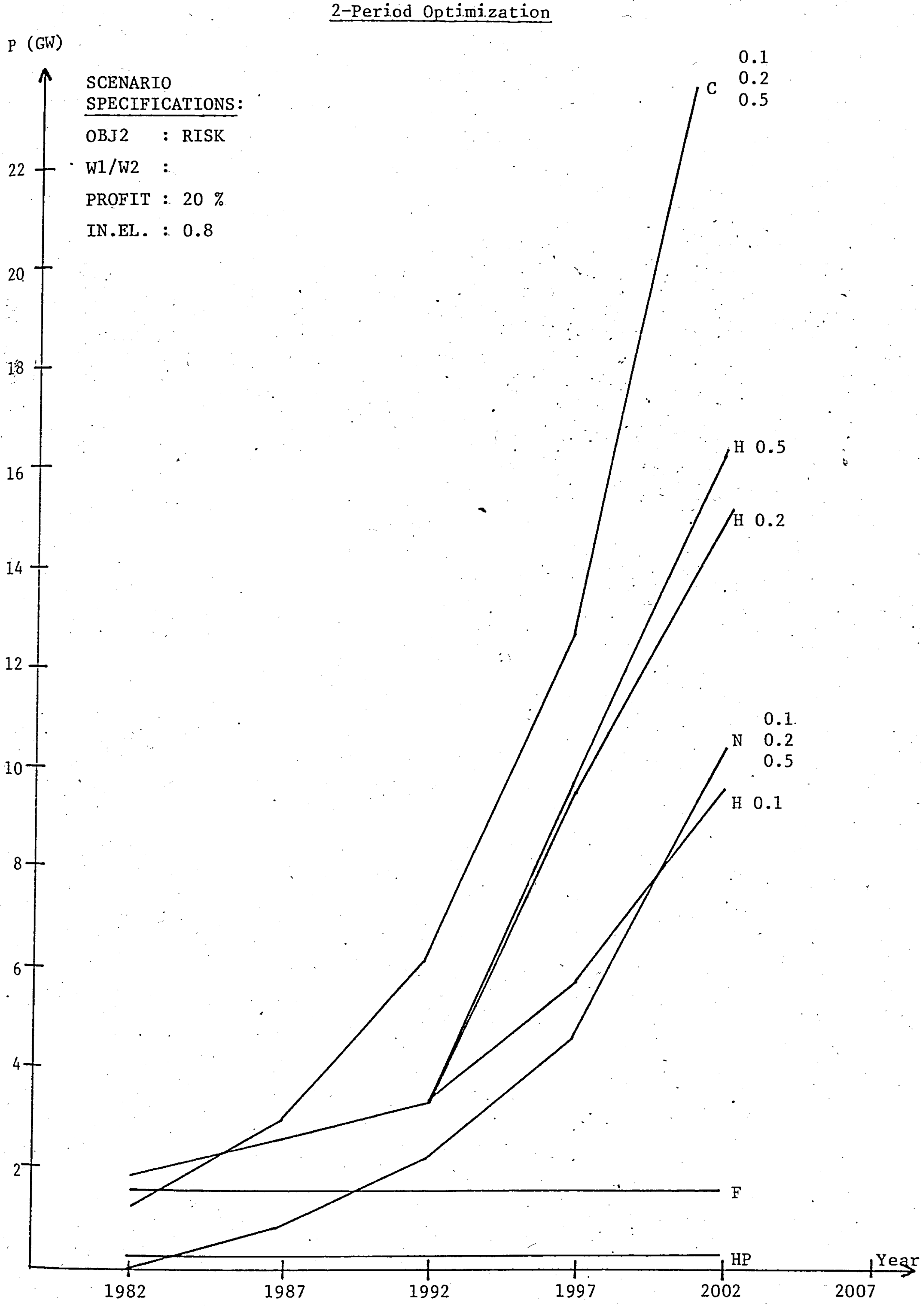

Figure IV.10. The Graphic of Risk Minimization for 2-Period Optimization

IV.5. AUTO CONTROL OF W1/W2 RATIO WITHIN A SPECIFIC SCENARIO THE ITERATIVE APPROACH:

IV.5.1. SUBROUTINE ADJUST

Subroutine ADJUST enables the user to vary with time W1/W2 ratio i.e. the trade-off between objectives within a specific scenario. Therefore a certain type of power plant may be restricted once it reaches a certain percent of the total capacity just by changing W1/W2 ratio thus unfavouring additional capacity of that power plant with the new W1/W2 ratio which has to be given as data being an alternative to the second scenario specification S_2. So in line with the nature of the solution obtained, the utility function of the decision maker may change and it may have a different trade-off from then on. Subroutine ADJUST has this flexibility and is applied to Nuclear Power plants for Risk optimization case, especially because that nuclear power plants are either at their maximum or minimum levels, so it may be desired to have nuclear power capacities at intermediate levels. Subroutine ADJUST enables the user to control W1/W2 ratio within a specific scenario in order to restrict nuclear capacity once it reaches a certain level just by changing W1/W2 ratio and thus unfavouring additional nuclear capacity but still optimizing the remaining periods.

Once the new restriction for nuclear power plants is violated at any period, the iteration counter is no longer increased by 1, but a new solution with the new W1/W2 ratio which will not favour additional nuclear capacity any more will be chosen. Now the user has initially an aim which should be satisfied at each iteration, if not, the iteration will be repeated with the new condition to satisfy his aim. This mainly constitutes the iterative approach of the study.

IV.5.2. APPLICATION FOR NUCLEAR POWER PLANTS

Subroutine ADJUST is applied to Nuclear Power Plants for Risk optimization case.

The execution starts by W1/W2 ratio equal to 1.0 and then changes it to 0.1 to emphasize risk consideration, i.e. to unfavour additional nuclear

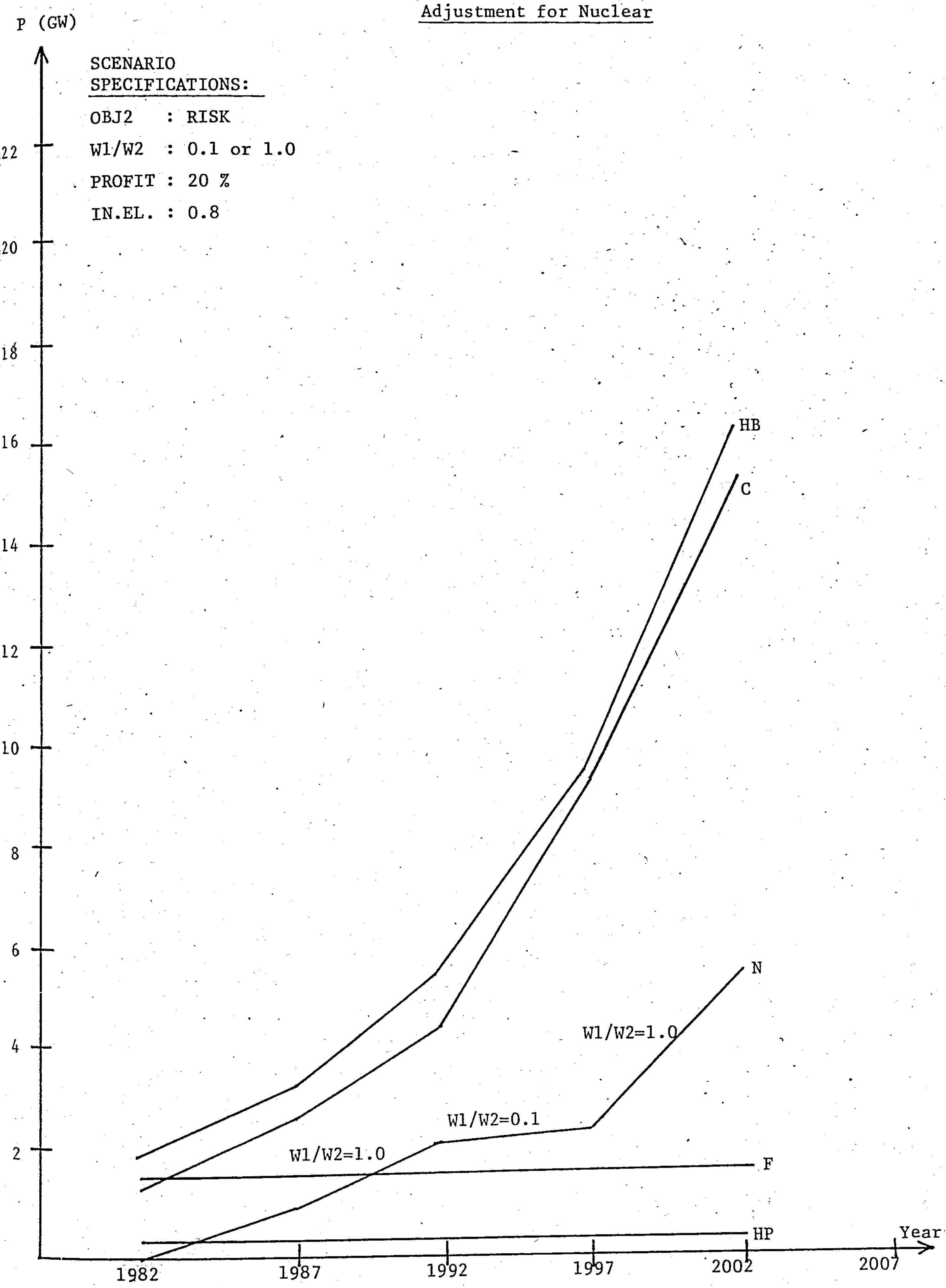

Figure V.1. The Graphic of Risk Optimization Case with Adjustment for Nuclear Power Plant capacity for each iteration where the energy generated from the nuclear plants is greater than 1/6 of the total energy generated. The results are shown in Figure V.1. As it can be observed from the figure, W1/W2 ratio is adjusted for the third period and it doesn't need any further adjustment for other periods. The resulting existing capacity of 5.71 GW in 2002 is an intermediate value which is not encountered neither in five-period optimization nor in two-period optimization case.

CHAPTER V

CONCLUSIONS AND EVALUATION

The decision process and the tools used in that process are consistent with the recent developments in environmental concern and issues of social risk which have changed the nature of power systems expansion decisions. The significance of hard-to-quantify aspects such as risk involved, pollution and space occupied can be determined through scenario-analyses. The modelling technique and the solution procedure employed in this study offer several advantages. The linear programming model is a well-known and established technique. Bicriterion optimization enables the user to consider different objectives and the trade-offs between them. The basic objective of economic efficiency subject to certain technical considerations is thus revised. Due to the adaptive approach, the periodic review of the system at the end of each period permits the necessary adjustments and from that point of view, it is superior to other approaches. Another desirable feature of the adaptive approach is the fact that it eliminates the end-effects since the total planning horizon is enlarged and the relevant planning horizon is less than this total planning horizon. The iterative nature of the procedure gives the flexibility to the trade-offs between objectives under new circumstances.

The results obtained from the application of the model to the Turkish Electrical System can be summarized as:

- There are not many alternatives for the first periods and we have to increase our capacities for hydro and coal power plants as much as we can do during the first periods.

- During the planning horizon, there will be no need for additional hydro-peak capacity.

- The cost of the electricity will decrease since fuel plants are no longer favoured. Keeping the prices constant may be a good approach to eliminate possible unsatisfied energy demands.

- We are not too late to build nuclear power plants but we will need nuclear energy in the short-run.

- Energy demand constraints are always satisfied with equality or unsatisfied demand occurs whereas the power demand constraints may remain redundant. So the country may face energy shortages rather than power shortages.

As a final word, I would like to emphasize the importance and capabilities of the model hoping that interested readers or researchers may find it usefull, so the further analysis and improvements of the model will take place.

Another feature of the study is that the model can easily be used for the analysis through the scenario specifications; and the feature added by the subroutine ADJUST can be further elaborated so as to simulate the decision making process and to model the preferences and the behavior of the decision maker much more closely.

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APPENDIX I

APPENDIX I
USERS MANUAL

In order to execute the program, the following steps have to be followed:

1) Load constant data
2) Execute the program for a specified scenario.

I.1. LOAD CONSTANT DATA

Constant data is the portion of the total data which is not influenced by the scenario changes. So once it is loaded as a data file, there is no need to read it each time a new scenario is executed. The following run stream has te be run to load the constant data.

```
@RUN
@DELETE,C       VERI.
@ASG,UP         VERI.
@DATA,IL        VERI.

           data cards

@FIN
```

Data cards have the following structure:

1) The right hand side array BB is inputted according to the format (10F8.4).

2) The array IEQ (Index specifying type of the constraints) is inputted according to the format (40I2).

where 0 for $\leq$ constraint;
1 for = constraint; and
2 for $\geq$ constraint

are used.

3) The coefficient matrix AN is inputted columnwise and by its nonzero elements. First, the number of rows in which nonzero entries appear in each column is inputted according to the format (I2); then the row indices and the coefficient values are inputted according to the format (8(I2,F8.4)).

4) All elements of the cost objective are inputted rowwise according to (10F8.4) format.

I.2. EXECUTION

In order to execute the program the following run steam is required:

```
          RUN
          ASG,AX      VERTEZ.
          ASG,AX      VERI.
          XQT.        VERTEZ.MAIN
                  parameter card
                  OBJ2  cards
          XQT         VERTEZ.MAIN
                  parameter card
                  OBJ2  cards


          FIN
```

Where OBJ2 cards consist of all element of the objective specified in the parameter card and are inputted rowwise according to (10F8.4) format as in the cost objective case.

The parameter card defines a scenario and has the following structure:

Variable		FORMAT
MM	: Number of constraints	(I5)
N	: Number of variables	(I5)
DEL	: Accuracy limit for comparison with zero	(F10.6)
W1W2	: W1/W2 ratio	(F10.6)
PROFIT	: Profit margin (%)	(F10.6)
GNE	: Income elasticity	(F10.6)
PRINIT	: Initial price of the electricity (TL/KWH)	(F10.6)
IOBJ2	: Parameter specifying OBJ2 1 for risk minimization 5-period optimization 2 for risk minimization 2-period optimization 3 for pollution minimization 5-period optimization 4 for pollution minimization 2-period optimization 5 for space minimization 5-period optimization 6 for space minimization 2-period optimization.	(I5)
ADJ	: Lower value of W1/W2 if adjustment for nuclear power is desired, blank otherwise.	(F5.1)

APPENDIX II

```
TEZ(1).ANA
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON/BL1/ ITERNM,N35,W1W2,STMX(5,50),STZZ(5,2),IOTIP,PROFIT
      COMMON/BL8/ ADJLOW,NADJUS
      READ(5,7001) ADJLOW
 7001 FORMAT(F5.1)
      NADJUS=0
      ITERNM=0
      CALL STORE
 7002 ITERNM=ITERNM+1
      IF(ITERNM.GT.5) GO TO 7999
      WRITE(6,6228) ITERNM
 6228 FORMAT(1X,'ITERATION',2X,I1,1X,'STARTED'/)
      CALL MAIN
      CALL STORE
      CALL ADJUST
      GO TO 7002
 7999 CALL RWRITE
      WRITE(6,7004)
 7004 FORMAT(1H1)
      STOP
      END
```

TEZ(1)•MAIN→BLP

```
      SUBROUTINE MAIN
C     M=# OF OBJ., N=# OF VAR., MM=# OF CONS., DEL=ACCURACY
C     CN=NONBASIC COST MATRIX, AN=NONBASIC COEFF. MATRIX, BB=RHS
C     IXN=NONBASIC VAR. SET, IBE=BASIC VAR. OF EQUATION
C       IEQ=0 FOR LE CONSTR. ; =1 FOR EQ CONSTR. ; =2 FOR GE CONSTR.
        IMPLICIT DOUBLE PRECISION(A-H,O-Z)
        DIMENSION IEQ(50),NT(50),IVEC(50),IRT(50,50),IV1(50,50),IV2(200,5
       *),CC96NN(50)
        COMMON/BL1/ ITERNM,N35,W1W2,STMX(5,50),STZZ(5,2),IOTIP,PROFIT
        COMMON/BL2/ GNE,EDPD(5,5),PDED(5,5),PRICEN(5)
        COMMON/BL8/-ADJLOW,NADJUS
        COMMON/GUL1/M,MM,NMM,DEL,BB(50),AN(50,100),CN(3,100),ZZ(3)
        COMMON/GUL2/CP(100),ZP,IXN(100),IBE(50),IPHASE,IFLAG.
        COMMON/GUL3/LJ,JT(50),WU,WL
        M=2
        NMITER=1
        DO 2468 I=1,50
        DO 2468 J=1,100
        AN(I,J)=0.0
  2468  CONTINUE
        IF(ITERNM.GT.1) REWIND 9
        IF(ITERNM.EQ.1) READ(5,900) I97I,I98I,R95I,R96I,R97I,R98I,R99,I99
        MM=I97I
        N=I98I
        DEL=R95I
        W1W2=R96I
        IF(NADJUS.GT.0) W1W2=ADJLOW
        PROFIT=R97I
        GNE=R98I
        PRINIT=R99
        IOTIP=I99
   900  FORMAT(2I5,5F10.6,9X,I1)
        N35=N
        WLU35=1.0/(W1W2+1.0)
        WL=WLU35-0.01
        WU=WL+0.02
        READ(9,901) (BB(I),I=1,MM)
   901  FORMAT(10F8.4)
        READ(9,902) (IEQ(I),I=1,MM)
   902  FORMAT(40I2)
        DO 910 J=1,N
        READ(9,903) KR
        READ(9,904) (I,AN(I,J),K=1,KR)
   910  CONTINUE
        READ(9,901) (CN(1,J),J=1,N)
        IF(ITERNM.EQ.1) READ(5,901) (CC96NN(J),J=1,N)
        DO 2842 J=1,N
  2842  CN(2,J)=CC96NN(J)
   903  FORMAT(I2)
   904  FORMAT(8(I2,F8.4))
        IF(ITERNM.GT.1) GO TO 1758
        IEQ(21)=1
        BB(21)=1
        GO TO 1868
  1758  CALL UPDATE
  1868  DO 17 INEWS=1,5
        EDPD(ITERNM,INEWS)=BB(INEWS)
        PDED(ITERNM,INEWS)=BB(INEWS+5)
    17  CONTINUE
```

```
      IF(ITERNM.EQ.1) PRICEN(1)=PRINIT
      DO 1 J=1,N
      IXN(J)=J
    1 CONTINUE
      IF(WL.EQ.0..AND.WU.EQ.1.) GO TO 4
      M=3
      IW=1
      DO 13 J=1,N
   13 CN(3,J)=(1.-WU)*CN(1,J)+WU*CN(2,J)
    4 K=0
      N1=N
      DO 10 I=1,MM
      IF(IEQ(I).EQ.1) GO TO 10
      IF(IEQ(I).EQ.0) GO TO 9
      N1=N1+1
      AN(I,N1-K)=-1.
      IXN(N1-K)=N1
      GO TO 10
    9 N1=N1+1
      K=K+1
      IBE(I)=N1
   10 CONTINUE
      N2=N1
      NMM=N1-K
C     NMM= # OF NONBASIC VARIABLES
      DO 20 I=1,MM
      IF(IEQ(I).EQ.0) GO TO 20
      N1=N1+1
      IBE(I)=N1
   20 CONTINUE
      N1=N1-N2
C     N1 IS THE # OF ARTIFICIAL VARIABLES
      IF(N1.EQ.0) GO TO 100
      IPHASE=1
      ZP=0.
      DO 25 J=1,NMM
   25 CP(J)=0.
C     FORM PHASE1 OBJECTIVE
      DO 30 I=1,MM
      IF(IBE(I).LE.N2) GO TO 30
      ZP=ZP-BB(I)
      DO 30 J=1,NMM
      CP(J)=CP(J)-AN(I,J)
   30 CONTINUE
C     MINIMIZE PHASE1 OBJECTIVE
   40 KE=0
      DO 50 J=1,NMM
      IF(CP(J).GE.-DEL) GO TO 50
      KE=J
      GO TO 55
   50 CONTINUE
      IF(ZP.GE.-DEL) GO TO 70
      WRITE(6,805)
  805 FORMAT(1H1,40X,'THERE IS NO FEASIBLE SOLUTION OF THE PROBLEM'//
      CALL RWRITE
      STOP
   55 CALL LEAV(KE,KMIN)
      IF(KMIN.EQ.0) WRITE(6,805)
      IF(IBE(KMIN).LE.N2) GO TO 65
      CALL PIVOT(KE,KMIN)
```

```
      NMM=NMM-1
      N1=N1-1
      IF(KE.EQ.(NMM+1)) GO TO 40
      DO 60 J=KE,NMM
      IXN(J)=IXN(J+1)
      CP(J)=CP(J+1)
      DO 58 I=1,M
   58 CN(I,J)=CN(I,J+1)
      DO 59 I=1,MM
   59 AN(I,J)=AN(I,J+1)
   60 CONTINUE
      GO TO 40
   65 KL=IBE(KMIN)
      CALL PIVOT(KE,KMIN)
      IXN(KE)=KL
      GO TO 40
C     PHASE1 OBJECTIVE MINIMIZED
   70 IF(N1.EQ.0) GO TO 100
C     THERE ARE STILL ARTIFICIAL VAR. IN BASIS
      K=1
   79 DO 80 I=K,MM
      IF(BB(I).GT.DEL) GO TO 80
      IF(IBE(I).LE.N2) GO TO 80
      GO TO 81
   80 CONTINUE
   81 DO 82 J=1,NMM
      IF(ABS(AN(I,J)).GT.DEL) GO TO 85
   82 CONTINUE
C     NULL EQUATION, DROP IT
      MM=MM-1
      N1=N1-1
      IF(I.EQ.(MM+1))GO TO 100
      DO 83 II=1,MM
      IBE(II)=IBE(II+1)
      BB(II)=BB(II+1)
      DO 83 J=1,NMM
      AN(II,J)=AN(II+1,J)
   83 CONTINUE
      IF(N1.EQ.0) GO TO 100
      K=I
      GO TO 79
C     ELIMINATE ARTIFICIAL VARIABLE
   85 CALL PIVOT(J,I)
      NMM=NMM-1
      N1=N1-1
      IF(J.EQ.(NMM+1)) GO TO 88
      DO 86 JJ=J,NMM
      IXN(JJ)=IXN(JJ+1)
      DO 87 II=1,M
   87 CN(II,JJ)=CN(II,JJ+1)
      DO 89 II=1,MM
   89 AN(II,JJ)=AN(II,JJ+1)
   86 CONTINUE
   88 IF(N1.EQ.0) GO TO 100
      K=I+1
      GO TO 79
C     AT THIS POINT WE HAVE INITIAL B.F.S.
  100 IPHASE=0
  101 KE=0
      DO 110 J=1,NMM
```

```
      IF(CN(M,J).GE.-DEL) GO TO 110
      KE=J
      CALL LEAV(KE,KMIN)
      IF(KMIN.EQ.0) GO TO 150
      KL=IBE(KMIN)
      CALL PIVOT(KE,KMIN)
      IXN(KE)=KL
      GO TO 101
  110 CONTINUE
      GO TO 200
  150 WRITE(6,806) M
  806 FORMAT(1H1,50X,'OBJECTIVE',I2,' IS UNBOUNDED'//)
      STOP
  200 IF(IW.EQ.0) GO TO 202
      M=M-1
      GO TO 289
  202 DO 203 J=1,NMM
      IF(CN(2,J).GE.DEL)GO TO 203
      IF(CN(1,J).GE.-DEL) GO TO 203
      CALL LEAV(J,KMIN)
      KL=IBE(KMIN)
      CALL PIVOT(J,KMIN)
      IXN(J)=KL
      GO TO 202
  203 CONTINUE
C     INITIAL EFFICIENT VERTEX FOUND
  289 IF(NMITER.EQ.1) RETURN
      IFLAG=0
C     L2=# OF COMPUTED EFF. VERTICES, L1=# OF NOT YET COMPUTED EFF. VERTIC
                                                                        ES
      L2=1
      L1=0
      DO 290 K=1,NMM
  290 IVEC(K)=IXN(K)
      CALL SORT(IVEC,NMM)
      DO 295 K=1,NMM
  295 IV2(1,K)=IVEC(K)
C     EFFICIENT EDGES WILL BE FOUND
  300 IF(L2-100)301,740,740
  740 WRITE(6,745)
  745 FORMAT(//,10X,'NO. OF EFFICIENT VERTICES IS GREATER THAN 200',/,1
     *X,'RUN IS TERMINATED')
      STOP
  301 CALL EDGE2
C     DETERMINE FEASIBLE ADJACENT SET
C     LJ=# OF EFFICIENT EDGES
C     LRT=# OF ADJACENT EFF. EXTR. PTS.
  311 LRT=0
      IF(LJ.EQ.0) GO TO 700
      DO 350 II=1,LJ
      J=JT(II)
      CALL LEAV(J,KMIN)
      LRT=LRT+1
      KK=IBE(KMIN)
      DO 320 I=1,NMM
  320 IRT(LRT,I)=IXN(I)
      IRT(LRT,J)=KK
C     SORT INDICES OF NBAS. VAR. OF EXTR. POINT
      DO 330 I=1,NMM
  330 IVEC(I)=IRT(LRT,I)
      CALL SORT(IVEC,NMM)
```

```
      DO 99 I=1,NMM
   99 IRT(LRT,I)=IVEC(I)
  350 CONTINUE
      LR1=0
C     FORM THE SET IRT-IV2
      DO 390 I=1,LRT
      DO 370 II=1,L2
      DO 360 K=1,NMM
      IF(IRT(I,K).NE.IV2(II,K)) GO TO 370
  360 CONTINUE
      GO TO 390
  370 CONTINUE
      LR1=LR1+1
      DO 380 K=1,NMM
  380 IRT(LR1,K)=IRT(I,K)
  390 CONTINUE
      IF(LR1.EQ.0) GO TO 700
      LR2=0
C     FORM THE SET IRT-IV1
      IF(L1)395,395,396
  395 LR2=LR1
      GO TO 435
  396 DO 430 I=1,LR1
      DO 410 II=1,L1
      DO 400 K=1,NMM
      IF(IRT(I,K).NE.IV1(II,K)) GO TO 410
  400 CONTINUE
      GO TO 430
  410 CONTINUE
      LR2=LR2+1
      DO 420 K=1,NMM
  420 IRT(LR2,K)=IRT(I,K)
  430 CONTINUE
      IF(LR2.EQ.0) GO TO 600
C     NEW VERTEX SELECTED FROM R2
  435 L2=L2+1
      DO 500 K=1,NMM
      NT(K)=IRT(LR2,K)
  500 IV2(L2,K)=NT(K)
      LR2=LR2-1
      IF(LR2.EQ.0) GO TO 590
C   FORM THE SET IV11
      DO 540 I=1,LR2
      L1=L1+1
      DO 540 K=1,NMM
  540 IV1(L1,K)=IRT(I,K)
  590 CALL MOVE(NT)
C  AT NEW EFF. VERTEX  NEW ITERATION STARTS
      GO TO 300
C     NEW VERTEX SELECTED FROM R1
  600 L2=L2+1
      DO 610 K=1,NMM
      NT(K)=IRT(LR1,K)
  610 IV2(L2,K)=NT(K)
      DO 650 I=1,L1
      DO 620 K=1,NMM
      IF(NT(K).NE.IV1(I,K)) GO TO 650
  620 CONTINUE
      L1=L1-1
      IF(I.EQ.L1+1) GO TO 690
```

```
      DO 630 IJ=1,L1
      DO 630 K=1,MMM
  630 IV1(IJ,K)=IV1(IJ+1,K)
      GO TO 690
  650 CONTINUE
  690 CALL MOVE(NT)
      GO TO 300
C     NEW VERTEX SELECTED FROM V1
  700 IF(L1.EQ.0) GO TO 9999
      L2=L2+1
      IFLAG=1
      DO 710 K=1,MMM
      NT(K)=IV1(L1,K)
  710 IV2(L2,K)=NT(K)
      L1=L1-1
      CALL MOVE(NT)
      IFLAG=0
      GO TO 300
 9999 WRITE(6,777)
  777 FORMAT(///,43X,'ALL EFFICIENT VERTICES HAVE BEEN ENUMERATED')
      WRITE(6,779) L2
  779 FORMAT(///,43X,'NO.EFFICIENT EXTREME POINTS = ',I3)
      STOP
      END
```

```
RTEZ(1).SORT
       SUBROUTINE SORT(IV,N)
       DIMENSION IV(50)
   C  IV IS THE VECTOR TO BE SORTED
   C  N IS THE DIMENSION OF THE VECTOR
       NN=N-1
       DO 1 I=1,NN
       II=I+1
       DO 1 J=II,N
       IF(IV(I).LE.IV(J)) GO TO 1
       ITEMP=IV(I)
       IV(I)=IV(J)
       IV(J)=ITEMP
      1 CONTINUE
       RETURN
       END
```

```
RTEZ(1).PIVOT
      SUBROUTINE PIVOT(KE,KMIN)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON/GUL1/M,MM,NMM,DEL,BB(50),AN(50,100),CN(3,100),ZZ(3)
      COMMON/GUL2/CP(100),ZP,IXN(100),IBE(50),IPHASE,IFLAG
      IBE(KMIN)=IXN(KE)
      AA=AN(KMIN,KE)
C     NORMALIZE
      DO 14 J=1,NMM
   14 AN(KMIN,J)=AN(KMIN,J)/AA
      BB(KMIN)=BB(KMIN)/AA
      AN(KMIN,KE)=1./AA
C     ELIMINATE ENTERING VAR. FROM OTHER EQNS.
      DO 15 I=1,MM
      IF(I.EQ.KMIN) GO TO 15
      AA=AN(I,KE)
      BB(I)=BB(I)-AA*BB(KMIN)
      DO 16 J=1,NMM
   16 AN(I,J)=AN(I,J)-AA*AN(KMIN,J)
      AN(I,KE)=-AN(KMIN,KE)*AA
   15 CONTINUE
      DO 17 I=1,M
      AA=CN(I,KE)
      ZZ(I)=ZZ(I)-AA*BB(KMIN)
      DO 18 J=1,NMM
   18 CN(I,J)=CN(I,J)-AN(KMIN,J)*AA
      CN(I,KE)=-AN(KMIN,KE)*AA
   17 CONTINUE
      IF(IPHASE.NE.1) GO TO 10
      AA=CP(KE)
      ZP=ZP-AA*BB(KMIN)
      DO 9 J=1,NMM
    9 CP(J)=CP(J)-AN(KMIN,J)*AA
      CP(KE)=-AN(KMIN,KE)*AA
   10 CONTINUE
      RETURN
      END
```

```
TEZ(1).LEAV
      SUBROUTINE LEAV(J,KMIN)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON/GUL1/M,MM,NMM,DEL,BB(50),AN(50,100),CN(3,100),ZZ(3)
      AMIN=1.0E+10
      KMIN=0
      DO 5 I=1,MM
      IF(AN(I,J).LE.DEL) GO TO 5
      AA=BB(I)/AN(I,J)
      IF(AA.GE.AMIN)GO TO 5
      AMIN=AA
      KMIN=I
    5 CONTINUE
      RETURN
      END
```

```
EZ(1).MOVE
      SUBROUTINE MOVE(INT1)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DIMENSION INT1(50)
      COMMON/GUL1/M,MM,NMM,DEL,BB(50),AN(50,100),CN(3,100),ZZ(3
      COMMON/GUL2/CP(100),ZP,IXN(100),IBE(50),IPHASE,IFLAG
C     IFLAG=0 IF MOVE IS TO ADJACENT VERTEX ,=1 OTHERWISE
      DO 1 II=1,NMM
      DO 2JJ=1,NMM
      IF(IXN(II).EQ.INT1(JJ)) GO TO 1
    2 CONTINUE
      KE=II
      IF(IFLAG.EQ.0) GO TO 500
C     KE'TH NONBASIC VAR. WILL BE ENTERING
      DO 10 IL=1,NMM
      DO 11 J=1,NMM
      IF(INT1(IL).EQ.IXN(J)) GO TO 10
   11 CONTINUE
      KL=INT1(IL)
      KMIN=0
      DO 13 I=1,MM
      IF(KL.NE.IBE(I)) GO TO 13
      KMIN=I
      IF(ABS(AN(KMIN,KE)).GT.DEL) GO TO 502
      GO TO 10
   13 CONTINUE
   10 CONTINUE
  502 CALL PIVOT(KE,KMIN)
      IXN(KE)=KL
    1 CONTINUE
      GO TO 900
  500 CALL LEAV(KE,KMIN)
      KL=IBE(KMIN)
      CALL PIVOT(KE,KMIN)
      IXN(KE)=KL
  900 WRITE(6,801)
  801 FORMAT(///,55X,'NEW EFFICIENT VERTEX',//,53X,24('*'),///)
      WRITE(6,802)(IBE(I),BB(I),I=1,MM)
  802 FORMAT(3X,'BASIC VARIABLES',/,2X,15('*'),/,(7('  X',J3,' =',F10.3
     *,/))
      WRITE(6,803)(I,ZZ(I),I=1,M)
  803 FORMAT(//,3X,'OBJECTIVES',/,2X,10('*'),/,3X,'OBJ',3(I1,' =',F10.3,
     *2X,'OBJ'))
      RETURN
      END
```

```
TEZ(1).EDGE2
      SUBROUTINE EDGE2
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON/GUL1/M,MM,NMM,DEL,BB(50),AN(50,100),CN(3,100),ZZ(3)
      COMMON/GUL2/CP(100),ZP,IXN(100),IBE(50),IPHASE,IFLAG
      COMMON/GUL3/LJ,JT(50),WU,WL
      LJ=0
      AMIN=1.0E+10
      DO 10 J=1,NMM
      IF(CN(2,J).LT.DEL) GO TO 10
      IF(CN(1,J).GT.-DEL) GO TO 10
      AA=CN(1,J)/CN(2,J)
      CN(3,J)=AA
      IF(AA.GE.AMIN) GO TO 10
      AMIN=AA
   10 CONTINUE
      WGHT=AMIN/(AMIN-1.)
      IF(AMIN.GT.999999.99) WGHT=0.0
      WGHT1=1.-WGHT
      WRITE(6,850) WGHT1,WGHT
  850 FORMAT(//,30X,'CORRESPONDING OBJECTIVE WEIGHTS ARE :',5F6.3)
      IF(WGHT.GT.WU.OR.WGHT.LT.WL) RETURN
      DO 30 J=1,NMM
      IF(CN(2,J).LT.DEL) GO TO 30
      IF(CN(1,J).GT.-DEL) GO TO 30
      IF(CN(3,J).GT.AMIN+DEL) GO TO 30
      LJ=LJ+1
      JT(LJ)=J
   30 CONTINUE
      RETURN
      END
```

```
ERTEZ(1).STORE
       SUBROUTINE STORE
       IMPLICIT DOUBLE PRECISION(A-H,O-Z)
       COMMON/BL1/ ITERNM,N35,W1W2,STMX(5,50),STZZ(5,2),IOTIP,PROFIT
       COMMON/GUL1/M,MM,NMM,DEL,BB(50),AN(50,100),CN(3,100),ZZ(3)
       COMMON/GUL2/CP(100),ZP,IXN(100),IBE(50),IPHASE,IFLAG
       IF(ITERNM.GT.0) GO TO 7028
       DO 7008 IST=1,5
       DO 7006 ITS=1,50
       STMX(IST,ITS)=0.0
  7006 CONTINUE
       STZZ(IST,1)=0.0
       STZZ(IST,2)=0.0
  7008 CONTINUE
       RETURN
  7028 DO 7048 ITS=1,MM
       IST=IBE(ITS)
       IF(IST.GT.N35) GO TO 7048
       STMX(ITERNM,IST)=BB(ITS)
  7048 CONTINUE
       STZZ(ITERNM,1)=ZZ(1)
       STZZ(ITERNM,2)=ZZ(2)
       RETURN
       END
```

```
TEZ(1).ADJUST
      SUBROUTINE ADJUST
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON/BL1/ ITERNM,N35,W1W2,STMX(5,50),STZZ(5,2),IOTIP,PROFIT
      COMMON/BL6/ ADJLOW,NADJUS
      NADJUS=0
      IF(ITERNM.EQ.1) RETURN
      IF(W1W2.GT.ADJLOW) GO TO 5028
      WRITE(6,5024) ITERNM
 5024 FORMAT(/1X,'FOR ITER.',I3,'  FURTHER ADJUST. REQUIRED')
      RETURN
 5028 ADTOT=4.57*(STMX(ITERNM,1)+STMX(ITERNM,6))+
     *       4.38*(STMX(ITERNM,2)+STMX(ITERNM,7))+
     *       5.57*(STMX(ITERNM,4)+STMX(ITERNM,9))+3.98*STMX(ITERNM,5)
      ADTOT=ADTOT/6.0
      ADNUC=4.57*(STMX(ITERNM,1)+STMX(ITERNM,6))
      IF(ADNUC.LE.ADTOT) RETURN
      WRITE(6,5048) ITERNM
 5048 FORMAT(/1X,'ITER.',I3,' ADJUSTED')
      ITERNM=ITERNM-1
      NADJUS=1
      RETURN
      END
```

```
TEZ(1).UPDATE
      SUBROUTINE UPDATE
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON/BL1/ ITERNM,N35,W1W2,STMX(5,50),STZZ(5,2),IOTIP,PROFIT
      COMMON/BL2/ GNE,EDPD(5,5),PDED(5,5),PRICEN(5)
      COMMON/BL5/ UNSD(5)
      COMMON/GUL1/M,MM,NMM,DEL,BB(50),AN(50,100),CN(3,100),ZZ(3)
      IF(ITERNM.EQ.2) UNSD(1)=0.0
      ITERNM=ITERNM-1
      ENCOST=45.7*STMX(ITERNM,1)+21.9*STMX(ITERNM,2)+
     *        20.0*STMX(ITERNM,10)+40.0*STMX(ITERNM,11)
      FXCOST=20.0*(STMX(ITERNM,1)+STMX(ITERNM,6))+
     *         3.5*(STMX(ITERNM,2)+STMX(ITERNM,7))+
     *         4.0*(STMX(ITERNM,3)+STMX(ITERNM,8))+
     *        10.0*(STMX(ITERNM,4)+STMX(ITERNM,9))+10.0*STMX(ITERNM,5)
      ENGN=22.85*STMX(ITERNM,1)+21.9*STMX(ITERNM,2)+
     *       5.0*STMX(ITERNM,10)+5.0*STMX(ITERNM,11)
      COSTKW=(ENCOST+FXCOST)/ENGN
      ITERNM=ITERNM+1
      PRICEN(ITERNM)=COSTKW*(1.0+PROFIT/100.0)
      IF(ITERNM.GE.3) PRICEN(ITERNM)=1.2*PRICEN(ITERNM)
      UPFAC1=PRICEN(ITERNM)/PRICEN(ITERNM-1)
      UPFAC1=UPFAC1**(-0.40)
      DENOMI=13.4
      IF(ITERNM.GT.2) DENOMI=EDPD(ITERNM-2,1)
      UPFAC2=1.155*EDPD(ITERNM-1,1)/DENOMI
      UPFAC2=UPFAC2**GNE
      DO 178 IUPD=1,5
      BB(IUPD)=EDPD(ITERNM-1,IUPD)*UPFAC1*UPFAC2
  178 CONTINUE
      DEM=4.57*(STMX(ITERNM-1,1)+STMX(ITERNM-1,6))+
     *     4.38*(STMX(ITERNM-1,2)+STMX(ITERNM-1,7))+
     *     5.57*(STMX(ITERNM-1,4)+STMX(ITERNM-1,9))+3.98*STMX(ITERNM-1,5)
      DEMDEM=BB(1)
      IF(BB(1).GT.DEM) GO TO 612
      UNSD(ITERNM)=0.0
      GO TO 688
  612 DEMDEM=BB(1)
  618 BB(1)=BB(1)-1.0
      IF(BB(1).GT.DEM) GO TO 618
      UNSD(ITERNM)=DEMDEM-BB(1)
  688 DEMR=BB(1)/DEMDEM
      DO 686 IJ=2,5
      BB(IJ)=BB(IJ)*DEMR
  686 CONTINUE
      DO 188 IUPD=1,5
      BB(IUPD+5)=BB(IUPD)/4.818
  188 CONTINUE
      DO 198 IUPD=1,4
      BB(IUPD+40)=STMX(ITERNM-1,IUPD)+STMX(ITERNM-1,IUPD+5)
  198 CONTINUE
      RETURN
      END
```

```
EZ(1).RWRITE
      SUBROUTINE RWRITE
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DIMENSION RWED(5),RWPD(5),RWMAT(100)
      COMMON/BL1/ ITERNM,N35,W1W2,STMX(5,50),STZZ(5,2),IOTIP,PROFIT
      COMMON/BL2/ GNE,EDPD(5,5),PDED(5,5),PRICEN(5)
      COMMON/BL5/ UNSD(5)
      WRITE(6,2)
    2 FORMAT(1H1/1X,'TERMINOLOGY'/1X,11('-')///
     *2X,'I : POWER PLANT TYPE          1 : NUCLEAR'/
     *2X,'                              2 : HYDRO-BASE (DAM)'/
     *2X,'                              3 : HYDRO-PEAK (TURBINE)'/
     *2X,'                              4 : COAL'/
     *2X,'                              5 : FUEL'/)
      WRITE(6,4)
    4 FORMAT(/2X,'T : TIME PERIOD',10X,'1.ITERATION  2.ITERATION  3.ITER
     *ATION  4.ITERATION  5.ITERATION'//
     *23X,'1 :  1982-1986    1987-1991    1992-1996    1997-2001    2002
     *-2006'/
     *23X,'2 :  1987-1991    1992-1996    1997-2001    2002-2006    2007
     *-2011'/
     *23X,'3 :  1992-1996    1997-2001    2002-2006    2007-2011    2012
     *-2016'/
     *23X,'4 :  1997-2001    2002-2006    2007-2011    2012-2016    2017
     *-2021'/
     *23X,'5 :  2002-2006    2007-2011    2012-2016    2017-2021    2022
     *-2026'/)
      WRITE(6,6)
    6 FORMAT(/'  P(I,0) : EXISTING CAPACITY (GW) FOR I TYPE POWER PLANT'
     *//'  P(I,T) : ADDITIONAL CAPACITY (GW) FOR I TYPE POWER PLANT DURI
     *NG PERIOD T'
     *//'  E(I,T) : ENERGY GENERATED (TWH) PER YEAR BY I TYPE POWER PLAN
     *T DURIND PERIOD T'
     *//'  ED(T)  : ENERGY DEMAND (TWH) PER YEAR DURING PERIOD T'
     *//'  PRICE  : PRICE OF THE ENERGY SUPPLIED (TL/KWH)'
     *//'  PROFIT : PROFIT MARGIN FOR THE ENERGY SUPPLIED (%)'
     *//'  IN.EL. : INCOME ELASTICITY'
     *//'  PR.EL. : PRICE ELASTICITY'
     *//'  D.RATE : DISCOUNT FACTOR (%) COMPOUNDED ANNUALLY'/)
      WRITE(6,10)
   10 FORMAT(//1X,'SCENARIO SPECIFICATIONS'/1X,23('-')///
     *2X,'OBJ1 : COST MINIMIZATION'/)
      IF(IOTIP.EQ.1.OR.IOTIP.EQ.2) WRITE(6,16)
      IF(IOTIP.EQ.3.OR.IOTIP.EQ.4) WRITE(6,17)
      IF(IOTIP.EQ.5.OR.IOTIP.EQ.6) WRITE(6,18)
   16 FORMAT(2X,'OBJ2 : RISK MINIMIZATION'/)
   17 FORMAT(2X,'OBJ2 : POLLUTION MINIMIZATION'/)
   18 FORMAT(2X,'OBJ2 : SPACE MINIMIZATION'/)
      WRITE(6,24) W1W2,PROFIT,GNE
   24 FORMAT(2X,'(W1/W2) =',F5.1//
     *        2X,'PROFIT  =',F5.1,' %'//
     *        2X,'IN.EL.  =',F5.1//
     *        2X,'PR.EL.  =  -.4'//
     *        2X,'D.RATE  =  8.0 %')
      DO 25 I=1,5
      DO 25 J=1,2
   25 STZZ(I,J)=-STZZ(I,J)
      WRITE(6,26) ((STMX(I,J),I=1,5),J=1,5)
      WRITE(6,27) ((STMX(I,J),I=1,5),J=6,14)
      WRITE(6,28) ((STMX(I,J),I=1,5),J=15,22)
```

```
      WRITE(6,29) ((STMX(I,J),I=1,5),J=23,35)
      WRITE(6,36) (PRICEN(I),I=1,5)
   26 FORMAT(1H1/2X,'VARIABLE                 1.ITER.    2.ITER.     3.ITER.
     *  4.ITER.     5.ITER.'/2X,8('-'),8X,5(4X,7('-'))//
     */3X,'P(1,0)',9X,5F11.2/
     *3X,'P(2,0)',9X,5F11.2/
     *3X,'P(3,0)',9X,5F11.2/
     *3X,'P(4,0)',9X,5F11.2/
     *3X,'P(5,0)',9X,5F11.2/)
   27 FORMAT(3X,'P(1,1)',9X,5F11.2/
     *           3X,'P(2,1)',9X,5F11.2/
     *           3X,'P(3,1)',9X,5F11.2/
     *           3X,'P(4,1)',9X,5F11.2/
     *           3X,'E(4,1)',9X,5F11.2/
     *           3X,'E(5,1)',9X,5F11.2//
     *           3X,'P(1,2)',9X,5F11.2/
     *           3X,'P(2,2)',9X,5F11.2/
     *           3X,'P(3,2)',9X,5F11.2)
   28 FORMAT(3X,'P(4,2)',9X,5F11.2/
     *           3X,'E(4,2)',9X,5F11.2/
     *           3X,'E(5,2)',9X,5F11.2//
     *           3X,'P(1,3)',9X,5F11.2/
     *           3X,'P(2,3)',9X,5F11.2/
     *           3X,'P(3,3)',9X,5F11.2/
     *           3X,'P(4,3)',9X,5F11.2/
     *           3X,'E(4,3)',9X,5F11.2)
   29 FORMAT(3X,'E(5,3)',9X,5F11.2//
     *           3X,'P(1,4)',9X,5F11.2/
     *           3X,'P(2,4)',9X,5F11.2/
     *           3X,'P(3,4)',9X,5F11.2/
     *           3X,'P(4,4)',9X,5F11.2/
     *           3X,'E(4,4)',9X,5F11.2/
     *           3X,'E(5,4)',9X,5F11.2//
     *           3X,'P(1,5)',9X,5F11.2/
     *           3X,'P(2,5)',9X,5F11.2/
     *           3X,'P(3,5)',9X,5F11.2/
     *           3X,'P(4,5)',9X,5F11.2/
     *           3X,'E(4,5)',9X,5F11.2/
     *           3X,'E(5,5)',9X,5F11.2/)
   36 FORMAT(/3X,'PRICE',10X,5F11.2/)
      WRITE(6,48) ((EDPD(I,J),I=1,5),J=1,5)
   48 FORMAT(/3X,'ED(1)',10X,5F11.2/
     *            3X,'ED(2)',10X,5F11.2/
     *            3X,'ED(3)',10X,5F11.2/
     *            3X,'ED(4)',10X,5F11.2/
     *            3X,'ED(5)',10X,5F11.2)
      RWA1=0.0
      RWF2=1.0/1.08
      DO 68 I=1,5
      RWF1=100.0*STMX(I,6)+70.0*STMX(I,7)+20.0*STMX(I,8)+
     *         60.0*STMX(I,9)+20.0*STMX(I,10)+40.0*STMX(I,11)+
     *         45.7*STMX(I,1)+21.9*STMX(I,2)
      IEX=5*I-2
      RWA1=RWA1+RWF1*RWF2**IEX
      RWED(I)=EDPD(I,1)
      RWPD(I)=PDED(I,1)
   68 CONTINUE
      RWA2=0.0
      IF(IOTIP.GT.4) GO TO 86
      IF(IOTIP.GT.2) GO TO 84
```

```
      DO 82 I=1,5
      RWA2=RWA2+8.0*STMX(I,6)+10.0*STMX(I,7)
   82 CONTINUE
      GO TO 88
   84 DO 85 I=1,5
      RWA2=RWA2+STMX(I,6)+10.0*STMX(I,10)+5.0*STMX(I,11)
   85 CONTINUE
      GO TO 88
   86 DO 87 I=1,5
      RWA2=RWA2+STMX(I,6)+10.0*STMX(I,7)+2.0*STMX(I,9)
   87 CONTINUE
   88 RWMAT(11)=4.570*STMX(1,1)
      RWMAT(12)=4.57*(STMX(1,1)+STMX(1,6))
      RWMAT(13)=4.57*(STMX(1,1)+STMX(1,6)+STMX(2,6))
      RWMAT(14)=4.57*(STMX(1,1)+STMX(1,6)+STMX(2,6)+STMX(3,6))
      RWMAT(15)=4.57*(STMX(1,1)+STMX(1,6)+STMX(2,6)+STMX(3,6)+STMX(4,6))
      RWMAT(26)=3.2850*STMX(1,2)
      RWMAT(27)=3.285*(STMX(1,2)+STMX(1,7))
      RWMAT(28)=3.285*(STMX(1,2)+STMX(1,7)+STMX(2,7))
      RWMAT(29)=3.285*(STMX(1,2)+STMX(1,7)+STMX(2,7)+STMX(3,7))
      RWMAT(30)=3.285*(STMX(1,2)+STMX(1,7)+STMX(2,7)+STMX(3,7)+STMX(4,7)
     *)
      DO 202 I=26,30
      RWMAT(I)=1.333*RWMAT(I)
  202 CONTINUE
      DO 204 I=1,5
      RWMAT(I)=STMX(I,1)
      RWMAT(I+15)=STMX(I,2)
      RWMAT(I+30)=STMX(I,3)
      RWMAT(I+45)=STMX(I,4)
      RWMAT(I+60)=STMX(I,5)
      RWMAT(I+5)=STMX(I,6)
      RWMAT(I+20)=STMX(I,7)
      RWMAT(I+35)=STMX(I,8)
      RWMAT(I+50)=STMX(I,9)
      RWMAT(I+65)=0.0
      RWMAT(I+40)=0.0
      RWMAT(I+55)=STMX(I,10)
      RWMAT(I+70)=STMX(I,11)
  204 CONTINUE
      USCOST=0.0
      DO 208 I=1,5
      USCOST=USCOST+100.0*UNSD(I)
  208 CONTINUE
      RWA1=RWA1+USCOST
      WRITE(6,92) RWA1,RWA2,(RWED(I),I=1,5),(UNSD(I),I=1,5)
   92 FORMAT(1H1/1X,23('*')/
     *1X,'*                     *                    OBJ1 :',F10.2/
     *1X,'*  AGGREGATE TABLEAU  *'/
     *1X,'*                     *                    OBJ2 :',F10.2/
     *1X,23('*')//
     *33X,'1982-1986   1987-1991   1992-1996   1997-2001   2002-2006'/
     *33X,'---------   ---------   ---------   ---------   ---------'//
     *1X,'ENERGY DEMAND (TWH) SATISFIED  ',F10.2,4F12.2//
     *1X,'ENERGY DEMAND (TWH) UNSATISFIED',F10.2,4F12.2//1X,89('-')/
     *1X,89('-')/)
      WRITE(6,104) (RWMAT(I),I=1,15)
  104 FORMAT(1X,'NUCLEAR'/1X,7('-')//
     *1X,'EXISTING CAPACITY   (GW)',5X,5F12.2/
     *1X,'ADDITIONAL CAPACITY (GW)',5X,5F12.2/
```

```
     *1X,'ENERGY GENERATED    (TWH)',5X,5F12.2//1X,89('-')/)
      WRITE(6,105) (RWMAT(I),I=16,30)
  105 FORMAT(1X,'HYDRO-BASE'/1X,10('-')//
     *1X,'EXISTING CAPACITY   (GW)',5X,5F12.2/
     *1X,'ADDITIONAL CAPACITY (GW)',5X,5F12.2/
     *1X,'ENERGY GENERATED    (TWH)',5X,5F12.2//1X,89('-')/)
      WRITE(6,106) (RWMAT(I),I=31,40)
  106 FORMAT(1X,'HYDRO-PEAK'/1X,10('-')//
     *1X,'EXISTING CAPACITY   (GW)',5X,5F12.2/
     *1X,'ADDITIONAL CAPACITY (GW)',5X,5F12.2//1X,89('-')/)
      WRITE(6,107) (RWMAT(I),I=46,60)
  107 FORMAT(1X,'COAL'/1X,4('-')//
     *1X,'EXISTING CAPACITY   (GW)',5X,5F12.2/
     *1X,'ADDITIONAL CAPACITY (GW)',5X,5F12.2/
     *1X,'ENERGY GENERATED    (TWH)',5X,5F12.2//1X,89('-')/)
      WRITE(6,108) (RWMAT(I),I=61,65),(RWMAT(I),I=71,75)
  108 FORMAT(1X,'FUEL'/1X,4('-')//
     *1X,'EXISTING CAPACITY   (GW)',5X,5F12.2/
     *1X,'ENERGY GENERATED    (TWH)',5X,5F12.2//1X,89('-'))
      RETURN
      END
```