EFFECTS OF RELATIVE PRICE CHANGES ON THE
OPTIMAL DEVELOPMENT OF THE ELECTRICITY SECTOR:
THE CASE OF TURKEY

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ABSTRACT

This thesis investigates the effects of changes in the relative prices of resources (namely, hydro, lignite, oil and nuclear sources) and primary factors (i.e., foreign exchange and domestic capital) on the optimal development of the Turkish Electricity sector over the 1982-2002 period. The study uses a multi-period linear programming model, which combines the analysis of investment choices with the treatment of plant operating schedules in a global framework. The numerical implementation of the model includes 20 alternative runs on the computer, which are designed in such away as to explore the nature of shifts in the structure of optimal investment programs under varying assumptions and ground rules of the analysis.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

Oil crisis that occurred in the late 1973 had a great impact on the world economy and its constituent parts. In most of the oil exporting and importing countries, the massive shift in oil prices has altered the balance of payments, growth prospects and energy perspectives in the short and long runs. The decline in the prices of other types of energy in real terms relative to the oil prices has given rise to a variety of attempts both at the national and international levels, to change the structure of energy consumption, production and development activities.

In the present thesis, an attempt is made to examine the sensitivity of the optimal electricity development programs in Turkey to changes that have occurred and likely to occur in the future in relative prices of energy resources (e.g., oil, lignite, hydro and nuclear sources) and of primary factors (namely, foreign exchange and domestic capital) used in electricity investments and production. Such an examination is needed on two accounts. Firstly, it is useful to understand the nature of shifts in the optimal configuration of the future power plants concurrent with the changes in world oil prices which caused a subtantial deterioration in Turkey's balance of payments prospects Secondly, an investigation of the impact

of relative price changes on the investment plans of the Turkish elect-
ricity sector is essential in view of the fact that the various factor
and commodity prices observed in the Turkish economic scene in the 1976/
1977 period are distorted for planning purposes in the sense that they
do not represent real social costs, i.e., true scarcities and opportunities
faced in the national development process.Hence,the present study is a
modest effort in the direction of filling a gap in the process of energy
planning in Turkey.

The linear programming model employed in the present study has
been originally developed by Dennis Anderson (1972), and has been fre-
quently used in the planning and projection studies of the Turkish
Electricity Authority. The main contribution of the author has been in
the area of re-estimation of the cost parameters from detailed project
data, and running the model for alternative cost combinations to explore
the changing nature of optimal solutions. In the re-estimation of the
cost parameters, an effort has been made to distinguish market prices
from social costs by leaving indirect taxes and subsidies out of the
cost and price picture. Another modest contribution of the study has been
in the form of introducing an advanced starting solution technique into
the computer program, which made substantial reductions in the compu-
ter time possible.

The study adopts a twenty-year planning horizon, 1982-2002, star-
ting with the base-year 1982. The latter is the terminal year of the
4th 5 year development plan. The shape of the power system by 1982 is
projected on the basis of the power projects already under construction.
Considering the long time lags between investments and production in
the electricity power sector, the projected optimal sequence and confi-
guration of plants for the 1982-2002 period would form a basis for new

investment choices in the 1977-1982 period.

In the present application of Anderson model four types of power plants (namely, hydro, lignite, fuel-oil and nuclear schemes) are considered. Hydro plants are characterized by their high installation and negligible operating costs. Lignite plants have higher installation but lower operating costs than the fuel-oil plants. Nuclear power plants are economically compatible with the other types over the 600 MW power level with the higher installation and low operating costs.

The arrangement of the remaining part of the study is as follows. The scope of electrical power sector within Turkey's total energy system and recent developments in the process of long-term electricity planning are discussed in Chapter II. The model used in the present investigation is presented, and its main features are discussed in Chapter III. In turn, Chapter IV outlines the major characteristics of the reference solution against which all alternative solutions are contrasted and examined. The optimal plant capacities and corresponding operating schedules found in the alternative solutions are presented in Chapter V. Finally, Chapter VI re-capitulates the principal conclusions of the study.

CHAPTER II

DEVELOPMENT PLANNING FOR THE ELECTRICITY

SECTOR IN TURKEY

II.1- Introductory Remarks

The purpose of this chapter is to provide a general background on
the perspectives of development for the electric power sector in Turkey.
The chapter briefly covers three major subjects as follows:

i) The scope of electrical power sector within the country's total
energy system;

ii) Recent developments in the process of long-term investment
planning in the electricity sector proper; and

iii) Possible impact of the 1973 world oil crisis on the long-term
investment programs of the electricity sector.

II.2- The Scope of the Electricity Sector in the National Energy System

In conjunction with the rapid growth of non-agricultural output
and general improvement in the standard of living, the primary energy
demand has shown a remarkable growth since the beginning of the planned
development in the early sixties. Table II-1 provides data on the expansion
of the primary energy demand and its major constituent parts over the

Table II-1: PRIMARY ENERGY DEMAND IN TURKEY IN 1962-2002

(Unit:Mteo) 1/

Resources	1962	1972	1982	1992	2002 2/
Coal	2.384	2.820	6.031	9.790	13.400
Lignite	1.005	1.940	14.660	28.186	39.100
Oil	2.834	10.532	28.669	50.445	69.800
Hydro	0.284	0.807	3.692	10.194	18.500
Wood	3.910	4.045	3.184	1.254	0.500
Dung	2.037	2.487	2.353	1.604	1.100
TOTAL	12.454	22.631	58.589	101.473	142.400
Per Capita Consumption (kg/Man) :	453	620	1100	1688	2100
Average Rate of Increase/Year(%):		12.0	12.4	10.3	9.6

1/ Mtoe= Million tons of Oil Equivalent
10^6 tons of coal = 0.7 Mtoe.

2/ The estimates of the author obtained by extrapolation of the offical projections given for the 1982-1995 period.

Source: State Planning Organization Studies.

1962-1972 decade covering the 1st and 2nd Five-Year Plans implemented in this period. The same table also gives the official estimates of the projected primary energy demand over the 1982-2002 period, which is the appropriate horizon for long-term investment planning in the energy sectors characterized by long time-lags in capacity expansions.

In turn, Table II-2 shows the evolving pattern of primary energy production in Turkey during 1962-1972, and over the planning horizon 1982-2002. A comparision of these two tables reveals the import requirements of the country for each major category . of primary energy.

TABLE II-2: PRIMARY ENERGY PRODUCTION IN TURKEY IN 1962-2002

(Unit:Mtoe)

Resources	1962	1972	1982	1992	2002
Coal	2.371	2.827	3.562	3.562	3.562
Lignite	0.948	2.039	12.730	20.148	26.200
Oil	0.625	3.557	3.150	3.150	3.150
Hydro	0.284	0.807	3.692	10.194	18.500
Wood	1.705	1.957	1.467	1.254	0.500
Dung	2.035	2.487	2.353	1.604	1.100
TOTAL	7.970	13.674	26.954	39.912	53.012

1/ Units and data source are the same as in Table II-1.

Table II-3 presents data on the expansion of the electrical power and energy over the same 1962-2002 period. A close study of the data in these tables indicates the steadily growing importance of lignite and hydro sources in the total energy picture, which is primarily due to the falling share of oil as a resource in electricity generation beyond 1982 on the account of increased oil prices after the world energy crisis experienced in the 1973/1974 period.

The official projections summarized in Tables II-1,2 and 3 can be critisized on both substantive and methodological grounds. It is observed that the projections beyond 1982 do not incorporate nuclear and possibly geothermal power schemes, which are currently in the planning stage in various government agencies in Turkey. Moreover, the oil consumption projections for 1982 onwards are likely to be inconsistent with the balance of payments constraint of the Turkish Economy in the 1980's. Considering the limited volume of oil reserves known to exist in Turkey, and the expected foreign exchange bottlenecks in the Fourth Five Year Plan period (1978-1982), it would be quite unrealistic to

Table II-3: ELECTRICITY SECTOR IN TURKEY IN 1962-2002

		1962	1972	1982	1992	2002
Power (MW)	:	725	1982	6384	17000	39000
Energy (GWh)	:	3560	11000	35430	95000	217000
Energy (Mtoe) [1]/	:	0.306	0.946	3.047	8.170	18.662
Per Capita Consumption (KWh/Man)	:	118	294	728	1527	2818 [2]/
Annual Average Energy Increase (%)	:		12.0	12.5	10.5	8.7

1/ Energy Conversion Factors are taken as follows:

10^6 tons of coal = 0.7 Mtoe

1GWh (=10^6 kWh) of electricity = 0.000086 Mtoe.

2/ Population in 2002 is estimated 76 732 950.

Source: 1962-1982 data from Third Five Year Plan., Ref. [6].

1982-2002 data from TEK forecasts, Ref. [21] and Ref. [25].

expect the amount of oil consumption as projected for the 1982-1992 period.

From methodological point of view, the long-term energy projections would be more meaningful and internally more consistent, if they were prepared within the framework of national energy balances systematically matching the sources and uses of energy in a matrix form which also covers the interactions among the primary and secondary energy production activities. Such a balance sheet would also distinguish the indigenous and imported sources of energy, thus furnishing a basis for import projections under alternative energy policies. Table II-4 gives on illustration of a set of national energy balances for the Turkish Economy

Table II-4: ENERGY BALANCES FOR TURKEY IN 1972

Unit: Mtoe	Coal and Lignite	Crude Oil	Wood and Dung	Electricity	Hydro	Total
Indigenous Supply	4.183	3.503	7.250		0.360	15.296
– Net Imports		8.335				8.335
– Export		–0.958				–0.958
– Bunkers		–0.115				–0.115
– / + Stock Changes 1/	0.027	–0.426				–0.399
TOTAL PRIMARY ENERGY	4.210	10.399	7.250		0.360	22.159
Electricity Generation	0.924	1.202		–0.967	0.360	1.519
Manufactured Gas	0.758					0.758
TOTAL FINAL CONSUMPTION	2.528	9.137	7.250	0.967		19.882
Energy Sector, Losses and Own Consumption	0.301	0.309		0.189		0.799
Industry	0.701	1.774		0.505		2.980
Transportation	0.561	3.426		0.130		4.000
Residential/ Other	0.965	3.628	7.250	0.260		12.103

1/ (–) Withdrawals

   (+) Additions

for the year 1972. This table was prepared by the author for a different purpose, and is probably the first attempt in this field in the Turkish context.[1] If energy projections were to be made using such a format preferably with the aid of a suitable mathematical model, it would then be a quite useful task to explore alternative substitution possibilities on the production and demand sides under different economic policies. In the absence of such an integrated modeling framework for the Turkish energy sector, we adopt in this thesis official electricity demand projections of the Turkish Electricity Authority (TEK) without going into the discussion of underlying premises and assumptions.[2]

II.3- Long-Term Investment Planning in the Turkish Electricity Sector

The long-term investment planning for the development of the Turkish Electricity sector is quite a complex process, which involves a number of government agencies under the broad coordination of the State Planning Organization (SPO). The planning process is quite continuous, but becomes a highly active affair at the occasion of the preparation of Five Year Plans. Although the major staff work is undertaken by TEK, the long-term investment plan becomes the product of a network of special commissions created and broadly managed by the SPO.

In view of the long leads and lags in capacity expansions in this sector, TEK appropriately considers a planning horizon of 20 years.

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[1] This work was undertaken as part of a seminar (OR 692-Energy Systems Planning)at the Middle East Technical University in 1976. See Celasun and Pinto (1975) for the elaboration of national energy balances.

[2] An effort in this direction is being made by the University of Boğaziçi (1977) in the form of constructing a comprehensive energy model for Turkey, Ref. [13].

In the preparation of long-term projections and investment programs for the Fourth Five Year Plan (1978-1982), TEK planners focus on the 1982-2002 period, the base year of which is 1982. It is assumed that the shape of the power system in 1982 is to a large extent determined by the projects under construction. The long-term projection studies are therefore carried out with a view of clarifying the nature of optimal choices of new projects to be started in the near future (i.e, in the 1978-1982 period).

The projected structure of the interconnected system in 1982 is shown in Table II-5, including the autonomous electric power producers in Turkey. It may be noted that in the planning exercises, the hydrolic power is reduced from 3593 MW to 3400 MW because of the 50% hydro-thermal balance imposed on the system.

Table II-5: THE TURKISH ELECTRICITY PROJECTED SYSTEM IN 1982 [1]

Plant Type	T E K Power (MW)	T E K Energy (GWh)	Autonomous Power (MW)	Autonomous Energy (GWh)	TOTAL Power (MW)	TOTAL Energy (GWh)	Share in Total (%) Power	Share in Total (%) Energy
Hydrolic	3374	13640	219	1152	3593	14792	41	32
Lignite	3723	23030	7	40	3730	23070	43	50
H.Coal	200	1200	24	85	224	1285	3	3
Fuel-Oil	680	4550	436	2448	1116	6998	13	15
TOTAL	7977	42420	686	3725	8663	46145	100	100

[1]   This table is based on various TEK publications.

Upon establishing the base-year system estimates, TEK then proceeds to develop long-term demand projections by the use of regression

methods which attempt to relate electricity demand to factors such as industrial output, residential use and, to a smaller extent, transport sector, Table II.6 gives annual peak load and energy estimates over the 1982-2002 period. To provide a more detailed basis for capacity expansion studies, the projected annual demands are represented by load duration curves, which are approximated by several discreet blocks as discussed further in the following two chapters in the present study.

Having developed a set of long-term demand projections for the benchmark years in the planning horizon, the problem then becomes one of analyzing alternative combinations of prospective power projects, by also taking into account various technical restrictions and resource constraints (see Table II.7). Since 1972, TEK has been actively using an investment planning model originally constructed by Anderson (1972) which aims at finding a least-cost capacity expansion program in the long run.

It is important to note at this juncture that the aggregation of various types of power plants into a finite number of categories is a crucial problem in long-term investment planning. In the official TEK studies, hydro plants are classified into six groups on the basis of their installation costs and load factors. In the present study, hydro plants are aggregated into one class and their characteristic features are represented by country-wide average estimates. The latter approach is justified to a large extent by the fact that the solutions to the investment model which we are using are not sensitive to changes in the way the hydro plants are classified. Similarly fuel oil and gas turbine plants are aggregated into one category on the basis of their comparable economic and technical characteristics. It is needless to mention that reduction in the number of alternative plant types greatly reduces computer time, particularly when the focus is on the sensitivity analysis of a reference optimum solution.

Table II-6 : POWER AND ELECTRICAL ENERGY DEMAND IN TURKEY

Years	Peak Load		Energy	
	MW	Increase(%)	GWh	Increase(%)
1982	6370	11.5	35150	11.4
1983	7250	13.8	39600	12.6
1984	8010	10.4	43750	10.4
1985	8850	10.4	48350	10.5
1986	9785	10.5	53430	10.5
1987	10810	10.4	59040	10.4
1988	11900	10.0	64900	9.9
1989	13100	10.0	71400	10.0
1990	14400	9.9	78500	9.9
1991	15800	9.7	86300	9.9
1992	17400	10.1	95000	10.0
1993	19000	9.1	104000	9.4
1994	21000	10.5	114000	9.6
1995	23000	9.5	125000	9.6
1996	25000	8.6	135000	8.0
1997	27000	8.0	146000	8.1
1998	29000	7.4	158000	8.2
1999	31000	6.8	170000	7.5
2000	34000	9.6	185000	8.8
2001	36200	6.4	201000	8.6
2002	39000	7.7	217000	7.9

Source: TEK forecasts , Ref. [21] and Ref. [25].

Table II-7: RESOURCE AVAILABILITY FOR ELECTRICITY PRODUCTION[1]

Plant Types	Capacity in 1982 (MW)	Max.Capacity Available After 1982 (MW)
Hydro 1	0	1800
" 2	0	1420
" 3	0	3850
" 4	0	970
" 5	3400	4260
" 6	0	2540
Sub.Total	3400	15040
Gas Turbine	436	Unlimited
Fuel-Oil	680	"
Sub.Total	1116	Unlimited
Lignite	3700	9000
Nuclear	0	Unlimited
TOTAL	8216	54600

[1]   Estimated power by the end of 2002 including reserve capacity.

Source: See Ref. [24].

II.4   Impact of World Oil Crisis on Long-Term Development Strategies
        for the Electricity Sector

The massive increase in world oil prices in late 1973 has brought
a new planning perspective for the Turkish electricity planners, who
became conscious of the rapidly rising costs of imported oil and of the
need to develop indigenous hydro and lignite resources at a rapid pace.
In fact, in the more recent official applications of the Anderson model,
the additional fuel-oil plants are not included as alternative possibili-
ties of capacity expansion in the 1982-2002 period as a pre-determined
political choice imposed on the system.

In the present study, the numerical implementation of the model
originally developed by Anderson is renewed with a more elaborate emphasis
on sensitivity analysis involving alternative oil prices, lignite-operating
and hydro-capital costs foreign exchange rates and interest factors.
The overall aim is to explore the shifts in optimal configuration of the
future operating and reserve plants under different factor (i.e.capital
and foreign exchange) and resource (i.e., fuel-oil, lignite and hydro)
prices. The underlying intention is to uncover problem areas which require
more detailed project studies in the electricity planning process.

CHAPTER III

THE MODEL

III.1 -Models for Investment Analysis

The application of mathematical programming to the investment plan-
ning problems of electrical power utilities has seen the successful use of
linear programming (LP) models as a basis for comprehensive long-term
planning of all relevant types of power systems.

Possible approaches to the investment planning problem are reviewed
and summarized in this chapter, and models of these approaches are briefly
explained. The methodological review reported here draws heavily from an
extensive literature survey prepared by Anderson (1972) and a thesis study
by Güven (1972) which provides a useful discussion of electricity planning
models from an OR perspective. In the literature, approaches to invest-
ment planning problem are usually classified into three main categories
namely, marginal analysis, marginal analysis using simulation models, and
global models.

III.1.1-Marginal Analysis

In General, marginal analysis refers to a framework of analysis
based on the relations between changes in variables. In France,P.Massé

and R.Gibrat at late in 1940 first applied marginal analysis to investment planning in electricity generation industry (see e.g., Bessière (1969)). As a general rule, the application of marginal analysis starts with a given reference solution, and seeks to achieve improvements by marginal substitutions in terms of either reduced costs or increased benefits. In evaluating alternative power generating schemes, the reference solution and the solution which is obtained by marginal substitutions satisfy the same power and energy demands.

For example, consider two alternative projects A_1 and A_2 which satisfy a given electricity demand (see, Anderson (1972)). Supppose that the corresponding investments of two alternative projects are I_1 and I_2 respectively.

The A_1 may require a higher investment than A_2 (i.e $I_1 > I_2$), but on the contrary the total system operating costs in subsequent years may be less.

The total, discounted system operating costs in year t are:

$$(1+r)^{-t} \sum_{j=1}^{J} \sum_{v=-V}^{t} F_{jvt} \cdot U_{jvt} = (1+r)^{-t} \emptyset_{th} \quad \text{if } A_1 \text{ is adopted}$$

$$= (1+r)^{-t} \emptyset_{tf} \quad \text{if } A_2 \text{ is adopted}$$

The present value (PV) of differences between total cost is given in the following:

$$PV = (I_2 - I_1) + \sum_{t=0}^{T} (1+r)^{-t} (A_{2t} - A_{1t})$$

Concluding remark:

If $PV > 0 \implies A_1$ preferable to A_2,

If $PV < 0 \implies A_2$ preferable to A_1,

where   T: planning horizon

           r: discount rate

           t: denotes the year

The difficulty of marginal analysis arises in two differents ways. First, it is cumbersome to calculate operating costs for a long term horizon in the context of several other plants jointly operating in the system. Secondly, number of possible marginal substitutions may be very large. The first difficulty is put aside by simulation models, and the second difficulty is overcome by global models.

III.1.2- Simulation Models

Simulation models are complementary tools of marginal analysis. If a reference solution of an investment program is postulated, simulation models can be used to calculate the optimum operating schedules and costs. The simulation model is therefore used to calculate more accurately the operating savings associated with any marginal substitution (See, Anderson (1970)).

There are three approaches in simulation models.

(i)   Models which integrate the load duration curve directly,

(ii)   Models which use Dynamic Programming,

(iii) Models which use Linear Programming.

III.1.3- Global Models

Global models consider investment and operating costs (and schedules) in an integrative framework. They seek to explore and determine the costs of a large number of present and future investment strategies and select an overall optimum. For each investment program for which they find out the cost, they simulate system operation and calculate optimum operating schedules and costs.

In the sense of mathematical programming, two types of global model have been used in the country applications.

(i) Linear Programming

Linear programming is being succesfully in system planning by most of the developed countries. In France, the investment planning problem in electricity generation in terms of LP was first formulated by Massé and Bessière in the early 1950's. Although there has not been significant changes in the basic principles being employed, the increase in the memory capacity and the speed in execution of computer has enabled more detailed studies. Linearization technique has been employed by utilizing interpolation methods even in the case of non-linear cost functions, which exhibit convexity properties. In general, linear programming formulations are simple to design, but the solutions may be difficult to obtain, because of the size of the linear program required to incorporate all the relevant constraints operating on the system.

(ii) Non-Linear Programming

Since it takes too much computer time, the large extension of the constraint set is one of the most important disadvantages of linear programming problems. It was impossible to solve the linear programming problems with numerious constraints in 1960's by using computer time. Therefore, the techniques of non-linear programming were adopted (see Bessièree (1969)). Non-linear programming overcomes to a large extent the constraint problem of the linear programming problem.

On the other hand, formulation of the non-linear programming problem is technically more difficult to derive and solve, but more economical than linear programming on computer time and space. The usage of non-linear programming is restricted by the difficulties in its formulation. In general non-linear programming is not as flexible as linear programming, and, it requires more detailed, and specified formulas.

III.2- General Description of the Model

The linear programming model used in the present study was originally formulated and statistically implemented by Anderson and Tarkan (1972) for the case of Turkey. The model was also numerically applied in a thesis study by Güven (1972) using the available data in 1971/1972. Since its initial formulation and application, the model has been adopted as a working tool in some of the official planning studies carried out by the Turkish Electricity Authority -TEK- (see, e.g., papers by Kıcıman (1976,1977)). Thus, the present analysis has benefitted greatly from the early formulation and use of the Anderson model in the Turkish development context. As noted earlier in Chapter I, the present thesis work centers upon the use of this model to re-explore Turkey's realistic options in the development of its power sector in light of changes that have occurred in relative prices (of fuels, foreign exchange and capital) after the advent of the oil crisis experienced in late 1973. The relative prices are re-estimated by the author using the 1976 data. On the computational side the present study also provides a contribution in the way of substantially reducing computer time by introducing starting-solution, revise and modify procedures into the TEK modeling system which integrates Z-transform, matrix generator and LP (Linear Programming) format in a single computer program. Z-transforms are discussed in Section III.5.

In the present application of the Anderson model, four types of plants (namely, hydro power plants, lignite power plants, nuclear power plants, and fuel-oil power plants) are considered. The fuel-oil category included in the model incorporates fuel-oil, and gas turbine plants. The costs of the latter are estimated by the author on an average basis using the projected relative weights in the base year (1982).

Hydro power plants have relatively high capital costs but they have negligible operating costs. Lignite power plants have relatively high capital and operating costs. Nuclear power plants have very high capital costs and relatively low operating cost. The fourth type, fuel-oil power plants have relatively low costs of capital, but they have relatively very high costs of operation.

III.3- Structure of the Linear Programming Model

III.3.1- Definition of Variables of the Model

The focus of the model is on the optimal investment and operating decision variables. That is, two types of decision variables are considered in this model.

(i) The types of plant to be chosen, and the amount of capacity to be built in each of the investment period of the planning horizon. This type of variables are denoted by X in the model.

(ii) The optimum mode of system operation or the so called optimum load dispaching schedule of the system. The latter type variables are denoted by U (or Z when using Z- substitutes) in the model.

III.3.2-Objective function of the Model

The objective function K (X,U), to be minimized, is the sum of capital and operating costs. All costs used in this model are discounted to the base year.

This objective function is formulated as follows:

Let the load duration curve is broken down into p= 1,2, ...,P discrete rectangular blocks, each spanning a time interval of θ_p. The objective is to choose the investment decisions X_{jv} and associated operating decisions U_{jvtp} over the interval t=1, ...,T. Note that, inherited plant, denoted by v=-V, ...,0, must also be operated. That is old vintages of plant must be entered the investment decision.

Hence, objective function is:

$$\text{Minimize } K\ (X,U) = \sum_{j=1}^{J} \sum_{v=1}^{T} C_{jv} \cdot X_{jv} +$$

$$\sum_{j=1}^{J} \sum_{t=1}^{T} \sum_{v=-V}^{t} \sum_{p=1}^{P} F_{jtv} \cdot U_{jtvp} \cdot \theta_p \quad \text{(III.1)}$$

Where

X_{jv} : decision variable denoting capacity of plant type (j=1, ...,J), vintage v;

C_{jv} : corresponding capital cost per MW.

U_{jtvp} : decision variable denoting power output of plant j, vintage v, in year t, and block p on the load duration curve;

F_{jtv} : corresponding operating cost per MW.

(This does not vary with P.)

III.3.3- Constraints of the Model

So the aim of the model is to find the value of X_{jv} and U_{jvt} which minimize the function K (X,U) subject to some conditions which are given in the following.

Peak Demand Constraints

Available installed capacity must be sufficient to meet the expected peak demand with a margin of reserve capacity (m) and to allow for demand above expected levels.

Put briefly,

Available installed capacity $\geqslant$ Peak demand at all times.

$$\sum_{j=1}^{J} \sum_{v=-V}^{t} a_{jv} \cdot X_{jv} \geqslant Q_{tp} (1+m), \qquad \begin{array}{l} t=1 \text{ to } T \\ p=1 \end{array} \qquad \text{(III.2)}$$

Where

Q_{tp} (for p=1): the peak demand (load) in year t;

X_{jv} for v:-V,....,0 defines inherited plant;

a_{jv}: the availability of plant j, vintage v.

Operating Constraints

The second contraint sets refers to operation.

(i) Instantaneous Demand Constraint

The plants in operation must be sufficient to meet the instantaneous power demand at all times.

In brief:

Total output $\geqslant$ Instantaneous demand, at all times.

$$\sum_{j=1}^{J} \sum_{v=-V}^{t} U_{jtvp} \geqslant Q_{tp}, \qquad \begin{array}{l} t=1 \text{ to } T \\ p=1 \text{ to } P \end{array} \qquad \text{(III.3)}$$

Where

Q_{tp} : the demand in year t, interval p of load duration curve.

(ii) Available Capacity Constraints

The output of each plant must be less than the available capacity.

In brief:

Output from each plant $\leqslant$ Available capacity of the plant.

$$U_{jtvp} \leqslant a_{Jv} \cdot X_{jv},$$

$$t=1 \quad \text{to} \quad T$$
$$p=1 \quad \text{to} \quad P$$
$$v=-V \quad \text{to} \quad t \qquad \text{(III.4)}$$
$$j=1 \quad \text{to} \quad J$$

Where

a_{jv}: the availability factor of plant j, vintage v.

(Note that, to reduce the large number of these constraints Z-substitutes method is adopted as shown in Section III.5).

Hydro Output Constraints

In any year, the energy output from a hydro plant must be less than available energy in the water supplies.

In brief:

Energy output of hydro plant $\leqslant$ Available energy at all times.

$$\sum_{p=1}^{P} U_{jtvp} \cdot \theta_p \leqslant b_j \cdot X_{jv},$$

$$t=1 \quad \text{to} \quad T$$
$$v=-V \quad \text{to} \quad t \qquad \text{(III.5)}$$
$$j=\text{hydro plant}$$

Where

b_j: the load factor of the hydro plant.

Hydro-Thermal Balance Constraints

The total installed capacity of the system must be less than a given percentage of the peak load levels.

In brief:

Total hydro capacity $\leqslant$ Given percentage of the peak demand.

$$\sum_{v=-V}^{t} X_{jv} \leqslant R.Q_{tp}, \qquad \begin{array}{l} t=1 \text{ to } T \\ P=1 \\ j= \text{ hydro} \end{array} \qquad \text{(III.6)}$$

Where

R = Given percentage of peak demand.

Resource Availability Constraints

(i) For Hydro Power Plants:

The total installed hydro power capacity must be less than the potential hydro capacity available in the country.

In brief:

Installed hydro plant $\leqslant$ Potential hydro capacity

$$\sum_{v=1}^{T} X_{jv} \leqslant X_{jmax}, \qquad j=\text{hydro} \qquad \text{(III.7)}$$

Where

X_{jmax} = the potential hydro capacity.

(ii) For Thermal Power Plants:

The total installed capacity of type j thermal power plant must be less than the potential capacity of type j thermal power available in the country.

(Note that, there is no restriction on nuclear and fuel-oil power plants, i.e., in principle, nuclear and fuel-oil power are unlimited.)

In brief:

Installed thermal plant $\leqslant$ Maximum potential capacity

$$\sum_{v=1}^{T} X_{jv} \leqslant X_{jmax.} \quad , \qquad j = \text{thermal} \quad \text{(lignite)} \qquad \text{(III.8)}$$

Where

$X_{jmax.}$: the maximum potential capacity of type j thermal power in the country.

A Priori Choices on Capacity Limits

In the real life planning applications, a number of a priori invest-ment decision constraints on the capacities of certain types of plant may be incorporated into the model to reflect either certain political consi-derations and/or planning decisions that have already been taken by the authorites.

$$X_{jvmin.} \leqslant X_{jv} \leqslant X_{jvmax.} \qquad \text{(III.9)}$$

Where

$X_{jvmin.}$ and $X_{jvmax.}$ are pre-defined constraints determining the lower and/or upper limits for the installation of plant j in year v.

Non-Negativity Constraints

All $X, U \geqslant 0$ \qquad\qquad\qquad\qquad\qquad (III.10)

III.3.4- Compact Form of the Model

In a compact form, the model is summarized as follows:

$$\text{Minimize } K(X,U) = \sum_{j=1}^{J} \sum_{v=1}^{T} C_{jv} X_{jv} +$$

$$\sum_{j=1}^{J} \sum_{t=1}^{T} \sum_{v=-V}^{t} \sum_{p=1}^{P} F_{jtv} \cdot U_{jtvp} \cdot \Theta_p \qquad \text{(III.1)}$$

Subject to:

$$\sum_{j=1}^{J} \sum_{v=-V}^{t} a_{jv} \cdot X_{jv} \geqslant Q_{tp}(1+m) \; ; \qquad \begin{array}{l} t=1 \text{ to } T \\ p=1 \end{array} \qquad \text{(III.2)}$$

$$\sum_{j=1}^{J} \sum_{v=-V}^{t} U_{jtvp} \geqslant Q_{tp} \; ; \qquad \begin{array}{l} t=1 \text{ to } T \\ p=1 \text{ to } P \end{array} \qquad \text{(III.3)}$$

$$U_{jtvp} \leqslant a_{jv} \cdot X_{jv} \; ; \qquad \begin{array}{l} t=1 \text{ to } T \\ p=1 \text{ to } P \\ v=-V \text{ to } t \\ j=1 \text{ to } J \end{array} \qquad \text{(III.4)}$$

$$\sum_{p=1}^{P} U_{jtvp} \cdot \Theta_p \leqslant b_j \cdot X_{jv} \; ; \qquad \begin{array}{l} t=1 \text{ to } T \\ v=-V \text{ to } t \\ j=\text{hydro} \end{array} \qquad \text{(III.5)}$$

$$\sum_{v=-V}^{t} X_{jv} \leqslant R \cdot Q_{tp} \; ; \qquad \begin{array}{l} t=1 \text{ to } T \\ p=1 \\ j=\text{hydro} \end{array} \qquad \text{(III.6)}$$

$$\sum_{v=1}^{T} X_{jv} \leqslant X_{jmax.} \; ; \qquad j=\text{hydro} \qquad \text{(III.7)}$$

$$\sum_{v=1}^{T} X_{jv} \leqslant X_{jmax} \; ; \qquad j=\text{thermal} \qquad \text{(III.8)}$$

$$X_{jv} \text{ min} \leqslant X_{jv} \leqslant X_{jv} \text{ max.;} \qquad j = \text{relevant plant types} \qquad \text{(III.9)}$$

and

$$\text{All} \quad X, U \geqslant 0 \qquad \qquad \text{(III.10)}$$

III.4- Cost Coefficient of the Model

A useful feature of the Anderson model is that it allows time-dependent changes in the values of cost coefficients due to expected technical improvements and/or economies of scale in the future periods. Thus, the cost coefficients C_{jv} and F_{jvt} are altered as follows:

$$C_{jv} = C_j (1+r)^{-v} \cdot (1+g_j)^{-v}$$

$$F_{jtv} = F_j (1+r)^{-t} \cdot (1+h_j)^{-v}$$

Where

r = the interest rate (discount rate).

g_j = the annual rate of decline of capital cost of new vintages of plant j due to economies of scale and technical progress.

C_j = the capital cost of plant j in the first year of the planning period (MTL/MW).

h_j = the rate of decline of the generation costs of new vintages of plant j due to improvements in thermal efficiency.

F_j = the generation costs of plant j in the first year of the planning period (MTL/MW-YR).

If it becomes necessary to increase the costs by the time instead of to decrease them, g and h may take negative (-) values.

III.5- Using Z - Transformation(Substitutes) In the Model

The time shape of the load duration curve indicates that the power output of plant in period p is always more than the power output of plant

in period $p+1$, where $1 \leq p \leq P$ and P is the number of intervals of load duration curve (see Anderson (1972)).

In other words; $U_{jtvp} \geq U_{jtvp+1}$, for all j, t, v, p (III.11)

In that case, it is possible to reduce the number of capacity contraints by the rate of $1/P$ by introducing a new positive Z_{jtvp} as a new operating decision variable such that;

$$Z_{jtvp} = U_{jtvp} - U_{jtvp+1} \geq 0 \; ; \qquad p=1 \text{ to } P-1 \qquad \text{(III.12)}$$

with: $\quad Z_{jtvP} = U_{jtvP} \geq 0$ (III.13)

When moving along the load duration curve to the right, as load decreases, the power output of plant j,v, never increases; it follows that the sum of power reductions from $p=1$ to P is less than the available power capacity of plant j,v. Hence:

$$\sum_{p=1}^{P} Z_{jtvp} \leq a_{jvt} \cdot X_{jv} \; ; \qquad \text{for all } j,t,v \qquad \text{(III.14)}$$

This constraint is necessary and sufficient for equation (III.4).

First, from equation (III.13) it can be inferred that U_{jtvP} is non-negative if Z_{jtvP} is nonnegative, and if Z_{jtvp} is nonnegative for all p, and so U_{jtvp} must be nonnegative too (in view of equation (III.12)).

Secondly, according to (III.14), no combination of the values of Z_{jtvp} can exceed $a_{jvt} \cdot X_{jv}$.

From (III.12) and (III.13), the following relationship can be derived

$$U_{jtvp} = \sum_{p'=p}^{P} Z_{jtvp'} \leq a_{jvt} \cdot X_{jv} \qquad \text{(III.15)}$$

Thus, U_{jtvp} can not exceed $a_{jvt} \cdot X_{jv}$ if above 3 equations (III.12), (III.13), and (III.14) are satisfied.

Finally, using the substitution $U_{jtvp} = \sum_{p'=p}^{P} Z_{jtvp}$,

the number of capacity constraints (equation III.4) is reduced by $1/P$.

Therefore the new decision variables Z_{jtvp} are used instead of U_{jvtp}.

CHAPTER IV

BASIC DATA AND REFERENCE SOLUTION

This chapter consists of two main parts, one presenting the basic data for the model formulated in Chapter III, and the other describing the major features of the Reference Solution.

IV.1 Basic Data

The basic data were collected from the planning and statistical offices of TEK (Turkish Electricity Authority), DSI (State Hydrolic Works), TKI (Turkish Coal Authority), MTA (Institute of Mining Investigation), TPAO (Turkish Petroleum Company), Petrol İşleri Genel Müdürlüğü (Petroleum Works Authority), and DYB (State Investment Bank).

The basic data for the reference solution are given in the following:

IV.1.1- The Planning Horizon and Investment Periods

The planning horizon of the model is 20 years, (1982-2002), broken down into 5 two-year investment periods with one last investment period (terminal period) of ten years.

Each investment period is characterized by a benchmark year, which is assumed to represent the average demand, supply and operating characteristics of the years included in the period. The benchmark years of the model solutions are as follows:

Benchmark Years	Length of Investment Period Represented
1983	2 years
1985	2 years
1987	2 years
1989	2 years
1991	2 years
1997	10 years (1992-2002)

IV.1.2- Demand Forecats in the Benchmark Years

The electricity demand forecasts prepared by TEK in 1976 are used as basic demand data in all the model solutions as shown in Table IV-1.

Table IV-1: ELECTRICITY DEMAND IN THE BENCHMARK YEARS

Benchmark Years	Demands	
	Power (MW)	Energy (GWh)
1983	7250	39600
1985	8850	48350
1987	10810	59040
1989	13100	71400
1991	15800	86300
1997	27000	146000

Source: TEK forecasts, Ref. [21] and Ref. [25].

IV.1.3- The Load Duration Curve

The load duration curve is divided into 3 load intervals as the peak load, off-peak, and the base load demand.

The situation is summarized in Table IV-2.

Table IV-2: DEMAND INTERVALS OF LOAD DURATION CURVE

Peak Load Interval•	% of Peak Demand	Duration of Demand (Hrs./Yr.)	Demand in Benchmark Years (MW)					
			1983	1985	1987	1989	1991	1997
Peak	95	384	6888	8408	10270	12445	15010	25650
Off-Peak	80	1560	5800	7080	8648	10480	12640	21650
Base	60	8760	4350	5310	6486	7860	9480	16200

It should be noted due to the linearization of the load curve; peak load demand was reduced from %100 to 95% of the actual demand. Since the reserve capacity was determined to be approximately 1/3 the total installed capacity for the Turkish interconnected system a 5% excess capacity was added to the reserve capacity to compensate for the reduction due to linearization of the load curve; As a result the total installed capacity is taken to be 1.4 which leads to a 40% security proportion.

IV.1.4- Power Plant Groups

The existing and future power plants are aggregated into four broad groups as hydrolic, lignite, nuclear, and fuel-oil power plants.

IV.1.5- Prices of Primary Factors

An exchange rate of US$ 1.00=TL 16 (in constant 1976 world and domestic prices) is used for conversion of the foreign exchange costs into domestic-

currency. Discount rate is taken as 11.5% which is given by DYB (State Investments Bank). All costs used in this study are discounted to the base year 1982 with a discount rate of 11.5%.

In some of the model runs, the relative prices of the foreign exchange and domestic capital are revised so as to explore the implications of possible devaluations and interest rate changes for investment choices in the electricity sector.

IV.1.6- Existing Electricity Generating System by 1982

In the base year 1982, 8216 MW power capacity is expected to be in operation. The power and electrical energy projections for 1982 are given in Table IV-3.

Table IV-3: ELECTRICITY SYSTEM BY 1982

Plant Type	Power (MW)	Energy (GWh)
Hydro	3400	11150
Lignite	3700	22800
Nuclear	0	-
Fuel-Oil	1116	7450
TOTAL	8216	41400

Note that, the estimated value of hydrolic power plants (3600 MW) is scaled down to 3400 MW, because of the hydro-thermal balance constraints in the system.

IV.1.7- Availability and Load Factors of the Power Plants

Availability factors are assumed 1.0 for all type power plants, but they have different load factors as indicated in Table IV-4.

Table IV-4 :AVAILABILITY AND LOAD FACTORS OF POWER PLANTS

Plant Type	Load Factor	Availability Factor
Hydro	0.42	1.0
Lignite	0.68	1.0
Nuclear	0.75	1.0
Fuel-Oil	0.75	1.0

IV.1.8- Capital and Operating Costs of the Power Plants

The cost data for the four types of power plants are estimated.in constant 1976 prices as shown in Table IV-5. The official price estimates developed in the earlier years have been adjusted to constant 1976 prices by the author using the new wholesale price index of the Ministry of Commerce. The cost estimates for each plant type are average figures taking into account the varying cots of different schemes included in each type. The 1982 relative weights are used in deriving average cost estimates.

It is important to note at this juncture that the estimated operating cost of fuel-oil plants (namely, 2.02 MTL/MW) is based on 1976 crude oil prices which averaged around $12/bbl in c.i.f. terms. In the estimation of the price of fuel-oil the stamp duty and customs taxes of imported oil are not included so as not to distort the comparative social costs of electricity generation in alternative types of plants.

Table IV-5: CAPITAL AND OPERATING COSTS OF THE POWER PLANTS

Plant Types	Capital Cost (MTL/MW)	Operating Cost (MTL/MW-YR)
Hydro	10.6	0.16
Lignite	11.0	1.11
Nuclear	15.2	0.87
Fuel-Oil	8.0	2.02

IV.1.9- Hydro-Thermal Balance

The total power capacity of the system should consist of 50% hydrolic capacity and 50% thermal capacity. It has been assumed that the hydrolic and lignite plants will be in operation 4500 hours/year and 6000 hours/year, respectively. The nuclear and fuel-oil power plants are expected to be in operation 6500 hours/year.

IV.1.10- Peak Load Security Proportion

Although, normally, the reserve peak capacity is about 1/3 of peak demand, it is assumed to extend to 40% due to linearization of load duration curve.

The summary of the basic data input for the reference solution is given in Table IV-6.

Table IV-6: LIST OF DATA FOR THE REFERENCE SOLUTION

DISCOUNT RATE = 0.115
NUMBER OF PLANT TYPES = 4
NUMBER OF PERIODS = 6
LENGTH OF EACH PERIOD(YEAR) = 2 2 2 2 10
NU. OF LOAD INTERVALS ON LOAD DURATION CURVE = 3
PROPORTIONS OF THE LOAD INTERVAL CURVE = 0.04 0.14 0.82
PEAK LOAD SECURITY PROPORTION (RESERVE) = 0.4
HYDRO/THERMAL BALANCE = 0.50

PLANT TYPES	CAPITAL COST COEFFICIENTS (ML/MW)	OPERATING COST COEFFICIENTS (ML/MW-YR.)	BASE YEAR CAPACITY MW	AVAILABILITY FACTOR	LOAD FACTOR	ADDITIONAL POTENTIAL CAPACITY AFTER 1982 (MW)
HYDRO	10.60	0.160	3400.0	1.0	0.42	15040.0
LIGNITE	11.00	1.110	3700.0	1.0	0.68	9000.0
NUCLEAR	15.20	0.870	0.0	1.0	0.75	99999.0
F.-OIL	8.00	2.020	1116.0	1.0	0.75	99999.0

POWER DEMAND IN BENCHMARK YEARS FOR LOAD INTERVALS (MW)

LOAD INTERVALS	1083	1985	1987	1989	1991	1997
PEAK	6888	8408	10270	12445	15010	25650
OFF-PEAK	5800	7080	8648	10480	12640	21600
BASE	4350	5310	6486	7860	9480	16200

IV.2- Reference Solution

The model solution obtained using the basic data input presented in the preceding section of this chapter represents the base case against which the results of alternative solutions may be contrasted and evaluated. It is therefore called the Reference Solution to the model numerically implemented in the present study.

The optimal installed capacities and load dispatching schedules obtained in the Reference Solution are given in the Tables IV-7.a and 7.b for the benchmark years of the planning horizon. The overall results indicate the central characteristic of the optimal investment policy, namely, a strong reliance on the development and effective use of hydro and lignite plants in the 1982-1992 period, followed by a carefully balanced use of nuclear and fuel-oil plants in the subsequent periods. It should be emphasized that this overall conclusion rests on the major implicit assumption that the hydro and lignite power projects may be prepared, constructed and put into an effective operation in the decade of 1982-1992 at such a speed that Turkey's additional potential hydro and lignite capacities are fully developed in a consistent fashion with the hydro-thermal balance imposed on the system. Whether or not such an investment time-phasing would be technically feasible (on engineering grounds) is an important question which should be investigated in detail by TEK planning authorities.

A noteworthy feature emerging from the Reference Solution is that the fuel-oil plant capacities are also augmented in a substantial way in the first decade (1982-1992) of the planning horizon, although they are not in service as illustrated by the optimal operating schedules of the initial four benchmark years. Put differently, the relatively high operating cost of fuel-oil plants does not prohibit the steady expansion of such plants as reserve

capacity in the national power system because of the relatively low investment costs associated with these plants. The latter is also a significant conclusion of the present analysis, especially in light of the current public opinion against the further development of fuel-oil based schemes in the future. Thus, objective and more detailed project and reliability studies are needed to examine the ways in which reserve capacity requirements will be met in the 1980's taking fully into account the long time lags that characterize the development of hydro and lignite resources.

The dual variables associated with resource availability, hydro-thermal balance and demand constraints also provide a useful insight into the relative gains to be realized from accelerating or decelerating the development of hydro and lignite resources, or from alternative demand management policies. In particular, the dual variables associated with demand constraints, if adjusted to unit marginal cost per kWh, would be highly useful in the analysis of tariff and pricing policies in various demand intervals (peak, off-peak, and base load) in the future benchmark years. The author suggests the latter as a promising area for further research in electricity economics.

Finally, it should be noted that the policy conclusions that emerge from the Reference Solution need to be re-examined in the light of the results of alternative solutions reflecting certain possible changes in the basic assumptions. In particular, such a re-examination becomes indispensable in an economic environment, such as Turkey's which faces critical uncertainties about the major relative prices that will (or ought to) prevail in the future. Realizing that the Turkish economy has yet to adjust more fully to the new conditions created by the world oil crisis (in the sense of adjusting the price of foreign exchange, the cost of domestic

capital -i.e., discount rate-, and the relative prices fuels), an effort is made in Chapter V to carry out an elaborate sensitivity analysis to determine how robust the Reference Solution is with respect to changes in some of the basic data input.

Table IV-7.a: CUMULATIVE TOTAL INSTALLED CAPACITY ON POWER SYSTEM (MW): Reference Solution

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	4718	5759	7034	8524	8524	12699
NUCLEAR	J	–	–	–	–	–	4415
F.-OIL	1116	1481	1808	2208	2675	4984	5969
Total	9643	9643	11771	14377	17422	21013	35908

Total Discounted Cost : 165 728.45 MTL.

Table IV-7.b: OPTIMUM OPERATING SCHEDULES (MW): Reference Solution

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	–	1328	1124	1965	–	4050
	Off-Peak	1450	1419	–	2101	3160	4054
	Base	1185	1457	2112	2157	2583	4495
	H.TOTAL	2635	4204	3236	6223	5743	12599
LIGNITE	Peak	1088	–	498	–	–	–
	Off-Peak	–	351	2162	519	–	–
	Base	3165	3853	4374	5703	5797	8636
	L.TOTAL	4253	4204	7034	6222	5797	8636
NUCLEAR	Peak	–	–	–	–	–	–
.	Off-Peak	–	–	–	–	–	1346
	Base	–	–	–	–	–	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	–	–	–	–	2370	–
	Off-Peak	–	–	–	–	–	–
	Base	–	–	–	–	1100	–
	F.TOTAL	0	0	0	0	3470	0
TOTAL OPERATING CAPACITY (P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

CHAPTER V

ALTERNATIVE SOLUTIONS TO THE MODEL

V.1- Introduction

Alternative solutions will be presented in this chapter by changing certain inputs of the basic data used in the Reference Solution discussed in Chapter IV. As in the Reference Solution, the possible additional potential capacities with respect to the type of the plants which can be constructed within the 1982-2002 planning horizon for all alternative solutions are specified as follows: 15040 MW for hydrolic power plants, 9000 MW for lignite power plants, 99999 MW for nuclear and fuel-oil power plants. The alternative solutions presented in here are the significantly meaningful ones chosen from a large number of computer runs obtained.

These alternative solutions are defined in Table V-1. They are discussed with respect to the changes made in the basic assumptions, and are grouped as follows:

(i) Changes in fuel-oil prices;

(ii) Changes in lignite operating costs;

(iii) Changes in hydro capital costs;

(iv) Changes in the foreign exchange rate;

Table V-1: SPECIFICATION OF ALTERNATIVE SOLUTIONS TO THE MODEL

Alternative Solutions	F.-Oil Operating Cost (MTL/MW-YR)	Lig. Operating Cost (MTL/MW-YR)	Hydro Cap. Cost (MTL/MW)	Foreign Exch. Rate (TL/$)	Interest Rate (%)	Restriction on F.-oil Plants (Period)
a. Reference Solution:	2.02	1.11	10.6	16.0	11.5	None
b. Changes in F.-oil Prices:						
Alt. Solution 1	1.01	R	R	R	R	R
" 2	2.82	R	R	R	R	R
" 3	3.34	R	R	R	R	R
" 4	3.89	R	R	R	R	R
c. Changes in Lig. Operating Cost:						
Alt.Solution 5	R	0.8	R	R	R	R
d. Changes in Hyd. Cap. Cost:						
Alt. Solution 6	R	R	12.5	R	R	R
" 7	R	R	15.0	R	R	R
e. Changes in Fore. Exch. Rate:						
Alt. Solution 8	R	R	R	24.0	R	R
f. Changes in Int. Rate:						
Alt. Solution 9	R	R	R	R	6	R
" 10	R	R	R	R	17	R

1/ R denotes "Same as in the Reference Solution".

Cont.'d

Table V-1: SPECIFICATION OF ALTERNATIVE SOLUTIONS TO THE MODEL (Cont.'d)

Alternative Solutions	F.-Oil Operating Cost (MTL/MW-YR)	Lig. Operating Cost (MTL/MW-YR)	Hydro Cap. Cost (MTL/MW)	Foreign Exch. Rate (TL/$)	Interest Rate (%)	Restriction on F.-Oil Plants (Period)
g. Changes in Restriction on F.-Oil Plants:						
Alt. Solution 11	R	R	R	R	R	6th.
Alt. Solution 12	R	R	R	R	R	All
h. Comb. Changes:						
Alt. Solution 13	2.82	R	15.0	R	R	R
" 14	3.34	R	15.0	R	R	R
" 15	3.89	R	15.0	R	R	R
" 16	R	0.8	15.0	R	R	R
" 17	R	R	15.0	24.0	R	R
" 18	R	R	15.0	R	R	6th
" 19	R	R	15.0	R	R	All

(v) Changes in the interest rate;

(vi) Changes in the restrictions on the fuel-oil plants; and

(vii) Combined changes in some of the basic assumptions.

As discussed in Chapter IV the year 1976 is considered as the base period for all cost and price calculations incorporated into the basic data input to the model. Stated differently, all cost and price estimates specified in nominal terms for the future are deflated to the base year 1976 to provide a consistent relative.Price base for the analysis.

The main objective in the discussion of the alternative solutions is to examine the evolving pattern of different types of plants over the planning horizon and the corresponding changes in the operating schedules under varying assumptions and ground rules imposed on the model.

V.2- Effects of Changes in Some of the Basic Assumptions

V.2.1- Changes in Fuel-Oil Prices (Alternative Solutions 1 to 4)

Alternative fuel-oil operating costs (Million TL/MW-Year) are considered in a consistent fashion with alternative assumptions on international crude oil prices as shown in Table V-2.

Table V-2: FUEL-OIL OPERATING COSTS

| | | (1976 prices) |
Solutions	Fuel-Oil Operating Costs (MTL/MW-YR)	Corresponding International Crude Oil Prices ($/bbl.)
Reference Solution	2.02	12
Alternative Solution 1	1.01	4.4
Alternative Solution 2	2.82	18
Alternative Solution 3	3.34	22
Alternative Solution 4	3.89	26

It should be noted that the crude-oil price 4.4 $/bbl., given in the Alternative Solution 1 is the price before the 1973 oil crisis measured in 1976 prices, taken into account the 1973-76 world inflation, estimated by the World Bank.[1] The fuel-oil operating costs are estimated by the auther using all available data on fuel-oil production and distribution costs under different world oil prices.[2]

It is clearly seen that 1973 crisis has altered the relative fuel prices for the electricity production alternatives in Turkey like in all oil importing countries. In the absence oil price changes, it would have been possible to close the gap between the electricity demand and supply by installing fuel-oil plants which are easier to build with short installation periods as compared to the other types as illustrated in Tables V.3.a and b. The picture emerging in this case would be approximately 54% fuel-oil, 36% hydrolic and 10% lignite plants of the total power generation capacity in 1977.

One of the most important outcomes of the Alternative Solutions 1 to 4 together with the Reference Solution is that the exhaustion of the hydro sources is inevitable irrespective of the changes in the fuel-oil prices associated with the 1973 crisis. On the other hand, the rise in fuel-oil prices forces the exhaustion of the lignite sources as observed from the Alternative Solutions 2, 3 and 4 (see Tables V- 4,5 and 6) together the Reference Solution. Another impact of the increase in fuel-oil prices is the introduction of the nuclear power plants in the last period of the planning horizon.

1/ See Commodity Trade and Price Trends, World Bank, August 1976.

2/ The author is grateful to T.P.A.O. and TEK for the fuel-oil price data and fuel-oil plant operating cost estimates at Ambarlı.

In summary, the 1973 world oil crisis and the subsequent increase in fuel-oil prices result in the full utilization of the lignite and hydro sources and the introduction of the nuclear power. The model solutions using the new oil prices also indicate that fuel-oil plants should be installed for reserve capacity purposes. Since Turkey needs about 5000 MW additional fuel-oil power capacity in the 1982-2002 period, it should be a matter of consideration that emphasis on the installation of the fuel-oil plants might compensate for the large possible gap in the electricity demand and supply due to delays in the realization of the planned hydro and lignite projects.

V.2.2- Changes in Lignite Operating Cost (Alternative Solution 5)

In Alternative Solution 5 (see Table V-5 a and b), the lignite operating cost is taken to be 0.8 MTL/MW-YR which is the value being used and proposed by TEK. This price is lower than 1.11 MTL/MW-YR taken in the Reference Solution. At lower lignite cost, installed capacities of any of the plant types are not affected in the terminal year. On the other hand, more emphasis is given on the installation sequence of the lignite plants compared to the fuel-oil plants in the fifth period. As a consequence, the lignite plants are put into operation at an increasing pace and also being used as peak load plants especially in the 5th period.

V.2.3- Changes in Hydro Capital Costs (Alternative Solutions 6 and 7)

The hydro capital costs are increased to 12.5 MTL/MW and 15 MTL/MW in Alternative Solutions 6 and 7 respectively, to see their consequent effects on the optimal investment choices in the expansion of the power sector. In these two solutions, hydro installation is not realized in

substantial amounts, in the 3rd, 4th, and 5th periods, but almost all the hydro resources are utilized in the last period (see Tables V-6,7 a,b)Although the rise in the hydro cost does not prevent the planning objectives from utilizing them all, the emphasis is focused primarly on the rapid expansion of lignite plants. As the hydro capital cost is increased to 15MTL/MW then the total utilization of the hydro sources are delayed by the end of the last period. Lignite sources are exhausted at an increasing pace. It is also seen that nuclear and fuel-oil installation capacity is increased due to the delay in utilization of the hydro capacity. As a consequence, the nuclear and fuel-oil plants are introduced into the system with increasing capacities.

In summary, the increase in the hydro capital costs force electricity production to be dependent on foreign sources and technology. The overall implication of these results is that hydro projects should be carefully planned and executed to economize on the use of available capital, manpower and equipment to be used in the construction process.

V.2.4- Changes in the Foreign Exchange Rate (Alternative Solution 8)

In the Reference Solution and all alternative solutions (except No.17), foreign exchange rate is taken as $ 1 = TL 16. In Alternative Solution 8, it is assumed $ 1 = TL 24.

Compared with the Reference Solution, Alternative Solution 8 gives more emphasis to the rapid expansion of the lignite plant capacities in the 1990's. To ensure maximum savings in the use of foreign exchange, lignite plants are put into operation at an increasing pace from 1990 onwards, and also being used as peak load plants especially in the 3rd and 5th periods (See Table V -8 a and b)

V.2.5- Changes in the Interest Rate (Alternative Solution 9 and 10)

The discount rate being 11.5% in the Reference Solution is reduced to 6% and increased to 17% in the Alternative Solutions 9 and 10, respectively. The results are not significantly different except the increase in the fuel-oil plant installation and a decrease in the hydro and lignite plant installations in the fifth period, when the discount rate is increased (see Tables V-9 and 10 a,b). This is due to the relatively lower unit capital costs of the fuel-oil power plants which play a more prominent role under a more restrictive capital constraint in the power sector.

The utilization of the lignite plants in the sixth period and fuel-oil plants in the fifth period increase as the discount rate increases, so as to ensure a maximum savings of capital by limiting the expansion of hydro capacities in the system. As the discount rate is decreased to 6% hydro plant operation at peak load is increased whereas the lignite plant operation is decreased.

V.2.6- Changes in the Restrictions on Fuel-Oil Plants (Alternative Solutions 11 and 12)

When the computer program is restricted, to stop the installation of the fuel-oil plants in the sixth period, mainly for political reasons to reduce dependence in imported oil, fuel-oil plant installation is shifted to the fifth period whereas some of the hydro plant installation is shifted from the fifth to the sixth period. There is also a change in the operation schedule such that hydro capacity is decreased whereas fuel-oil capacity is increased (see Tables V-11 and 12 a,b).

It is clearly seen that for a total restriction on fuel-oil plant installation, the resulting gap is totally compensated by nuclear power.

Consequently, the operational power of lignite plants is increased in the fifth and nuclear plants in the sixth periods.

The significant result of these alternative solutions is that the nuclear power plants will play a crucial role in the future if fuel-oil projects are eliminated from the investment program for political reasons as observed in the preliminary official studies carried out for the Fourth Five Year Plan (1978-1982) [1].

V.2.7- Combined Changes in Some of the Basic Assumptions (Alternative Solutions 13 to 19)

When hydro capital cost is taken 15 MTL/MW-YR and fuel-oil operating costs are assumed to be 2.82, 3.34 and 3.89 MTL/MW-YR there is no installation of hydro power plants except in the 6th period, so the tendency in construction is towards lignite for the first five periods and fuel-oil power plants for the firsth four periods. The case of nuclear power is not basically altered, except a somewhat earlier nuclear plant installation in the planning horizon as illustrated in Tables V-13,14, and 15 a,b.

Lignite plant operation is seen to be increasing except the sixth period in the operation schedules. In summary, for the hydro capital cost being increased to 15 MTL/MW-YR, the installation of hydro plants is stopped even if the fuel operating costs are increased.

The hydro capital cost being 15 MTL/MW-YR and lignite operating cost being 0.8 MTL/MW-YR in Alternative Solution 16, expansion of lignite plant capacities is completed at the fifth period whereas hydro plant installation

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1/ See, e.g. Ref. [14]

is completed at the sixth period only. Consequently, the emphasis in operating schedules is mainly on lignite plants. The overall result of this solution is that any increase in hydro costs will lead emphasis on lignite plants (see Table V-16 a and b).

The combined effect of foreign exchange rate and hydro costs increase to 15 MTL/MW as depicted in Alternative Solution 17 accelerates the installation of the lignite and fuel-oil power plants. (see Tables V-17 a and b). As compared to Alternative Solution 8, this emphasis is mainly due to the increasing hydro costs. Consequently the total power of lignite plants is increased whereas base load operation of fuel-oil plants is stopped. The fuel-oil plants are then utilized as peak load and reserve plants. This is mainly due to the increase in fuel-operating costs because of the assumed rise in the foreign exchange rate.

The increase in hydro capital cost together with the political restrictions on the expansion of fuel-oil plants in the sixth period as assumed in Alternative Solution 18 leads to an increased installed capacity for nuclear power plants in the same period (see Table V-18 a and b). In turn, Alternative Solution 19 restricts expansion of fuel-oil plants in all periods, and gives rise to a very rapid development of lignite resources in 1980's, and to a heavy reliance on nuclear power in the 1990's, taking into account, hydro-thermal balances imposed on the system (see Table V-19 a and b). In the latter solution, Turkey's potential lignite plant capacity (considering all the known lignite deposits) is reached at 1992, implying an unprecendented growth in lignite mining operations and power plant facilities. The engineering and technological implications of such an investment program need to be examined separately.

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	4204	4204	4204	12825
LIGNITE	3700	3700	3700	3700	3700	3700	3700
NUCLEAR	0	-	-	-	-	-	-
F.-OIL	1116	2499	3867	6473	9518	13109	19383
Total	8216	9643	11771	14377	17422	21013	35908

Fuel-Oil Operating Cost = 1.01 MTL/MW-YR. (Crude oil price: $ 4.4/bbl.)
Total Discounted Cost = 143 478.48 MTL.

TABLE V-1.b: OPTIMUM OPERATING SCHEDULES (MW):
Alternative Solution 1

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDDRO	Peak	-	1328	-	302	-	4050
	Off-Peak	1450	1419	-	2620	2974	4330
	Base	1186	1457	1766	1282	1230	4445
	H.TOTAL	2636	4204	1766	4204	4204	12825
LIGNITE	Peak	1088	-	1622	-	-	-
	Off-Peak	-	351	1411	-	-	-
	Base	1290	953	-	-	-	-
	L.TOTAL	2378	1304	3033	0	0	0
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	N.TOTAL	0	0	0	0	0	0
F.-OIL	Peak	-	-	-	1663	2370	-
	Off-Peak	-	-	751	-	186	1070
	Base	1874	2900	4720	6578	8250	11755
	F.TOTAL	1874	2900	5471	8241	10806	12825
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Table V-2.a: ~~AL INSTALLED CAPACITY ON POWER SYSTEM (MW):
Alternative Solution 2

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	4718	5759	7034	8524	10281	12699
NUCLEAR	0	–	–	–	–	–	4415
F.-OIL	1116	1481	1808	2208	2675	3227	5969
Total	8216	9643	11771	14377	17422	21013	35908

Fuel-Oil Operating Cost = 2.82 MTL/MW-YR. (Crude oil price : $ 18/bbl.)
Total Discounted Cost = 165 861.12 MTL

TABLE V-2.b: OPTIMUM OPERATING SCHEDULES (MW):
Alternative Solution 2

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	–	1328	1124	1965	–	4050
	Off-Peak	1450	1419	–	2101	3160	4054
	Base	1185	1457	2112	2157	2583	4495
	H.TOTAL	2635	4204	3236	6223	5743	12599
LIGNITE	Peak	1088	–	498	–	2370	–
	Off-Peak	–	351	2162	519	–	–
	Base	3165	3853	4374	5703	6897	8636
	L.TOTAL	4253	4204	7034	6222	9267	8636
NUCLEAR	Peak	–	–	–	–	–	–
	Off-Peak	–	–	–	–	–	1346
	Base	–	–	–	–	–	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	–	–	–	–	–	–
	Off-Peak	–	–	–	–	–	–
	Base	–	–	–	–	–	–
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	4718	5759	7034	8524	10281	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1481	1808	2208	2675	3227	5969
Total	8216	9643	11771	14377	17422	21013	35908

Fuel Oil Operating Coast = 3.34 MTL/MW-YR. (Crude oil price : $ 22/bbl.)

Total Discounted Cost = 165 861.12 MTL

TABLE V-3.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 3

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	1124	1965	-	4050
	Off-Peak	1450	1419	-	2101	3160	4054
	Base	1185	1457	2112	2157	2583	4495
	H.TOTAL	2635	4204	3236	6223	5743	12599
LIGNITE	Peak	1088	-	498	-	2370	-
	Off-Peak	-	351	2162	519	-	-
	Base	3165	3853	4374	5703	6897	8636
	L.TOTAL	4253	4204	7034	6222	9267	8636
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	1346
	Base	-	-	-	-	-	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak		-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve CAPACITY)		2755	3363	4107	4977	6003	10258

Table V-4.a: CUMUL... AL ... LED CAPA... ON ... (...):
Alternative Solution 4

Plant Types	Base Year 1982	Benchmark Years 1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	4718	5759	7034	8524	10281	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1481	1808	2208	2675	3227	5969
Total	8216	9643	11771	14377	17422	21013	35908

Fuel Oil Operating Cost = 3.89 MTL/MW-YR. (Crude oil price : $ 26/bbl.)

Total Discounted Cost = 165 861.12 MTL

TABLE V-4.b: OPTIMUM OPERATING SCHEDULES (MW):
Alternative Solution 4

Plant Types	Intervals of Load Curve	Benchmark Years 1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	1124	1965	-	4050
	Off-Peak	1450	1419	-	2101	3160	4054
	Base	1186	1457	2112	2157	2583	4495
	H.TOTAL	2636	4204	3236	6223	5743	12599
LIGNITE	Peak	1087	-	498	-	2370	-
	Off-Peak	-	351	2162	519	-	-
	Base	3165	3853	4374	5703	6897	8636
	L.TOTAL	4252	4204	7034	6222	9267	8636
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	1346
	Base	-	-	-	-	-	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY (P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	4718	5759	7034	8524	10281	12699
NUCLEAR	0	–	–	–	–	–	4415
F.-OIL	1116	1481	1808	2208	2675	3227	5969
Total	8216	9643	11771	14377	17422	21013	35908

Lignite Operating Cost = 0.8 MTL/MW-YR.

Total Discounted Cost = 152 069.44 MTL.

TABLE V-5.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 5

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	842	1328	1256	1522	–	4050
	Off-Peak	1450	–	2162	2620	3160	4054
	Base	1152	1713	1717	2081	2583	4495
	H.TOTAL	3444	3041	5135	6223	5743	12599
LIGNITE	Peak	246	–	366	443	2370	–
	Off-Peak	–	1770	–	–	–	–
	Base	3198	3597	4769	5779	6897	8636
	L.TOTAL	3444	5367	5135	6222	9267	8636
NUCLEAR	Peak	–	–	–	–	–	–
	Off-P lak	–	–	–	–	–	1346
	Base	–	–	–	–	–	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	–	–	–	–	–	–
	Off-Peak	–	–	–	–	–	–
	Base	–	–	–	–	–	–
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY (P.Load)		6888	8404	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	5135	5135	12825
LIGNITE	3700	4718	5759	7034	9196	9909	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1481	1808	2208	3091	5969	5969
Total	8216	9643	11771	14377	17422	21013	35908

Hydro Capital Cost = 12.5 MTL/MW.

Total Discounted Cost = 171 442.39 MTL.

TABLE V-6.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 6

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	1124	1965	-	4050
	Off-Peak	1450	1419	-	1332	3160	4054
	Base	1185	1457	2112	1838	1588	4496
	H.TOTAL	2635	4204	3236	5135	4748	12600
LIGNITE	Peak	1088	-	498	-	-	-
	Off-Peak	-	351	2162	1288	-	-
	Base	3165	3853	4374	6022	6738	8635
	L.TOTAL	4253	4204	7034	7310	6738	8635
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	1346
	Base	-	-	-	-	-	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	-	-	-	-	2370	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	1154	-
	F.TOTAL	0	0	0	0	3524	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3400	3400	3400	3400	3400	9696
LIGNITE	3700	4745	6255	8105	10267	10267	12699
NUCLEAR	0	-	-	-	-	-	6167
F.-OIL	1116	1498	2116	2872	3755	7346	7346
Total	8216	9643	11771	14377	17422	21013	35908

Hydro Capital Cost = 15.0 MTL/MW-YR.

Total Discounted Cost = 176 376.03 MTL

TABLE V-7.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 7

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	767	1965	-	4050
	Off-Peak	1450	850	-	104	2405	2117
	Base	1167	1222	1397	1331	995	3530
	H.TOTAL	2617	3400	2164	3400	3400	9697
LIGNITE	Pek	1088	-	855	-	-	-
	Off-Peak	-	920	2162	2516	-	1403
	Base	3183	4088	5089	6229	6982	8383
	L.TOTA1	4271	5008	8106	9045	6982	9786
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	1880
	Base	-	-	-	-	-	4287
	N.TOTAL	0	0	0	0	0	6167
F.-OIL	Peak	-	-	-	-	2370	-
	Off-Peak	-	-	-	-	755	-
	Base	-	-	-	-	1503	-
	F.TOTAL	0	0	0	0	4628	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	4718	5759	7034	8524	10281	12699
NUCLEAR	0	—	—	—	—	—	4415
F.-OIL	1116	1481	1808	2208	2675	3227	5969
Total	8216	9643	11771	14377	17422	21013	35908

Foreign Exchange Rate : $ 1 = 24 TL.

Total Discounted Cost = 200 786.20 MTL.

TABLE V- 8.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 8

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	1088	920	—	1522	—	3279
	Off-Peak	1162	—	2162	2620	1922	—
	Base	1194	1730	1768	2080	2805	5256
	H.TOTAL	3444	2650	3930	6222	4727	8535
LIGNITE	Peak	—	408	1622	443	2370	—
	Off-Peak	288	1770	—	—	1238	4957
	Base	3156	3580	4718	5780	6675	7743
	L.TOTAL	3444	5758	6340	6223	10283	12700
NUCLEAR	Peak	—	—	—	—	—	771
	Off-Peak	—	—	—	—	—	443
	Base	—	—	—	—	—	3201
	N. TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	—	—	—	—	—	—
	Off-Peak	—	—	—	—	—	—
	Base	—	—	—	—	—	—
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY (P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity		2755	3363	4107	4977	6003	10258

Alternative Solution 9

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	4718	5759	7034	8524	10281	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1481	1808	2208	2675	3227	5969
Total	8216	9643	11771	14377	17422	21013	35908

Discount Rate : 6%

Total Discounted Cost = 265 423.66 MTL.

TABLE V-9.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 9

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	-	1622	1965	-	-
	Off-Peak	883	1077	-	2101	3160	5400
	Base	1288	1572	2092	2157	2583	4415
	H.TOTAL	2171	2649	3714	6223	5743	9815
LIGNITE	Peak	1088	1328	-	-	2370	2900
	Off-Peak	567	693	2162	519	-	-
	Base	3062	3738	4394	5703	6897	8520
	L.TOTAL	4717	5759	6556	6222	9267	11420
NUCLEAR	Peak	-	-	-	-	-	1150
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	3265
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Table V-10.a: CUMULATIVE TOTAL INSTALLED CAPACITY ON POWER SYSTEM(MW):
Alternative Solution 10

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	65 20	12825
LIGNITE	3700	4718	5759	7034	8524	8524	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1481	1808	2208	2675	5969	5969
Total	8216	9643	11771	14377	17422	21013	35908

Discounted Rate: 17%

Total Discounted Cost = 113 001.35 MTL.

TABLE V-10.b: OPTIMUM OPERATING SCHEDULES (MW):
Alternative Solution 10

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	1088	-	-	1965	-	4050
	Off-Peak	1162	1770	2162	2101	-	444
	Base	1194	1447	1768	2157	2738	5144
	H.TOTAL	3444	3217	3930	6223	2738	9638
LIGNITE	Peak	-	1328	1622	-	1478	-
	Off-Peak	288	-	-	519	-	4956
	Base	3156	3863	4718	5703	5738	7744
	L.TOTAL	3444	5191	6340	6222	7216	12700
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	3312
	N.TOTAL	0	0	0	0	0	3312
F.-OIL	Peak	-	-	-	-	892	-
	Off-Peak	-	-	-	-	3160	-
	Base	-	-	-	-	1004	-
	F.TOTAL	0	0	0	0	5056	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Table V-11.a: CUMULATIVE TOTAL INSTALLED CAPACITY ON POWER SYSTEM (MW):
Alternative Solution 11

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	6520	12825
LIGNITE	3700	4718	5759	7034	8524	8524	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1481	1808	2208	2675	5969	5969
Total	8216	9643	11771	14377	17422	21013	35908

Fuel Oil 6th Period = 0 (Restriction 7)

Total Discounted Cost = 165 845.15 MTL.

TABLE V-11.b: OPTIMUM OPERATING SCHEDULES (MW):
Alternative Solution 11

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	1124	1965	-	4050
	Off-Peak	1450	1419	-	2100	3160	4054
	Base	1186	1457	2112	2157	2170	4495
	H.TOTAL	2636	4204	3236	6222	5330	12599
LIGNITE	Peak	1088	-	498	-	-	-
	Off-Peak	-	351	2162	520	-	-
	Base	3164	3853	4375	5703	5796	8636
	L.TOTAL	4252	4204	7034	6223	5796	8636
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	1346
	Base	-	-	-	-	-	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	-	-	-	-	2370	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	1514	-
	F.TOTAL	0	0	0	0	3884	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7505	12825
LIGNITE	3700	5083	6451	8126	10083	12397	12699
NUCLEAR	0	-	-	-	-	-	9268
F.-OIL	1116	1116	1116	1116	1116	1116	1116
Total	8216	9643	11771	14377	17422	21013	35908

Fuel Oil in the All Periods = 0 (Restriction 7)

Total Discounted Cost = 173 407.35 MTL.

TABLE V-1.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 12

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	-	1965	-	4050
	Off-Peak	1450	1419	-	2100	3160	2574
	Base	1186	1457	2156	2157	2583	4761
	H.TOTAL	2636	4204	2156	6222	5743	11385
LIGNITE	Peak	1088	-	1622	-	2370	-
	Off-Peak	-	351	2162	520	-	-
	Base	3164	3853	4330	5703	6897	4996
	L.TOTAL	4252	4204	8114	6223	9267	4996
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	2826
	Base	-	-	-	-	-	6443
	N.TOTAL	0	0	0	0	0	9269
F.-OIL	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Table V-13.a

Table V-13.a: CUMULATIVE TOTAL INSTALLED CAPACITY ON POWER SYSTEM (MW): Alternative Solution 13

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3400	3400	3400	3400	3400	12825
LIGNITE	3700	4745	6255	8105	10267	12699	12699
NUCLEAR	0	–	–	–	–	–	4415
F.-OIL	1116	1498	2116	2872	3755	4914	5969
Total	8216	9643	11771	14377	17422	21013	35908

Hydro Capital Cost = 15.0 MTL/MW

Fuel-Oil Operating Cost = 2.82 MTL/MW-YR   (Crude oil price: $ 18/bbl.)

Total Discounted Cost = 176 598.96

TABLE V-13.b: OPTIMUM OPERATING SCHEDULES (MW): Alternative Solution 13

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	–	1328	767	1965	–	4050
	Off-Peak	1450	850	–	104	2405	4054
	Base	1167	1222	1397	1331	995	4495
	H.TOTAL	2617	3400	2164	3400	3400	12599
LIGNITE	Peak	1088	–	855	–	2370	–
	Off-Peak	–	920	2162	2516	313	–
	Base	3183	4088	5089	6529	8485	8636
	L.TOTAL	4271	5008	8106	9045	11168	8636
NUCLEAR	Peak	–	–	–	–	–	–
	Off-Peak	–	–	–	–	–	1346
	Base	–	–	–	–	–	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	–	–	–	–	–	–
	Off-Peak	–	–	–	422	–	–
	Base	–	–	–	–	–	–
	F.TOTAL	0	0	0	422	0	0
TOTAL OPERATING CAPACITY (P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Table V-14.a: ⌐ ⌐ ⌐ ⌐L INSTALLED CAPACITY ON POWER SYSTEM(MW):
  Alternative Solution 14

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3400	3400	3400	3400	3400	12825
LIGNITE	3700	4745	6255	8105	10267	12699	12699
NUCLEAR	0	-	-	-	-	106	4415
F.-OIL	1116	1498	2116	2872	3755	4808	5969
Total	8216	9643	11771	14377	17422	21013	35908

Hydro Capital Cost = 15.0 MTL/MW

Fuel Oil Operating Cost = 3.34 MTL/MW-YR (Crude-oil price: $22/bbl.)

Total Discounted Cost = 176 619.99 MTL.

TABLE V-14.b: OPTIMUM OPERATING SCHEDULES (MW):
  Alternative Solution 14

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	767	1965	-	4050
	Off-Peak	1450	850	-	104	2405	4054
	Base	1167	1222	1397	1331	995	4495
	H.TOTAL	2617	3400	2164	3400	3400	12599
LIGNITE	Peak	1088	-	855	-	2370	-
	Off-Peak	-	920	2162	2516	723	-
	Base	3183	4088	5089	6529	8411	8636
	L.TOTAL	4271	5008	8106	9045	11504	8636
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	32	1346
	Base	-	-	-	-	74	3069
	N.TOTAL	0	0	0	0	106	4415
F.-OIL	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY (P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Table V-15.a: CUMULATIVE TOTAL INSTALLED CAPACITY ON POWER SYSTEM (MW):

Alternative Solution 15

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3400	3400	3400	3400	3400	12825
LIGNITE	3700	4745	6255	8105	10267	12699	12699
NUCLEAR	0	--	-	-	-	106	4415
F.-OIL	1116	1498	2116	2872	3755	4808	5969
Total	8216	9643	11771	14377	17422	21013	35908

Hydro Capital Cost = 15.0 MTL/MW

Fuel Oil Operating Cost = 3.89 MTL/MW-YR. (Crude oil price: $26/bbl.)

Total Discounted Cost = 176 619.99 MTL.

TABLE V-15.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 15

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	767	1965	-	4060
	Off-Peak	1450	850	-	104	2405	4054
	Base	1167	1222	1397	1331	995	4495
	H.TOTAL	2617	3400	2164	3400	3400	12599
LIGNITE	Peak	1088	-	855	-	2370	-
	Off-Peak	-	920	2162	2516	723	-
	Base	3183	4088	5089	6529	8411	8636
	L.TOTAL	4271	5008	8106	9045	11504	8636
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	32	1346
	Base	-	-	-	-	74	3069
	N.TOTAL	0	0	0	0	106	4415
F.-OIL	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Table V-16 a: INSTALLED CAPACITY ON POWER SYSTEM (MW):

Table V-16 a: INSTALLED CAPACITY ON POWER SYSTEM (MW):

Alternative Solution 16

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3400	3400	3400	3400	3400	12825
LIGNITE	3700	4745	6255	8105	10267	12699	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1498	2116	2872	3755	4914	5969
Total	8216	9643	11771	14377	17422	21013	35908

Hydro Capital Cost = 15.0 MTL/MW

Lignite Operating Cost = 0.8 MTL/MW-YR.

Total Discounted Cost = 161 610.17 MTL.

TABLE V-16.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 16

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	816	1328	208	-	-	4050
	Off-Peak	1450	-	2162	2405	2405	4054
	Base	1134	1375	1030	995	995	4495
	H.TOTAL	3400	2703	3400	3400	3400	12599
LIGNITE	Peak	272	-	1414	1965	380	-
	Off-Peak	-	1770	-	215	755	-
	Base	3216	3935	5456	6865	8485	8636
	L.TOTAL	3488	5705	6870	9045	9620	8636
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	1346
	Base	-	-	-	-	-	3069
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	-	-	-	1990	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	1990	0	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3400	3400	3400	3400	3400	12825
LIGNITE	3700	4745	6255	8105	10267	12699	12699
NUCLEAR	0	-	-	-	-	-	4415
F.-OIL	1116	1498	2116	2872	3755	4914	5969
Total	8216	9643	11771	14377	17422	21013	35908

Hydro Capital Cost = 15.0 MTL/MW

Foreign Exchange Rate : $ 1 = 24 TL.

Total Discounted Cost = 214 564.05 MTL.

TABLE V-17.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 17

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	1088	755	-	-	-	3280
	Off-Peak	1131	-	2162	2405	-	-
	Base	1181	1398	1039	995	1428	5255
	H.TOTAL	3400	2153	3201	3400	1428	8535
LIGNITE	Peak	-	573	1622	1965	380	-
	Off-Peak	319	1770	-	215	3160	4956
	Base	3169	3912	5447	6865	8052	7744
	L.TOTAL	3488	6255	7069	9045	11592	12700
NUCLEAR	Peak	-	-	-	-	-	770
	Off-Peak	-	-	-	-	-	444
	Base	-	-	-	-	-	3201
	N.TOTAL	0	0	0	0	0	4415
F.-OIL	Peak	-	-	-	-	1990	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL t	0	0	0	0	1990	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Alternative Solution 18

Plant Types	Base Year 1982	Benchmark Years					
		1083	1985	1987	1989	1991	1997
HYDRO	3400	3400	3400	3400	3400	3400	9696
LIGNITE	3700	4745	6255	8105	10267	10267	12699
NUCLEAR	0	-	-	-	-	-	6167
F.-OIL	1116	1498	2116	2872	3755	7346	7346
Total	8216	9643	11771	14377	17422	21013	35908

Fuel-Oil in the 6th Period = 0 (Restriction 7)

Hydro   Capital Cost = 15.0 MTL/MW.

Total Discounted Cost = 176 376.03 MTL.

TABLE V-18.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 18

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	767	1965	-	4050
	Off-Peak	1450	850	-	104	2405	2117
	Base	1167	1222	1397	1331	995	3529
	H.TOTAL	2617	3400	2164	3400	3400	9696
LIGNITE	Peak	1088	-	855	-	-	-
	Off-Peak	-	920	2162	2516	-	1403
	Base	3183	4088	5089	6529	6981	8384
	L.TOTAL	4271	5008	8106	9045	6981	9787
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	1880
	Base	-	-	-	-	-	4287
	N.TOTAL	0	0	0	0	0	6167
F.-OIL	Peak	-	-	-	-	2370	-
	Off-Peak	-	-	-	-	755	-
	Base	-	-	-	-	1504	-
	F.TOTAL	0	0	0	0	4629	0
TOTAL OPERATING CAPACITY (P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

Alternative Solution 19

Plant Types	Base Year 1982	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	3400	3444	4204	5135	6223	7198	12825
LIGNITE	3700	5083	6451	8126	10083	12699	12699
NUCLEAR	0	-	-	-	-	-	9268
F.-OIL	1116	1116	1116	1116	1116	1116	1116
Total	8216	9643	11771	14377	17422	21013	35908

Fuel-Oil in the all Periods = 0 (Restriction 7)

Hydro Capital Cost = 15.0 MTL/MW

Total Discounted Cost = 187 166.56

TABLE V-19.b: OPTIMUM OPERATING SCHEDULES (MW):

Alternative Solution 19

Plant Types	Intervals of Load Curve	Benchmark Years					
		1983	1985	1987	1989	1991	1997
HYDRO	Peak	-	1328	-	1965	-	4050
	Off-Peak	1450	1419	-	2100	3160	2574
	Base	1186	1457	2156	2157	2424	4761
	H.TOTAL	2636	4204	2156	6222	5614	11385
LIGNITE	Peak	1088	-	1622	-	2370	-
	Off-Peak	-	351	2162	520	-	-
	Base	3164	3853	4330	5703	7026	4996
	L.TOTAL	4252	4204	8114	6223	9396	4996
NUCLEAR	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	2826
	Base	-	-	-	-	-	6443
	N.TOTAL	0	0	0	0	0	9269
F.-OIL	Peak	-	-	-	-	-	-
	Off-Peak	-	-	-	-	-	-
	Base	-	-	-	-	-	-
	F.TOTAL	0	0	0	0	0	0
TOTAL OPERATING CAPACITY(P.Load)		6888	8408	10270	12445	15010	25650
UNUSED CAPACITY (Reserve Capacity)		2755	3363	4107	4977	6003	10258

CHAPTER VI

CONCLUSIONS

In the aftermath of the 1973 world oil crisis and the subsequent increase in fuel-oil prices, Turkey's optimal policy for the development of its electricity sector becomes one of (i) accelerated utilization of the lignite and hydro sources in the 1982-1992 decade, and (ii) balanced construction and use of fuel-oil and nuclear power plants from 1992 onwards. Another notable feature of the optimal policy , which is quite robust with respect to changes in the assumptions on resource costs, is the continued installation of fuel-oil plants as reserve capacities in the system.

As hydro capital costs increase in real terms, the optimal policy shifts towards a more rapid development of lignite sources causing an earlier exhaustion of Turkey's better lignite deposits. Bringing lignite forward in the investment plans results, however, in escalated outlays of foreign exchange expenditures. A very rapid expansion of lignite capacities also implies substantial increases in lignite mining output.

If fuel-oil projects are eliminated from the investment program for political reasons to reduce dependence on imported oil, nuclear power plants start playing a more crucial role at earlier stages.

In any case, nuclear power plants will play a central role in electricity supply programming in the 1990's with the implication that the country should evolve an active training and design program in this field in the early 1980's.

In the light of current public opinion against the further development of fuel-oil power plant capacities, the author suggests a more detailed treatment of the ways in which the reserve capacity requirements may be met in the 1980's. The latter should take into account the long investment periods, and various environmental and technical uncertainties associated with Turkey's hydro and lignite resources.

To improve the investment planning model used in this study the author suggests (i) a more systematic, treatment of gestation processes in power plant investment, (ii) plant performance reliability aspects together with the probable operating costs of plants serving as reserve capacities; and (iii) discrete and lumpy nature of power projects, which often exhibit economies of scale in construction and production.

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