A PLANNING INVESTMENT MODEL FOR THE ELECTRIC POWER INDUSTRY SUBJECT TO UNDER-DEVELOPMENT CONSTRAINTS

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NOMENCLATURE

x_{tk} - capacity of plant type k to be built in year t

y_{tk} - capacity of plant type k to be utilized during the off period in year t

T - number of years considered in planning period

n - number of plant types available

C_{tk} - discounted construction cost of plant type k, construction of which started in year t

F_{tk} - discounted salvage value of plant type k, construction of which started in year t

λ_k - average technically feasible plant capacity factor during the peak demand period

Θ_k - average technically feasible plant capacity factor during the off-peak demand period

q - number of hours of peak period in a year

f_{tk} - fuel cost per KWH generated by type $\overset{k}{i}$ plant in year t

P - number of hours of off-peak period in a year

$PF_{r,t-1}$ - discounting factor for a given interest rate and year

E_k - existing installed capacity of plant type k before the planning horizon

δ_k - construction period of plant type k

D_t - level of peak demand in year t

d_t - level of off-peak demand in year t

B_ℓ - amount of capital available for planning period

H - maximum hydro potentials available during planning horizon

C_{tki} - discounted costs of one unit size of plant type k_i construction of which started in year t

M_{tki} - discounted costs of maintenance of type ki plant construction of which started in year t

F_{tki} - discounted salvage value of type ki plant construction of which started in year t

z_{tki} - number of size i plant in the category of plant type k to be built in year t

λ_{ki} - average feasible plant capacity of plant type ki during peak demand period

f_{tki} - fuel cost per KWH generated by plant type ki in year t

W_{tki} - capacity of type ki plant to be utilized during off-peak period in year t

E_{ki} - existing installed capacity of plant type k size i before the planning horizon

δ_{ki} - construction period of plant type k size i

U_{ski} - unit size i of plant type k at time t

Θ_{ki} - average technically feasible capacity factor of plant type ki during off-peak period

H_i - maximum hydro potentials available for hydro size i

x_k - capacity of plant type k

CHAPTER I

INTRODUCTION

The economics of developing countries has become one of the major concerns in present day business and economic circles. Broad theoretical questions, dealing with general topics like agricultural versus industrial development or the importance of capital accumulation, dominate the field. There is a need for in-depth study of specific industries within developing countries. Industrial engineers and development economists in those countries should in part provide needed specific studies.

This study will treat optimal investment planning in the electric power industry in Iran. There are several significant reasons for focusing on this specific industry. Sustained and substantial industrial growth and economic expansion call for a supply of power which is reliable and sufficient. The electric industry could fill this need. The electric industry is also a key industry in terms of allocation of capital and competition for foreign exchange. Since a developing country's financial resources are limited, priorities must be established for large capital investments. Often, necessary equipment must be purchased from industrialized nations using foreign currency, not the currency of the country itself.

In recent years, the Iranian economy has expanded rapidly in response to a variety of stimuli. The electric power industry has kept pace with this expansion, but even now more developments are being undertaken which will create even larger demand. For example, in order to combat widespread illiteracy, the government has instituted a long-range literacy program utilizing educational television. This will augment traditional teaching methods. Many areas of Iran, presently inaccessible and in need of trained personnel, can be reached by television. In order to broadcast the program, Iran has purchased a satellite. The recent acquisition of this satellite has given added impetus to the expansion of the electric power system, since electricity must be made available for the satellite's ground operations and electricity must be available for television sets.

Basic industries in developing countries, such as electric power, are conceived as necessary components of economic growth and are operated by the government. Government expenditures in large public investments require an explicit determination of the costs and benefits of such investments. Market prices by temselves do not reflect social valuation of the resources used and of the commodities produced or the services rendered.

In evaluating the nature of economic benefits from a public investment like electric power, it is not sufficient to analyze the benefits from electric power systems in terms of the consumer alone. In addition to the consumption of electric power as a final product, it is also used as an intermediate commodity in the production of other goods and services. This means that power supply investments will affect the costs of energy consumed directly, and will influence indirectly the costs of production of various commodities. In this case, the evaluation and determination of true benefits becomes more complex than when electric power output is consumed only as a final product. In some cases, benefits from public investments in basic industries from the society's point of view are adequate to justify the costs of the investments.

Considering the imperfections of capital markets and restriction of budgets, an investment cannot be justified merely by demonstrating that its discounted benefits are greater than its discounted costs. The feasible technological choices for alternative means of power production creates a problem as to the kind, size, and duration of the investment to be undertaken. The investor must choose from various types of construction separated according to their nature, location, and size. One must decide between a higher immediate capital investment and lower operating and maintenance costs later on, or a lesser capital investment and higher operating and maintenance costs for equal services rendered. The choice between hydro and thermal plants is an example of such a decision.

In examining the nature of economic benefits from a public investment like electric power industry, this study provides a framework for evaluation and raises some doubts about the adequacy of existing investment criteria. The broad outline of alternative criteria based on the multi-variable policy functions is explored, which suggests objective other than maximization of pure efficiency may be relevant in evaluating large public investments.

The problem of optimum resource allocation, as it pertains to the electric power industry, is formulated as one of constrained optimization with respect to an appropriate objective function, and results are generalized by means of mathematical programming. In the linear programming model, the behavior of continuous, non-negative variables subject to a system of linear inequalities are investigated. However, in dealing with investment problems characterized by technological indivisibilities and increasing returns to scale, it becomes necessary to restrict the continuity conditions on some of the variables. The mathematical programming models developed in this thesis seek a wide area of generality and relevance; their implications for other investment planning problems where applicable is evident.

The mathematical programming models developed here require extensive data on costs of construction and operation. Therefore, part of the analysis attempts to establish an empirical basis for data from the available resources of data such as the Ministry of Energy in Iran, United Nations publications on electric power in the Far East and Pacific, ECAFE and UNIDO publications. However, the quantity and availability of existing information has limited the scope of this research to the solution of the linear programming model. In solving the model, the effects of some important factors such as inflation, construction period, interest rates, technical progress and the availability of investment funds on the optimal investment decisions have been investigated.

The solution of the optimum investment model as a rule has dual pricing implications. The Lagrange multipliers of a constrained optimization problem are equivalent to marginal value of the inputs and can be used as a powerful guide to pricing of output. Although the determination of a rate schedule for the output of electric power industry is outside the scope of this thesis, the implications of marginal cost pricing are explored. The pricing implications are found to be quite significant, for the actual impact of electric power systems on the economy will depend on the way their input is priced. Since electricity is largely an intermediate product, any pricing policy will affect costs of production and relative prices throughout the economy.

Research Objectives

The first objective of this research is to explore the nature of costs and benefits of public investment like the Electric Power Industry, and to determine whether the usual investment criteria will in fact reflect the true social valuations. The second objective is to formulate the resource allocation problem, as it pertains to the electric power industry, as a constrained optimization model with respect to an appropriate objective function. The third is to demonstrate the application of the derived model to the problem of optimizing selected investment decisions in the electric power industry in Iran. The effects of important factors, such as construction period, inflation, discounting, technical progress, and the availability of investment funds on the investment planning are examined. Finally, extra economic factors and consequences of investments in the power system than cannot be measured by quantitative techniques are examined.

Review of Related Literature

After reviewing related literature in the investment planning for electric power industry, it was shown that for the investment planning in the electric power industry there are two distinguished approaches:

the marginal approach and the global approach.[1]

Marginal Approach

In the late 1940s, for the first time, the marginal approach was applied to investment problems in electric power supply by Electricite de France.[2] This approach utilizes project-by-project comparisons and starts from an arbitrary but reasonable initial program, and then searches for improvement (reduced costs) by marginal substitution. For example, a comparison between hydro and nuclear alternatives requires the calculation of the present worth of the savings if the nuclear is substituted for the hydro. According to whether the difference is positive or negative, the nuclear substitution is or is not accepted. The value of the calculated present worth is known as the relative profitability of the nuclear investment.

A critical assumption of the marginal approach is that the alternatives being compared are equivalent. In other words, they would produce an equivalent amount of power and energy, and they would be operated in a similar manner for the various levels of demand in the different seasons. A major difficulty with this approach is the large number of marginal substitutions to a basic plan that must be considered over time, when there are more than two types of plants on the system, and when the expansion of the system introduces new types of plants while replacing others.

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[1] For notable examples of application of mathematical programming to the investment planning problem for various other industries see Henderson (32), Manne and Markowitz (47), Kendrick (40), and Manne (48).

[2] See Masse (53).

A useful example of marginal approach is given by Manners (49), when the choice is between locating a conventional thermal plant near the coal mine or near the demand centers in the city. However, when the marginal approach is used to compare alternatives that are not equivalent, the results could be misleading.

Global Approach

The global approach to investment planning is more general than the marginal approach, and its validity is not dependent upon the equivalence of the investments under construction. Since it compares alternative systems which will result from alternative investments, it is able to compare options which differ widely in terms of technology, plant size, timing of construction, and pattern of operation.

Simulation, linear, and nonlinear optimization models are special cases of the global approach. Even in the global approach, however, the models must include all effects deemed important to the decision, or else make provision for their separate consideration.

Simulation

Simulation techniques utilize digital computer programs that simulate a number of alternative expansion plans consisting of plant types, sizes and timing of construction proposed by experienced planners and engineers. Each plan would result in a different power system over time, with different possibilities for system operation. The future operation of the system resulting from each plan is simulated on the computer by a fairly sophisticated load dispatching routing, and the resulting fuel costs are thereby calculated; this is done for each of the various systems resulting from each of the various plans. The expansion plan chosen is the one with the lowest total cost.

The advantages of this technique are its accurate estimate of the costs of a given expansion plan and the fact that it can specify with a fair amount of confidence that a certain plan is better than any of the others considered. A disadvantage is that it considers only those plans that are explicity proposed; it contains no reference to plans not explicity suggested. This is, perhaps, only a minor limitation inasmuch as an experienced engineer could probably come very close to the optimal expansion plan by suggesting a relative small number of plans for examination.

Linear Programming

In contrast to simulation techniques, mathematical programming is inherently more appropriate for analyzing optimization problems. It has the ability of cutting across the enormous combinatorial range of alternatives. Mathematical programming provides a systematic search through the very large number of combinations of plant types, sizes, and locations.

A linear programming formulation of the problem was first used in 1950s by Masse and Gibart (54). In 1962, Masse (53) formulated the problem more generally. In this model, the investment alternatives consist of eight different plant types, e.g., conventional thermal, nuclear, gas turbine, run-of-the-river hydro, etc. Each plant type is assumed to form a homogeneous group with its own construction and operating cost; any size plant in a given group, therefore, has the same average construction cost and average operating cost as any other plant in that group. Investment decisions are made concerning the amounts of the eight different types of capacity to be built in six regions in each of the three five-year periods in the model.

The objective function, to be minimized, is the sum of construction costs of new investments and the resulting costs of operating the existing and the new capacity. The constraints require supply to equal or exceed demand in each region; in addition, they require output levels to be within capacity limits for all types of equipment.

Nonlinear Programming

Nonlinear programming models have been developed to eliminate the hypothesis of homogeneous plants used in linear programming models and to take the economies of scale into consideration. They have also been used to reduce the number of constraints employed in linear models.

A dynamic programming formulation has been employed by Dale (15) in which investment variables are discrete rather than continuous. Choices are made from among several plant sizes for both hydro and thermal capacity. Fuel costs are estimated in a subroutine whenever a given investment strategy is to be examined.

Peterson (60) has also formulated the problem into a dynamic programming model involving four state and four decision variables. The model determines the least cost mix capacity expansion, considering the size of plants to add to the system and the timing of these additions for hydro, thermal and nuclear plants.

Phillips, et al. (61) have presented a nonlinear model to show how nonlinear programming can reduce the number of constraints employed in the linear programming model. The idea of pre-arranging all of the plants that are or may be connected to the system in any year in "merit order" in the data input is used. That is, the operating sequence is decided in advance by inspecting the marginal operating costs before the computer run is done.

Various modeling efforts of finding the optimal investment decisions for electric power supply systems, ranging from marginal analysis to simulation, linear and nonlinear programming, have been reviewed. The development of these models has provided an efficient technique of choosing a good alternative from among a large number of possibilities. Such efficiency of choice is essential in dealing with the investment decisions involving different combinations of techniques, sizes, and locations of plants.

Outline of the Following Chapters

In Chapter II, certain characteristics of the electric power industry and the electric power potentials in Iran are considered.

In Chaper III, first the problem of evaluating public investments in a perfect competition economy is discussed. Then, the effects of market imperfections as well as the social valuations of factors and products on public investments are discussed. Finally, the nature of costs and benefits of the electric power supply system and the contribution of electric power supply investment toward fulfilling the goals of economic policy are investigated.

Chaper IV is devoted to the development of linear and integer programming models to study the problem of optimum investment in the electric power industry. Technological factors for alternative means of production are discussed.

In Chapter V, first the derivation of construction, maintenance, and fuel costs are presented. The computer solutions of the programming model with respect to various factors are presented and analyzed. Finally, the problem of efficient pricing policy for electric power is discussed.

In Chapter VI, the problem of efficient pricing policy for electric power output is considered.

Chapter VII discusses the importance of extra economic factors on the investment plans, which cannot be measured by quantitative techniques.

Conclusions and recommendations are presented in Chapter VIII.

CHAPTER II

ELECTRIC POWER IN IRAN

Background Information

Since electric power in Iran is considered a strategic factor in promoting economic development, investment funds required for capacity expansion are financed through the government. In fact, the development of electric power is being considered as one of the government's responsibilities as a part of an integrated economic development plan. For this purpose, the Ministry of Energy (MOE) was established in 1964 under the name of "Ministry of Water and Power." This name was changed to the "Ministry of Energy" in 1974.

Prior to the establishment of MOE, the installed capacity of electric power plants in the entire country was approximately 700 MW. Power systems were operated by private organizations. Applicants for electric power were required to deposit a considerable amount of money with such organizations, and their deposits were never returned. Electric power was considered a luxury. Consequently, the majority of people were unable to afford electricity. Another factor to be considered is hydropower. This requires a high initial capital investment, which was not attractive and therefore not considered by the private sector.

In 1967, the installed capacity of electric power plants amounted to 1559 MW and has increased to about 4117 MW in 1973--an average compounded annual increase of 17.6 percent. At the end of 1975, the total national installed capacity amounted to 5069 MW, out of which 3652 MW was installed by MOE systems, and the remaining 1417 MW was owned by private sector (industries having self-generation). National installed capacity has increased with an average compounded annual increase of 16.6 percent since 1967 (see Table I).

TABLE I

NATIONAL INSTALLED CAPACITY
(unit: MW)

	MOE		Others		
Year	Capacity	Percent	Capacity	Percent	Total
1967	894	57	665	43	1559
1968	1008	59	702	41	1710
1969	1313	61	831	39	2144
1970	1396	59	459	41	2355
1971	1997	64	1120	36	3117
1972	2094	63	1260	37	3354
1973	2794	68	1323	32	4117
1974	3215	70	1365	30	4580
1975	3652	72	1417	28	5069

Source: Ministry of Energy, *Electric Power Industry in Iran*, Tehran, Iran, 1974, 1975.

Ministry of Water and Power, *A Report on Power and Water Resources in Iran*, Tehran, Iran, 1969.

The MOE power system includes the installed capacity of 834 MW of hydropower plants, 2283 MW of steam power plants, and 535 MW of gas turbine power plants (see Figure 1).

Thermal power plants have been a major part of power systems mainly for the following reasons:

(1) Thermal power plants have shorter construction periods than do hydropower plants, which is an important factor in meeting the rapidly increasing demand for electric power.

(2) Thermal plants require less initial capital expenditure than do hydropower plants.

(3) Primary sources of energy (oil, gas, coal) are abundant in Iran.

National energy generation and per capita energy generation have increased during the last few years, with an average compounded annual growth of 19 percent and 15.3 percent, respectively (see Table II). However, the per capita energy generation is still much lower than those of advanced countries (see Table III). Therefore, with the consideration of the utmost importance of electric power to the overall economic growth, the development of the power supply in the future is one of the essential tasks to be accomplished.

Electric Power Potential in Iran

Hydropower

Iran is classified as a semi-arid country because of its geographic position and topography. The Caspian litoral and the western regions, with only 25 percent of total land area, account for 52 percent of the

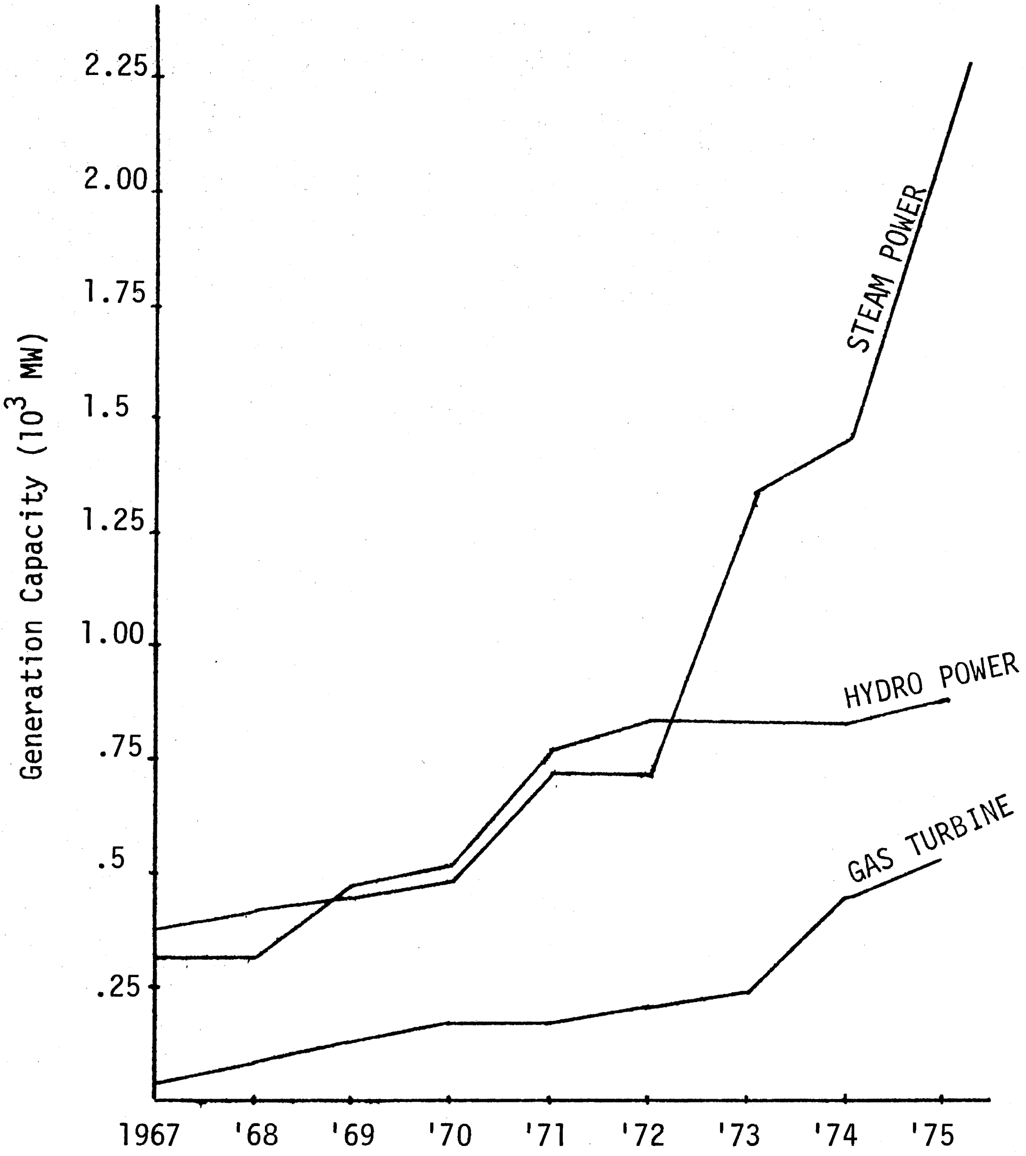

Figure 1. Installed Generation Capacity by MOE

total precipitation in Iran. The central plateau, with 50 percent of the total land area, accounts for only 28 percent of the total precipitation. The east and south parts of the country, which have 26 percent of the total land area, account for the remaining 20 percent of the total precipitation.

TABLE II

TREND OF NATIONAL ENERGY GENERATION
(Unit: GWH)

Year	MOE	Others	Total	per capita Generation (KWH)
1967	1842	2291	4133	157
1968	2431	2194	4625	171
1969	3197	2342	5539	200
1970	4256	2502	6758	238
1971	5490	2616	8106	203
1972	6870	2683	9953	307
1973	9324	2769	12093	378
1974	11164	2840	14005	425
1975	13272	2905	17103	514

Source: Ministry of Energy, _Electric Power Industry in Iran_, Tehran, Iran, 1974, 1975.

Ministry of Water and Power, _A Report on Power and Water Resources in Iran_, Tehran, Iran, 1969.

TABLE III

PER CAPITA ENERGY GENERATION IN SELECTED COUNTRIES
(Unit: KWH)

Country	per capita Generation	Country	per capita Generation
Canada	11854	Italy	2651
U.S.A.	9254	Iran	378
U.K.	5044	Turkey	324
West Germany	4529	Iraq	234
Japan	4339	Egypt	228
U.S.S.R.	3662	India	125
France	3339	Pakistan	64
Israel	2740	Afghanistan	25

Note: All figures are based on 1973 statistics with the exception of Pakistan, which is based on 1971; Iraq and India are based on 1972.

Source: United Nations Statistical Yearbook, New York, 1972, 1973, and 1974.

In view of the limited and scattered water resources of Iran, most of the hydro electric power plants are built in the northern part of the country. The construction of hydro plants will contribute toward the conservation of other sources of energy--especially oil. Hydro plants also have great value for allocating water resources for urban centers, agricultural use, and flood control. The development of hydro potential should be considered seriously, since it can serve a variety of needs. It can provide electric power as well as allocating water resources for agricultural, industrial, urban, and rural development sectors. The estimated hydro electric potential in the whole country isabout 9398 MW.

Thermal Power

The power system in Iran is heavily dependent on thermal plants (see Figure 1) due to Iran's abundant petroleum resources. Fossil fuels like oil, natural gas, and coal, are all locally available. The recoverable reserves of natural gas, oil, and coal in the whole of Iran are estimated at 200 trillion cubic feet, 65 trillion cubic feet, and 385 million metric tons, respectively (72)(75).

The demand for commercial energy increases continuously. Factors contributing to this ongoing and increasing need are the growth of population and the displacement of non-commercial energy (firewood, charcoal, and animal dung) as household fuel by commercial energy (oil, natural gas, and coal). On the other hand, the major source of income consists of revenues derived from exports of oil and natural gas. So, in the future, we may be faced with a shortage of oil and steeply rising energy costs. Therefore, long-term planning should carefully evaluate the competitive position of the present thermal plants as compared with nuclear, hydro, geothermal, and solar plants.

A positive factor which weighs in favor of the construction of thermal plants is technology. Technological progress has contributed greatly to reducing both capital and fuel costs for thermal plants. This cost reduction has promoted a tendency to install increasingly large generating units to derive maximum benefit from the economic of scale. In Iran, the largest unit size of a thermal plant was 156 MW in 1974.

Atomic Power

In 1974, the Iranian Congress approved the construction and utilization of atomic power plants for the purpose of generating electricity as well as providing for desalination processes. Purchase contracts for power plants have been made with KWU in West Germany and Fromatome in France. It is expected that the capacity of nuclear power plants will expand to 23,000 MW by 1985 (2). Nuclear power plants have the following economic characteristics which render them particularly useful:

(1) Nuclear power is more competitive in larger quantities. For reasons of system reliability, it is desirable that the proportion of total capacity represented by a single plant should not exceed a relatively small fraction so that the normal systems reserve can be counted upon in the event of unpredictable difficulties.

(2) A high utilization factor is desirable in order to make the most economical use of capital costly nuclear power plants (35).

From the results of even brief observations of different power potentials for electric power development, it is apparent that the line of power development in Iran is fairly new. In order to determine the future requirements of industrialization and to provide proper direction for development, especially in the industrial sector, careful economic and technical studies are needed.

CHAPTER III

EVALUATION OF PUBLIC INVESTMENT CRITERIA AND ELECTRIC POWER SYSTEM

The protection and help afforded domestic industry through public investments in developing countries constitutes one of the most compelling reasons for such public investments. Investment and production, public sponsored as well as private, should normally be required to be either profitable or at least cost-recovering. However, there are special cases for public investment projects which do not recover their costs in the commercial sense. Economists refer to these investments as "infrastructure" investments. Nevertheless, a careful determination of the costs and benefits of public investments is required. Public investments do not deny the existence of market relations between producers and customers. However, imperfections in the market do exist.[1] Therefore, market prices do not reflect the social valuation of the resources used and the commodities produced. In this chapter, the first problem discussed concerns the evaluation of public investment in a "perfect competition economy." The next considerations deal with the effects of market imperfections as well as the social valuation of factors and products on public investments. The final part of this

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[1] Market imperfections are more serious in developing countries than in advanced countries. For detailed discussion on this subject see Eckaus (19), Kindleberger (41) Chapter III, Balogh (3).

chapter provides an investigation into the nature of costs and benefits of the electric power supply system, and an evaluation of the contribution of electric power supply investment toward fulfilling the goals of economic policy.

Investment Criteria in a Perfect Competition Economy

Perfect competition exists in an economy where there are no extra effects in consumption or in production. Indeed, the market prices reflect both the social valuation of the resources invested and the commodities produced. Hence, private and social values converge and the market allocation is an efficient allocation. In any determination of an optimal program, i.e., optimal allocation of resources and technology of production, perfect competition will guarantee that the value of the national product at given prices of final commodities is maximized if productive factors are utilized so as to equate their value productivities with their rentals.

As a rule, an investment shows profit when the total flow of discounted benefits is greater than the total flow of discounted costs. The present discounted value of benefits minus costs is maximized when marginal benefits are equal to marginal costs. If vector $\underline{x} = (x_1, x_2, \ldots x_m)$ indicates the outputs and vector $\underline{y} = (y_1, y_2, \ldots y_n)$ indicates the input, then G(x) and K(y) represent gross income and total costs, respectively. The efficiency criterion is the maximization of G(x) - K(y) and can be expressed as follows:

$$\text{Max } Z = \sum_{t=1}^{T} \left[G_t(X_t) - C_t(y_t) - M_t(y_t)\right] r_t$$

Subject to budget constraint

$$C_t(y_t) \leq B_t \text{ for all } t$$

and the production function

$$g(y_{1t}, y_2t, \ldots y_{nt}) \leq X_t \text{ for all } t$$

where $G_t(x_t)$ refers to the gross income in period t, $C_t(y_t)$ is the capital cost in period t, $M_t(y_t)$ refers to maintenance and operating costs in period t, $K_t(y_t) = C_t(y_t) + M_t(y_t)$, r_t is the discount factor applicable to period t, B_t and X_t refer to the budget available and maximum output possible in period t, respectively.

The investment problem can also be evaluated by means of benefit-cost ratios[2] familiar in engineering economy analyses; the marginal conditions of maximization problem can be written as:

$$\frac{\sum_{t=1}^{T} \left[G_{ti}(X_{ti})' \frac{\delta X_{ti}}{\delta_{yj}} - \frac{\delta M_t}{\delta y_j} \right] r_t}{\sum_{t=1}^{T} \left[\frac{\delta c_t}{\delta y_j} \right] r_t} = 1$$

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[2] This technique has for some time been used by the United States Government in the design and justification of dams and other water improvements. Currently, the government is trying to adapt this technique to other public investment programs. However, the major shortcomings of this technique are (1) it ranks the project in terms of only economic efficiency which, at the national level, means that projects are judged by the amount that they increase the national product, and (2) projects with higher gross returns and operating costs are at a relative disadvantage when compared with projects with low gross returns and operating costs.

which indicates that the ratio of the present discounted value of the marginal gross income less the marginal recurring costs to the present discounted value of the marginal capital costs must be unity. The degree to which the benefit--cost ratio--exceeds unity, indicates the relative scale of profitability among candidate projects.

Imperfections of the Markets

In the real world, imperfections exist due to a variety of reasons including the indivisibility of resources and imperfect knowledge. In this way, free market sources will lead to derivations from the optimum. The existence of market imperfections makes it necessary to go beyond the market mechanism in evaluating public investments as well as imputing their social costs and benefits. The derivations of optimal criteria is one which seeks to determine the social optimum rather than merely corresponding to private valuations. Such a derivation is crucial for public investments, especially because there is no market mechanism available which can reflect real costs and benefits adequately.

In a case where market imperfections characterize economics, prices do not reflect all of the direct and indirect influences on costs and benefits. Since these prices do not reflect such influences, they do not transmit such influences either. Where perfect competition is assumed and where real and nominal values are equivalent (10), then prices do reflect and transmit such direct and indirect influences on costs and benefits. Money expenditures and market valuations of goods and services will be different significantly from the real social costs and benefits which derive from a particular investment effort. In that case, when determining the optimal mix for the economy or when choosing an optimal technique of production, optimization criteria derived from nominal values would be highly inappropriate. The real social costs of resources are not reflected when institutionally determined rates of interest are used.

It would appear that the desirability of a particular public investment should be considered in the light of global opportunity cost of resources as against their pure market valuation. It is difficult to determine the opportunity cost of each unit of investment in a complex and growing economy. It has been proposed that the shadow prices of production factors may represent the opportunity cost of investment decisions (9). In the language of mathematical programming, the shadow prices are equivalent to the lagrange multipliers of a constrained optimization problem or, similarly, the dual of the primal solution. Shadow prices are interpreted economically as corresponding to the marginal value of scarce resources which have been employed in an optimal investment program. However, solving a full scale optimization problem with all possible inter-dependencies in investment activity throughout the economy is not an easy task to accomplish. Short in solving a problem of this magnitude, it is possible to derive shadow prices on a more or less approximate basis (9). The approximate estimates of shadow prices will be more nearly correct for investment decisions than the observed market prices.

While evaluation of investment projects with shadow prices of factors make the investment criteria more realistic, sole reliance on them may be unsatisfactory in situations where the objective function is combined of various objectives. In reality in most development plans, objectives are characterized by an underlying multiplicity of goals which may or may not be consistent. The planners' objective may combine factors such as the maximization of national income, the creation of new employment, and regional growth of underdeveloped areas. In such cases, the relative importance of objectives must be specified in a quantitative manner, i.e., each objective would have a specific weight attached to it. If the objectives are weighted appropriately, a meaningful solution can be obtained. This can be done by maximizing one objective, subject to the constraint that other objectives are fulfilled with respect to given minima or, alternatively, by maximizing the weighted sum of objectives. No aggregate criterion, such as the national income test, is sufficient to determine socially optimal allocations of resources when maximization is desired with respect to the components of an objective function. Efficiency concerns itself with the size of aggregate income. It does not deal with the distribution of such income. Due to this situation, maximization assumes that either the economy begins with a desirable distribution of income or that distributive questions are not meaningful to the planners. But it is apparent that such assumptions do not reflect adequately the real environment in which investment decisions are made. When redistributive questions enter into consideration, the evaluation of the desirability of investment must then make clear reference to the relative importance of the objectives underlying the investment.

In terms of the marginal social significance of a project's contribution--the explicit--quantitative weights assigned to objectives reflect a value judgement. For example, a weight on redistributive objectives may mean that society considers a unit of extra income to be more desirable when assigned to a landless farmer than when assigned to a white collar worker.[3] The relevance of these objectives for investment decisions has often been questioned on grounds of efficiency. The argument is made that scarce investment resources should be allocated to those sectors where their yield is highest. In other words, allocation should make the most efficient use of resources, especially those which are scarce, because future investments and growth depend on surpluses accumulated from current investment effort. Sometimes specific objectives such as stimulating the growth of underdeveloped regions and reducing unemployment conflict with the actual goals of efficiency maximization. Considering the reduction of unemployment as an objective of public policy, it would appear that investments which create productive employment for idle manpower should be preferred over those which do not. Proper weight must be assigned to the long-term opportunities for productive employment where an assessment is made of the social returns from any particular investment.[4]

Pure considerations of efficiency necessitate investing resources in higher yielding sectors while at the same time employment objectives may lead to an investment pattern that is less optimal. Alternative investment patterns can be utilized to achieve various goals in public policy. But in real terms, a trade-off always occurs by sacrificing one for the other. The maximizations of total income and a desirable state of distribution cannot be ensured automatically by any one allocation of resources. A community's choice of achieving certain

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[3] This is a major concern of the White Revolution in Iran. The White Revolution in Iran occurred in February, 1963.

[4] This is of extreme importance in developing nations where unemployment is a major problem of growth.

objectives at the expense of others is especially relevant in a case of defining operational criteria for investment choices. Investment policy can point the economy toward a more desirable social equilibrium by availing itself of a multiplicty of objectives.

The preceding discussion of investment criteria as it applies to policy objectives was not intended to provide an easy solution for a problem which is highly complex in practicality. Indeed, the purpose of the discussion was to emphasize the multivariable nature of policy objective functions. Such functions usually characterize large public investments. The discussion also serves to point out the inadequacy of any single criterion to cope fully with a decision-making problem. Each criterion helps to make clear the choices in a particular context or under a certain set of assumptions. However, no choice can be clearly shown to be superior to others in all likely circumstances.

A minimal set of operationally meaningful criteria--those which can guide the allocation of resources--are required when critical choices must be made among various investment alternatives.

Electric Power System and its Benefits to the Economy

The objectives of the construction and expansion of the electric power system in Iran can be stated as follows:

(1) raising the standard of living through the use of power in household and community activities;

(2) reducing illiteracy to a large degree by broadcasting educational programs over a television network;

(3) increasing agricultural productivity through power-operated

agricultural equipment and power irrigation, and

(4) introducing additional employment and investment opportunities.

The goals of economic policy must be balanced against the actual social costs of displaced resources. Any reasonable criterion for the evaluation of the worthiness of investments in the electric power supply should try to do this. The circumstances in which the market valuation of resources will almost surely fail to reflect the true cost of the resources and in which a correction by means of shadow prices of factors would seem to be necessary have been previously outlined. It is less clear whether the estimated economic benefits will reflect the social benefits.

The general rule that with a given social rate of discount the present value of the investment should reflect the discounted stream of the net addition to the national income appears to be an insufficient criterion in view of the fact that the objective function is frequently a multi-variable rather than a single-variable function. However, the problems in estimating the benefits of a multi-variable function are so great that it is practically impossible to obtain a meaningful measure of those benefits. A knowledge of the actual magnitude of the effects of an investment in terms of the stated goals would be needed to derive the benefits of a multi-variable function. This is so because each new investment has indirect effects that go beyond the production of immediate goods and services. A general equilibrium analysis of such indirect effects can be determined quantitatively, but such analysis is an extremely intricate piece of work.

The benefits of electric power system investment can be divided into categories like short term and long term, direct and indirect, etc.

The determination of benefits from investments in electric power systems can be made in terms of efficiency benefits, redistribution benefits, and regional development benefits. Efficiency benefits are the increments of gross national products. The increments of the actual income of specific groups of beneficiaries are considered redistribution benefits. Regional development benefits are also more difficult to specify in quantitative terms. Planners might set indices to measure and evaluate regional development.

The efficiency benefits derived from the development of the electric power system in agricultural and industrial sectors of the economy are most likely to be positive. This is because the existence and expansion of electric power should make it possible to create large industries as well as small industries. As a consequence, there should be an increase in production and employment in the industrial sector of the economy. The electric power supply also causes an increase in agricultural products, since power is used as an intermediate product in the farming process. Thus, the direct benefits would increase the incomes of people employed in farming and industry and, as a result, increase the national economy at large.

The redistribution of benefits of investments in the electric power system may simply be regarded as increments of the income of those benefiting from additional employment. Electric power supply makes it possible for small industries to grow and increase employment opportunities. Furthermore, power-using processes have the effect of increasing productivity which, in turn, makes additional employment profitable. Programs for small industry development are beneficial with respect to the objectives of redistribution of income and regional development.

Regional development benefits from investments can be measured by the degree of productive employment created or by the value of increased production in the considered regions.

It is quite possible to consider the long-term or indirect benefits of investments in the economy as external economies of technological nature. The power transmission network will cut the cost of communications since it can also be used to carry telephone and telegraph lines. Another indirect benefit could be found in the increase in the productivity of existing firms. This increase would come about as a result of power supply investments. Such an increase would be implemented by making possible combinations of factors which contribute to an increase in productivity or by supplying an essential input.

Other benefits of electric power can be determined from the amount of electricity used for residential lighting. The most direct measure of such benefits is the price that the potential consumers are willing to pay. When a community consumes electricity as a public good it derives benefits from varied uses such as street lighting, public health, and education.

Considerable data concerning the utilization of power from existing structures as well as the relationship of power to marginal increases in production are required to make investment decisions. This is especially true when investment decisions concern the construction and expansion of the electric power system and a most efficient use of resources is desired. But it must be possible to question the merit of these investments. The existing criteria do not take into account the benefits of power supply to both the consumers and the nation as a whole. There is no certainty that the true social benefits are reflected even when the contribution of power to marginal increases in the production can be estimated. No precise answer can be provided for the question of whether the true benefits do indeed exceed the social costs of resources displaced in the economy.

It is evident that any public investment which involves significant and discontinuous variations in the economy broaches two separate though related questions:

(1) Is the investment advantageous or not?

(2) Considering both construction and operating conditions, what is the optimal choice from all of the feasible technological variants?

The first question is the more difficult. The nature of the question relates to non-economic factors--factors which actually dominate the area. Exact answers are not always possible. More or less qualitative judgements must serve, although such judgements are not entirely satisfactory. The second question is, fortunately, less intractable. A meaningful solution to the problem can be found in a situation where a well defined objective function with appropriate constraints is specified. Such a solution must minimize the stream of total costs to the economy without any change in corresponding benefits. In the next chapters this task will be undertaken where the optimum composition of alternative technological designs for the electric power supply systems will be determined by quantitative analytical methods.

CHAPTER IV

A MATHEMATICAL PROGRAMMING ANALYSIS OF OPTIMAL INVESTMENT PLANS

This chapter develops the basic mathematical framework for determining an optimal investment strategy for the electric power supply system. In general, formulating a large complex economic problem into a meaningful mathematical model requires a number of simplifying assumptions. The limitations and imperfections which are posed by the assumptions would prevent us from finding a solution which agrees entirely with real world decisions. However, despite this, the application of the mathematical model to practical problems can be quite instructive. The mathematical modeling enables us to focus on the relevant and exclude the irrelevant. In general, power utility planners are faced with the following problems:

(1) What are the best possible combinations of plant types for the industry over a planning horizon?

(2) The second problem deals with determining the size of the plant in a case where economics of scale exist. This means, for example, that the construction cost of one large plant would be less than that of several smaller plants of the same total capacity. In order to come to a decision on plant size, the siting of the plants must be considered, since the transportation cost of inputs (oil, gas, etc.) and outputs (electricity) are major factors offsetting economics

of scale.

(3) Finally, the timing of the introduction of additional capacity to meet anticipated growth of demand must be considered.

While all of these problems are distinguished conceptually, they are all, at the same time, interrelated. The choice of production technique interacts with the problem of when, where, and how large. These require a simultaneous treatment.

Discounting

In general, the choice between two alternative investment patterns is a choice between two alternative cost or revenue schedules. If the two types of projects provide equal services but have different patterns of cost (or revenue) over time, it is then necessary to discount the future streams of cost (revenue) to the present. The investment pattern which corresponds to the lowest (highest) value of the discounted total costs (revenues) is chosen. Depending on the nature of the analysis, of course, there are other criteria, such as minimum annual revenue requirement, internal rate of return, average return on investment, etc., which can be used. Thus, the choice of discount rate has a significant effect on the choice of investments.

a clash of opposing views.

There is a great controversy concerning the derivation of a proper social discount rate (SDR). In general, there are three prevalent ideas:

(1) Some believe that the social time preference rate (STPR) should be used, since the SDR should reflect society's preference for present benefits over future benefits. However, there are disagreements over how such a rate is determined.

(2) Others reject the relevance of the STPR to investment decisions and suggest that the SDR, for use in public projects, should reflect the rate of return foregone on the displaced project. The assumption is usually made that the appropriate rate of discount is the rate of return on marginal projects in the private sector. This is known as social opportunity cost of capital (SOCC).

(3) The third group believes that some synthetic rate reflecting both STPR and SOCC must be used. However, the derivation and determination of an appropriate discount rate is not an easy task, since market imperfections and social values are involved.

Prest and Turvey (62) in their survey conclude that:

> .....Discussion about the social rate of time preference, social opportunity cost, etc., do not cut very much ice in most empirical work, and we have not been able to discover any cases where there was any convincingly complete application of such notions (pp. 699-700).

It is not my intention to search deeply into the problems of the selection of an appropriate discount rate. Perhaps the most logical way of finding such a rate would be to investigate the sensitivity of investment decisions to different discount rates within a defined range.

Cost Classification in Power Systems

Adaptation of cost minimization as an objective requires a definition of costs associated with the power system. In general, costs are divided into two categories: fixed costs and variable costs. Fixed costs include the initial costs of plant and equipment and, in addition, those maintenance costs which are independent of the level of operation. Variable costs are regarded as those costs which are dependent on the level of operation, and are mainly fuel costs.

Planning Horizon

In evaluating alternative investment plans, the discounted cost streams must be summed up over a finite or infinite time. If the planning horizon is fixed and less than the life of the plant being considered, the discounted value of the remaining life of the plant is subtracted from the initial capital costs as its salvabe value. In calculating the value of the remaining life of a plant, the principle of double declining balance depreciation is used. In effect, the system is forced to pay for only that portion of capital services which is utilized during planning horizon of the model.

Linear Programming Model

The feasible technological alternatives in the electric power system are characterized by varying degrees of capital intensity and widely divergent operating conditions. In other words, feasibility surface extends from lumpy equipment involving heavy capital cost and low variable cost, to light equipment whose characteristics are the reverse. The useful, operating life of various categories of equipment ranges from ten years for small combustion engines to fifty to sixty years for hydro. The supply system is faced with a peculiar demand characteristic with peak and off-peak loads.

A power system must be designed to meet both peak and off-peak demand. Since electric power is not storable, it is the peak demand which determines the required capacity of the power system. However, it should be noted that part of the available capacity will be idle during the off-peak period. Therefore, in programming the model, the level of operation for the off-peak period as well as the capacity of each type of plant become decision variables.

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The linear programming model which is discussed in this chapter incorporates the broad analysis outlined above, so that the optimum combination of different plants in the power systems can be identified.

Objective Function

As indicated previously, the level of operation for the off-peak period as well as the capacity of each type of plant become decision variables. Let x_{tk} represent the capacity of type k plant to be built in year t, and y_{tk} the capacity of plant type k to be utilized during the off-peak period in year t. If the construction of x units of type k plant is started in year t, the discounted construction cost will be $C_{tk}x_{tk}$. If F_{tk} represents the discounted salvage value of plant type k whose construction started in year t, the cost of capital that is utilized within the planning horizon of the model will be $(C_{tk} - F_{tk})x_{tk}$ for type k plant built in year t. The construction of a plant would require maintenance costs; the discounted costs of maintenance should also be included in the fixed costs. Denoting the discounted costs of maintenance of type k plant whose construction is started in year t as M_{tk}, the fixed costs of x units of type k constructed in year t are $(C_{tk} + M_{tk} - F_{tk})$. The total fixed costs during the planning horizon are

$$\sum_{t=1}^{T} \sum_{k=1}^{n} \left(C_{tk} + M_{tk} - F_{tk}\right) x_{tk}$$

When the construction period is considered for each plant, the construction cost will be distributed across the construction period. Thus, the construction costs occurring after year t should be discounted back to year t in computing C_{tk}.

Now, we should consider the fuel costs which depend on the level of operation. Experience proves that it is not possible to utilize fully the capacity of each plant every year, due to regular maintenance and unexpected failures. Thus, x_k is characterized by its peculiar performance characteristics or technical coefficients, γ_k and Θ_k, which signify its contribution to the system's capacity for peak and off-peak power outputs. Since all of the available capacity will be utilized during the peak period, the total fuel costs of meeting peak demand can be presented as follows:

$$\sum_{t=1}^{T} \sum_{k=1}^{n} q\lambda_k f_{tk} \sum_{s=1}^{t} x_{sk}$$

where q represents the number of peak hours in a year, and f_{tk} is the fuel cost per KWH generated by plant type k in year t. On the other hand, y_{tk} represents the level of operation of type k plant at off-peak period in year t. Hence, the total fuel costs of meeting off-peak demand can be expressed as:

$$\sum_{t=1}^{T} \sum_{k=1}^{n} \overset{\theta_k}{P} f_{tk}\, y_{tk}$$

where P is the number of off-peak hours in a year.

Adding fixed and variable costs discussed above and discounting them back to year 1, then the objective function can be written as:

$$\sum_{t=1}^{T} \sum_{k=1}^{n} \left[\left(C_{tk} + M_{tk} - F_{tk} \right) x_{tk} + q\lambda_k f_{tk} \sum_{s=1}^{t} x_{sk} + Pf_{tk} y_{tk} \right] PF_{r,t-1}$$

where $PF_{r,t-1}$ is the appropriate discounting factor for a given interest rate and year.

Constraints

There are six types of constraints in the model:

(1) constraints requiring the installed capacity for every year be adequate for meeting the peak demand in that year;

(2) constraints requiring the level of operation of installed capacity during the off-peak time in every year be adequate for meeting off-peak demand in that year;

(3) constraints forcing the capital expenditure for each planning period be less than or equal to the available capital for power development in that period;

(4) constraints requiring the level of operation of each plant type in every year be less than or equal to the available capacity of the plant type in that year;

(5) constraints preventing the development of hydro projects more than the hydro potentials available, and

(6) non-negativity constraints for the continuous variables.

Peak Demand Constraints

In order to satisfy peak power demand, the peak demand constraints require that the total installed capacity must be greater than or equal to peak demand for each year. As indicated previously, only a fraction of the installed capacity of each plant is available for power output. Capacity utilization of hydro plants is also limited by the inflows of water into hydro power plants.

The appropriate constraints are given by

$$\sum_{k=1}^{n} \lambda_k \left[E_k + \sum_{s=1}^{t-\delta_k} x_{sk} \right] \geq D_t \quad \text{for all } t \text{ and } t > \delta_k$$

$$\sum_{k=1}^{n} \lambda_k \left[E_k \right] \geq D_t \quad \text{for all } t \text{ and } t \leq \delta_k$$

where

E_k = the existing installed capacity of plant type k before the planning horizon

δ_k = construction period of plant type k

D_t = level of peak demand in year t

$\sum_{s=1}^{t-\delta_k} x_{sk}$ represents the increment of capacity of type k plant between years 1 and t. Therefore, the above constraint states that the total available capacity in year t must be greater than or equal to peak demand, D_t, in year t.

Off-peak Demand Constraints

Off-peak demand constraints require that for each year, the level of operation during the off-peak period in year t be greater than or equal to off-peak demand, d_t, in year t. Thus, the following condition must be satisfied:

$$\sum_{k=1}^{n} y_{tk} \geq d_t \qquad \text{for all } t$$

Budget Constraints

The availability of funds for the choice of investments in the electric power industry is a factor of utmost importance. The availability of capital is also a crucial factor for determining the rate of growth and expansion in the electric power industry. Therefore, the scarcity of available funds for power investment should be incorporated into the model. Hence, the following budget constraint is introduced into the model:

$$\sum_{t+\delta \& \ell} \sum_{k=1}^{n} C_{tk} x_{tk} \leq B_\ell \qquad \text{for all } \ell$$

where C_{tk} is the construction cost occurring in year $t+\delta$ for type k plants whose constructions are started in year t. B_ℓ represents the amount of capital available for planning period ℓ.

Capacity Constraints

The available installed capacity of k plant in year t must be greater than or equal to the level of operation of type k plant during the off-peak period in year t. In other words, for each plant and each year, the following condition must be satisfied:

$$\Theta_k \left[E_k + \sum_{s=1}^{t-\delta_k} x_{sk} \right] \geq y_{tk} \qquad \text{for all } t \text{ and } k$$

In general, Θ_k is different from λ_k since regular maintenance can be scheduled to be done during the off-peak period.

Hydropower Constraints

Since the availability of hydro potentials is limited, the development of hydropower during the planning horizon cannot be greater than the hydro potentials. Thus, the following constraint is required:

$$\sum_{t=1}^{T} x_{tk} \leq H \qquad \text{for } K = 1$$

where H is the maximum hydro potential available for the planning period.

Complete Linear Programming Model

The complete linear programming model can be presented as follows:

$$\text{Minimize} \quad \sum_{t=k}^{t} \sum_{k=1}^{n} \left[\left(C_{tk} + M_{tk} - F_{tk} \right) x_{tk} + q\lambda_k f_{tk} \sum_{s=1}^{t} x_{sk} + Pf_{tk} y_{tk} \right] Pf_{r,t-1}$$

S. T.:

$$\sum_{k=1}^{n} \lambda_k \left[E_k + \sum_{s=1}^{t-\delta_k} x_{sk} \right] \geq D_t \qquad \text{for all } t$$

$$\sum_{k=1}^{n} y_{tk} \geq d_t \qquad \text{for all } t$$

$$\sum_{t+\delta_k \& \ell} \sum_{k=1}^{n} C_{tk} \, x_{tk} \leq B\ell \qquad \text{for all } \ell$$

$$\Theta_k \left[E_k + \sum_{s=1}^{t-\delta_k} x_{sk} \right] \geq y_{tk} \qquad \text{for all t and k}$$

$$\sum_{t=1}^{T} x_{tk} \leq H$$

$$x_{tk} \geq o,\ y_{tk} \geq o$$

Mixed Integer Programming Model

The linear programming model assumes that there are no economics of scale in the electric power systems. Therefore, it is desirable to have a model which considers the factor of economics of scale without significantly affecting the tractability of the model. For this purpose, the problem will be reformulated into a mixed integer programming model.

Objective Function

The objective function that was previously described in the linear programming model will be changed to:

$$\text{Minimize} \quad \sum_{t=1}^{t} \sum_{k=1}^{n} \sum_{i=1}^{M} \Bigg[\left(C_{tki} + M_{tki} - F_{tki} \right) z_{tki} + q\lambda_{ki} f_{tki} \sum_{x=1}^{t} z_{ski}$$

$$Pf_{tki}\ W_{tki} \Bigg]\ PF_{r,t-1}$$

where

C_{tki} = discounted construction costs of one unit size of plant type ki whose construction started in year t

M_{tki} = discounted cost of maintenance of type ki plant whose construction started in year t

F_{tki} = discounted salvage value of type ki plant whose construction started in year t

z_{tki} = number of size i plant in the category of plant type k to be built in year t

λ_{ki} = average feasible plant capacity of plant type ki during peak demand period

f_{tki} = fuel cost per KWH generated by plant type ki in year t

W_{tki} = capacity of type ki plant to be utilized during off-peak period in year t

z_{tki} is restricted to be non-negative integer while W_{tki} can be any non=negative number

Peak Demand Constraints

$$\sum_{k=1}^{n} \sum_{i=1}^{M} \lambda_{ki} \left[E_{ki} + \sum_{s=1}^{t-\delta_{ki}} U_{ski} \, z_{ski} \right] \geq D_t \qquad \text{for all } t$$

where

E_{ki} = existing installed capacity of plant type k size i before the planning horizon

δ_{ki} = construction period of plant type k size i

U_{ski} = unit size i of plant type k at time t

Off-peak Demand Constraints

$$\sum_{k=1}^{n} \sum_{i=1}^{M} W_{tki} \geq d_t \qquad \text{for all } t$$

Budget Constraints

$$\sum_{t+\delta_{ki} \& \ell} \sum_{k=1}^{n} \sum_{i=1}^{m} C_{tki} z_{tki} \leq B_{\ell} \qquad \text{for all } \ell$$

Capacity Constraints

$$\Theta_{ki} \left[E_{ki} + \sum_{s=1}^{t-\delta_{ki}} U_{ski} z_{ski} \right] \geq W_{tki} \qquad \text{for all } t \text{ and } k \text{ and } i$$

where Θ_{ki} is the average technically feasible capacity factor of plant type k_i during off-peak period.

Hydropower Constraints

$$\sum_{t=1}^{T} U_{tki} z_{tki} \leq H_i \qquad \text{for all } i \text{ and } k = 1$$

where H_i represents the maximum hydro potentials available for hydro size i.

The models elaborated on in this chapter require substantial data for a meaningful solution. In order to establish an empirical base for data, I have exhausted all of the possible available sources of data, such as that provided by the Ministry of Energy in Iran, UN publications, UNIDO publications, etc. I found some useful information, but there were many gaps. Hence, the quantity and availability of existing information limits the scope of this research to the solution of linear programming model which will be undertaken in the next chapter.

CHAPTER V

SOLUTIONS OF THE PROGRAMMING MODEL

General Considerations

As indicated previously, the critical consequence of a linear programming model is the elimination of the economies of scale. However, in this study, it is assumed that the capacity of the various alternatives considered for the planning horizon is limited within a range. It is also assumed that constant return to scale is applicable within the assumed range of capacity. Economies of scale can be divided into two kinds: (1) those reflected in the purchase cost of equipment, and (2) those which cause the operating and maintenance costs to decrease with increasing size. For gas turbine power plants, it is assumed that the capacity of 25 MW to 60 MW will be constructed. The range of 60 MW to 250 MW is considered for steam power plants. For hydro and nuclear power plants, the ranges of 22 MW to 100 MW and 850 MW to 950 MW, respectively, are considered. The nuclear power plants of small sizes are not considered, since their prices are at a level that will not be competitive to those of steam power plants during the planning horizon. Nuclear power plants larger than 950 MW are not considered, for security reasons. Since the larger the plant, the more severe are the economic consequences of an unexpected shutdown. This is an especially important factor in developing countries due to the lack of nuclear skills and experiences.

Planning Horizon

The planning horizon of the model is ten years--from 1977 to 1985, divided into two five-year periods. Investment decisions are made concerning what types and sizes of capacity should be constructed in each of the five-year periods. The ten-year planning horizon was chosen so that the immediate and medium term implications of various investment alternatives could be considered explicitly and fairly accurately by the model. A longer range planning horizon was not considered because of greater uncertainty regarding demand and cost parameters.

Cost Estimates

Due to the lack of data, it is difficult to derive completely accurate cost estimations of various techniques in the electric power industry in Iran. The primary source of information was the data provided by the Ministry of Energy and the Harza Engineering Company in Iran. The lack of data for nuclear power plants was supplemented from references (59) and (24).

Construction Costs

Hydro Power Plants. Since the construction cost of hydropower plants varies from site to site depending upon the characteristics of each site, it is difficult to choose a representative figure to be used in the analysis. The construction cost of hydro power plants in Iran is in the range of \$217 to \$388 per KW of installed capacity (Table XIX). Assuming that the development of hydro power will be in the range of 22 MW - 100 MW, the weighted average of $342 per KW of installed capacity is accepted to represent the construction cost of hydro power plants.

Gas Turbine. The construction cost of gas turbine plants with the size 25 MW to 60 MW is estimated to be $96 per KW of installed capacity. This cost is the weighted average of the costs of gas turbine plants recently constructed in Iran (see Table XX).

Steam Power Plants. The construction costs of steam power plants in Iran varies from $122 per KW of installed capacity to $376 per KW of installed capacity (see Table XXI). Assuming that plants in the range of 60 MW to 250 MW will be constructed during the planning horizon, the figure $211 per KW is chosen to represent the construction cost of the steam power plants in the range of 60 MW - 250 MW.

Nuclear Power Plants. As of today, no nuclear power plants have been constructed in Iran; therefore it becomes apparent that the construction cost of nuclear power plants will be uncertain until experience is gained through construction and completion of such power plants. In order to derive a reasonable figure for the construction cost of nuclear plants in Iran, the construction costs of various nuclear power plants constructed recently in the Federal Republic of Germany and France were obtained (see Table XXII). Assuming that nuclear power plants in the range of 800 MW to 950 MW will be constructed during the planning horizon, the figure $340 per KW of installed capacity is chosen. Since it is suggested that the construction cost of nuclear power plants in developing countries should be increased about 15 to 30 percent, the construction cost of nuclear power plants can be estimated to be in the range of \$391 to \$442 per KW of installed capacity (17).

Fuel Costs

Gas Turbine. The fuel cost per KWH generated by a gas turbine with a heat rate of 15,000 BTU per KWH generated is estimated to be seven mills. This figure is obtained by accepting 1,000 BTU/cu ft of natural gas and a cost of 47 cents/1000 cu ft of natural gas:

$$47 \times \frac{15{,}000 \text{ BTU}}{1{,}000{,}000 \text{ BTU}} = 7 \text{ mills}$$

Steam Power Plants. Heavy oil is used as the only source of fuel for all of the steam power plants in Iran. Approximate cost of heavy oil per barrel is \$1.70. Assuming 6,287,000 BTU per barrel of heavy oil, the cost of one million BTU is about 27 cents (6). If the required heat rate per KWH generated by steam power plants is accepted to be 11,000 BTU, the fuel cost per KWH generated is:

$$27 \times \frac{11{,}000 \text{ BTU}}{1{,}000{,}000 \text{ BTU}} = 3 \text{ mills}$$

Nuclear Power Plants. The cost structure of the nuclear fuel cycle is different than are those of conventional fuels and varies from one reactor system to another. The fuel costs of conventional power plants is essentially the cost of fuel consumed, whereas in nuclear power plants the fuel cost is more than the cost of uranium consumed. In addition to the cost of uranium, the cost of preparing and fabricating the fuel is also included in the cost of nuclear fuel. The fuel cost for nuclear power plants of 300 MW and larger, with the heat rate of 10,000 BTU to 12,000 BTU, is estimated to be in the range of .81 to 4.48 mills per KWH generated in the United States (24). Accepting a heat rate of 10,500 BTU for the nuclear power plants, the fuel cost is estimated to be about five mills per KWH generated. The fuel costs for various techniques are assumed to be constant over the planning horizon, since Iran is a major producer of oil and gas. Nuclear fuel is also assumed to be constant through the planning horizon assuming that negotiations between the Iranian government and international producers would prevent any increase in nuclear fuel costs.

Maintenance Costs

In 1974, the average annual maintenance costs of hydro, gas turbine, and steam power plants were estimated to be \$2.56, \$2.15, and \$2.01 per KW of installed capacity, respectively. For nuclear power plants, it is assumed that the maintenance cost would be about one percent of the initial capital cost.

Table IV shows the estimated costs of different techniques. The construction and maintenance costs are adjusted to the 1976 prices by applying a price index (36).

Demand

Demand for electricity varies greatly from hour to hour and from week days to week end (Figure 3) for a typical pattern of hourly demand in Iran. The only variation for demand within the planning horizon is assumed to be the hourly variation between peak and off-peak times. It is also assumed that this hourly variation, as shown in Figure 3, can be approximated by a load curve with two levels of demand, as shown in Figure 2.

TABLE IV

COST ESTIMATES

Technique	Capital Cost $/KW	Annual Maintenance Cost - $/KW	Fuel Costs Mills/KWH
gas turbine	123	2.77	7
steam power	272	2.59	3
hydro power	441	3.30	0
nuclear power	442	4.42	5

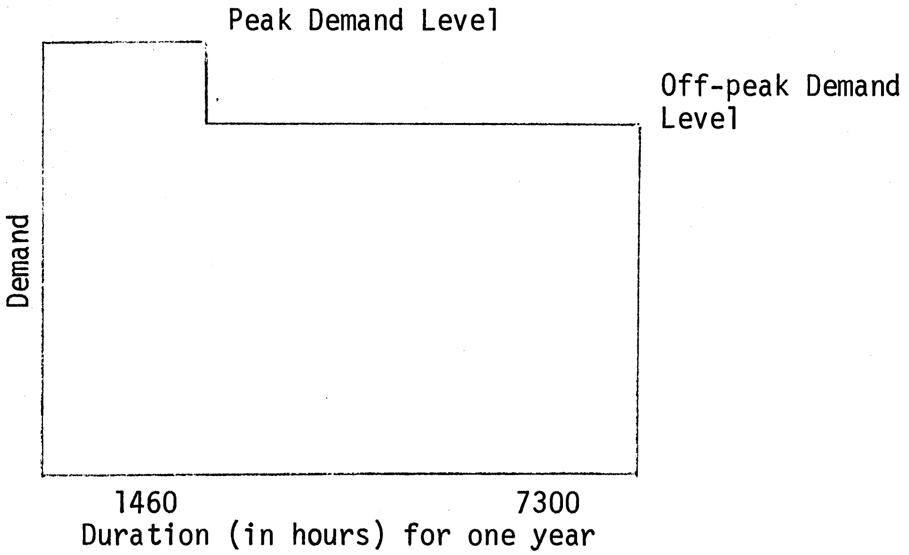

Figure 2. Load Curve for a Given Time Period

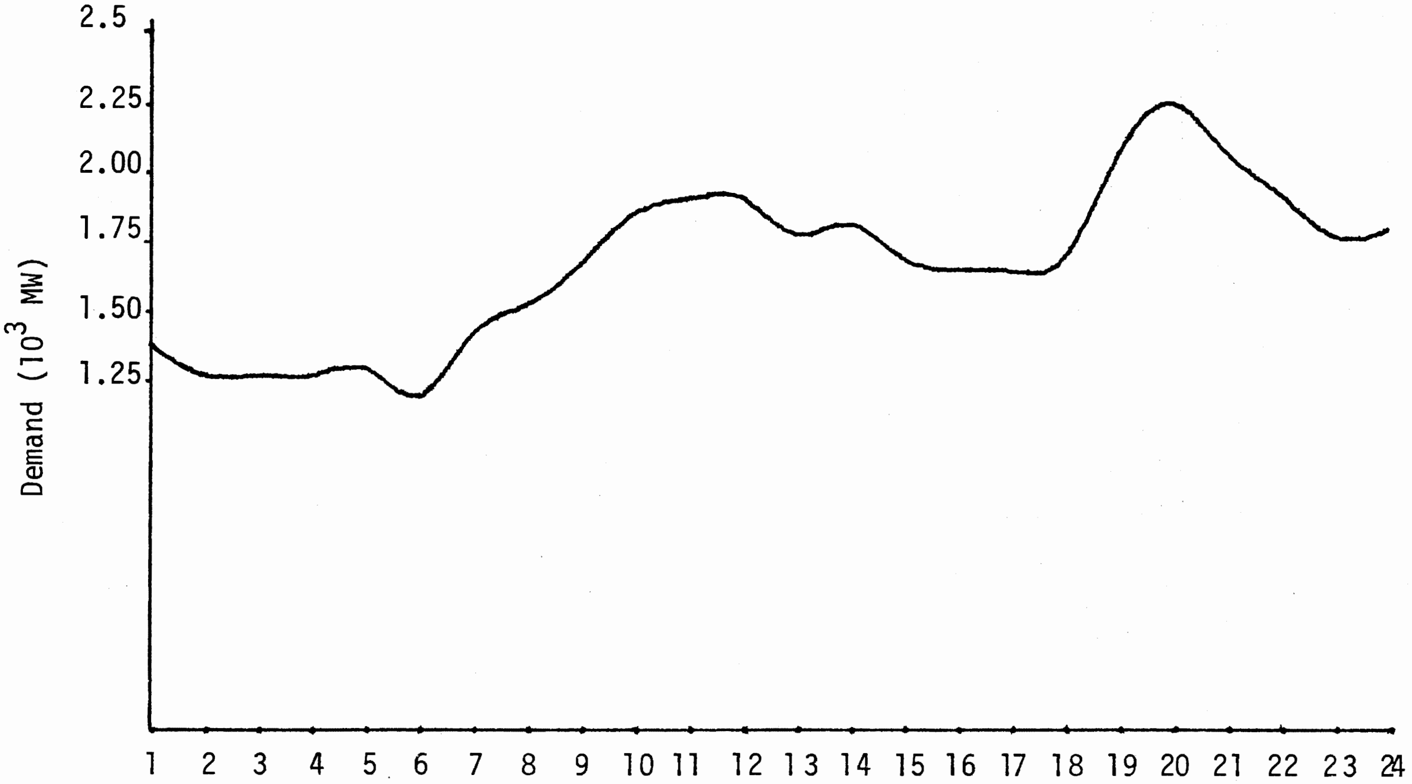

Figure 3. Hourly Demand Variations (September 8, 1975)

The demand for electricity will always be at one of these two levels in a year. The peak demand level has a duration of 1460 hours in each year (roughly 17 percent of the total number of hours); the off-peak demand level has a duration of 7300 hours (roughly 83 percent of the total).

Relatively accurate demand projections are an essential prerequisite for a sound development plan for electric power; however it is difficult to obtain accurate demand projections in Iran because of lack of data and the rapid structural changes of economy. Thus, power demand projections are subject to a wide range of disagreement and error.

The demand for electric power in the planning horizon is based on the projection made by the Ministry of Energy in Iran (June, 1975). The consumers are classified as commercial, industrial, residential, and others. The elasticity method is used to forecast total electric power demanded in every year.

According to the projection, it is estimated that the demand for electric power would grow with an average compounded 18 percent annually during the first planning period (1977-1981), and 14 percent per year during the second planning period (1982-1986)(see Table V). In general, the growth of demand through time is the result of four concurrent effects: (1) increase in industrial or semi-industrial production; (2) gradual process of electrification, either through a greater degree of mechanization or through the use of electricity as a heating agent; (3) fundamental changes in the structure of production (technological changes) resulting in an increase of power-consuming industries, and (4) higher standard of living resulting in an increase of power consumption in the public and domestic sectors.

Demand projection is usually stated in terms of annual generation of electric power. However, to satisfy the consumers' need all of the time, the level of peak demand must be decided for every year, since it is the peak demand which determines the required capacity. The peak demand is calculated by applying the following formula to the annual demand:

$$\text{peak demand (KW)} = \frac{\text{annual demand (KWH)}}{8760(\text{load factor})}$$

TABLE V

DEMAND PROJECTION

Year	Annual Demand (GWH)	Peak Demand (MW)	Off-peak Demand (MW)
1977	27102.3	4759.8	2760.7
1978	33869.85	5948.3	3450
1979	41864.03	7352.3	4264.3
1980	51225.47	8996.4	5218
1981	62095.59	10905.4	6325.2
1982	74615.50	13104.2	7600.5
1983	88909.19	15614.5	9056.4
1984	105113.75	18460.4	10707.1
1985	123288.06	21652.3	12558.3
1986	143692.56	25235.8	14636.8

$$\text{Off-peak demand} = \frac{(\text{annual demand} - \text{peak demand} \times 1460)}{7300}$$

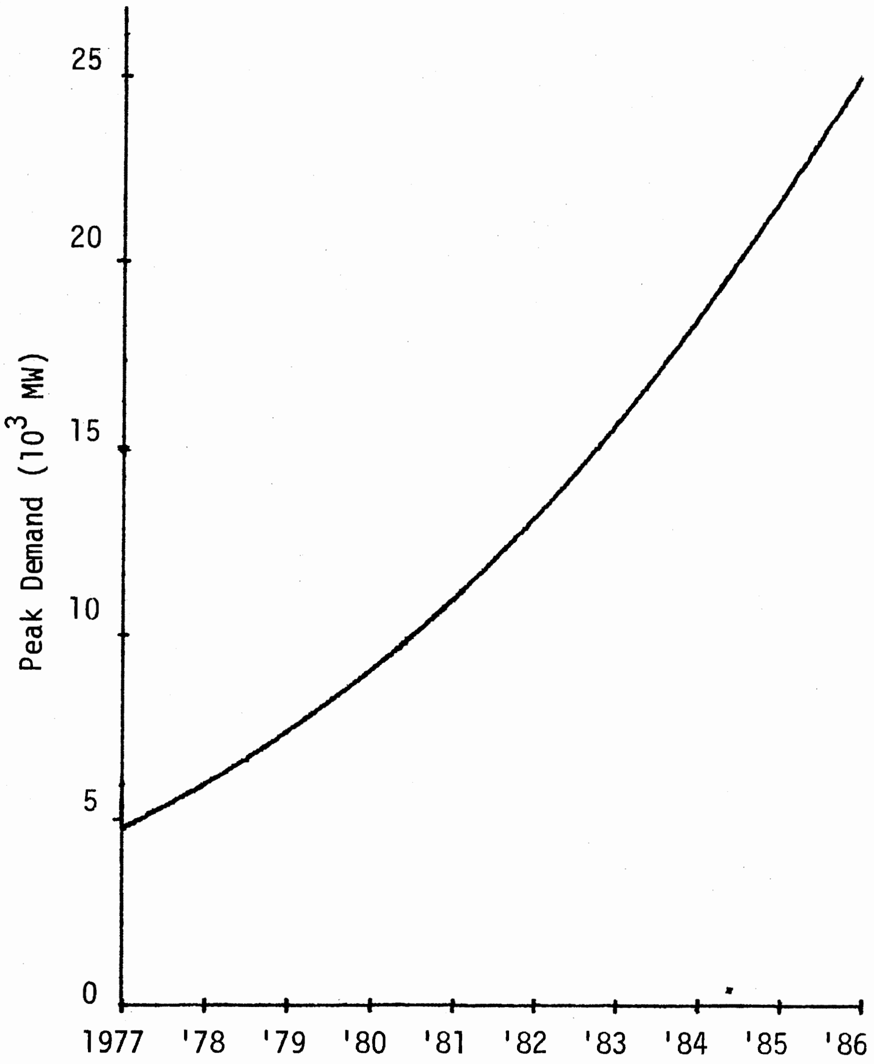

Figure 4. Projected Peak Demand for the Planning Horizon

Load factor is an index of the efficiency with which the electric supply system operates. It is defined as the ratio of the average demand for a certain period of time, such as a year, a month, or a day, to the maximum demand for a short interval of time during the same period.

$$\text{load factor} = \frac{\text{average demand}}{\text{maximum demand}} \times 100$$

A load factor of 100 percent or 24 hours per day operation at a peak load is the maximum attainable.

For the projection, the load factor is taken to be 65 percent and is assumed to be constant during the planning horizon, admitting that the structure of power demand will not change drastically.

9

Capacity Availability

Unexpected failures and regular maintenance prevent the full utilization of the power system's installed capacity. Therefore, total installed capacity cannot be considered to be available for meeting the demand for electric power. For steam and gas power plants, it is assumed that 80 and 60 percent of total installed capacity, respectively, will be available during peak demand period. For off-peak demand period, 64 and 42 percent, respectively, are assumed for steam and gas power plants. Lower availability factors are used for off-period by assuming that regular maintenance could be scheduled to be done mainly during the off-peak period. These figures are chosen somewhat arbitrarily and are based on the availability of steam and gas power plants in 1974 in Iran (55).

The availability of a hydropower plant is very uncertain unless it has sufficiently large reservoir; thus the availability of a hydropower plant depends largely on the inflow of water. However, providing a reservoir increases the availability of a hydropower plant, this would require an additional cost. Hence, the determination of optimum size of a reservoir to be constructed for a hydropower plant is by itself an interesting problem to be studied. In general, the availability of a hydroplant should be determined on the basis of hydrological data over a considerable length of time. This kind of hydrological data is not yet available in Iran. In 1974, the average plant factor of three hydroplants was approximately 59 percent. This figure is used to represent availability factors for hydro power during both peak and off-peak periods.

American electric companies are experiencing about 90 percent availability of nuclear power plants. Economically, nuclear power plants are best suited for base load operation. It is assumed that nuclear power plants in Iran have a higher availability factor than do steam power plants. For this reason, 85 percent availability factor is assumed and is used for both peak and off-peak periods.

Foreign Exchange

The development of electric power in developing countries requires a considerable amount of foreign exchange, since necessary equipment is purchased from developed nations. The foreign exchange requirement should be considered in the programming model. This can be done in two ways; one is to introduce additional constraints for availability of foreign exchange into the model and the other is to add a premium to the foreign exchange rate. In general, it is difficult to determine in advance the amount of foreign exchange which is available for power development over the planning horizon. It is also true that it is not easy to determine an appropriate rate to represent the foreign exchange rate. However, for this analysis for the foreign exchange treatment, the method of exchange rate premium is used. In practice, the black market rate can be used as the upper limit for the foreign exchange rate.

Capital Budget

The Plan and Budget Organization in Iran provided projected budgetary figures covering the next ten years concerning the field of electric power development program. Table VI presents the amount of capital budgeted for power development for each 5-year planning period.

TABLE VI

PROJECTED CAPITAL BUDGET FOR ELECTRIC POWER DEVELOPMENT
(in U. S. Dollars)

Planning Period	Budget
1977-1981	3150704225
1982-1986	6530925746

a. Exchange rate: R 71.45 : U. S. $1.

b. The budget for transmission and distribution facilities are not included.

Source: Data supplied by Dr. M. Farsad, Plan and Budget Organization, Tehran, Iran, May, 1976.

Sensitivity of the Choice of Technique to Inflation Rate

For this test, zero construction period is assumed for various techniques. This test is designed to investigate competitive position of various techniques at different inflation and discount rates. The inflation rate in Iran has decreased from roughly eleven percent to nine percent in the past three years. Assuming that inflation will be controlled and will continue to decrease, the inflation rates of seven, eight, and nine percent are chosen for this study. Some of the results are summarized in Tables VII, VIII, IX, and Figure 5. It is assumed that all of the projected budget will be available for the planning horizon. The following results are derived:

(1) Hydro and nuclear power plants are not competitive, regardless of the choice of inflation and discount rates.

(2) Construction and maintenance costs of each technique are increased every year with the appropriate inflation rate during the planning horizon. Considering that fuel costs are constant during the planning horizon and the fixed costs of each technique are affected by the inflation rate chosen, the choice of discount rate at various levels of inflation rate has no significant effect on the choice of technique, as shown in Figure 6. This is mainly because inflation affects the larger portion of the cost (capital and maintenance) more than does the discount rate. However, as the rate of inflation increases, the gas turbine plants become more desirable. This is primarily because of having a fixed budget, since the value of money decreases when inflation increases.

TABLE VII

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT INFLATION RATES

Planning Period	Inflation Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Total
1977-1981		468	9367	-	-	9835
1982-1986	9	16342	5654	-	-	21996
Total		16810	15021	-	-	31831
Percent		53	47	-	-	100
1977-1981		-	9718	-	-	9718
1982-1986	8	14069	7359	-	-	21429
Total		14069	17077	-	-	31146
Percent		45	55	-	-	100
1977-1981		-	9718	-	-	9718
1982-1986	7	10935	9709	-	-	20644
Total		10935	19427	-	-	30362
Percent		36	64	-	-	100

a. Eight percent discount rate is used.
b. Zero construction period is assumed.

TABLE VIII

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT INFLATION RATES

Planning Period	Inflation Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Total
1977-1981		468	9367	-	-	9835
1982-1986	9	16342	5654	-	-	21996
Total		16810	15021			31831
Percent		53	47			100
1977-1981		-	9755	-	-	9755
1982-1986	8	13225	7954	-	-	21179
Total		13225	17709			30934
Percent		43	57			100
1977-1981		-	9718	-	-	9718
1982-1986	7	10935	9709	-	-	20644
Total		10935	19427	-	-	30362
Percent		36	64	-	-	100

a. Six percent discount rate is used.
b. Zero construction period is assumed.

TABLE IX

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT INFLATION RATES

Planning Period	Inflation Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Total
1977-1981		468	9367	-	-	9835
1982-1986	9	16342	5654	-	-	21996
Total		16810	15021	-	-	31831
Percent		53	47	-	-	100
1977-1981		-	9755	-	-	9755
1982-1986	8	13225	7954	-	-	21179
Total		13225	17709	-	-	30934
Percent		43	57	-	-	100
1977-1981		-	9718	-	-	9718
1982-1986	7	10095	10339	-	-	20434
Total		10095	20057	-	-	30152
Percent		33	67	-	-	100

a. Four percent discount rate is used.
b. Zero construction period is assumed.

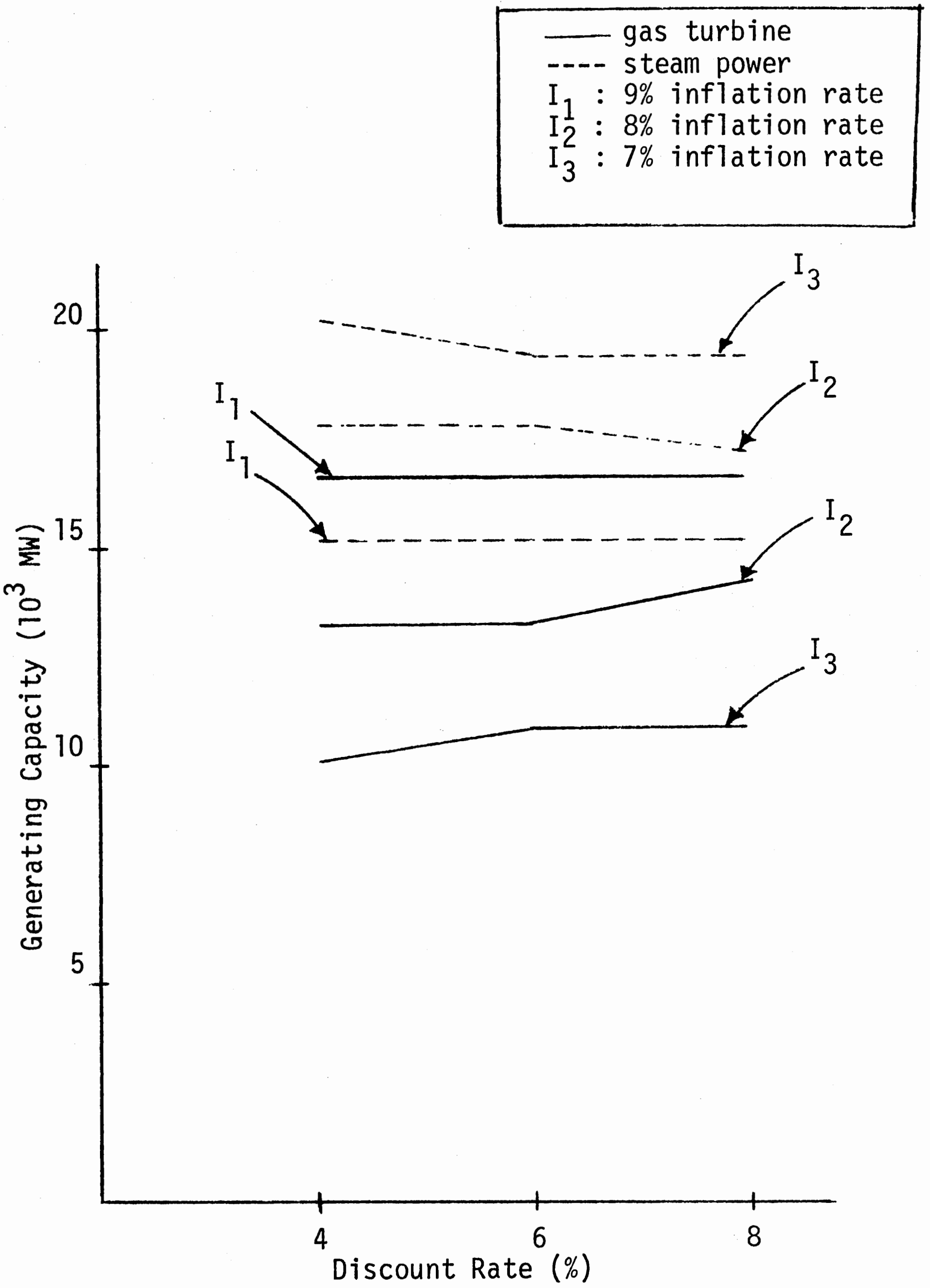

Figure 5. The Effects of Inflation Rate and Discount Rate on the Choice of Technique

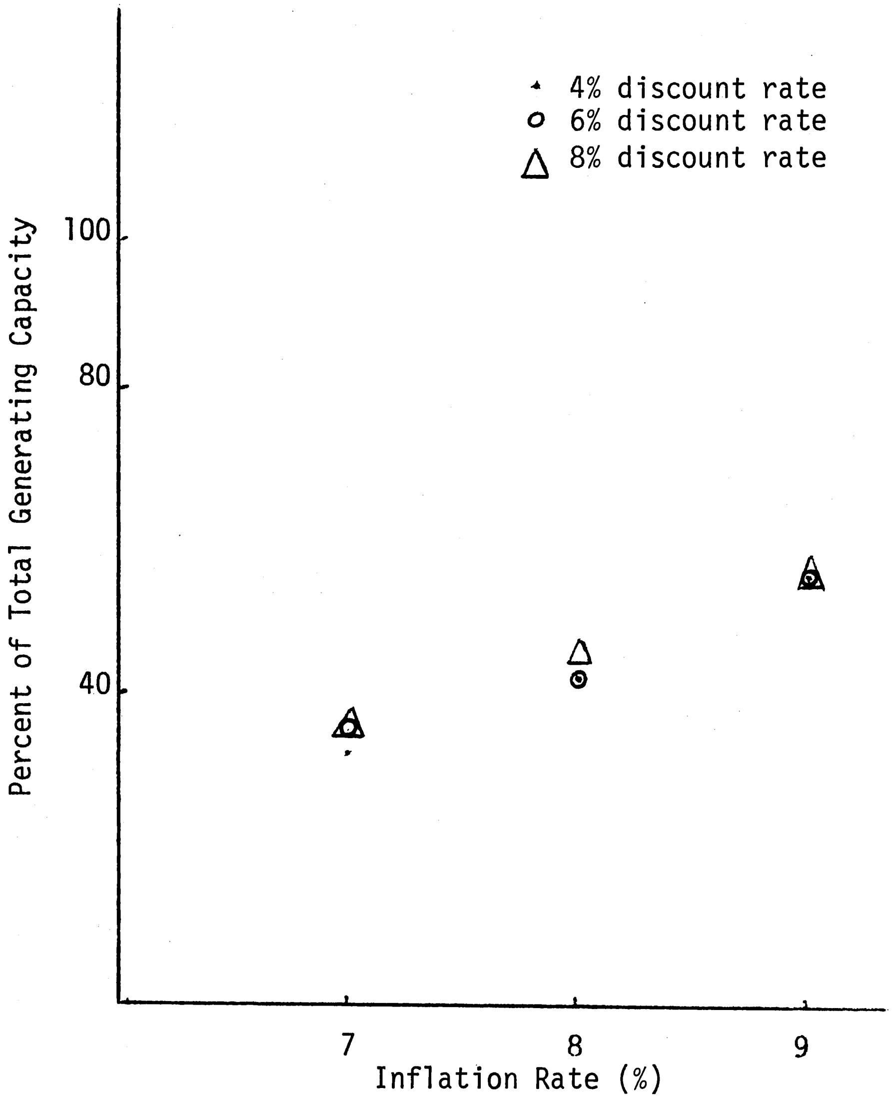

Figure 6. The Effect of Discount Rate at Various Levels of Inflation Rates on the Gas Turbine Power Plants

(3) At seven percent inflation rate and four percent discount rate, steam power plants are dominant. This is mainly because of the importance of the discount on the future fuel costs. Gas turbine plants become more desirable at higher discount rates, since their higher operating costs are discounted heavily.

It seems that seven percent could be chosen as an appropriate rate of inflation with the assumption that no drastic change will occur in the price of oil for the planning horizon.

A crucial difficulty rests on the choice of an appropriate discount rate to be used. Some believe that interest rates in many developing countries are relatively high -- sometimes as high as 16, 18, and 20 percent. However, even if this were true, it does not necessarily mean that a high discount rate should be accepted as the socially appropriate rate in evaluating alternative techniques in public utilities such as electric power. Objections to accepting the market rate of interest as a discount rate are based on the fact that market rates do not reflect the socially correct discount rate because of the existence of market imperfections, the existence of extra-economic values, and the existence of market rate on the existing distribution of wealth and income. These objections are especially valid in developing nations where the factors mentioned above are significant.

The choice of discount rates is really dependent on many factors, such as market rate, political decision, etc., and cannot be accomplished in terms of a precise criterion. It is not surprising to see that political leaders in developing countries put more emphasis on the future and sacrifice the present for the future. This would result in a tendency for favoring a lower discount rate in evaluating government investment projects. However, in this thesis, instead of choosing a specific discount rate, sensitivity of investment decisions to various discount rates has been tested.

Impacts of Construction Period on the Choice of Techniques

This test is designed to investigate the competitive position of various techniques at different discount rates with the consideration of the construction period for various techniques. A two-year construction period is assumed for gas turbine and steam power plants; four years for hydropower, and six years for nuclear power plants. Some of the results are summarized in Table X. It is assumed that all of the projected budget will be available for the planning horizon.

It is interesting to note the results. It is noted that the development of steam power plants is reduced from 67 percent of total capacity expansion to 42 percent of total capacity expansion at a four percent discount rate. It is also noted that the development of hydropower plants becomes feasible where at four percent discount rate hydropower forms 19 percent of the total capacity. This is because of distributing the construction costs across the construction period; construction costs occurring after the year in which construction is started are discounted back to that year. This would result in a less cost for each alternative than those in the previous assumption. However, no nuclear power plants will be developed during the planning horizon. The results also indicate that the introduction of the construction period to the model is crucial, and the exclusion of this factor would leave the planner with decisions that are misleading.

TABLE X

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT DISCOUNT RATES

Planning Period	Discount Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro Power	Total
1977-1981		-	9187	-	721	9908
1981-1986	8	15029	3137	-	4747	22913
Total		15029	12324	-	5468	32821
Percent		46	38	-	16	100
1977-1981		-	7642	-	2816	10458
1981-1986	6	12493	5944	-	3522	21959
Total		12493	13586	-	6338	32417
Percent		39	42	-	19	100
1977-1981		-	7334	-	3235	10568
1981-1986	4	12492	6252	-	3104	21847
Total		12492	13586	-	6339	32415
Percent		39	42	-	19	100

a. Inflation rate, 7%

b. Construction period:

Gas turbine plants:	2 years
Steam power plants:	2 years
Hydropower plants:	4 years
Nuclear power plants:	6 years

Impact of Technological Progress and Availability of Funds

Technological progress is a combination of several factors, such as economies of scale and pure technological changes. Technological progress has contributed significantly to the reduction of both labor and capital requirement per KW of installed capacity, and also the fuel requirement per KWH generated in the electric power industry. It is more than likely that such technological progress will continue in the future. Technical progress is used to assume that it will reduce the fixed and variable costs of each plant every year. As far as steam power plants are concerned, technical progress has followed, roughly, a smooth trend. Technical progress in nuclear power has been more rapid than that of steam power plants. No technical progress is assumed for gas turbine plants, since there is no evidence that technical progress has recently contributed much in this field. No technical progress is assumed for hydro on the basis that hydro power plants vary from one site to another, and consideration of any technical progress will be offset by this variation. Although there have been numerous attempts to measure the contribution of technical progress to the power system, in practice the prediction of technical progress for the future cannot be accomplished accurately. For this reason, some hypothetical figures are utilized in order to investigate the effects of technical progress on the choice of techniques. For steam power plants, two different rates of technical progress are used: one percent per year, and two percent per year. As to nuclear power plants, it is assumed that the rate of technical progress will be higher than those of steam power.

Therefore, three and four percent are used to represent the rate of technical progress for nuclear power plants. No technical progress is assumed for hydro and gas turbine plants.

The results of these tests indicate that nuclear power development is justified when the rate of one and four percent are used for steam and nuclear power plants, respectively. Table XI and Figure 7 represent the optimal capacity expansion when one and four percent are accepted as the rate of technical progress for steam and nuclear power plants, respectively. The results indicate that at a discount rate lower than eight percent, nuclear power development is encouraged to the extent that nucelear power forms 48 percent of total capacity in the second planning period. It is also interesting to note that the competitive position of gas turbine is discouraged, and no gas turbine plants are developed in the planning horizon. This is not unexpected, since gas turbine plants are the most expensive to operate and have considerably lower availability factor than do those of nuclear and steam power plants.

So far, the analysis has been made under the assumption that all of the amount budgeted will be available during the planning horizon. In reality, as experience proves, it is scarcely convincing to assume that all of the projected budget will be available for investment.[1] In order to consider this uncertainty of available capital, the tests have been repeated under different levels of availability of the budget for

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[1] In the past few years, many projects sponsored by the Iranian government were delayed much longer than expected, due to the lack of capital. Construction of the Tehran Airport is an example of such delays.

TABLE XI

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT DISCOUNT RATES WITH THE CONSIDERATION OF TECHNOLOGICAL PROGRESS

Planning Period	Discount Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Total
1977-1981		-	7486	-	3027	10513
1982-1986	8	-	9442	7970	-	17412
Total		-	16928	7970	3027	27925
Percent		-	61	29	10	100
1977-1981		-	7333	-	3235	10568
1982-1986	6	-	9442	7970	-	17392
Total		-	16775	7970	3235	27980
Percent		-	60	29	11	100
1977-1981		-	7333	-	3235	10568
1982-1986	4	-	9113	8280	-	17393
Total		-	16446	8280	3235	27961
Percent		-	59	30	11	100

a. Seven percent inflation rate is used.
b. Technological progress: Steam power: 1% per year
Nuclear power: 4% per year
c. Construction period: Gas turbine: 2 years
Steam power: 2 years
Nuclear power: 6 years
Hydro-power: 4 years.

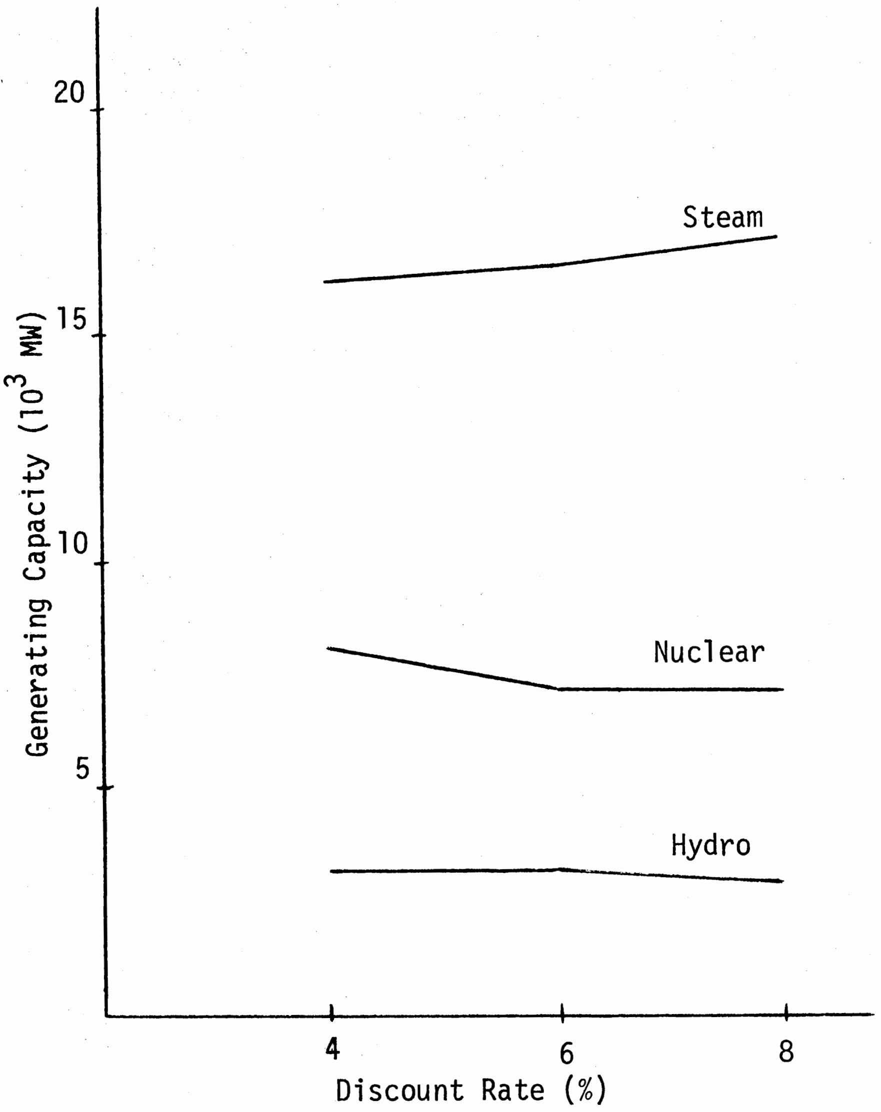

Figure 7. Effects of Discount Rate on the Choice of Technique at 100% Availability of Budget

power development.

It is interesting to note the relationships between availability of budget and the choice of techniques. Tables XII, XIII, and XIV, and Figures 8, 9, and 10 are obtained by varying the level of budget at seven percent inflation rate and different discount rates.

At 90 percent availability, gas turbine plants are introduced to power system where at eight percent discount rate gas turbine plants form 17 percent of the total capacity. At 80 percent availability, the development of hydropower is discouraged, regardless of the interest rate. At 70 percent, neither nuclear nor hydropower is developed. As the availability of budget decreases, the development of gas turbine power plants increases, whereas at 60 percent availability, gas turbine becomes the only alternative for power development. The results also indicate that regardless of the discount rate chosen, the development of hydropower at 90 percent availability is less than eight percent of total capacity expansion during the planning horizon. By assessing the marginal value of capital, it will be concluded that the lower the discount rate, the greater the impact of budget constraints on the choice of technique. This finding is not unexpected, since the competitive position of a less capital expensive technique will strengthen as the discount rate increases. These results indicate that when decision makers tend to favor a lower discount rate in favor of capital intensive fuel-saving techniques, their intention can actually be realized if a feasible solution exists with the limited funds available. However, the existence of the tight budget constraints overcomes the effect of other parameters in the model, such as discount rate and the choice of technique is limited to the development of gas turbine and

TABLE XII

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT DISCOUNT RATES AND NINETY PERCENT AVAILABILITY OF BUDGET

Planning Period	Discount Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Marginal Value of Capital	Total
1977-1981		-	8959	-	1030	.02	9989
1982-1986	8	4783	9442	4594	-	.05	18819
Total		4783	18401	4594	1030		28808
Percent		17	64	16	3		100
1977-1981		-	8719	-	1355	.02	10074
1982-1986	6	2820	9442	5981	-	.07	18243
Total		2820	18161	5981	1355		28317
Percent		10	64	21	5		100
1977-1981		-	8296	-	1929	.11	10225
1982-1986	4	1015	9354	7336	-	.14	17705
Total		1015	17650	7336	1929		27930
Percent		4	63	26	7		100

a. Seven percent inflation rate is used
b. Technological progress: Steam power: 1% per year
Nuclear power: 4% per year
c. Construction period: Gas turbine: 2 years
Steam power: 2 years
Nuclear power: 6 years
Hydro-power: 4 years

TABLE XIII

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT DISCOUNT RATES AND EIGHTY PERCENT AVAILABILITY OF BUDGET

Planning Period	Discount Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Total
1977-1981		1839	8339	-	-	10178
1982-1986	8	11922	7841	1061	-	20824
Total		13761	16180	1061	-	31002
Percent		45	52	3	-	100
1977-1981		1580	8533	-	-	10113
1982-1986	6	10757	7647	2065	-	20469
Total		12337	16180	2065	-	30582
Percent		40	53	7	-	100
1977-1981		1264	8771	-	-	10035
1982-1986	4	9423	7412	3230	-	20065
Total		10687	16183	3230	-	30100
Percent		35	53	12	-	100

a. Seven percent inflation rate is used

b.	Technological progress:	Steam power:	1% per year
		Nuclear power:	4% per year
c.	Construction period:	Gas turbine:	2 years
		Steam power:	2 years
		Nuclear power:	6 years
		Hydro-power:	4 years

TABLE XIV

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT DIFFERENT DISCOUNT RATES AND SEVENTY PERCENT AVAILABILITY OF BUDGET

Planning Period	Discount Rate (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Total
1977-1981		5685	5455	-	-	11140
1982-1986	8	18980	3676	-	-	22656
Total		24665	9131	-	-	33796
Percent		73	27	-	-	100
1977-1981		5396	5671	-	-	11067
1982-1986	6	18511	4027	-	-	22538
Total		23907	9698	-	-	33605
Percent		71	29	-	-	100
1977-1981		5186	5829	-	-	11015
1982-1986	4	18041	4380	-	-	22421
Total		23227	10209	-	-	33436
Percent		69	31	-	-	100

a. Seven percent inflation rate is used
b. Technological progress: Steam power: 1% per year
Nuclear power: 4% per year
c. Construction period: Gas turbine: 2 years
Steam power: 2 years
Nuclear power: 6 years
Hydro-power: 4 years

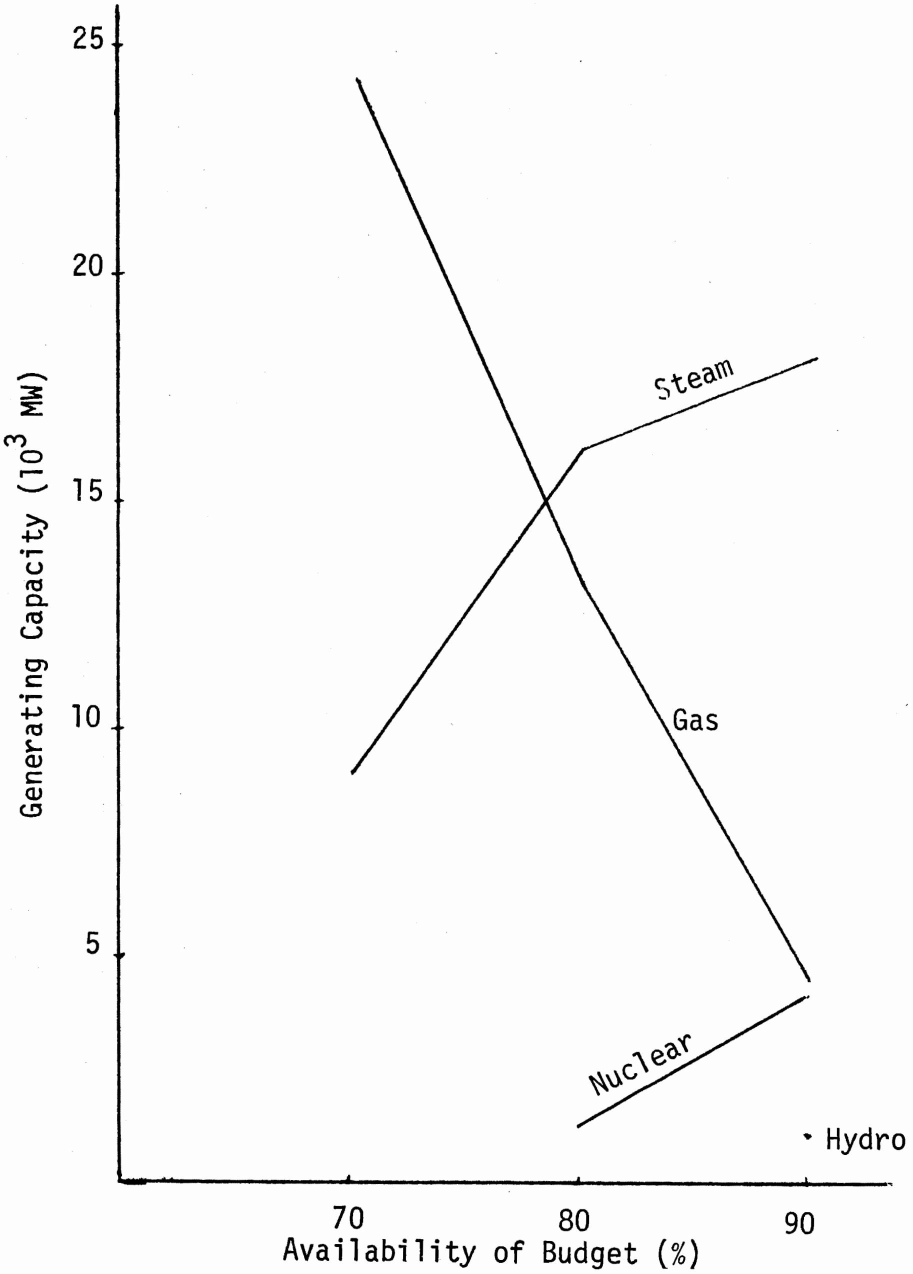

Figure 8. The Effects of Availability of Budget on the Choice of Technique at Eight Percent Discount Rate

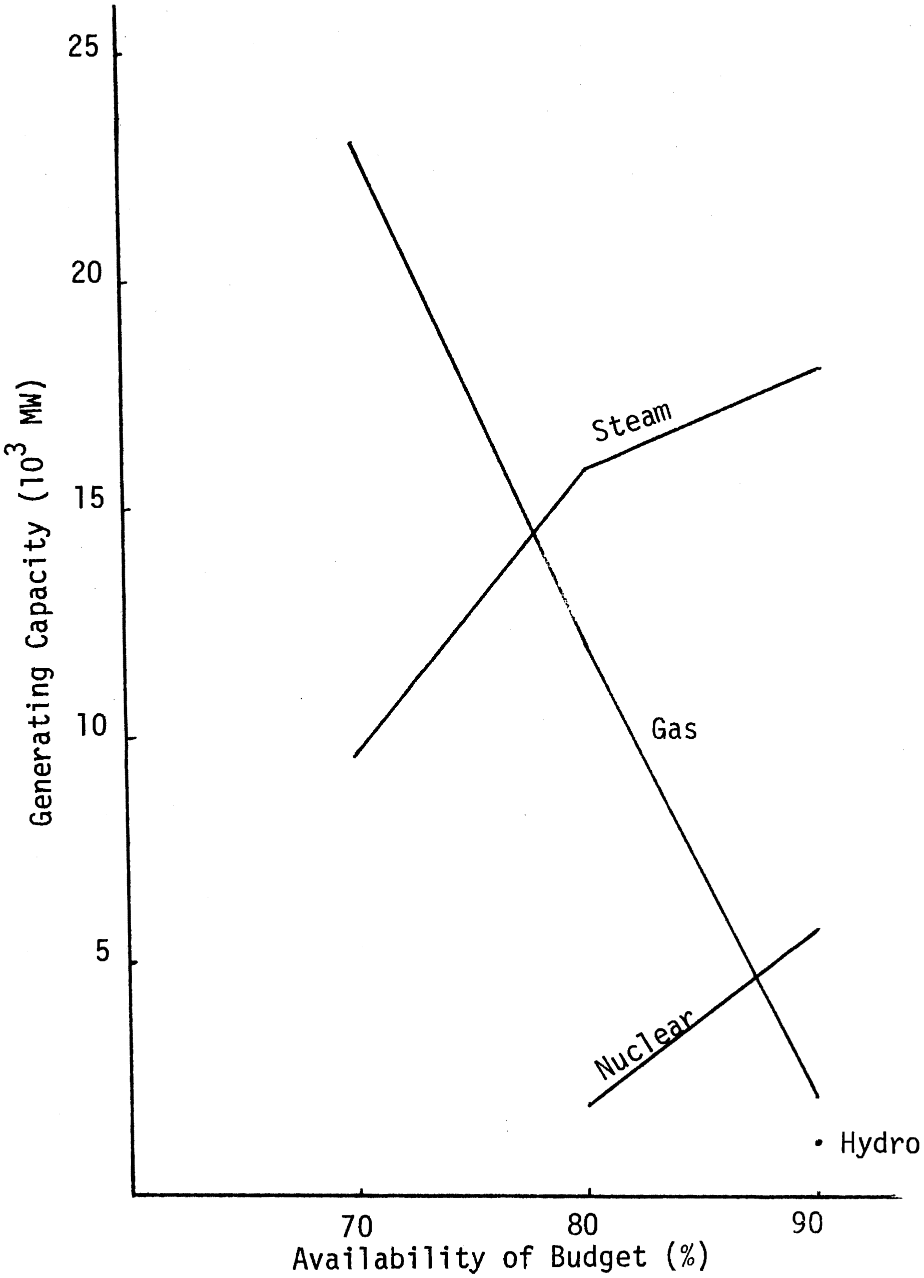

Figure 9. The Effects of Availability of Budget on the Choice of Technique at Six Percent Discount Rate

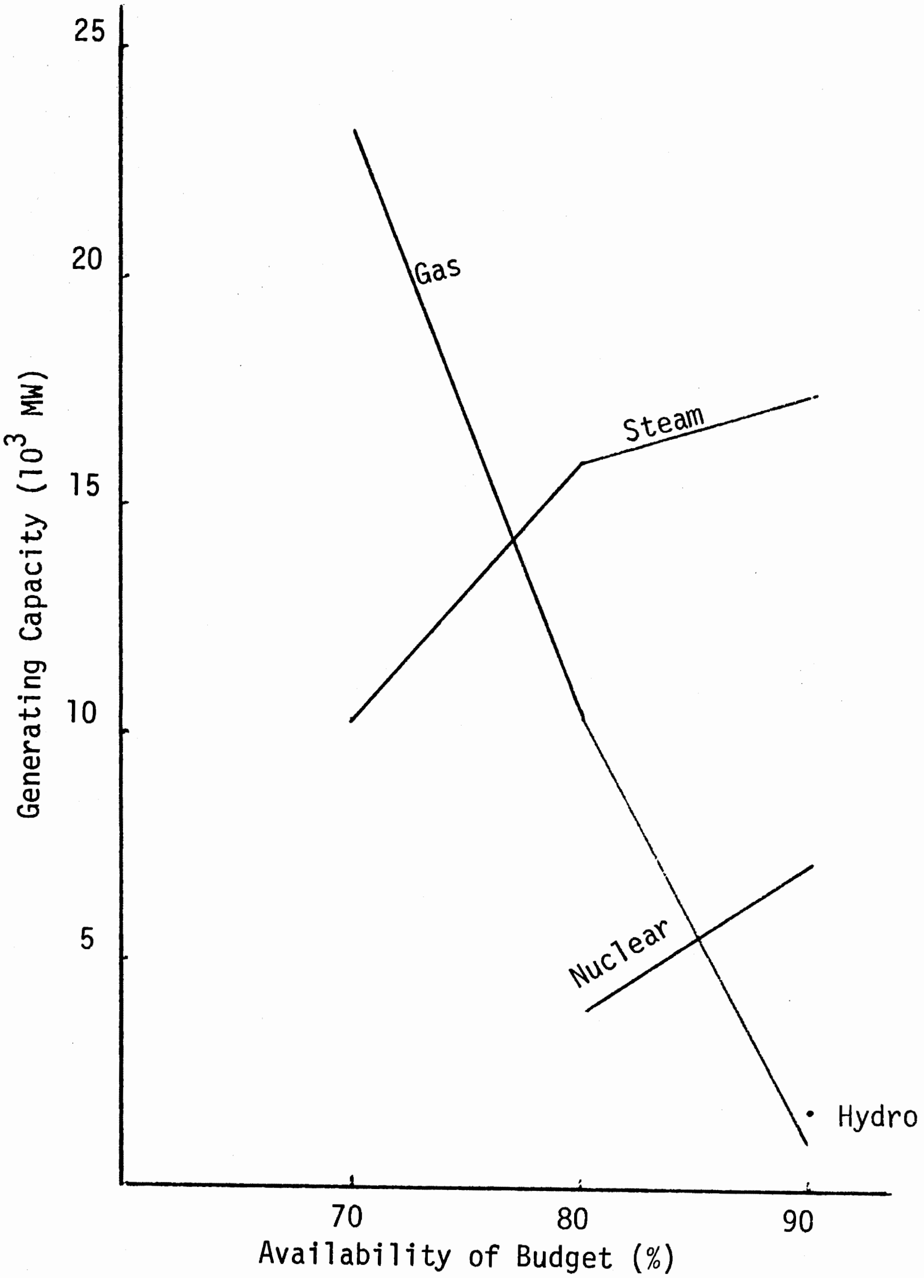

Figure 10. The Effects of Availability of Budget on the Choice of Technique at Four Percent Discount Rate

steam power plants regardless of the discount rate used in the model. Tables XVII and XVIII present some suggestive information as to timing of the introduction of nuclear and hydropower to the power system when different levels of budget availability and discount rates are used.

Impacts of Demand Variations

There is no question about the fact that there will be some variations in projected demand during the planning horizon. Then the question is how a decision maker takes this matter into account in his decision making so that the harmful impact of such variances can be minimized. Decision theory under uncertainty would provide a rational solution if the probability distribution of demand, penalty cost of not meeting demands, and the cost of additional capacity can be estimated. However, lack of data at the present time makes it almost impossible to derive a probability distribution of demand for electric power in Iran. At best, a number of different projections can be made under different assumptions as to the development and structural change of the economy. Tables XV and XVI represent the optimal pattern of capacity expansion and cost savings from not meeting some portion of the projected demand (one to ten percent per year) at 100 and 80 percent availability of the budget. It is apparent that the tighter the budget, the greater the cost reduction, from not meeting some portion of the projected demand. However, the cost reduction should be compared with the estimated value of the penalty costs of not meeting the demand. If the penalty cost of not meeting the demand is not much higher than the cost of providing additional capacity and the budget is very tight, then the planners may favor the idea of not meeting some portion of the demand.

TABLE XV

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT VARIOUS LEVELS OF PEAK DEMAND AND HUNDRED PERCENT AVAILABILITY OF BUDGET

Planning Period	Level of Demand (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Cost Reduction in Millions ($)
1977-1981		-	7259	-	3203	
1982-1986	99	-	9348	7890	-	46.2
1977-1981		-	7186	-	3170	
1982-1986	98	-	9254	7811	-	92.3
1977-1981		-	7113	-	3138	
1982-1986	97	-	9159	7731	-	138.5
1977-1981		-	7034	-	3106	
1982-1986	96	-	9065	7651	-	184.8
1977-1981		-	6966	-	3073	
1982-1986	95	-	8970	7572	-	231.0
1977-1981		-	6892	-	3041	
1982-1986	94	-	8875	7491	-	277.3
1977-1981		-	6819	-	3009	
1982-1986	93	-	8782	7412	-	323.5
1977-1981		-	6746	-	2976	
1982-1986	92	-	8686	7332	-	369.8
1977-1981		-	6673	-	2944	
1982-1986	91	-	8593	7253	-	416.0
1977-1981		-	6599	-	2912	
1982-1986	90	-	8498	7173	-	462.3

a. Seven percent inflation rate is used
b. Six percent discount rate is used
c. Technological progress: Steam power: 1% per year
Nuclear Power: 4% per year
d. Construction period: Gas turbine: 2 years
Steam power: 2 years
Nuclear power: 6 years
Hydro-power: 4 years

TABLE XVI

OPTIMAL INVESTMENT DECISIONS IN MW GENERATING CAPACITY AT VARIOUS LEVELS OF PEAK DEMAND AND EIGHTY PERCENT AVAILABILITY OF BUDGET

Planning Period	Level of Demand (%)	Gas Turbine	Steam Power	Nuclear Power	Hydro-Power	Cost Reduction in Millions ($)
1977-1981		1260	8676	-	-	
1982-1986	99	9829	7309	2872	-	67.1
1977-1981		939	8819	-	-	
1982-1986	98	8900	6969	3678	-	131.5
1977-1981		619	8962	-	-	
1982-1986	97	8096	6957	3920	-	193.2
1977-1981		299	9105	-	-	
1982-1986	96	7433	7319	3962	-	251.8
1977-1981		-	9238	-	-	
1982-1986	95	6750	7691	4005	-	309.9
1977-1981		-	9231	-	-	
1982-1986	94	5785	8190	4047	-	362.9
1977-1981		-	9118	-	-	
1982-1986	93	4958	8627	4089	-	415.9
1977-1981		-	8500	-	598	
1982-1986	92	4750	8547	4190	-	468.6
1977-1981		-	8259	-	793	
1982-1986	91	4012	8380	4620	-	520.8
1977-1981		-	8017	-	988	
1982-1986	90	3274	8213	5130	-	572.8

a. Seven percent inflation is used
b. Six percent discount rate is used
c. Technological progress: Steam power: 1% per year
Nuclear power: 4% per year
Construction period: Gas turbine: 2 years
Steam power: 2 years
Nuclear power: 6 years
Hydro-power: 4 years

Planners in developing countries may favor to choose an optimal pattern with the consideration of not meeting some of the projected demand for two reasons: (1) the penalty cost of not meeting demand in developing nations is far less than those of industrialized nations, and (2) because of the uncertainty in availability of capital for the electric power development. Table XVI shows the effect of variations in peak demand at 80 percent availability of budget. If the planner decides not to meet some portion of demand when all of the budget may not be available, it is noted the more the level of peak demand is decreased, the greater is the development of the more fuel economy power plants. When the level of demand is 92 percent or less of the projected demand, the construction of hydro power is encouraged and the development of gas turbine plants is reduced from 40 percent to 18 percent of total capacity expanded during the planning horizon.

General Implications of the Tests

The optimality conditions explored in this chapter have been designed to investigate the significance of some important factors on the choice of technique in the electric power industry in Iran. The optimum capacity expansion has been obtained under a number of different assumptions as to these factors. The following generalization, with some qualifications in mind, could be derived.

(1) Assuming that the present fuel costs will remain constant throughout the planning horizon, the choice of technique is insensitive to inflation rate. Taking around seven percent as appropriate inflation rate, the development of steam power plants dominate the power system.

(2) Significant technological progress has been realized in the

field of nuclear power, and this technological progess is more or less likely to continue in the future. The consideration of such technical progress in the field of nuclear power provides a competitive position for nuclear power when compared with other techniques in the planning horizon. However, the introduction of the first nuclear power plant should be in the last half of the second planning period. Earlier construction of nuclear power plants is not justified economically.

(3) Development of hydropower is encouraged when a four-year construction period is considered. However, the availability of the budget for electric power has a significant effect on the development of hydropower. At 80 percent or lower availability of the budget, no hydropower will be developed in the planning horizon regardless of the discount rate used. A large proportion of capacity expansion during the planning horizon will consist of steam power plants, and the optimum decisions under different assumptions remain very similar regardless of the discount rate utilized. The construction of a considerable capacity of gas turbine will be required to satisfy the growing demand if the availability of capital for power development becomes critical.

CHAPTER VI

MARGINAL COST POLICY

Pricing Implications

In general, the optimal solution of an investment problem has dual pricing implications, to which this part is devoted. So far, this research has largely ignored any consideration of the pricing or financing of the electric power systems. This was done on grounds of analytical distinction between the question of investment in the power industry and the question of pricing for its output. For investment decisions, the relevant consideration is the level of total social benefits resulting from the investment; the latter is justified so long as the benefits can be shown to exceed the costs, regardless of the consideration as to what part of the costs should be recovered from direct users. However, in order to design a pricing policy, roundabout benefits become somewhat less relevant. This is so because there is a group of immediate and principal beneficiaries from the electric power system who should contribute toward the costs through appropriate user charges. Furthermore, the actual impact which electric power will have on the national economy will depend greatly on the way it is priced.

Marginal Cost Pricing a Theoretical Consideration

A thorough discussion of rate-making policies or determination of specific user charges is outside the scope of this research. The following discussion includes some of the relevant theoretical and practical aspects of an optimal pricing policy for electric systems. When all prices equal marginal costs, assigning the price of i^{th} investment output to its marginal cost would satisfy the necessary conditions for an efficient allocation of resources throughout the economy. However, in the presence of imperfection of markets and external factors, marginal cost pricing would lead to financial losses which must be covered by subsidy if the continuation of investment is desired. On the other hand, pricing the output considerably higher than marginal cost may result in an under-utilization and, consequently, financial loss.

It is generally believed that if an investment has a general impact throughout the economy, its output should be priced at marginal cost and the resulting losses be covered through general taxation. If the investment is not one of which the benefits are more or less widely spread over the entire society, those who are benefiting from the investment should pay for it. This requires that the investment be financed through user charges, and implies either discriminatory pricing or uniform prices higher than marginal costs. The rate practices of electric utilities roughly correspond to the principle of a two-part electricity tariff. Under this principle, the user pays a fixed amount for the privilege of using the service, and then pays a variable amount equal to the marginal cost of power actually consumed by him. The former corresponds to marginal capacity costs and the latter to marginal energy costs.

The justification and optimality of multi-part tariffs depends on the extent to which the fixed charges approximate the consumer surplus to each user, i.e., the price that he is willing to pay for the use of the facility rather than go without it. However, in reality, such pricing is impossible. There is no way of empirically determining the equality of consumer surplus to the fixed charges. Furthermore, the marginal capacity cost which roughly corresponds to fixed charge component of a two-part tariff is more or less an accounting figure since changes in capacity are not continuously divisible.

It is often thought that in an economy where average cost pricing is applied, pricing of public investment output at marginal cost would lead to overproduction in the public sector and, consequently, would result in the misallocation of resources. The transfer of productive resources from sectors where marginal cost price equality holds to those where it does not, would increase the value of the national product since the marginal value factor of products at current prices in the latter will be higher than in the former sectors. The argument seems to be valid if it is assumed that the ratio of marginal-to-average cost is the same everywhere in the economy. However, application of the average cost pricing to a public facility like electric power supply would be neither feasible nor desirable. It would not be feasible because total social benefits would exceed direct benefits and, hence, total costs could not be recovered from direct beneficiaries. Its desirability can be questioned on the ground that such a policy would effectively make the power systems a private undertaking which probably will not be able to recover its costs. Furthermore, since the feasibility of a private undertaking depends on its ability to make use of output contingent on payment of a price to cover all costs, it probably will not undertake to build capacity without concluding agreements in advance with potential consumers to obtain compensation for investment costs. In almost all developing countries the willingness of potential consumers to pay for power output is quite low; therefore, a private undertaking of power systems is improbable.

Marginal Cost Pricing in the Electric Power Industry

How can the principle of marginal cost pricing be approximated toward an optimal pricing policy for electric power systems? If an acceptable solution to the problem exists, it is possible to deduce jointly the optimal conditions for pricing outputs as well as for investment capacity.

Under the simplest conditions, the total cost of a plant is divided into short run and long run costs. Short run cost, SC(p), of a plant with a given capacity, x, can be represented as

$$\begin{array}{lll} SC(p) = f(x,p) = & Ax + Bp & o \leq p \leq x \\ & \infty & p > x \end{array}$$

where p is power output per unit of time, A represents the marginal capacity cost, and B is short run marginal cost, corresponding roughly to fuel costs of the plant. The long run cost function can be written as follows:

$$LC(p) = g(X,p) = AX + Bp \qquad p \geq o$$

where capacity, X, is assumed to vary in the long run. Now, if we assume that the load curve for a period of T units of time is known, the peak of the system, $p(\ell)$, occurs at time ℓ, which corresponds to the peak capacity, x. The total cost for the entire period will be

$$\sum_{t=1}^{T} \quad Ax + Bp(t) \quad = TAx + B\sum_{t=1}^{T} p(t)$$

Now, if prices are uniformally set equal to marginal cost, i.e., if $k(t) = B$ for $t=1, \ldots, T$, the total income for the period will be

$$\sum_{t=1}^{T} k(t)p(t) = B\sum_{t=1}^{T} p(t)$$

showing a deficit in the amount of TAx for the period. Fot $t=1, \ldots, T$ and $T \neq \ell$, prices $k(t)$ are set equal to B so long as $p(t) \leq x$, the capacity limit. Since short run marginal cost is indeterminant at maximum output, the peak price $k(\ell)$ would be subject to the inequality, $k(\ell) > B$.

However, if the peak output is priced at its long run marginal cost, i.e., the marginal cost of additional capacity plus marginal fuel costs, $k(\ell) = TAX + B$, the total income would increase to

$$(TAX + B)p(\ell) + B\sum_{\substack{t=1\\ t\neq\ell}}^{T} p(t)$$

and the deficit will be eliminated. The optimality is thus assured in the sense that the income associated with the last unit of capacity, i.e., $(TAX + B)p(\ell)$, is equal to the marginal cost of keeping and using that unit of capacity. Should this equality fail to hold, the plant capacity would need to be adjusted--upward if marginal income exceeds marginal cost, and downward otherwise.

The foregoing discussion has been derived from basic ideas concerning the marginal cost pricing in the electric power industry as advocated by Boiteus (7). The pricing policy conclusions that can be drawn from marginal cost pricing is to price the output at its marginal cost, so long as there is excess capacity. The marginal energy costs are fairly straightforward; these are simply the costs of production at the generating stations and are proportional to output. Efficient pricing will require the recovery of these costs from the users, either as a specific charge proportional to output or as a rate differentiated according to the time or location of consumption. The indivisible costs of power supply should be regarded as the cost of a public good, and be recovered by a general taxation.

CHAPTER VII

EXTRA FACTORS

In Chapter V, results of various tests on investment plans have been presented. These results were obtained from a number of simplifying assumptions and the exclusion of extra economic factors. These assumptions and the elimination of extra economic consequences tend to bias the conclusions in certain ways. Thus, it would be worthwhile to look into the importance of these assumptions and extra economic factors.

Development of Hydropower

In the previous chapter, the development of hydropower was considered for the purpose of power generation only, and therefore in some instances could not compete with steam or nuclear power plants. The generalization made throughout this research has a limited value because of the variability of each hydro site. Each hydro site has its own peculiar physiognomy and, in general, the evaluation of each hydro site must be carried out, including the benefits from flood control, irrigation, and the supply of industrial water. In addition to these benefits, other considerations should also be included in the evaluation of hydropower.

Transmission Costs and Relocation of Farmers

Transmission costs are one of the factors that should be considered in the development of hydropower, since hydro sites may be far from the market where the electric power is needed. In some cases, transmission costs are the major factor in discouraging the development of a hydro site. Another major factor that may not be favorable in the construction of hydropower plants is the relocation of farmers.

Employment

The development of a hydro plant provides a great employment effect during the construction period. In developing countries, there is a considerable amount of disguised unemployment in the rural areas, and Iran is no exception. The construction of hydropower plants will effectively utilize the disguised unemployment. Such utilization is desirable from the viewpoint of social policy as well as economic policy.

Flexibility of Supply and Water Resource

In general, a hydropower plant is able to respond more quickly to the system frequency. This quicker response time is useful for governing the system frequency. Development of hydropower plants also provides waterpower as a domestic natural resource; such a resource has special advantages from the standpoint of security of national water supply, although they are difficult to calculate.

Interdependence of Hydro Sites Along the Same River

In our models, it is assumed that each hydro site is independent of other hydro sites. However, this is not true for the sites along the same river. For example, storage of water at upstream power plants would reduce the uncertainty of the power output of all plants downstream.

Nuclear Power Development

Under the assumptions made in our analysis, the question of having nuclear power plants in Iran is not one of principle, but one of suitable timing. It has also been indicated that dominance of nuclear power in Iran may be delayed, mainly because of the lack of availability of capital for power development. However, nuclear power is a complex technological field in which the scale of development will depend largely on the expertise built up in all of its aspects. Therefore, in an analysis for nuclear power development, pure economic feasibility is not sufficient. Examination of the technological, social, and political factors as well as economic factors is required in determination of the development and timing of the introduction of nuclear power. In fact, political and industrial situations of the country have a great impact in making this decision. In this section, some important factors, favorable and unfavorable ignored in the model, will be investigated. Factors favoring development of nuclear power can be considered as follows:

Political Factors

Political leaders in developing countries often favor the earlier introduction of nuclear power for the sake of the country's prestige. This kind of political desire favors development of nuclear power regardless of economic feasibility.

Technical Skills

The construction and utilization of a nuclear power plant require special skills in fields such as the installation of reactor components, reactor shielding, welding, etc. The operation of a nuclear plant requires a highly technical staff of nuclear engineers, reactor operators, and skilled technicians.[1] Hence, an earlier development of nuclear power plants will facilitate the development of such technical skills. This development will contribute to scientific and technical progress in Iran, although Iran will not be able to promote the development and utilization of nuclear power independently in the foreseeable future.

Some factors that are unfavorable to the development of nuclear power are:

Safety Considerations

Although the safety and control provisions incorporated in various types of commercial nuclear power plants have performed satisfactorily,

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[1] Last year, the Iranian government contracted with the Massachusetts Institute of Technology for the purpose of training Iranian students in the field of nuclear engineering. Other contracts have been made with West Germany and France for the purpose of training Iranian technicians in the field of nuclear power.

extra safety considerations are of even more concern among members of the industrial, government, and scientific communities. It is conceivable that new safety considerations will add additional cost to the field of nuclear power.

The considerations of safety require the adoption of nuclear power legislation--one of the important prerequisites for undertaking a nuclear power plant. Such legislation is necessary to establish regulatory control over nuclear power facilities and materials with a view to protect society.

Nuclear Fuel

The fuel supply arrangement for nuclear power could pose certain special problems not encountered in conventional fuel power plants. While conventional fuels are available from domestic resources, there is a great government involvement in the procurement and use of nuclear fuels. Suitable short- or long-term contracts for the supply of nuclear fuel should be arranged before the construction of nuclear power plants. Although negotiation of fuel supply between countries would approximate the actual cost of production, one cannot rule out the influence of other factors. In our analysis, the costs of nuclear fuel are assumed to decrease with the progress of nuclear technology. However, the price of fuel may go up as demand increases, and offset any reduction in fuel requirements attained by technical progress.

Plant Availability and Unexpected Failures

Capital intensive nature of nuclear power requires high and dependable capacity factors for such plants. In the early stage of nuclear introduction, it is conceivable that the plant availability factor be low because of the lack of technical skills and expertise. The dependability of nuclear power has to be carefully evaluated in the future. For example, Miami's Turkey Point power plant has experienced five failures in its cooling pumps in the past two years, and Commonwealth Edison's Dresden II reactor at Morris, Illinois, had experienced unscheduled shutdowns due to the rapid fluctuations of the water level in the reactor vessel. Probably, unexpected failures are more frequent and the cost of required readjustment may be higher in developing countries than in developed nations. Also, the economic consequences of an unexpected failure will be more severe in the case of nuclear power because plants will be typically larger than conventional plants.

Domestic Fuel Prices

Any future comparison of nuclear and conventional power involves certain assumptions about the future prices of fossil fuels. Since Iran is one of the major producers of gas and oil, the price of fossil fuels will be held constant for the domestic use. This fact gives rise to two specific advantages of conventional power plants; one is the saving of foreign exchange, and the other is the security of supply. Under critical availability of foreign exchange for electric power development, it is advisable to give priority to fossil fuel power plants. Domestic resources also contribute to the security of the power supply. This advantage is certainly difficult to calculate, but it cannot be ignored.

Consideration of the factors mentioned above certainly suggest that the use of mathematical programming techniques will not eliminate the importance of the detailed evaluation of each project. The simplifications and assumptions required in the model are too extreme to allow us to expect anything like a precise investment schedule for the planning horizon. However, we can obtain a fairly generalized pattern of the main lines of electric power development which a long-run planning ought to follow.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

The basic objective of this study was to provide an investment pattern for the electric power industry in Iran for the next ten years. Throughout this study, I have been constantly aware of certain limitations imposed by the nature of the study. These limitations concern the application of quantitative techniques to the relatively complex investment problems at industry level in developing countries such as Iran. However, a clear and reducible function, a well structured model, and abundant and reliable data are necessary and essential for any successful application of quantitative techniques to industry level problems as well as nationwide planning problems. In this analysis, we have seen that not all of the aspects of investment problems over time and space in the electric power industry could be reflected adequately by simple models. Furthermore, reliable data are in short supply, and uncertainty is significant in developing countries. Nevertheless, this study has demonstrated that the application of mathematical programming to the investment problems in key industries provides meaningful insight for solving investment problems in developing countries. The usefulness of such an application can be demonstrated through the following considerations.

(1) In order to investigate the nature of costs and benefits of a public investment such as the electric power system, the investment

objectives and criteria underlying the electric power systems were examined. The inadequacy of any single criterion in view of multiplicity of objectives that normally characterize public sector investments was underlined.

(2) In order to formulate the problem, it was necessary to ascertain the true objectives of these investment problems. It was also necessary to identify the complex interrelations among the variables. Obviously, some of the objectives were difficult, if not impossible, to measure quantitatively, and complex interrelations among variables could not be reflected by the models. Nevertheless, simplifications and assumptions made to clarify the objectives and interrelations contribute a great deal toward the understanding of those problems. In this way, such assumptions yield clear insight into the problem.

(3) Sensitivity analysis has been used mainly in handling the uncertainty surrounding such factors as inflation rate, discount rate, availability of capital, and demand. The application of sensitivity analysis to the investment problems highlighted the importance of the discount rate, and the availability of capital for power development. It seems to me that the most critical weakness of sensitivity analysis rests on the fact that it provides a large volume of numbers which are difficult to display, while the decision maker is interested in one readily discernible figure. Sensitivity analysis provides an array of optimal solutions under various conditions imposed by the analyst. The choice from the members of this array remains in the hands of the decision makers.

(4) It has been shown how scarce resources can be explicitly incorporated into the model and how their values in the industry can

be estimated through the utilization of the concept of shadow prices. Where market prices do not reflect the real values of resources, the concept of shadow prices can be used for improving the allocation of these resources. For example, the shadow price of capital for power development in each planning period was obtained in the study. This type of information could be useful in re-evaluating the budget allocation between planning periods in the electric power industry and other key industries which compete for capital with the electric power industry.

(5) It has been suggested that the application of mathematical programming would not eliminate the importance of the detailed evaluation of each project. However, the application of mathematical programming at industry level would provide a fairly generalized picture of the broad lines of power development. Such a generalized picture as to the nature and direction of power development can certainly be useful in a long-run power development plan.

Recommendations

Although there is a scarcity of data, data should become more readily available for various techniques in Iran's power industry. As this occurs, the solution of the mixed integer programming model developed in this study would provide more accurate plans for power industry investments. This is so, since the heterogeneity of hydro sites and the indivisibilities in such investment decisions are better represented by discrete variables for each such decision. Similarly, fixed-charge construction costs for conventional or nuclear power plants are much more realistic than average costs used in the linear programming model.

These considerations, the various aspects of hydro site evaluations and the treatment of transmission and distribution costs would provide sugject matter for another study.

There are certain questions in hydro site evaluation the solution of which would be valuable to the decisions makers. First, the question of power capacity (MW) to be installed at a given hydro site, rather than determining the capacity in advance and then answering the question of whether or not to build a plant of the specified capacity. A better approach would be to allow the MW capacity at a given site to be a variable within a range and the cost of the plant to be a function of its capacity. Second, the question of external economics between hydro sites along the same river. These interrelationships could have an important influence on the costs, capacities, and construction scheduling of such hydro sites. Third, the question of the possibility of multi-purpose projects where the water is used not only for power production, but also for irrigation. The benefits of such projects are multiple in nature, and the costs can therefore be attributed to the alternative uses. However, the exact division of the costs is a difficult question. An additional problem is due to the sometimes conflicting demand for the water, i.e., the farmer might want the water now for irrigation but the industrialists might require the water later for power.

The second general area is the explicit consideration of transmission and distribution costs for each plant. This is especially important for the determination of the size and location of power plants, since the transmission and distribution costs can be a major factor offsetting the economics of scale.

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APPENDIX

TIMING OF NUCLEAR AND HYDROPOWER PLANTS, AND CONSTRUCTION COSTS OF VARIOUS PLANT TYPES

TABLE XVII

TIMING OF NUCLEAR POWER

Construction Starts	Year in Service	Capacity in Service (MW)	Discount Rate	Availability of Budget
1979	1985	3755	8	100
1980	1986	4215		
1978	1984	3755	6	100
1980	1986	4215		
1978	1984	4064	4	100
1980	1986	4216		
1979	1985	3755	8	90
1980	1986	839		
1979	1985	1764	6	90
1980	1986	4216		
1979	1985	3121	4	90
1980	1986	4215		
1979	1985	1061	8	80
1980	1986	2065	6	80
1980	1986	3230	4	80

a. Inflation rate: 7 percent per year
b. Construction period: 6 years
c. Technical progress: 4 percent per year

TABLE XVIII

TIMING OF HYDRO-POWER

Construction Starts	Year in Service	Capacity in Service (MW)	Discount Rate	Availability of Budget
1977	1981	3027	8	100
1977	1981	3235	6	100
1977	1981	3235	4	100
1977	1981	1030	8	90
1977	1981	1355	6	90
1977	1981	1929	4	90

a. Inflation rate: 7 percent per year
b. Construction Period: 4 years

TABLE XIX

HYDRO-POWER PLANTS IN IRAN

Plant	Capacity (MW)	Cost ($/KW)
Farahnaz Pahlavi Dam	22.5	312
Arad Dam	22	298
Shahpoor Aval Dam	6	217
Shahbanoo Farah Dam	87.5	388
Shahabbass Kabir Dam	55.2	280
Reza Shah Kabir Dam	100	352

Source: Ministry of Water and Power. Annual Report, 1970-1973, Tehran, Iran.
Ministry of Energy, Annual Reports, 1974-1975, Tehran, Iran.

TABLE XX

GAS TURBINE POWER PLANTS IN IRAN

Plant	Capacity (MW)	Cost ($/KW)
Shiraz	60	105
Tabriz	30	85
Tehran	25	95
Bandar Abbas	50	102
Shiraz	45	85

Source: Ministry of Water and Power, Annual Report, 1970-1973, Tehran, Iran.
Ministry of Energy, Annual Reports, 1974, 1975, Tehran, Iran.

TABLE XXI

STEAM POWER PLANTS IN IRAN

Plant	Capacity (MW)	Cost ($/KW)
Manjil	240	208
Shahryar	624	312
Esfahan	120	376
Shahabad	37.5	122
Farahabad	272	182
Zarand	60	194
Ahvaz	145	167

Source: Ministry of Water and Power, Annual Report, 1970-1973, Tehran, Iran.
Ministry of Energy, Annual Report, 1974, 1975, Tehran, Iran.

TABLE XXII

NUCLEAR POWER PLANTS COMPLETED IN FRANCE AND GERMANY

Country	Plant	Type of Reactor*	Capacity (MW)	Cost ($/KW)
Germany	Gundremminegeni	BWR	250	486.4
Germany	Lingen KWL	BWR	268	408.27
France	Chooz Sena	PWR	325	250.5
Germany	Obrigheim KWO	PWR	345	368.69
Germany	Neckar GKN	PWR	805	347.82
Germany	Philippsburg 2	BWR	900	309
France	Fessenheim	PWR	925	325.65
France	Bugey 5	PWR	957	384.94
France	Bugey 3	PWR	957	331.78

*BWR = boiling water reactor.
PWR = pressurized water reactor.

Source: Nuclear Engineering International, January, 1975 (pp. 394-398).

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