THE ECONOMICS OF HYDRO-ELECTRIC POWER IN IRAN

Cyrus Ebrahimzadeh

The fast increase in the demand for household and industrial electricity in recent years, which is an outcome of the increase of the population, the expansion of urban centres, the rise in industrial incomes and the expansion of industrial investment, has caused a considerable shortage in electric power. Blackouts have become much more frequent especially in the period since the Second Development Plan. In order to eliminate this deficiency in the main consuming centres, the Plan Organization appropriated a large funds and, with the help of the local municipalities, succeeded in importing and installing thermal units which would provide the electrical requirements of some of these districts, reinforce already existing supplies in others, and create new power networks in still others. But apart from these measures, the great rivers of Iran have attracted attention for two reasons: firstly they could be used to secure water for domestic and agricultural purposes by harnessing the spring floods and preventing the wastage of billions of cubic metres of water every year the value of which, in a dry country like Iran, is much greater than gold; secondly they could provide reliable and low priced electricity for domestic and industrial purposes.

Thus a series of comprehensive studies were made, from both a financial and a technical standpoint, and these resulted in the formulation of projects for utilizing the waters of the Sefid Rud for Gilan, the Karaj river for Tehran, and the Karun for the province of Khuzestan. Contracts for building multi-purpose dams over the rivers were signed and billions of rials were spent in their completion.

In 1961 50,000 kilowatts of power reached Tehran from the Karaj dam but, despite the newly installed power plant at Tarasht, whose capacity is 50,000 kilowatts, Tehran was still short of electricity. Hence the planners of the

Sefid Rud dam decided to utilize it for supplying electricity to the central part of the country and for watering the Ghazvin plain. Preliminary steps were taken to install the steel towers and the Manjil - Tehran main line and it is estimated that within two months the Sefid Rud will also supply Tehran with 50,000 kilowatt hours of electricity. Apart from this, the Latian dam was finished at the beginning of the current year and it is intended to appropriate its 52 million kilowatt hours in order to ease the electricity shortage in Tehran. Despite all these efforts, and despite the fact that a large thermal power plant is being installed in the east of Tehran, it is felt that the danger of an electricity shortage will still persist.

The completion of the Dez dam in Khuzestan and the immense power it is expected to produce has brought about the idea of using this power to help Khorram Abad, Boroujerd, Kermanshah, Hamadan and Tehran. Last June the idea approached its realization and a contract for constructing a transmission line from Dez to Tehran was concluded.

In this article we will make an economic analysis of production in the hydro-electric power stations and will examine the problems of supply and demand and the cost of one kilowatt hour of hydro-electric power.

Karaj Dam

This dam, situated 63 kilometres north-west of Tehran on the Karaj — Chalus road, is built over the Karaj river. Its main purpose was to meet the water requirements of Tehran and her suburbs and, at the same time, to produce electric power for domestic and industrial consumption. The lake behind the dam is filled by the spring torrents which are gradually let out for Tehran's consumption. The height of the water behind the dam reaches its lowest limit in the middle of March. The Karaj river actually has two dams.The main one is curved on two sides, has a height of 180 metres from the river bed, and a spillway capacity of 1,450 cu. metres per second. The hydro-electric power plant is located in this dam. The electric turbines work mostly at peak hours (which are normally in the evening) but, since the water which is used to set these turbines in motion is not all consumed at this time, it is collected behind the other dam to be used the next day. This second dam is known as the "regulating" dam and its construction was only necessary because of the hydro-electric power plant. It is 50 metres high and its resevoir has a capacity of 850 thousand cubic metres.

In the power plant of the Karaj dam two groups of electric generating turbines have been installed. Their specifications are as follows:

Power of each turbine:	35,000 kilowatts
Speed of rotation:	333 R.P.M.
Height of fall of water:	147 metres
Maximum height of fall:	157 metres
Minimum height of fall:	78 metres

The average amount of electricity wich can be sold annually is about 150 million kilowatt hours.

The electricity obtained from the water of the Karaj dam is transferred to Tehran through a power transmission line 60 kilometres long. It is utilized in the Tarasht power plant (Alsthom) by the Tehran Regional Electricity Company and is distributed in the city. This line, which has a tension of 132 thousand volts, is stretched over 107 steel towers, the maximum distance between the towers being 990 metres. It has already been said that the electricity of the Karaj Dam is transmitted to Tehran during the early evening when consumption is at its peak. Thus, as the generating power changes proportionally with the height of the water in the resevoir, the minimum power production over a month will be 5 million kilowatt hours. Obviously the amount of electricity generated depends on the quantity of the water in the river and hence on the amount of rainfall but still, consulting engineers think that the Karaj Dam can produce an average of 150 million kilowatt hours per year. In some months (March to August) when the river water and the water consumption in Tehran are at their highest point, a greater amount of electricity can be produced. But unfortunately, since the Tehran power distribution network is incomplete, the Tehran Regional Electric Company cannot make the most of this surplus in production.

Early in 1962 contract for the sale of the electricity produced by the Dam was concluded with the Tehran Electricity Board. Its terms are as follows:

1. The first 60 kilowatt hours are to be sold at an average of 0.435 rials per kilowatt hour.

2. After the first 60 kilowatt hours, the electricity is to be sold at 0.36 rials per kilowatt hour.

As can be seen, the price of the electricity is comparatively low. The reason for this is that if the Tehran power plant were to utilise hydro-electric power, then it would have to stop its steam units because the power distribution network is not able to distribute the two types of power at the same time. This would involve great expenditure for the power plant. Steam turbines have to use fuel for some time to heat the water so that steam has to be produced before the turbines turn, whereas hydraulic turbines begin to generate as soon as the water are opened. The Tehran power plant did not turn off its steam turbines completely and could not, therefore, pay for the depreciation and operation of the steam turbines and at the same time buy the Karaj hydro-electric power in amounts equal to those it could produce in its own steam turbines. Therefore the price of the electricity supplied by the dam had to be cheap enough to encourage purchase on a large scale. However, efforts should have been made to fill the reservoir behind the dam with flood water so that surplus water would have passed through the generators making it unnecessary to open the flood gates. Tehran's water right is 60 million cubic metres per year and any quantity exceeding that limit is purchased by the Tehran Water Organization at 0.9 rials per cubic metre.

The construction costs of the Karaj Dam. The total costs of the Dam are 5,000 million rials of which 3,671 million rials have been spent on the main dam, overflow gates and other installations, and 1,329 million rials on power generation such as the construction of the regulating dam, the purchase and installation of turbines, the power transmission line, the steel tower supports, voltage transformers etc. If we want to look at this huge investment from the point of view of profitability then we can say that the Karaj water and Power Organization will certainly be unable to pay the installments on its depreciation because, by taking 2 per cent interest on capital and 100 years for depreciation, the annual installments for principal and interest will amount to 181 million rials. Now, in order to obtain such an amount, the Karaj Water and Power Organization would have to raise the price of its water and electricity and this is not practicable as, in that case, the cost of producing one cubic metre of water would be 1.3 rials.[1]

If we divide this investment into two parts, power and water, and depreciate the price of the power at 3 per cent over a period of 30 years, the selling rate of electric power produced by the Karaj Dam would be 0.95 rials.[2]

1. See the Report of the Karaj Water and Power Organisation (1963).
2. I bid. p.10.

In other words, the Karaj Water and Power Organization is, according to agreement, selling each kilowatt hour (cost 0 95 rials) at a loss of 0.6 rials (0.95 rials— 0.35 rials). If the annual average production is 150 million kilowatt hours, as the Water and Power Organization has claimed, then the loss each year will be 90 million rials and this figure does not include all the investment costs. Repairs, maintenance and operation have not been considered and we have undercalculated the interest of capital of this type by putting it at 3 per cent instead of the more usual 6 per cent.

However, in order to make an accurate economic analysis of the cost of investment in hydro-electric power, we must take into consideration the fact that the huge cost of the construction of the Karaj dam cannot be included. According to its planners and designers, no other site could have adequately provided the water supply needed by Tehran, so that even though it is an uneconomic project, it is a social necessity. Our attention is therefore focused on investment in the hydro-electric power plant alone which comes to total of 1,329 million rials. 1,145 rials relate to the generation of power and the erection of the regulation dam and 184 million rials to the purchase and installation of steel towers and a power transmission line.

The fixed annual cost, based on the percentage of investment in the former generating section will be:

Insurance, tax etc.	2.5%
Interest	6.0%
Depreciation	1.0%
Operation and maintenance	2.5%
Total	12%

1,145 x 12 ÷ 100 = 137. 4 (million rials)

In the power transmission section, the fixed annual cost is:

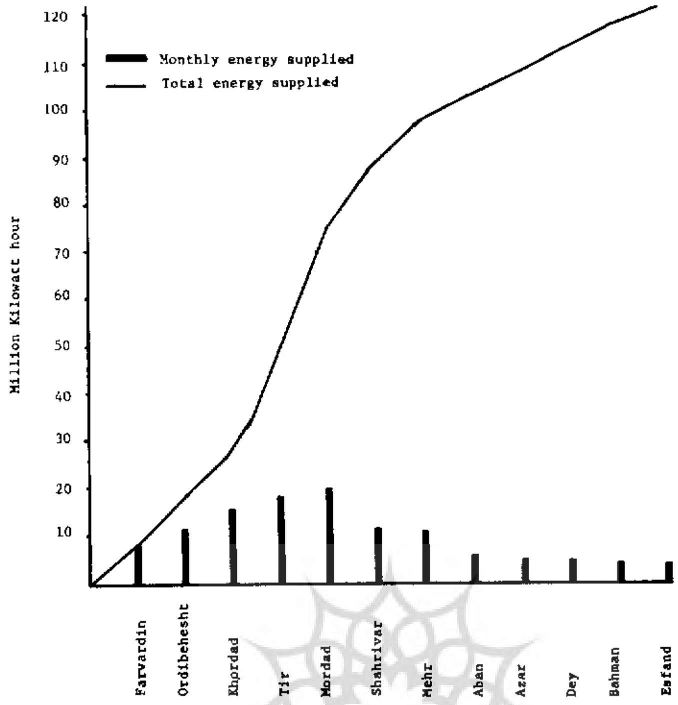
Interest	6.0%
Depreciation (33 years)	1.0%
Operation and maintenance	2.0%
Insurance, tax etc.	1.0%
	10.0%

Altogether 184 million rials has been spent on the power transmission section. Thus the fixed annual expenditure is as follows:

184 x 10 ÷ 100 = 18.4 (million rials).

137. 4 + 18.4 = 155.8 (total of both expenses in million rials).

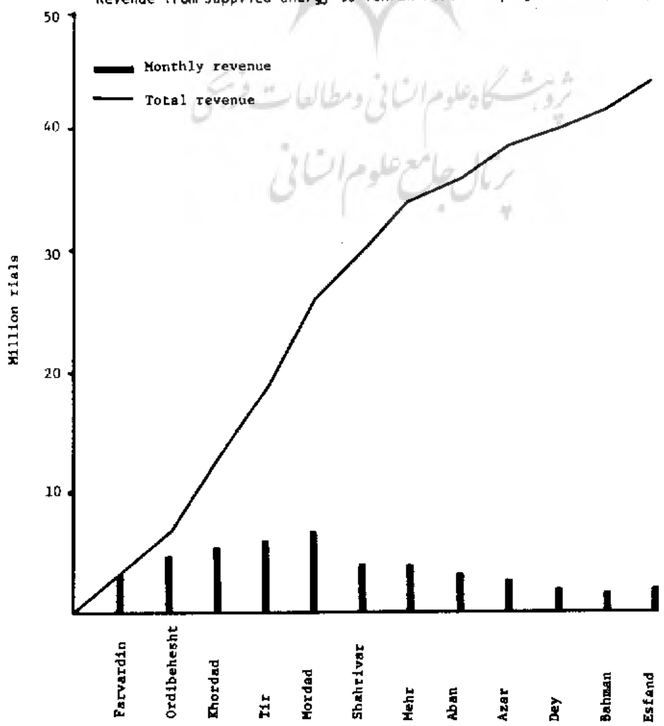
Energy supplied to Tehran Power Company in 1342(1963)



From the Report of the Karaj Water and Power Organization in 1342.

Figure 2

Revenue from supplied energy to Tehran Power Company in 1342(1963)



Thus the cost of producing 150 million kilowatts per year is 155.8 ÷ 150 = 1.5 rials. According to the agreement with the Tehran power plant this electricity is sold at an average of 0.35 rials per kilowatt hour hence the loss is 0.70 rials per kilowatt hour which comes to 105 million rials per year.

Even with this loss, if the dam could ensure the electricity supply of Tehran, it would be justifiable. But 150 million kilowatt hours is not enough to meet the shortage in the early evening hours. Let us see, therefore, if there is any way in which the consumption requirements of Tehran can be met without an annual loss or even with an annual profit.

Project for thermal power instead of hydro-electric power. We know that the consumption of electricity in Tehran is growing day by day but, despite the Karaj Dam project, this need has not been met and hydro-electric power has incurred heavy economic losses. The alternative would have been to develop thermal power instead of investing in the power section of the Karaj Dam. In principle there is no reason why investment should have been made in hydro-electric power before a study of its economics had been made. It would have been much more rational to have purchased two groups of steam turbines (with a power of 30,000 kilowatts each) instead of the hydro-electric turbines, and installed them in the south west of Tehran. The north east and the central part of the city are already well provided for by a turbine situated in Jaleh square and another situated in Tarasht which has a capacity of 50 million watts, so that new turbines situated in the south west could provide the needs of Mehrabad airport, industrial factories on the southern Karaj road, as well as the household consumption of the population of the south and south-west. In any case the turbines would provide 60,000 kilowatt hours each. The cost of purchasing and installing them would be 13,000 rials per kilowatt hour and would total 780 million rials.

The fixed annual cost, based on a percentage of investment and totalling 117 million rials would be divided as follows:

Interest	6%
30-year depreciation	1.5%
Cost of operation and maintenance	4.5%
Insurance, tax etc.	3.0%
	15%

If these two units worked an average of 7,000 hours per year, the amount of power produced from them would be 60,000 x 7,000 = 420 million kwh.

Assuming that the cost of the fuel had not been included in the exploitation and maintenance cost, given the price of fuel oil in Tehran, the cost of fuel to produce 1 kilowatt hour of electricity would be 0.22 rials. Therefore the price for 420 million kilowatt hours would be 92.4 million rials. The total fixed annual cost, together with the cost of fuel would therefore have been 209.4 million rials. To simplify the computation we shall consider this as 210 million rials.

Now let us see what the income from the sale of electric power produced by this method would be. The Regional Electricity Company sells electricity in the early evening hours at 2 to 2.5 rials per kilowatt hour. Suppose it were to sell at an even lower price, say 1.5 rials. In this case the sale of electricity would bring in 630 million rials and the yearly profit would be 420 million rials. Thus, had we bought thermal power instead of hydro- electric power, not only would a loss of 100 million rials a year have been avoided, but also a profit would have been made.

Comparison of the two projects. Low cost hydro-electric power is undoubtedly much better than thermal power at the same price because the hydro-electric power can be more easily utilized when required. It is enough just to turn on the water at the dam and the current will reach the consumers in a few seconds. But we have seen, unfortunately, that the electricity produced by the Karaj Dam is not at all cheap. The high cost of supplying drinking water and water for agricultural use to Tehran is reasonable as there might have been no alternative. The architects and consulting engineers are not to be blamed, even if they have failed to take the economic aspect into account, as Tehran was badly in need of water for industrial and domestic use. Also, although the dam was not built primarily for agricultural purposes, the harnessing of spring floods facilitate the distribution of water rights and to some extent causes an increase in agricultural productivity. But the question of extracting hydro-electric power, in relatively small quantities and only in the early evening hours from a dam which is small in comparison with the great dams of tbe world, is one that needed a great deal of contemplation.

In principle there is no reason why hydro-electric turbines should not be installed wherever a suitable dam is built. Obviously it is a very desirable aim both to supply needs and plentiful and cheap power by the same means, but unfortunately the Karaj Dam is not of the correct type. The planning engineers should not have installed turbines and a transmission line until such time as the economics of the venture had been worked out. A comparison of the Karaj Dam electricity and that produced by steam turbines raises the following points.

1. The expenses of electric installations in the Karaj Dam amounted to 1,329 million rials whereas the similar costs of installing two steam turbines would have been saved if the latter project had been carried out could have been used for other useful projects.

2. With all this heavy expenditure the average amount of electricity produced by the Karaj Dam is only 150 million kilowatt hours per year, whereas the proposed thermal power could produce 420 million kilowatt hours per year (3 times that of Karaj) and thus meet the greater part of our electrical requirements.

3. In view of this alternative we can only conclude that the use of hydro-electric power means an annual loss of about 100 million rials. The thermal power plant would have made a profit of 420 million rials each year so that the saving would actually have been 5,200 million rials. This amounts to more than the money spent on the whole of the Karaj Dam (3,671 million rials). The 30 years life span of the thermal turbines would yield, therefore, 15,600 million rials which could be used to depreciate the cost of constructing the Karaj Dam and build four similar dams across rivers in the South West of Iran without imposing on the budget of the Plan Organization or of the Ministry of Water and Power.

4. Not only is the electricity of the Karaj dam unavailable until the evening, but also, it is subject to the uncertainties of the amount of snow and rainfall. Thus it is unreliable and in dry years likely to be of little use.

5. The construction of the Karaj Dam took several years and its hydro-electric power was not available until its completion. If funds had been allocated to thermal power the turbines could have been installed and in use much earlier than 1961 (when the dam began to operate.)

6. The Karaj-Tehran transmission line is subject to the elements and at any time an earthquake, a flood, frost or a storm mean that Tehran's electricity could be cut off. The steam turbines, on the other hand, would have underground cables which are much more reliable.

7. Part of the power produced is lost as heat along the transmission line and while, at the beginning, this might seem insignificant, it would amount to several thousand kilowatt hours per year. We have not included the heat

losses (dissipated power) in the wire in our calculations.

Another proposal for lowering the price of electricity. We have already said that petroleum could be used to provide the power for steam turbines. We have also calculated that the cost of fuel for producing 420 million kilowatt hours of electricity per year would be 92 million rials. It would be a great saving to make use of the city garbage as a source of steam producing power. The population of Tehran city amounts to 300,000 households, each producing an average of one can of garbage per day. The 3,300 persons who officially work for the municipality as sweepers call every morning at the houses and shops and collect about 1,300 tons of garbage which they deposit at 432 places throughout the city. They then rent the garbage to those seeking paper, cardboard, bottles, scrap iron etc. and wait for the truck owners to come and take it out of the city. The truck owners, in order to sell the garbage at a high price to planters or owners of gardens, often go out of the city for some 80-90 kilometres on the Saveh-Qum highway. The proceeds of this sale go to the truck owners and not the municipality.

If we reckon that out of 1,300 tons of garbage some 100 tons is glass, rubber and scrap iron, there remains an average of 1,200 tons of garbage every day consisting of paper, cardboard, wood, packing material, boards, rags, fruit wastes etc. This could be burned to produce the steam needed for the turbines and since the quantity of garbage produced in a year is 432,000 tons (1,200x360), for each kilowatt hour we have more than one kilogram of garbage. The average heat obtained from burning one kilogram of garbage is 4,000 kilo-calories while the heat needed for producing one kilowatt hour of electricity is only 3,00 kilo-calories. Thus the advantage of using garbage over fuel oil can be summarized in the following manner:

1. The main advantage is that garbage has no cost as every day the municipality must collect the waste materials produced in the city. The existing trucks belonging to the municipality, and even the sweepers, could easily deliver the garbage to the furnace of the Tehran Regional Electricity Company.
2. The second advantage is that this is an inexhaustible source of fuel which will increase as the population of the town and their per capita income increases. Garbage is probably the only fuel whose supplies will not run out after a time.
3. If garbage were to be burned in this way a good contribution would be made to the sanitary conditions of the city especially since the rubbish

dumps are breeding rounds for mosquitos and other flies.

4. The renting of garbage by the chief sweepers is an ugly sight in the city and is a source of income for them alone. Furthermore it delays the transportation of garbage to the outskirts.

5. Every day the truck owners transport the garbage out of the city, sometime 90 kilometres away, but only after it has been lying around for days or weeks. Assuming that each truck can take an average of three tons of garbage, 4 times a day, 100 trucks will be transporting 1,200 tons on the roads every day. This means that 800 single journeys to and from the city are made every day and this causes considerable crowding, especially on the Qum-Saveh road. It also increases the danger of traffic accidents.

6. In 1967 the municipality signed a contract with a foreign country for 400 garbage carrying trucks. Had the suggested project been carried out these would have been unnecessary. Taking the purchase price of each truck as 400,000 rials, the total amount spent must have been 160 million rials.

7. If the garbage were burned to produce steam, an important by product would be ash which could be used as fertilizer. 200 tons of ashes could be obtained by burning each 1,200 tons of garbage and could be sold at 2 rials per kilogram giving a daily income of 400,000 rials to the Tehran Municipality. This would mean an income of 144 million rials per year which, over the thirty year depreciation period, would come to 4,320 million rials. This figure is, once more, greater than the construction cost of the Karaj Dam.

We are now in a position to calculate the total annual income that would have been gained if the steam-turbine project, using garbage for fuel, had been adopted instead of the Karaj Dam project.

1.	Difference in investment between hydro-electric and steam turbines:	549 million rials.
2.	Income from the sale of electricity from steam turbines:	420 million rials.
3.	Prevention of Annual Loss on Hydro-Electric Power:	100 million rials.
4.	Sale of ashes as fertilizer:	144 million rials.
5.	Economizing on the purchase of fuel oil:	92 million rials.
	Total annual income	1,305 million rials.

Sefid Rud Dam

The construction of the Sefid Rud dam, located 240 kilometres from Tehran on a rock gorge 200 metres thick, was completed in 1962. Behind the dam there is a reservoir of 56 square kilometres and in order to construct this, about 1,800 hectares of cultivable land has been submerged. The specifications of the dam are as follows:

Height	106 metres.
Capacity of the Reservoir	1,800 million cu. metres.
Useful capacity of the Reservoir	1,200 million cu. metres.
Length of the top of the dam	425 metres.

The total land area to be watered by the dam is 100,000 hectares. The cost of the dam in the irrigation section and that of the network including channels 2 and 3 varies in different publications. In one place it is put at 9,425.2 million rials,[1] in another at 8,850 million rials[2] while the Plan Organization has calculated the cost of construction of the main body of the dam, and the irrigation networks 1 and 2, at 8,290 million rials (without any power production installations).[3] If we add to this the cost of the third stage irrigation networks it would come to a total of 11,980 million rials. If we take this as a basis and add to it 6 per cent interest on fixed capital during the construction period, the total cost would come to about 14,930 million rials. This means that about 149,300 rials have been invested in the irrigation of one hectare of land. If we compute the annual fixed expenditure of this investment per hectare and deduct it from the value of the crops we will see that the ratio of capital to output is about 14:1 which does not seem to be very economical. However our task is not the economics of irrigation but an examination of the power production section of the dam. Thus our analysis will leave aside the costs of the construction of the dam and the irrigation channels and focus on the electric power section.

The power plant of the dam consists of two groups of 1,500 kilowatt turbines producing electricity for Gilan. The specifications are as follows:

1. For the specifications of the Sefid Rud dam and its economic aspects, see the publication of the Ministry of Water and Power, Aban 1343, p.33.
2. Mansur Rouhani: *The Distribution of the Water Resources of Iran: Difficulties and Solutions*. Bahman 1342, p.26.
3. An Economic Analysis of the Sefid Rud Dam, Plan Organization, Planning Office, Khordad 1343, Table 1.

Type of Turbines: Francis vertical:	300 R.P.M.
Maximum power of each turbine:	24,500 H.P.
Electrical power for Rasht and Pahlavi:	35,000 kilowatts.
Nominal height of fall of water:	63 metres.
Water required for producing 17,500 kilowatts in each turbine:	29 cu. metres per second.

The electricity production is divided into two parts. 2 turbines produce for Gilan and another 3 for the Ghazvin Plain and Tehran. The transmission line.for Rasht and Pahlavi, with a tension of 132,000 volts,sends 35,000 kilowatts to Gilan; that of the Ghazvin plain, whose tension is 220,000 volts transmits about 50,000 kilowatts to Tehran and Ghazvin. Our primary object is to study the economics of the high pressure line to Ghazvin and Tehran, however we will also include a study of the power transmitted to Gilan.

If there were to be a drought like the one of Autumn 1951, the reserve water and its height behind the dam would go down and the minimum height of water can only produce 100,000 kilowatt hours every day. The transmission of 100,000 kilowatt hours to Rasht and Pahlavi means that about 5,000 would be destroyed through heat loss in the transmission line i.e. only 95,000 kilowatt hours would be transmitted to Gilan every day whereas the actual consumption is about 123,000 kilowatt hours per day.In other words, the minimum water level can meet only 76 per cent of the needs of the population and the other 24 per cent has to be provided by thermal power.

Cost of generation of electric power by the Sefid Rud. We have already said that 2 groups of turbines have been purchased and installed for transmitting power to Rasht and Pahlavi at a cost of 1,150 million rials. If we take the fixed annual cost of this investment to be 12 per cent like the Karaj Dam, the annual expenditure would be 138 million rials. The cost of transmission of power to Gilan is 300 million rials, the fixed annual cost of which, at 10 per cent of the investment, would be 30 million rials. The total cost of production and transmission would therefore be 168 million rials. As the irrigation season is mid March to mid August, and during this period there is a flow of water through the aqueducts, it is in these months that electricity is generated. The production of power over these 5 months is 130.2 million kilowatt hours. Fortunately it is in this period that the rural population needs a great deal of electricity to operate its pumps. In the evening the power is used for household purposes and after midnight for irrigation purposes. Quite obviously in non-irrigation hours the dam is unable to help peak period requirements in Rasht and Pahlavi and here too there is a need for thermal power. The dam itself does not permanently supply Rasht and Pahlavi. During the irrigation period the increase in rural consumption means that the power is completely used up, and, during the other months of the year, the full power is required for only a few hours a day at peak periods. Thus the power produced during the irrigation period is good only for a few hours.

If the suction pumps pull the water up from a depth of 2 metres and operate up to a radius of 30 metres, the power needed for irrigating one square kilometre would be 250,000 kilowatt hours i.e. a minimum of 75 million kilowatt hours per year for 300 square kilometres. In years of drought, production is half the amount, i.e. 38 million kilowatt hours. Let us suppose that there has been no drought and that 130.2 million kilowatt hours has been produced during the whole irrigation period. To be more conservative we will suppose that in the other months of the year another 38 million kilowatt hours has been produced.This makes the total power produced about 168 million kilowatts hours per year. If we divide this into the fixed annual cost,the cost of producing 1 kilowatt hour would be about 1 rial. This is somewhat expensive since it is about 5 times the selling price of 1 kilowatt hour of hydro-electric power generated at one of the U.S. dams.[1] If thermal power had been in Rasht instead of hydro-electric power, the position would have been as follows:

Power production:	35,000x7,000=245 million kwh.
Investment cost of this production:	35,000x13,000=455 million rials.
Fixed annual cost (on a 15% basis):	455x15÷100=68.25 million rials.
Cost of fuel at 0.3 rials per kilowatt hour:	245x0.3=73.5 million rials.
Sum of the two costs:	73.5+68.25=141.75 million rials.
Difference between the annual expenditure on hydro-electric and thermal power:	168 ÷ 141.75=26.25 million rials.

In other words, if instead of hydro-electric power we had used equivalent thermal power, then:

1. The production of power would be 245 million kilowatt hours per year instead of 168 million.

1. The Bonneville Dam.

2. The saving would have been 26 million rials. Despite this we are of the opinion that the transmission of hydro-electric power to Gilan is justifiable. What we are really interested in is the other line to Ghazvin and Tehran.

We have said that the water required for producing 17,500 kilowatts of electricity in each turbine is 29 cubic metres per second, Now, should all the 5 groups of turbines work, the result would be:

5 x 29 = 145 cu. metres.

in one hour this would come to:

60 x 60 x 145 = 522,000 cu. metres.

If we compute the number of hours of power production in a year as only 7,000 the result would be: 522,000x7000=3,654 million cubic metres. In other words, if we wanted to produce electricity f-r 7,000 hours (290 days) we would need 3,654 million cubic metres of water. This is not possible since the maximum capacity of the Sefid Rud Dam is 1,800 million cubic metres and its useful capacity 1,200 million cubic metres i.e.$\frac{1}{3}$ of the capacity needed. If the 5 turbines of the Dam were to work together the water of the Dam would be sufficient for only 97 days electricity production. Suppose that instead there were enough water to produce electricity for 155 instead of 97 days. In this situation 3 groups of turbines would supply 195.3 million kilowatt hours to Tehran of which 10 per cent would be lost on the way.

The cost of purchase and installation of three hydro-electric turbines is about 1,300 million rials. The cost of the power transmission line from Manjil to Tehran is 480 million rials. The fixed annual cost of investment for producing the power on the basis of 12 per cent is: 1,300 x 12 ÷ 100 = 156 million rials. The fixed annual cost of the power transmission line is 480 x 10 ÷ 100 = 48 million rials. Therefore, the total fixed annual cost is 204 million rials which means that the cost of producing one kilowatt hour of electricity for Tehran is 204 ÷ 176 = 1.16 rials. The excessive cost of such electricity can be better understood when it is compared with thermal power produced in some areas of the United States and sold at one fifth of this price (i.e. at about 5 shahis).

If, instead of bringing hydro-electric power 240 kilometres to Tehran and the Ghazvin plain, two steam turbines, each with a capacity of 25,000 kilowatts, had been purchased for Ghazvin the costs would have been as follows:

Purchasing costs of the turbines:	25,000x2x13000=650 million rials.
Fixed annual costs at 15% investment:	650x15÷100=97.5 million rials.

Amount of electricity generated in 7,000 hours	7,000x5,0000=350 million kwh. hours.
Cost of fuel at 0.25 rials per kwh.	350x0.25=87.5 million rials.
Total annual expenditure	97.5+87.5=185 million rials.
Cost price of electricity at Ghazvin	185 ÷ 350=0.53 rials.

If each kilowatt of electricity produced in this way were sold at the cost price of one kilowatt hour of the hydro-electric power of the dam, the profit would be 0.63 rials per kilowatt hour which adds up to 220.5 million rials of profit per year. Over the 30 years depreciation period of the thermal turbines the profit would be 6,615 million rials. This is roughly twice the construction cost of the Karaj dam and is no insignificant amount.

Latian Dam

This dam has been built on the Jajrood river to the north-east of Tehran. It started operations in April 1966. Its specifications are as follows:

Height	104 metres.
Capacity of the Reservoir	95 million cu. metres.
Useful capacity of the Reservoir	85 million cu. metres.
Present electricity production	2 x 18000 kilowatts.
Maximum possible annual production	72.4 million kilowatt hours.

The main aim of building this dam was to supply Tehran with water and its creation overshadows purely economic considerations. Moreover it is, comparatively speaking, a small dam; a useful capacity of 85 million cubic metres makes it one thirty-sixth the size of the Dez Dam and one three hundred and sixtieth the size of the U.S. Hoover Dam. If the amount of water the dam holds were to be compared with the annual production of oil from Iranian wells it comes to far less.

We will, therefore, leave aside considerations of the construction cost of the dam and concentrate upon its electric power. At present only one hydro-electric turbine is working but, if a second unit were to be installed, the total annual production of the dam would be 72.5 million kilowatts(about half the level of the production of the Karaj Dam). At present only 51 million kilowatt hours are produced. The costs of producing one kilowatt hour are as follows:[1]

1. Publication of the Ministry of Water and Power, Ordibehesht 1343.

Purchase and installation of turbine:	460 million rials.
Power transmission line:	40 million rials.
Fixed annual expenditure on purchase and installation at 12%	55.2 million rials.
Fixed annual transmission cost at 10%:	4 million rials.
Total fixed annual cost:	59.2 million rials.

Since the total annual production is 51 million kilowatt hours, the cost of one kilowatt hour will be 1.16 rials which is one quarter higher than the cost of Karaj electricity and 7 times higher than the cost of one kilowatt hour of electricity produced by the Bonneville Dam in Oregon U.S.A.

If this electricity were sold to the Tehran Power Organization at 0.66 rials (twice the price of the Karaj Dam electricity), the loss would be 0.5 rials per kilowatt hour, which amounts to an annual loss of 25.5 million rials.

An Economic Analysis of the Hydro-electric Power of the Pahlavi Dam

This is the largest dam in Iran and is situated in Khuzestan.

Particulars of the Dam. The Dam is situated several kilometres lower down from the confluence of the Bakhtiari and Marbarreh streams on the Dez river. Its specifications are as follows:

Height:	203 metres.
Capacity of the reservoir:	$3\frac{1}{3}$ billion cu. metres.
Surface of the reservoir:	6,300 hectares.
Length of the reservoir:	60 kilometres.
Electricity production:	130 million watts.
Maximum capacity for electricity production:	520 million watts.
Power of turbines:	110,000 H.P., 250 rotations per minute.

The canal leading to the turbines is 138 metres long with a diameter of 4 metres and a flow capacity of 60 cubic metres per second to produce maximum power from any one unit. High tension lines from the dam to Ahwaz have a voltage of 230 thousand from Ahwaz to Khorramshahr and Abadan, a voltage of 132 thousands and in the feeder lines, a voltage of 33 thousand. The length of these lines is about 400 kilometres.

The hydro-electric power of the Dam supplies the cities of Abadan,Khorramshahr, Dezful, Ahwaz, Andimeshk and Shoush. Before the construction of the dam the electric power for these major centres of consumption was supplied by the oil refinery at Abadan which posseses one of the most powerful and best equipped thermal power stations in Iran. It generated 130 thousand kilowatts of electricity annually, an amount equal to that produced by the dam. This power not only met the industrial requirements of the refinery itself but also those of Abadan, Ahwaz and Khorramshahr. Since the steam turbines were installed a long time ago (except for one new 40,000 kilowatt unit), the cost of investment had by and large depreciated, the production costs were low, and power was sold very cheaply to the municipalities of the region. Apart from this, fuel costs were nil because gas, an otherwise useless by product of petroleum refinement, was used. To supplement this, natural gas was taken by pipeline to the refinery from Aghajari. Since the depreciation cost of the pipeline had expired this gas was also virtually free.

After the turbines had been installed in the dam the Khuzestan Water and Power Organization undertook the distribution of hydro-electric power to cities which had formerly been supplied by the turbines of the refinery. It even entered into negotiations with the Oil Consortium to stop their own thermal turbines and use the power produced by the dam. However, the Consortium has not yet given a positive reply since its own turbines produce at a much lower cost than those of the dam.

For transmitting the power of the dam a distance of 400 kilometres, a new transmission line has been constructed with seventeen major stations and substations along the route to the consumption centres.

Production capacity of the dam. According to Figure 3, shown in a publication of the Khuzestan Water and Power Organization, the electricity produced by the Dam in 1963 (first year of its operation) was 11 million kilowatt hours. In 1964 this figure rose to 17 million. Had this figure not been published by the Water and Power Organization itself, one might have thought that there had been an error.. Even if one of the turbines had worked with a load coefficient of 25 per cent, it must have produced more than 140 million kilowatt hours. It therefore appears that during the first and even the second year, only one turbine has worked for only two hours a day. Otherwise, if a 65,000 kilowatt turbine worked for two hours a day, it would produce more than 46 million kilowatt hours. It is therefore certain that one of the two turbine units installed at the Dam has been continuously idel. If production was increased by 100 per cent in 1965 (which is impossible), this would only have come to 34 million kilowatt hours. The same increase in 1966 would have resulted in an annual production of 68 million kilowatt hours or one-third of the production of the Karaj Dam. This low level of production can be accounted for by the fact that Khuzestan has no industrial centre to consume the electricity except the Oil Refinery. This, and the fact that such a large increase in demand for electricity could only take place if there was a very large increase in per capita income, makes these figures somewhat ephemeral. Nevertheless we will suppose that there has been a four-fold demand and see what the cost of producing electricity would be on this generous basis.

Calculation of the cost of power production. We have already noted that two hydro-electric turbine units, each having a capacity of 65 thousand kilowatts, have been installed at the dam. The value of these is 1,530 million rials. The cost of transferring power from the Dam to Ahwaz, Abadan and Khorramshahr is 1,110 million rials. [1] On the basis of a 12 per cent investment cost, the fixed annual cost of the two sets of turbines would be 183.6 million rials. On the same basis the annual fixed cost of the transmission line would be 111 million rials. The total of the two costs per year would be 294.6 million rials.

According to a publication of the Khuzestan Water and Power Organization, the price of Khuzestan electricity is the lowest in the history of electric power in Iran and is currently the lowest in this part of the world.[2] According to Figure 3 we mentioned above, the production of electricity in 1963 amounted to 11 million kilowatts. Hence, the cost of production of one kilowatt hour in the same year was 294.6 ÷ 11 = 26.8 rials. It seems that no more expensive electricity has ever been produced in the world. The cost of one kilowatt hour of Khuzestan electricity is twenty-two times the price of the industrial power offered by the Tehran Power Organization and still, the electricity produced for industry in Tehran is among the most expensive in the world. Obviously, at that price, the electricity would not be bought. Therefore, the Khuzestan Water and Power Organization, with a view to encouraging applicants for the consumption of their hydro-electric power, have prepared a tariff table which shows the monthly rates for electricity as follows:

---

1. Mansour Rouhani opcit.
2. Report on the activities of the Khuzestan Water and Power Organization.

Power services for small public premises:

Price of monthly consumption for the first 300 kilowatt hours: 2.5 rials per kwh.

Price of monthly consumption upward of 700 kilowatt hours: 2 rials per kwh.

Price of monthly consumption upward of 3,000 kilowatt hours: 1.2 rials per kwh.

Large consumption services (40-50,000 kilowatt hours per month):

Price of monthly consumption for the first 25,000 kilowatt hours: 0.9 rials per kwh.

Price of monthly consumption upward of 975,000 kilowatt hours: 0.7 rials per kwh.

Price of monthly consumption upward of 1,000,000 kilowatt hours: 0.5 rials per kwh.

The latter part of this tariff (for consumption above a million kilowatt hours) is only for very large factories which do not, at present, exist in Khuzestan. In order to stick close to reality let us consider the power consumption of small public premises of 3,000 kilowatts upwards because this covers ordinary establishments and small factories. The rate we are considering is 1.2 rials per kilowatt hour. Our calculation (for 1963 when the production was 11 million kilowatt hours) will deduct the cost price from the sale proceeds and multiply it by the annual production.

26.8 - 1.2 = 25.4 loss per kwh.

25.6 x 11 = 281.6 million rials loss per year in 1963.

In order to determine the cost price of one kilowatt in 1964, we divide the total annual fixed cost by the amount of production.

294.6 ÷ 17 = 17.33 Cost price of one kwh. in 1964.

17.33 ÷ 1.2 = 16.13 Loss on one kwh.

16.13 x 17 = 274.21 Million rials loss in 1964.

Taking the production in 1965 as twice that of 1964,i.e. 34 million kilowatt hours, the losses would be as follows:

294. 7 ÷ 34 = 8.66 rials. Cost price of one kwh. in 1965.

8.66 -1.2 = 7.46 Loss on one kwh.

7.46 x 34 = 253.64 Probable loss in 1965.

We are presuming that our assumption of the amouut of power produced in 1964 is close to reality since, according to Figure 4 published by the Khuzestan Water and Power Organization, the total number of electricity consumers in that year was 54,000. If we suppose that each Khuzestani client consumed as much electricity in 1965 as did each Tehrani in 1967 (and this is generous as the per capita consumption of electricity in Tehran is much higher than that in the provinces), this, according to the Plan Organization's figure for Tehran, would be 560 watts. By the end of the Third Plan the total consumption figure would be:

560 x 54,000 = 30.24 million kilowatt hours, which is a little less than the figure we had assumed. In any case, the definite minimum loss in the years 1963 and 1964 is:

281.6 x 274.21 = 555.81 million rials.

Thus, during its two years of operation, the Dez Dam has lost a little over 550 million rials. Without question only one of the two turbines has been working for only a few hours a day and this fact is completely contrary to the Plan Organization's calculation which reads: 'An estimate of consumption shows that it is necessary to install generator No. 3 of the dam before the beginning of the year 1966. If we allow for two years for its manufacture and installation an order should be placed for it in the second year of the Third Plan.' As we have seen, by the end of 1965, not even one of the two turbines was working continuously. Moreover, if we take the loss in the year 1965 to be 250 million rials, the total loss over the period of four years in which the Dam has been operating comes to 1,059.45 million rials. Such a loss would lead us to conclude that the construction of the dam's power station has not been based on rational economic calculations or that, at the very least, its construction has been premature.

Some may argue, that, despite these figures, the losses sustained by the electric power section of the dam are compensated for by the sale of water for irrigation purposes and that any consideration of the economics of the dam should take this into account. However, given that this argument is correct, we would still maintain that there is no reason why we should lose by producing electricity at a cost of 10 rials per kilowatt hour and compensate for this loss by profits made in another section of the dam. A further objection to our argument is that Khuzestan could develop into the most important industrial centre in Iran. This is perfectly true; it has ample petroleum and rivers and railways provide easy access to ports. Already agreements have been concluded for the installation of aluminium and petro-chemical inudstries and these especially need ample supplies of low cost electric power. Still, we would argue that, despite the fact that plentiful supplies of electricity would encourage industrial investment in the region, and despite the fact that, if the power station of the Dez Dam were used to its full capacity, electricity could have been provided by other cheaper means. So as long as Khuzestan province is unable to absorb at least one-third of the final established power, hydro-electric power will be a losing bargain.

Perhaps the best way to have prevented the present losses from the power section of the Dam would have been to postpone the purchase and installation of the two turbines and the step-up transformers until such a time as important factories were built and the demand for power in the province increased. Transitional needs could have been catered for by the thermal power unit of the Oil Refinery which, with its established power of 130,000 kilowatts, could supply all the present requirements of the thickly populated areas of Khuzestan. If the erection of a few factories were to cause a rise in public demand, this could have been met by the installation of two thermal turbines of 30,000 kilowatts each in Ahwaz.

Of course, the main objection to thermal power when hydro-electric power can be made available, is the cost of the fuel needed to produce it. As a general rule this objection is correct but it does not hold for Khuzestan. Here, where oil is abundant, there would be no loss at all if thermal power were to replace hydro-electric power. However, some may say that it is stupid to convert petroleum into heat and electricity when it has a good market abroad and gain this is true. But we do not propose that petroleum should be used to produce thermal power because an even cheaper alternative is its by-product, natural gas. At present most of the billions of cubic feet of natural gas produced in the province is burnt out. In 1964 the Oil Operating Companies produced 412,958.05 millions of cubic feet of which 291,158.85 was burned. In the same year the National Iranian Oil Company produced 2,483 million cubic feet of which 1,797.63 million cubic feet was burned. The total amount of gas burned was therefore 292,956.48 million cubic feet or, in metric account, 8,370 million cubic metres. This is two and a half the volume of water stored behind the Dez Dam. With 1/10th of this amount of gas we could produce 2100 million kilowatt hours of electricity per year, which is equal to 70 times the amount of hydro-electric power produced by the Dez Dam in 1963 and 1964 or about half the hydro-electric power produced in France in 1963 (43.4 billion kilowatt hours). The posession of such a cheap fuel lowers the costs of operating and maintaining thermal units, especially if these are installed in consumption centres and involve no expenditure on power transmission lines, so much for the amount of power produced, now let us see what the difference is from the standpoint of investment.

The purchase of two thermal turbine units with a capacity of 60,000 kilowatts would cost only 780 million rials, whereas the cost of investment at the Dez Dam power section is as follows: the purchase and installation of turbines, 1,530 million rials; the cost of metal installations and a power transmission line, 1,110 million rials; total cost 2,640 million rials. The difference between the two investments is 1,860 million rials. However the Dez Dam has two hydro-electric units, each having a power of 65,000 kilowatts making a total capacity of 130,000 kilowatts hours, whereas the power station of the Oil Refinery has a capacity of 130,000 kilowatts and the turbines we proposed for Ahwaz would have a capacity of 60,000 kilowatts making a total of 130,000 kilowatts of thermal power. Thus we would have invested 1,860 million rials less and had an extra capacity of 60,000 kilowatts if we had decided on thermal power. The advantages of this project over the use of the Dez hydro-electric power in the first few years of operation would be:

1. We would have avoided a loss on hydro-electric power of 250 million rials a year.
2. We would have curtailed our investment by 1,860 million rials.
3. Interest on this excessive investment, at 6 per cent a year is 111 million rials. This, had the thermal power project been followed, would not have been imposed on the country's budget.
4. We would have utilised a good part of our national wealth, natural gas, which is at present burned.
5. The cost of production of one kilowatt hour of thermal power would have been less than the cost of hydro-electric power as the installments on the Refinery's steam turbines, as well as those on the gas pipeline to Abadan, have already been depreciated and no further expenses in this respect are involved.

Providing drinking water from the savings on the cost of electricity. We have already implied that the main reason for the great losses sustained by the Dez power station is the failure to wait for a reasonable demand for electricity in the Khuzestan Province. Instead two generating units were prematurely installed together with a high tension transmission line and then, after that, customers were sought for. With the hope of finding consumers in rural areas extension lines were given to villages along the main transmission line and an exhibition of electrical appliances was held in Ahwaz in order to encourage the use of these. It never occured to the authorities involved that the villagers in Khuzestan did not have an adequate income to buy electricity and that the consumption of one bulb in a rural household is not enough to justify the cost of distributing power to the villages. Farmers who were hitherto making use of moonlight are now economising on the consumption of electricity in their own home by sitting under the street lights at night. In fact this practice has become so widespread that the Khuzestan Water and Power Organization has had to put out the street lights in villages in order to compell the people to use the electric current in their own homes. Still, even if the electric lights on the village road were always burning and the people used their own light throughout the night, the consumption would not be enough to meet even the wiring costs let alone the depreciation costs of a huge turbine.

There is no doubt that if we had waited for a few years the demand for electricity in Khuzestan would have risen to such an extent that the Oil Refinery's turbines would have been inadequate. In this situation the dam's hydro-electric power might even have made a profit. The high level of production demanded would have reduced the cost of each kilowatt hour and even the Refinery would, at this point have applied to use the dam's electricity.

In any case the loss sustained in the first four years of operation is so heavy that, had it been avoided, a project for providing drinking water for several cities on the southern coast could have been financed. One city which needs a permanent and reliable source of drinking water is Bandar Abbas. With the implementation of large scale projects, such as the construction of jetties and first class roads, Bandar Abbas will soon be faced with the problem of an increase in population. At present its supplies of drinking water are inadequate. The inhabitants make use of deep wells dug in the district of Isin but there is always a danger that these will run out of water. If this were to happen, a city of 35,000 people which expects an influx of population from outside, would be faced with an acute problem.

Thus, studying the possibilities of constructing a dam on the Minab River, the merits of installing a plant to desalinate sea water should be considered. Probably one multi-effect water-distilling plant with a capacity of 16,000 cubic metres of water per day would ensure the water supply of Bandar Abbas for at least ten years. According to the 1966 census, the population of this port is 34,588. If the inflow of people from neighbouring towns and villages were to increase the population four times, the proposed desalination plant would be able to supply the public with its water requirements. 16,000 cubic metres of water per day amounts to 1.6 million litres. If we were to assume that the daily average per capita consumption would be 100 litres (the average per capita consumption in Tehran), there would be sufficient water for a population of 150,000.

The initial fuel for such a plant would be petroleum which, with the construction of the Bandar Abbas jetty, could be shipped from Bandar Mah-Shahr or Khark. In the same way the oil requirements of Bandar Abbas and of the coastal regions would also be supplied at a low price.

The cost of investing in one desalinating plant with a capacity of 16,000 cubic metres per day would be about 300 million rials. Should we take the annual fixed cost of this investment to be 15 per cent, it would cost 45 million rials per annum, i.e. each cubic metre of its water would cost about 8 to 10 rials. It is true that this is rather more expensive than the usual rate, but as already stated, all government activities are not based on material profit. Karaj Dam is a good example of a project undertaken to supply Tehran with drinking water whose economic aspect is of secondary importance.

If we were to install a water desalinating plant of 4,000 cubic metres capacity for Govatar, Chahbehar, Jask, Lingeh and Charak, the water required by the inhabitants of these ports would be ensured. The total cost of these five units would be about 420 million rials. Further four units with a capacity 1,200 cubic metres per unit installed in the islands of Hormoz, Gheshm, Larak and Lavan would cost 200 million rials. At present these islands largely lack drinking water that of Hormoz, for example, being shipped from Bandar Abbas which is itself short of this commodity.

The total investment cost of these 10 desalinating units is as follows:

300 + 420 + 200 = 920 million rials.

Thus, by economizing on the cost of the Dez dam, the country could have provided all the drinking water requirements for 6 ports and cities on the southern coast and 4 islands in the Persian Gulf.

If in the planning of power stations and hydro-electric power, the experts concerned had taken account of some of the difficulties mentioned above many losses would have been avoided, projects would have been completed much sooner and capital returns much more quickly realised. Finally, the income obtained from such projects would enable us to lay the foundation for other projects and to take longer steps towards economic development. This article cannot remedy the defects of what has already been carried out but, if it serves as a warning for future economic projects, then its main purpose has been achieved.