UNITED NATIONS

ECONOMIC
AND
SOCIAL COUNCIL

E

LIMITED

ST/ECLA/CONF.7/L.2.1
25 June 1961

ENGLISH
ORIGINAL: SPANISH

LATIN AMERICAN ELECTRIC POWER SEMINAR

Held under the joint auspices of the Economic Commission for Latin America, the Bureau of Technical Assistance Operations and the Resources and Transport Economics Branch of the United Nations, with the collaboration of the Government of the United Mexican States

Mexico City, 31 July to 12 August 1961

ECONOMIC CRITERIA FOR THE SELECTION AND DEVELOPMENT OF POWER STATIONS AND ELECTRICITY SYSTEMS

presented by

Raúl Saez

Note: This text is subject to technical and editorial revision.

CONTENTS

/(c) Interconnected

/SUMMARY

SUMMARY

1. Energy is a basic factor for a country's economic development. Consumption increases steadily and rapidly even in the most developed countries, and this growth is more rapid for the more complex forms of energy. Considerable capital is required for investment in the energy sector - never less than 12 per cent of the national investment total. The direct contribution of energy to the gross national product is small; it is important because it is a vital influence in the development of other productive activities, of transport and of social conditions. In other words, the development of the energy sector is closely related to the progress and nature of other economic activities.

2. Electricity represents 24.2 per cent of the world energy sector, but because of its multiple applications its growth is more rapid than that of other forms. Consequently investment in electricity represents between 50 and 70 per cent of the total for the energy sector. Electricity is closely related to other forms of energy because it competes with them, and because it can be generated from any large source of primary or secondary energy. When the possibilities of competing and the primary sources for generating electricity are surveyed, supply conditions and costs for the latter should also be studied to determine both the future reliability of supply and price stability, since prices may be distorted by many temporary measures of political economy. This point is well illustrated by the situation with respect to coal in Chile and Peru, and to coal and petroleum in Argentina.

In view of the increasing interdependence of the various sources of energy, it is advisable to entrust to a single authority the responsibility of formulating a consistent and stable energy policy that will not take account of temporary distortions.

3. Generally speaking the aim of economic analysis is to ensure that the available resources are used to achieve the maximum benefit. The problem is to determine what this is, since in the case of electricity systems the plant has to be designed far in advance and must produce its yield over a long period.

/There are

There are many factors that may be described as external to the project but which influence the level of the ensuing benefits and the manner of determining them. These factors include:

(a) The ownership of the electricity company. If it is a private company it must be bound by the income and expenditure shown on its balance sheet, and strive to attain the maximum direct profits. A public undertaking, on the other hand, must consider not only the direct return on its investment, but also the social or indirect effects. The indirect benefits would include, for example, economies in foreign exchange through the use of domestic instead of imported fuels, any increase in employment or economic activity resulting from the use of such fuels, the multiple purposes that an engineering project can serve, etc. This point is illustrated by the case of the Hell's Canyon project in the United States, the study of which led to the proposal of two different plans according to who was to undertake the work.

(b) Profitability and the economic cost of money. The cost of money has a direct influence on any comparison of alternatives. For a private enterprise this cost would be the value at which the money could be obtained in the capital market; for a public enterprise it is difficult to estimate the cost, especially if the allocation of funds has to be made on the basis of comparing electricity investment with other forms of public investment that usually produce only indirect benefits difficult to quantify. For a public electricity undertaking the legal interest established in the regulations governing the tariff can be used for this purpose, but it is suggested that if there is a great difference between this value and the interest rate in the market for private capital, a value between the two figures should be used as the maximum.

(c) Rates and tariffs. These influence not only the direct yield on capital, but also the whole development of the service, since they can influence consumption. Studies carried out in a number of countries have shown that there is considerable elasticity in the electricity service; in some cases this depends on the price of electrical appliances, and in others on the price of electricity and on how this price varies during the day or during the year.

(d) Lastly, there is another set of considerations that also affects the economic criteria on which the decision is based. These include (i) shortage of funds, which makes it necessary to choose the alternatives that are the least capital-intensive; (ii) an urgent need for the service, which in cases of electricity rationing strongly influences the decision, and (iii) economy of foreign exchange.

4. The development of electricity in Latin America is hampered by three basic shortages: lack of basic data, shortage of technical staff and limited funds. These limitations mean that priorities must be assigned in development. One criterion for priority would be the availability of an abundance of basic data to facilitate estimates of present and future demand and the natural resources available for supplying power, The criteria governing priority in the nationalized undertakings are defined in the directives approved by the higher authorities of the country, at the time when the enterprise was established or from time to time; however, there is still a considerable weight of responsibility left to the enterprise itself. There must be a distinction between the supply of power for convenience, or for social purposes, and supply for productivity, for production purposes. An appropriate decision with respect to one of these categories of power can provide a useful guide in establishing priorities.

5. (a) Complex methods for the comparative analysis of alternatives can only apply when the information used has the same degree of accuracy as that which it is hoped to attain by these methods. There is a widespread lack of sound basic data in Latin America for the study of various possible alternatives; consequently, in selecting the most appropriate hydroelectric formula simple quantitative estimates and qualitative evaluations are to be preferred. There should be a detailed comparison between this formula and the possible steam or diesel alternatives. The available technical staff should concentrate on working out a detailed plan of the project

/decided upon

decided upon rather than on a full discussion of the various possible alternatives. Nevertheless, for the large Latin American systems that already represent about one million kW a brief recourse to more detailed comparative methods is called for.

(b) When an electricity system has already attained a certain size the comparison is aimed at deciding not on one plant, but on a complex of structures to be completed within the period of the programme. Comparison between various alternative groups of plants calls for an accurate estimate of future consumption. Programming makes it possible to concentrate efforts on collecting basic data for the projects most likely to be undertaken, and thus avoid having to take hasty decisions under pressure of urgent consumer needs.

(c) There are characteristic variations in consumption during the course of the year and throughout the day. As electricity is a product that cannot be stored, it must be generated in accordance with changes in consumption. Thus the features of the plants must be in line with the features of consumption, a requirement which is particularly complicated in the case of hydroelectric plants, whose capacity varies with the flow that feeds them. Consumption requirements can be ensured when the system can meet the maximum demand in a dry year and can deliver all the power needed during the year and during the critical period for the system.

(d) Time and price are important factors in comparison methods. An analysis is made of the standard equivalent cost and present worth methods for the purpose of comparing investment costs, operating costs and revenue for a given period, and the present worth method is generally recommended. The rate of discounting will naturally correspond to the postulated cost of money. This is high in Latin America, but it is believed that there are good grounds for hoping that it will eventually fall. The view is expressed that the price factor must be based on present values because in practice it is impossible to make sound forecasts about its future development, except in special cases. Because of the high rate of discounting, it is considered that in general comparison periods need not exceed fifteen years, since developments after that period will have relatively little weight.

/(e) One

(e) One of the simplest methods of comparing alternatives is to determine the cost of production of the new plant compared with the present cost of the service or with the statutory tariff that would apply. Another method that would answer in many cases is direct comparison of a hydroelectric plant with the steam or diesel alternatives, when the hydraulic energy is fully used. However, the time factor is essential for the comparison. There is a fairly detailed account of the coefficient of worth method, which consists of comparing for a selected period the benefits produced by the hydroelectric plant under consideration and those produced by an equivalent thermal plant used as a point of reference. The benefits are measured by determining the present worth of revenue, investment and expenditure for the whole period for both plants. The difference between income and expenditure (investment and costs) for one plant gives its profit, which can be compared with that of the other plant; if the hydroelectric plant is superior to the thermal plant, there will be a relatively higher profit margin, and the higher this margin compared with investment, the higher the coefficient of worth. If all possible hydroelectric plants are studied they can be classified in descending order of coefficient of worth, which will provide a logical order for installing them.

An account is also given of the procedure used by the Russians, which is somewhat similar to the coefficient of worth method. Lastly, some methods are described that relate to appraising the value of the various types of power produced by the plants, which may provide the basis for methods of selecting the most appropriate plant by means of the trial and error method or approximations.

(f) Once the various plants have been compared, the most appropriate programme for the next five or ten years can be drawn up by means of the trial and error method. However, when the system is a large one and involves the selection of a large number of plants during the period of the programme (easily 50 for a European system), more systematic methods must be used. Linear programming is employed, and the system of equations must be used so as to minimize expenditure at present worth and to meet the aforementioned conditions of demand and consumption, in addition to

/other requirements

other requirements as the programme may be called upon to meet, such as the maintenance of a certain proportion of thermal capacity or a given level of foreign exchange expenditure. The unknowns are the characteristics of the plants, and it is assumed that all the conditions can be expressed as linear equalities or inequalities of the unknowns. When the values of the unknowns have been found the aim will be to find the plants with the highest coefficient of worth that meet these requirements. The procedure calls for some adjustments before the final answer is obtained.

(g) Lastly, with respect to the dimensions of the engineering works, some observations are made on the value of the marginal energy produced, which in the case of predominantly hydraulic systems has a relatively doubtful sales value. It is also noted that the high rate of discounting in Latin America reduces the possibilities of embarking on investment for development in the distant future.

6. (a) The most favourable operating conditions are produced by the combination of thermal and hydraulic resources. In a mixed system the thermal capacity constitutes the reserve, peak or supplementary power, according to its relative importance in the system. In the last case it makes possible the development of hydroelectric resources on the basis of very low levels of hydrologic probability. In any case, however abundant hydroelectric resources may be, they will lose their relative importance within a few decades.

(b) The operation of an electricity system must ensure the service with maximum economy. In a mixed system with storage and thermal plants, the combined operation is complex, and it can be established that the base power will always be provided by the run-of-river plants, the main modulation of the load being assumed by pondage and storage. The thermal plants operate either above or below the storage plants, according to the proportion of the latter and the nature of the hydrologic year. The situation in some Latin American countries is examined in the light of these principles.

/(c) Nuclear

(c) Nuclear power plants, even when very large, have a high cost per installed kW, and although nuclear fuel costs less per kWh than conventional fuels, it nevertheless represents a significant item of expenditure. Nuclear plants must therefore operate as base units. At present, countries wish to install nuclear power plants for three main reasons: (i) the lack of other means of generating power; (ii) the need to acquire the necessary technique for the manufacture of nuclear equipment, and (iii) the wish to obtain experience for future commercial development. At present it does not appear that circumstances justifying commercial nuclear installation exist in any Latin American country.

7. (a) There has been a gradual development of system interconnexion as the systems have been brought into contact as a result of their own growth. The first stage of interconnexion is that of "parallel operation", which obtains until interconnecting lines can be installed for the interchange of energy and power. During this second stage the systems can arrange large-scale exchanges of firm or seasonal power, but the most obvious advantage of joint operation is the use of the diversity in the load diagrams and generating conditions of the participating systems. Interconnexion makes it possible to use large sources of power which cannot be transported except as electricity (hydro power), or which it would be uneconomic to transport in any other form, such as light coal.

(b) There are many other advantages of interconnexion in addition to the foregoing: (i) better utilization of the equipment resulting from the hourly differences in the load diagrams; (ii) increased efficiency of operation through the availability of more generating sources; (iii) reduction in total reserve capacity; (iv) technical improvements due to the need to adopt the standards set by the most efficient of the interconnected systems; (v) the development of the joint resources on a larger scale, in a more complete form and in the most appropriate order, and (vi) the development of a spirit of co-operation.

Interconnexion gives rise to technical problems and problems relating to organization, communications and economics that must be solved

/jointly by

jointly by the connected systems. The joint operation of a number of connected systems is on the same general lines as for a single large system, the plants being used in such a way that they all have the same incremental cost.

(c) There is a brief analysis of the experience of some large interconnected systems in the United States, Europe and the Soviet Union, followed by an examination of the possibilities in Latin America with respect to the development of international projects, the interconnexion of local adjoining systems and the integration of various national systems. An account is given of the various criteria determining the approach to the last question in the national plans of a number of countries, and the question of whether interconnected systems are to be preferred to the establishment of plants in the various areas is discussed.

8. Lastly, two special problems are analysed. The first relates to isolated areas without an electricity service which must be supplied by their own sources of generation, and the second to the large areas where it is decided to make available a supply of power in excess of existing demand as a means of stimulating economic development. It is indicated that for the isolated areas the best method of determining demand is by comparison with other isolated areas with similar social and economic features where electricity has already been developed. It is suggested that these areas should be developed in accordance with uniform technical standards for the country, and that they should be given the necessary assistance during the installation period and subsequent operation. The possibility of future interconnexion should always be borne in mind, and in this connexion it is pointed out that even small hydraulic plants can be integrated in larger systems in an economically satisfactory form.

With respect to the supply of power in excess of present demand as a means of stimulating development, it is stated that electricity is a necessary factor, but that it will be a determining factor only when the other conditions that justify industrialization are potentially present. Some examples in different areas are quoted, in particular the case of Paulo Alfonso in Brazil.

/1. Introduction

1. Introduction

It is a commonplace today to assert that power, together with other important factors, is an essential element in development. Availability of raw materials, climatic and soil conditions, hydro resources, the educational level of the population, capital supply and intensity are so many additional factors conditioning the possibility and rate of a nation's economic development.

A number of studies have demonstrated that there is a clear correlation between power consumption and the gross national product. Even in those countries with the highest rate of power consumption, an upward trend is still apparent. Thus, according to the study Resources for the Future Inc. (1), the per capita power consumption in the United States between 1955 and 1975 will increase 33 per cent.

New methods of industrial production require types of energy that are easy to handle the use whereof should be simple to measure and control. Those best meeting the requirements are the so-called secondary forms: electricity, petroleum derivatives, coke and so on. Hence, there is a marked tendency for greater consumption of these forms of energy starting from the primary sources: coal, crude oil, natural gas, hydraulic energy, and so on.

The continuous rise in overall consumption, particularly of increasingly elaborate secondary forms of energy, implies considerable capital demand. Thus, in 1954, the seventeen countries forming the Organization for European Economic Co-operation (OEEC) allotted 18 per cent of their total investments, exclusive of housing programmes, to the energy sector. It is expected that in 1975 21 per cent of the same resources will be assigned to energy (2).

Although these figures seem extraordinarily high, they are not far from what actual figures for Latin America should be. In fact, from ECLA studies (3) it may be inferred that investment in power for internal consumption in Latin America as a whole during 1955 to 1965 would be about 10 per cent of total gross investment, housing investments included. As far as Chile is concerned, the General Economic Development Programme for the decade 1959-68 (4) contemplates an investment in the energy sector amounting to 13.6 per cent of total investment, excluding the housing programme.

This substantial investment is in contrast to the relatively small direct contribution from the energy sector to the growth of gross national produce. In the case of the OEEC group of countries, the contribution amounts to only 6 per cent of the GNP (2). In Chile the proportion is estimated to be almost exactly the same.

The foregoing considerations enable the problem to be viewed in its proper perspective. Three main observations may be made: (a) the power problem, because of its nature is classifiable among what are known to economists as structural problems. Therefore it should neither depend on the short-term economic position nor be subject to daily changes in policy in response to the exigencies of the moment; (b) if a country wishes to advance in any way whatsoever, the energy sector as a whole must improve rapidly in both quantity and quality; (c) the energy sector's direct contribution to the country's progress, in terms of the gross national product, is unimportant; the sector makes its influence felt indirectly by helping other activities to expand. This explains why there should be a close relationship between the criteria adopted for the development of the energy sector and for that of the other economic sectors.

2. Power policy

Electric power is a very important element in the energy sector. This is less true as far as quantity is concerned. Since of total world power consumption in 1958 (equivalent to 3,699 million tons of coal) electric power contributed $1,896.22 \times 10^9$ kWh; this, according to the caloric equivalence criteria adopted by the United Nations, represents no more than 238 million tons of coal equivalent, i.e. only 6.5 per cent of the total (5), but this figure is raised to 24.2 per cent if the more logical procedure is used of measuring electricity by the fuel equivalent required to generate it.

Electric power's true importance derives instead from four basic facts: (a) its pre-eminence as a source of mechanical power; (b) the forms of application, in which it is irreplaceable, such as electronics and

/derived uses,

derived uses, electrochemistry, etc; (c) its growing contribution of the world power supply; and (d) the size of the yearly investments required by its rapid rate of growth.

As far as the first point is concerned, mechanization - which is the most obvious indication of progress in productive methods - is mainly carried out on the basis of petroleum derivatives for mobile units and electric power for fixed systems.

Electronic appliances by definition need electric power; consumption is small in quantity, but the fact that such applicances are necessarily used on a wide scale makes it essential to have more and more of this form of power available. Moreover, certain electrochemical processes cannot be replaced by other methods yielding equivalent results. In such cases, electric power consumption may be very high.

Electric power consumption increases at a far higher rate than that of power in general. The usual electric power generation figure which doubles every ten years may be taken as representative of the world position. Furthermore, in spite of its considerable rate of growth, it shows no sign whatsoever of reaching saturation point.

Growth on such a scale can be met only by a sizable volume of investment, which explains why a major part of investment in the energy sector are assigned to electric power. Out of the large sum the OEEC countries will invest in the energy sector during 1955 to 1975, an estimated 72.2 per cent will go to hydro-, thermo-, nucleo-electric power generation, and to the transmission and distribution of the power generated (2). According to ECLA's aggregate estimates of Latin American investment in the energy sector (3) in 1955-65, 57 per cent should go to electric power. Estimates made in Venezuela of the gross investment needed up to 1968 to meet the internal requirements of the energy sector indicate that 42 per cent should go to electric power (6). In the Chilean Ten-Year Development Plan, which has already been mentioned, electric power represents approximately 65 per cent of total sectoral investment.

The fundamental importance of having a supply of power that is satisfactory in both quantity and quality, the volume of investment required to reach that goal, and the major role played by electric power

/within the

within the sector as a whole are closely linked with general ideas on a country's development, the policy pursued in the energy sector, and the economic criteria adopted for selecting and developing power plants and electricity systems.

There are two aspects in which electricity is closely linked to the energy sector as a whole, and which largely determine some of the criteria that are studied in this paper. They are: (a) the competitive position of electric power as against that of other forms of power in respect to a fairly large number of possible uses; and (b) the fact that electric power may be generated from any major form of primary or secondary power.

As regards the first aspect, there are a number of examples of logically possible competition: in household appliances electric power may be replaced by either coke gas or petroleum gas; in addition, coal, fuel-oil and paraffin should be borne in mind for heating in general. Diesel-oil and electric power are highly competitive in urban and railway transportation systems.

The supply conditions and relative prices of different forms of power suggest a certain power consumption structure. If this structure has been distorted because - over fairly long periods of time generally of several years duration - artificial conditions have been maintained in the market, such as rationing of some types of power, prices raised or lowered, tax policies or governmental subsidies, preferential exchange rates and the like, these factors should be carefully weighed before the selection criteria for future long- or short-term development are decided upon. In the case of long-term development in particular it should be determined what the position would be if artificial conditions tended to disappear and all economic sectors were placed on equal terms of comparison. This conclusion, which is certainly valid for the power sector as a whole, is of fundamental importance for electric power because of the scale of investment involved.

A concrete example will serve to illustrate the problem. From 1940 to recent years, Chile's main areas have been subject to a restricted electric power supply. This situation became particularly acute in Central Chile, the country's most densely populated and industrially developed zone, especially in 1946-52. However, low electricity rates and an absence of

/legal restraints

legal restraints led to a considerable increase in the use of electricity for household heating, although climatic conditions in that part are such that heating is necessary during four months of the year only and for a few hours daily. Thus, despite the fact that electric power was in short supply for essential uses, electric heating gained ground rapidly, under the stimulus of low rates and installation costs, until it represented more than 15 per cent of peak demand.

This absurd situation was subsequently remedied, in the first place through restrictions on household use of electric power in winter, and secondly, through more rational rate-fixing which placed the price of electric power at its true level. But it is obvious that consumption of the type described has a direct bearing on the criteria governing the selection of a suitable power plant.

Even more serious is the question of primary energy for electric power production. Although the original criterion - dating back to ten years ago - of endeavouring to produce electric power mainly from local primary sources is now less important from an economic standpoint, the difficulty of finding a reliable source of supply (the Suez crisis being a case in point), balance-of-payments conditions and the desire to protect internal wealth or production, are important factors in the making of decisions and may radically change those reached on the basis of considerations of economic cost alone. Hence the criteria used as a guide in choosing between two sources of electric power generation may derive from considerations of economic or social policy in the energy sector that should be studied particularly with a view to ascertaining whether they are likely to be permanent.

One of the most serious problems in the making of decisions on the primary sources that should be used in electric power generation is the forecasting of their medium- or long-term development. Forecasts of this kind are very difficult to make, particularly in relation to developing economies such as those in Latin America, where the bases for an estimate of the future and for assessing domestic wealth and reserves are very unreliable.

An interesting example in this respect is afforded by the petroleum industry, which has undergone a fundamental change in the course of a few

/years. Known

years. Known oil reserves now represent 50 years consumption, as gainst only 20 in pre-war days. This new situation has had a great influence on the price of petroleum, and therefore on its competitive position vis-a-vis coal. From a medium-term forecast it is difficult to judge whether coal will even be able to maintain its present production level in Europe (7). However, in the aforementioned study Resources for the Future Inc. (1), it was calculated, in estimating the evolution of the different sources of primary power in the United States between 1955 and 1975, that bituminous coal production should increase by 75 per cent. This example shows that the same general position may lead to extremely different forecasts in two consumption areas.

The case of Chilean coal is even more cogent. Up to a short while ago, Chile's coal supply was unquestionably insufficient, and it had to import a certain amount. Because of this situation and of studies on future demand, a programme of modernization and expansion was carried out in the principal collieries. In these circumstances, as the country has abundant reserves of hydraulic energy distributed over most of its territory, its production of coal and petroleum is inadequate and its balance of payments is unstable, the possibility of using thermal energy to produce electric power is worth considering only in areas that have no hydraulic energy (the northern desert) or to meet peak loads in winter and as a reserve for very low generation of kWh. In less than three years the situation has changed completely. Before the work of enlarging the coal mines is over, coal production in Chile will already be showing a surplus as the result of the substantial drop in demand.

From the studies undertaken it is evident that although the reduction in demand is partly the result of an unfavourable combination of circumstances, it is equally attributable to an ill-advised price policy in the energy sector and the lack of competition on the fuel market for a number of years.

In these conditions, one way of absorbing the production surplus would be to generate a certain amount of thermoelectric power on a permanent basis. This is an example of how, in an extremely short time, the forecasts made are radically changed, and circumstances with no bearing on the electricity

/problems may

problems may nonetheless influence the criteria by which the choice of the most suitable means of generation is governed.

The case of Chile is a good example of how a lack of continuity in energy policy has a fundamental effect on results. For instance, during the last twenty years, coal enjoyed official protection through the levying of import duties on petroleum derivatives. However, up to 1958, a system of multiple rates was in force which naturally meant that products imported at lower rates of exchange enjoyed a bonus. Petroleum was one of these, and, as a result, the intention of protecting coal was nullified through the application of preferential rates to imports of petroleum and its derivatives. The fact that this situation continued to exist for a long time was bound to produce a coal slump, aggravated by the drop in the world market price of petroleum. The system of multiple exchange rates to be found in various Latin American countries has also played an important part since it resulted in a definite bonus for products imported at lower exchange rates, such as petroleum derivatives.

A similar situation exists in Peru. Since 1954, Peru has been importing petroleum products on an increasingly large scale, while coal mining has been unable to develop properly owing to price conditions. In fact, the policy followed was that of keeping the price of petroleum products below world market quotations. This automatically pushed down the price of the coal-calorie, which had to compete on a market that was traditionally organized for the consumption of liquid fuels.1/

The foregoing examples seem to be sufficiently representative of the way in which the general conditions in the energy sector determine the guide-lines to be followed in choosing new means of generating electric power. In short, power and its development constitute a structural problem, and investment in the energy sector is substantial, slow and relatively inflexible. Decisions relating to the sector should be carefully weighed. Hence, the initial recommendation on the need for an energy policy. The growing interdependence of the different sources of energy makes it even

---

1/ No recent information is available, but it is thought that the situation in Peru has been remedied to some extent latterly (8), (9).

/more imperative

more imperative for the responsibility of formulating an energy policy to be handed over to a single authority in each country; however, in most countries today all questions relating to the different sources of energy are still dealt with by a number of administrative organizations that are entirely unconnected (10).

An energy policy might even include the programming, as recommended in the above-mentioned United Nations study, and should at least take the following general considerations into account:

(a) It should review the country's own natural resources, and on that basis, make the soundest possible projection of future power requirements;

(b) It should have sufficient continuity to allow for the development of large-scale investment in the sector;

(c) It should be directed towards obtaining the largest possible amount of power at the lowest possible cost and in conditions of maximum reliability (11).

There are obviously two fundamental aspects of any energy policy on which it is difficult to lay down principles that would be valid for every country. They are free market and free price conditions respectively, and both are of course inter-related to some extent. Free market conditions are expressed through the principle of non-discrimination with respect to prices among possible buyers in the same area and freedom of choice for the said buyers.

The price risk lies in the very varied factors that produce distortions. For instance, it is a recognized fact that in nearly every country taxes send up the price of liquid fuel considerably in comparison with that of coal. Again, imports of certain types of power are sometimes helped or hindered by special exchange rates, customs duties or other artificial conditions affecting their entry. These include the establishment of quotas, which is a fairly common practice in countries that generally have a deficit in their balance of payments.

Many of the distortions mentioned - and there are undoubtedly others - are unavoidable or necessary. What is important is to recognize them and determine their validity in terms of the energy policy that is required to prevent them from being altered for reasons unrelated to the ends pursued. If simply to obtain more revenue for the Treasury, taxes are imposed on certain types of energy and variations permitted in the tax rates the energy policy that is being devised may be totally disrupted. The authorization of fuel imports at preferential exchange rates or adoption of other indirect forms of subsidy whose cost and effect is very difficult to predict may have the same effect and, indeed, frequently does.

It is therefore imperative, in deciding between alternative solutions for electric power production, to see to what extent such decisions are influenced by permanent measures adopted as part of a consistent energy policy, or whether, on the contrary, they are governed by temporary distortions which deform the real criteria and, because of their transitory nature, have no claim to consideration in the decisions made.

/3. Some

3. Some special factors affecting economic criteria in electricity

In the foregoing chapters, attention was drawn to two groups of considerations which although not strictly part of the subject dealt with in this study, do none the less have a decisive influence on some of the economic criteria governing the choice of electricity systems and their development.

Firstly, it was recalled that the development of the electricity service was closely linked to other activities in a country or area. Secondly, attention was drawn to the close interdependence within the power sector between electricity, which quantitatively accounts for only a relatively small fraction of power, and other sources of energy. Relative prices, the quantity and quality of supply of the various forms of power in the present and immediate future, and equipment available for the use of the power supplied will influence consumers in their choice. In addition, the criteria used in determining the type and site of generating stations will also depend on present and future prices, amounts supplied and sureness of supply of the various existing primary resources. As the production and consumption of electricity depend on developments in the rest of the power sector, the economic criteria used in making decisions regarding power stations and the development of electricity systems will clearly depend on power policy and the continuance of such policy.

The present chapter will throw light on a group of conditions which are directly connected with the problem, although they are not exclusive characteristics of it.

The usual purpose of economic analysis is to bring about the use of available human, financial and natural resources in such a way as to ensure maximum benefits. This is what has in some cases been called economic efficiency defined "as a situation in which productive resources are so allocated among alternative uses that any reshuffling from the pattern cannot improve any individual's position and still leave all other individuals as well off as before" (12)

The really difficult problem is defining and measuring the benefits to be derived from various alternative projects, for producing different goods and services in different areas, particularly when such projects differ in nature from each other.

In dealing with electricity, the fact that any development programme involves large scale and long term investment, the benefits of which must be forecast for periods varying from thirty to sixty five years depending on the type of work to be undertaken, makes it even more difficult to make an evaluation of benefits.

(a) Ownership of electricity services

The criteria used in measuring benefits depend on a large number of special circumstances. These include, in the first place, the form of ownership of the electricity concern, which may be either public or private. After the war, the trend towards nationalization of electricity services became more pronounced throughout the world, and clearly Latin America is no exception to this general and well-known trend. There is, however, a fundamental difference in the criteria used in measuring the benefits and profits of a given project depending on whether the project concerned is publicly or privately owned. This fact must be taken into account in the making of any evaluation.

What is the main difference? According to the United Nations Manual on Economic Development Projects: "The private enterpreneur judges the merits of a project essentially in terms of the profits to be gained from it, and this is consequently the item which he hopes to increase to its maximum. On the other hand, he reduces all the resources utilized to obtain these profits to the common denominator of units of capital, the item which he is interested in lowering to the minimum consistent with the requirements of the project. The basic ..... criterion for the private entrepreneur is, therefore, that of securing maximum profits per unit of capital employed in the project" (13). Such an approach is in no way mistaken, for even though the concern has other responsibilities of a social kind, its first and essential responsibility, if it is to subsist in a competitive world, is to find the best way of satisfying the economic and financial aims for which it was established.

On the other hand, the favourable or unfavourable effects which may result from the execution and operation of projects originating in the public sector are of basic importance whether or not they are directly linked to the project.

/While the

While the private entrepreneur is compelled to give exclusive consideration to factors influencing the balance sheet, publicly owned concerns can and must take account of the social effects of their investments. These are sometimes called "indirect effects"; the quantitative evaluation of indirect effects and the determination of the extent of their influence "backwards" to the inputs and "forwards" to the end use of the goods and services produced is a very difficult but necessary task.

A few concrete examples will help clarify this point . Taking the the example of a thermoelectric power station whose completion involves deciding, for example, between fuel oil and coal, the private entrepreneur will adopt the solution which in the final analysis will give him the best return on his capital. A public concern, however, has to give special consideration to other factors such as possible savings of foreign currency as a result of preferring one of the fuels to the other, as the foreign currency saved in this way may provide the community with added benefits in other sectors owing to the more efficient utilization of other imports. The employment factor in the coal mines and the maintenance of the mines at a minimum level of production, etc. are indirect effects "backwards" which may be of considerable importance from the social point of view and may lead to deciding upon a fuel which would not have been chosen if the decision had been based solely on the need to derive maximum profit from the thermoelectric power station.

Frequently, publicly owned concerns decide to provide service in areas where normal returns on capital can clearly not be expected. Such a decision can be explained by the social benefits which can be derived simply from making electricity available; such benefits would clearly not be sufficient stimulus for the private entrepreneur and he will not be able to include them among the criteria underlying his decision.

(b) <u>Profitability and the economic cost of money</u>

Be this as it may, whether the electricity concern is publicly or privately owned, in order to choose between different projects, a comparison must be made of the direct and indirect benefits which will be obtained. Benefits, particularly indirect benefits, may vary in kind and a common yardstick must be found if they are to be added together and compared with the amount of the investment involved in the project concerned. Such a quantitative estimate of benefits will be even more necessary if within the public sector a decision is required between carrying out an electricity project and a problem of a different kind as for example the building of a road or an irrigation scheme.

No attempt will be made to consider here the criteria used in such an evaluation as this will be done at some length at a later stage in this paper. The sole purpose here is to point out that electricity development projects require very large-scale investment in relation to the price and value added of the service produced. This means that whatever the system used in comparing various alternatives, the cost of money will be of fundamental importance in deciding which of the alternatives is the most suitable.

For example, the studies carried out in connexion with the development of Hell's Canyon in the United States showed that if interest on money was 2.5 per cent (the rate used by the Federal Authorities in the economic analysis of the development of river basins), it was better to install a single reservoir rather than three reservoirs which was the solution finally adopted. If, however, the comparison was made on a basis of an interest rate of 5.5 per cent which was considered to correspond to the "opportunity cost" 2/ of capital in the United States (at the time of writing), the three reservoir solution was found to be more favourable.(12)

In the case of a privately owned electricity concern, the cost of the money involved in the investment is usually relatively easy to determine. In the great majority of cases, sales rates of electric power are controlled and regulated by government bodies. The regulations usually stipulate a maximum return on the current value of the investment.

2/ According to economists the "opportunity cost of a resource required for a project is that value - chargeable to this resource - which is no longer produced in some other activity in which it could be used, and from which it is diverted by its employment in the project" (13).

/In such

In such circumstances, the private entrepreneur must decide which of the alternatives within his reach will enable him to give the most efficient service. If the legal maximum return on investments is lower than the interest which capital can normally obtain on the private market where the concession raise usually deals, it will be possible to bring about the investment only if part of it can be financed from credits granted at interest rates lower than the legal fixed rate of return used in calculating electricity rates.

Publicly owned concerns are usually largely financed with national public capital either directly out of Government or municipal budgets, or with loans guaranteed by Government agencies or else with funds specially allocated to electricity development. The cost of such money is always considerably less than on the private capital market, a fact which can be easily explained, as private capital needs a direct stimulus to investment which is not the case with public capital. In the United States, for example, the Federal Power Commission calculates that the cost of money for hydroelectric projects financed from private sources is 6.75 per cent while with Federal financing the rate is only 2.625 per cent. 3/

One of the comparisons most frequently made in the study of alternative means of generating electric power in circumstances where interest on capital plays a decisive part, is between thermoelectric and hydroelectric power stations. If the rate of interest on the basis of which investment calculations are made is unusually low, the hydroelectric power station will be found more suitable; the reverse will occur if the rate of interest is high. What would be the most suitable rate to prevent an under-estimate of the cost of national public capital leading to waste of such capital on excessively capital-intensive projects? Mention has already been made of the notion of "opportunity cost"; it is, however, somewhat difficult to determine opportunity cost, particularly if study is confined to the alternative uses of funds in the public sector where many projects produce mainly indirect benefits which

3/ Data taken from the paper by Mr. Frank L. Weaver for submission to the Latin American Electric Power Seminar (14).

are somewhat hard to express in quantitative terms. If "opportunity cost" is considered for the whole range of possible projects, it will then be possible to determine a rate of interest analogous to that governing investment in the private sector; this, however, seems somewhat ridiculous if it is agreed that public capital should not be expected to respond to the same stimuli as private capital.

It is true that publicly owned concerns are subject to the same tariff regulations as private concerns and therefore the choice between alternatives can be based on the level of return on capital laid down in those regulations. The rate of interest laid down in the tariff regulations does not, however, reflect the real value of capital but, to a certain extent at least, indicates a basis for valuation deliberately established by the public authority.

In view of all the possible variations, from a minimum rate of interest - that granted to concerns out of national public capital - to a maximum which would be the cost of money on the private capital market,[4/] it is suggested that the problem should be studied applying various rates, the highest being half way between the legal rate of profit allowed and the cost of money on the private capital market.

Frequently a choice has to be made between alternative solutions proposed by publicly and privately owned concerns with respect to competitive electricity projects. In such cases it is not the problem of the cost of money alone which enters into play, for all the factors which in any way involve the subsidization of publicly owned concerns have also to be taken into account. In the United States for example, the Federal and State taxes which a private concern must pay in carrying out a hydroelectric project and from which Federal investments are usually exempt, represent approximately 6 per cent of the value of the investment (14).

Lastly, it has already been pointed out that electricity investments require a number of years between the time when it is decided to initiate them and the time when the resulting facilities come into operation. As,

4/ It is not bank interest that is being referred to but the rate of return which may normally be expected from safe investments in the private sector.

/in addition,

in addition, the useful life of any electricity investment usually covers many years, the choice between various alternatives will not depend on the factors seeming to provide the most favourable solution at the outset, but on factors covering a given period during which revenue and expenditure will be variable. Accordingly, forecasts are made of revenue and expenditure in the consideration of each alternative solution. There are various methods for comparing different situations, the most readily accepted today probably being the method of "current value" which consists simply of reducing any amount, or item of revenue or expenditure of the year n chosen at a given moment as the base year, the said amount being divided by $(1 + i)^n$, where i represents the unit cost of money. It would therefore seem possible over the long period and in conditions of economic stability and general development of the country concerned to assert that the high rates of interest at present prevailing in Latin America must tend to fall. As it is very difficult to make any reasonable forecast of the future cost of money, it is recommended that there should be no excessive increase in the rate used.

(c) Rates and Tariffs

Any electricity concern is by its nature a monopoly and is accordingly subject to restrictions laid down by higher authority. Electricity tariffs are fixed by regulation and as a result competitive conditions such as will contribute to ensuring that prices charged bear a relationship to the real value of the service provided are absent. This is a fact which all private and public electricity entrepreneurs must take into account in making their decisions.

The long useful life of electricity investments involves vulnerability as regards inflation, and variations in exchange rates and economic conditions, etc. and makes it particularly difficult to determine either an equitable rate of return on existing investments at any given time or correct depreciation rates.

The majority of the Latin American economies have been subjected to a high degree of currency depreciation. On the other hand, tariff regulations, until recent years, usually laid down a rate of return on investment related to "original and historic cost".5/ This means that

5/ See (15); regulations have in many cases been changed since.

real earnings on capital declined considerably all the time. What influence has this had on entrepreneurs? Faced with the obligation to meet growing demand for electricity service which is further stimulated by an artificially low price, entrepreneurs have sought solutions involving the smallest investment for them, even if these are not at minimum cost; this course of action is further encouraged by the fact that tariff regulations are usually based on the annual effective cost of operation and contain rate readjustment clauses to match rises in fuels, wages and other items of expenditure. In other words, tariff legislation such as that described unquestionably encourages the choice of thermal rather than hydroelectric power stations.

Depreciation is another factor which is usually subject to regulation and has a considerable influence on the course of action adopted. The maximum depreciation allowed, its method of calculation (linear or cumulative), its readjustment to historic or original cost, etc. are all factors which have great influence on the choice of alternatives. Furthermore, as depreciation is an item of expenditure which is not subject to profits tax, the frequent divergence between tariff regulations and tax legislation regarding the method of calculating depreciation also has an influence on decisions taken.

All concerns whether private, public or mixed must pursue a sound financial policy, and accordingly it is their duty not to allow their investment decisions to be influenced by conditions created artificially by legal provisions laid down for situations bearing no relation to facts. It should always be remembered that electricity investment is a long-term matter and that whatever happens any artificial situation will have to be rectified at a later stage

If the original purpose of the tariff structure was to produce income sufficient to cover operating costs and produce a normal yield on capital, tariffs charged will clearly have great influence over the development and characteristics of electricity systems. It must therefore be borne in mind that the tariff system which provides the entrepreneur with a fixed percentage return on his investment is not a good stimulus for the establishment of power stations which can produce at low cost,

/ but will

but will lead to the creation of power stations needing the smallest amount of investment and in the final analysis, the high cost of operation will whatever happens be passed on to the consumer. A dangerous situation of this kind calls for study with a view to elaborating tariff structures which will encourage entrepreneurs to undertake larger-scale investment involving lower cost and lower prices for power. The matter is of great importance and exerts considerable difference over the investment policies of private concerns.

Electric power consumption has a peculiarity which is not common to the majority of consumer goods. What the consumer needs is light, power or heat. To obtain these, electricity and a suitable appliance to transform the electric power into the usable good desired are simultaneously required. At times the larger or smaller consumption of electricity will depend solely on the price of the electrical appliance; this is true of the majority of household appliances such as radios, hair driers, washing machines, refrigerators, etc.; market research has provided reliable information that the electricity rates charged do not affect the use of such appliances (16). On the other hand, in household lighting, cooking, the use of small electric motors for various types of agricultural work, etc., the price charged for the electric power does in fact determine the intensity of consumption.

There has for long been research into the "elasticity of demand for electricity". In 1934 very thorough research was made into the subject in France by Mr. Genissieu. It was shown that domestic consumption had a lower degree of elasticity than consumption for motive power, but that both were fairly sensitive to price (17). Similar research carried out in other European countries and in the United States has shown that elasticity is an important factor and that price policies exert a definite influence over consumption.[6/]

6/ Very full research was made into this matter some years ago in the German towns of Karlsruhe and Treves (Trier) (18). Since 1957 a large scale experiment called the "Trois Villes" experiment (covering the towns of Avignon, Boulogne-sur-Seine and Orléans) has been undertaken in France. Preliminary results show, inter alia, a considerable shift of consumption to the off-peak hours amounting to 37 per cent, as compared with an increase in total demand of only 14 per cent. This has been achieved through direct measures of commercial policy and the establishment of special differential rates (19).

In some countries of Latin America where development, market, income, and educational conditions and consumer and savings habits are completely different, efforts should be made to carry out research of this kind directly related as it is to forecasting consumption and to determining the most suitable tariff policies and the criteria for choosing and preparing future electricity projects.

(d) Other factors affecting decisions taken

Lastly, there is another group of factors that should be taken into account in considering the selection and development of electricity systems. Although these are of an economic nature, they are not strictly speaking related to the usual methods used in comparing the ability of different kinds of electric installation to satisfy particular consumption requirements. These factors include:

(i) Scarcity of financial means. This may arise where the method of evaluation chosen shows one particular alternative as being the most suitable and yet the lack of immediately available financial resources means its rejection in favour of another alternative involving smaller investment.

An example of this appears in the report submitted to the Argentine Government by the firms giving advice on electricity problems (20). Comparative study of the desirability of setting up a hydroelectric station at Salto Grande as compared with a new thermal power station showed that the former was the more favourable; its execution was not, however, considered advisable as the amount of the investment involved would have been 100 million dollars more than for the thermal station.

(ii) The degree of urgency. It is perfectly conceivable that a scheme requiring a longer period of time for its execution would turn out to be economically more favourable, even taking account of interwoven interests during the period of construction and of the direct benefits deriving from the earlier completion of the alternative scheme, namely, when work on the slower scheme was still under way. But even though one solution may be more advantageous, the urgent need for energy may bring about the adoption of an alternative scheme requiring less time for completion.

/The foregoing

The foregoing factors may be of relatively slight value for a private concern but they are of undoubted importance for a public undertaking in whose decisions much weight is given to the indirect benefits which the community may derive from the availability of energy.7/ In Russia for example, in deciding between two generating stations of different types and requiring different time periods for completion, preference was given to the scheme that could be completed earlier; one of the factors influencing the decision was the total value of the output that would be lost during the extra number of months that the longer scheme would take to complete (21). Research carried out in Chile during the years of greatest electricity rationing (1946-1947) showed that the losses in output suffered by the industries for which there was a consumer market, represented a cost equivalent to the investment needed to eliminate rationing (22). This example shows the extent to which due and weighted consideration of indirect benefits may provide sufficient reason to opt for solutions which require less time for their completion.

(iii) Savings in foreign currency. Special mention is made of this factor because of the preponderant influence which it frequently exerts over decisions regarding various types of projects in Latin American countries where there is an unfavourable balance of payments situation.

The most economic schemes may require larger foreign currency investment or the use of imported fuels involving a given annual consumption of foreign currency. It can therefore be seen that reasons completely foreign to electricity problems may lead to decisions being taken that are different from solutions advocated in economic studies.

Further special conditions could be listed. The purpose here, however, has been to use a few examples to draw attention to the existence of a type of factor which in many cases arises as a result of special local conditions but which may influence decisions in a manner different from the criteria of assessment of worth studied below.

7/ Although the report on the subject makes no mention of it, in practice one of the basic reasons for preferring a thermal plant at Salto Grande is the eight-year period considered necessary for the study and completion of the required hydroelectric works.

/4. Determination

4. Determination of priorities

Before examining the bases for evaluating and deciding between technically equivalent alternative means of meeting needs for electricity service, it will be useful to lay down some general rules for establishing orders of priority for the development of electricity service.

In Latin America, electricity systems are faced with a scarcity of at least three basic factors: reliable information; technically trained labour, and financial resources. Accordingly, it does not seem possible to find a simultaneous solution for all present problems, such as the complete absence of electricity service in some areas and inadequate supply in others, combined as these are with a high rate of growth and relatively high elasticity of demand resulting from low per capita consumption. For that reason electricity development must involve the establishment of a certain order of priorities on bases different from those used in deciding, for example, between two alternative solutions with respect to generating stations designed to produce equivalent amounts of power in a single area.

It can quickly be understood that the problem just referred to does not have the same implications for a private concern as for a public undertaking, particularly if the latter is regional or even more so, if it operates nationally. In general, private concerns are granted a concession to provide service within a well-defined geographical area, and if the concern has already achieved a certain degree of development, its information and staff problems will have been at least partially solved; this may, however, depend on the size and long-standing of the concern and its administrative efficiency. The requirements of service combined with the inadequacy of financial resources means that the only solution is for the private concern to invest its resources in such facilities as will provide the best direct return. Priorities will accordingly be determined on the same basis as that underlying all its investment decisions. The only logical solution in the face of financial restrictions is to give private capital sufficient incentive to ensure a flow of funds adequate to overcome the obstacles referred to.

/The problem

The problem of establishing priorities is of far greater importance for national undertakings as these must distribute scarce resources in many areas where development conditions vary and economic expansion is at different stages and is progressing in different ways.

To solve this problem, the first requirement is, as has already been stated, to make up the deficiency in basic information. This is of two kinds: (a) information regarding present and future electric power needs, and (b) information regarding the natural resources available for producing such power.

Neither of these matters is strictly relevant to this paper.[8/] It is, however, interesting to draw attention to certain special aspects. In the matter of power forecasting, it should naturally be understood that separate information is necessary about the needs of the different supply areas even when they are interconnected, for interconnexion in itself does not imply that supply conditions are necessarily the same in the whole interconnected system.

It is difficult to estimate the overall electric power needs of a new country when no previous reliable statistics exist and when, furthermore, there are no economic indices which can be used for establishing suitable correlations, nor yet any accurate information about natural resources and the new productive activities which could be developed at some time in the future. It is still harder to make any definite overall forecast for the future when studies cover whole regions and an effort is made to determine future consumption by categories of consumers; this must, however, be done in order to establish orders of priority. If estimates for the future cover only restricted markets, there will, in accordance with the laws of probability, be a far greater margin of error.

Clearly, the validity of overall and sectoral forecasts will depend less on the methods of evaluation used than on the reliability of the data employed in preparing forecasts. The methods used and the results obtained

---

8/ The Latin American Electric Power Seminar will study two special items in this connexion: (a) Problems of determining requirements and specifying demand for electric power; (b) Problems of the economic evaluation of the primary resources available locally for generating electric power.

will be directly related to the greater or lesser degree of industrialization of the country or area under study, to the degree of State control over the economy as a whole and to the period covered by the forecast. At all events, and for the purposes of this paper, forecasting must not be confined to indicating a single trend; it must also take account of accidental variations which may upset the maximum and minimum figures of the forecasts made. The foregoing is evidence of the need for substantial improvements of statistical and market research systems; this is essential if forecasting is to achieve useful results for the planning of electricity systems.9/ However important basic information may be for the establishment of reliable forecasting of future electricity demand, it is even more important to have data regarding the natural resources available to meet forecast demand. The United Nations in stressing the urgency for such studies stated: "The lack of knowledge concerning local energy resources often impedes energy development; it may also lead to the wrong kind of investments. Hydro-power exploitation and fuel mining require many years of preparatory work; unless the survey of such resources is initiated early, their utilization may be postponed for years "(24).

There have been a number of instances in which a decision to develop electricity service in one area prior to another was based mainly on the greater availability of information regarding consumption and resources in one as compared with the other.10/ The choice of a generating station in preference to other possibilities is also frequently based on the greater availability of relevant basic information.

For example, the fact that priority was given to completion of the Sauzal Power Station in Chile rather than to other developments of equal size which were carried out later, was due to the far greater degree of information available in respect of this project. Reference has already been

---

9/ Examples of forecasting and forecasting methods are to be found in many of the documents submitted to the Fifth World Power Conference, Vienna, 1956. See general report on the subject (23) and also (13) and (14).

10/ This was in a certain way one of the factors influencing the decision of ENDESA (Chile) to give priority to the development of the Pilmaiquén system before other projects of greater economic urgency.

/made, in

made, in this connexion, to the influence which the length of the research period required may have exerted on the decision to postpone the building of the hydroelectric power station at Salto Grande in Argentina. In the electrification plan drawn up in Venezuela, attention was drawn to the importance of basic information and the element of insecurity which lack of such information introduced into recommendations regarding priorities. A summary of the recommendations of most immediate interest would include the following: "The continued serious lack of basic information - particularly as regards hydraulic production - could be made up by carrying out surveys at the earliest opportunity; such surveys will make it possible to draw up a list of feasible projects in Venezuela and at the proper time to choose those which qualitatively or quantitatively are the most likely to meet the clearly established power needs of the CADAFE system" (25).

Similar situations are fairly general. "Costa Rica has had to face a problem common to the majority of our countries, where there are needs for which immediate solutions must be found by developing projects for using hydroelectric resources, but where there is no broad basic information to make the best and most reliable use of the resources concerned" (26).

The need for the substantial improvement of basic information involves the compulsory transfer of a certain percentage of scarce technical personnel to this operation; this will bring about greater scarcity of personnel for the study of other alternative projects for determining the best ways to develop electricity power stations and systems. This is a difficulty of a practical nature which should be borne in mind at the time of determining priorities.

However necessary basic information may be to establish proper orders of priority for the development of electricity systems, and although the degree of availability of information will be a determining factor in this respect, the main factor conditioning a particular order of preference is the inadequacy of financial resources.

In a country or area where economic activity is in general subject, to a greater or lesser degree, to decision by the public authorities or to

/the practical

the practical application of economic plans, orders of priority will be established and financial and other resources for all economic projects will be allocated at one and the same time; in general, electricity concerns will be expected to provide service only within the framework of broader programmes. The problem of developing the electricity system of an area will consist in this case of choosing the solution which best satisfies the targets laid down in the plan and which can be carried out with the material, human and financial resources allocated for the purpose. The fixing of orders of priority for the development of various areas and for attention to particular types of consumption in preference to others, etc., is not a matter for decision by the electricity undertaking whose sole responsibility in this respect is to solve problems of lesser importance.

In Latin America there are frequently cases of electricity concerns being given the responsibility for dealing with electricity problems at a national or regional level, their development plans in this respect requiring periodic approval by higher authority. Orders of priority are in such cases determined to some extent at the level of the electricity concern but on the basis of orders from or standards approved at a higher level and as provided by statute or in legislation.

The United Kingdom would seem to provide a fairly typical example of what occurs in this respect. The higher authority is the Central Electricity Authority;[11/] it has behind it a long history of progressive nationalization of the electricity service. A study[12/] on the effectiveness of Government control over the Authority's decisions contains the following: "Control can be of two sorts, quantitative and qualitative, i.e., control of the amount of capital investment and control of its character. As regards qualitative control, the Government is naturally concerned in seeing that

11/ In reality the Central Electricity Authority is the governing agency for electricity service in England and Wales (90 per cent of the total). Similar bodies exist in Scotland and Northern Ireland and there are in addition a number of small private concessionnaires (27). The Central Electricity Authority has since been replaced by an Electricity Council.

12/ In the United Kingdom, the Government exercises control in this respect through the Ministry of Power (27). There is also Parliamentary control through the periodic issue of a White Paper in the financing of investments in the nationalized services and a number of other public agencies (28).

"major policy decisions, such as the proportions of expenditure on conventional and nuclear stations, on coal and oil-burning equipment and on thermal and hydro power, are in the best national interest. But these decisions are so largely determined either by economic or technology that the scope for lay judgement is relatively small" (28). In other words, the final responsibility for policy making rests with the body most directly concerned with electrification.

There are occasions when the bases for determining priorities are formulated explicitly. For example, in Costa Rica "the ICE has left behind the restricted approach of simply providing service to high intensity consumers, a task which any commercial electricity company could perform; it has now turned its attention to using power to develop the means for promoting national progress" (29). Clearly a definition of objectives of this kind is too broad to be in itself a basis for determining priorities; it is, however, developed with greater precision in the ICE's policies (29).

In Chile some of the main criteria for determining investment priorities are also established on the basis of the general instructions contained in the Electrification Plan (30).

Apart from overall standards which in themselves constitute bases for determining priorities, a large number of special circumstances also come into play depending on the particular characteristics of the country concerned. For example, the fact that current consumption is rationed is basically an indication that the solution of the particular problem involved has been given high priority; if, however, the consumption to which rationing is applied is of small economic significance (for example, domestic heating at Santiago in Chile) it may well be that there is no justification for establishing the priority in question.

Clearly, the allocation of orders of priority by a public undertaking frequently implicity involves a quantitative and qualitative valuation of indirect benefits. This means that the evaluation of projects is based on a comparison not of alternatives for a single electricity supply but of equivalent or different projects for dealing with different consumption needs.

/The choice

The choice will usually fall on the alternative giving the greatest benefit to the community, although it is realized that not all alternatives will serve the same need.

In this connexion it seems interesting to recall an idea put forward some time ago by the distinguished French engineer Armand (10) regarding the basic distinction which should be made between power for "comfort" and power for "productivity". It is not easy to draw up any final classification of the two main groups but in general the term power for "comfort" will be taken as meaning the power intended to improve welfare, and power for "productivity" as the power used in producing and transporting wealth. The obvious distinction between the two purposes has an influence on investment and tariff policies and may provide a good basis for determining priorities. Normally, countries with scarce capital resources give preference to "productivity" power, although this principle, which from some standpoints seems reasonable enough, is in direct opposition to generally accepted social and economic policies.

Social policies tend to encourage the use of power for "comfort" for the greatest number of persons, generally at a very low price and sometimes at less than cost for specific levels of minimum consumption. This policy can be explained by the undoubted effect of electricity in suddenly broadening people's contact with the outside world and increasing the possible number of hours of work. But as such a policy cannot be strictly confined to producing solely the effect desired, in practice it involves the use of scarce resources which would not normally be allocated to that purpose.

This type of problem, namely the concern to provide electricity service to communities where it does not exist and whose degree of economic development means that they can use it only for "comfort" purposes, involves the highest degree of political interference in public undertakings; in fact, public undertakings are liable to such interference as a result of their very nature. To solve this difficulty, clear priority standards must be approved and gradual development programmes established, completion being ensured. Such solutions applied systematically would make it possible to avoid the need to devote undue amounts of public resources to services which by their nature cannot have priority.

/It has

It has also been pointed out that the idea of giving priority to power for "productivity" runs up against a well-known principle of economic policy. Very frequently it is proposed to supply certain areas with electric power before demand itself exists; the purpose is to use the power as a development factor and it is usual to make this idea one of the guiding principles of any development plan. As a principle, the idea is of undoubted value and may also frequently be translated into reality; but as a basis for making decisions for the distribution of scarce resources such as financial means it is very much open to debate. At a later stage, this topic will be considered again, but this is a suitable place to stress that in an area where production is as yet relatively undeveloped, there are very few activities which will be stimulated as a result of supplying a given quantity of power.

To summarize, therefore, the establishment of an order of priorities for the public undertaking is equivalent to valuation in relation to certain established standards as to which of the possible methods of development best meet the standards. The most outstandingly important of these standards is the estimation of the direct and indirect benefits of each project in the manner already explained; furthermore, the greater or lesser degree of basic information available regarding projects under study may also play a decisive part.

5. Selection of type and size of sources of power for an electricity system

(a) Application of methods of comparative analysis to sources of energy: possibilities and limitations

The problem that project-makers and experts on the electricity economy most commonly have to face is that of choosing the best source of energy for a given electricity system in specific current and predictable conditions.

It is therefore assumed that the electricity system under study corresponds to a known situation in respect of the overall economy of the area served; and, similarly, that the general power policy has been clearly defined, that the competent authority has determined what fuels could be

/used, etc.

used, etc. Other known factors are the range of costs of money governing the possibilities of comparison, and the means of influencing the consumer market afforded by the legal tariff systems in force. It must also be assumed that factors external to the problem, - for instance, the limitations of financial resources, the possibility of using a specific proportion of foreign exchange for investment and operational purposes, the amount of basic data available, etc - are such that they allow a certain number of alternatives to be put forward which are comparable in value from both the technical and the economic standpoint.

This problem in its full magnitude is not of long standing. Until a few years ago, electricity systems served relatively small areas and tended to draw directly upon the natural sources of energy in the immediate vicinity of the consumer centres that they supplied. If the systems were far from water, the electricity supply depended essentially on whatever fuel could best be brought to the locality. If, on the other hand, the area was rich in water resources, the choice lay fundamentally between various hydroelectric alternatives - not more than two or three, in view of the scanty amount of basic data that the enterprises had as a rule been able to collect, owing to their lower economic potential and the relatively short time they had been in operation. As Mr. Durrieu has pointed out with respect to Electricité de France, the studies carried out in the past - on contrast to those of more recent date, which are of a quantitative nature - were purely qualitative. The decision to invest in the construction of a particular power station used to be taken because, given the immediate circumstances, special value attached to some argument in its favour. The direction in which investment was channelled was determined by the order of priority accorded to the factors in question (17).

The remarkable development of transmission media during the last few decades - which has considerably increased the possibility of enlarging the area served by one and the same system -, together with the growth of consumption, has necessitated more careful selection of the means of generation and at the same time has confronted project-makers with a much larger number of economically comparable alternatives. Hence the several studies

/and methods

and methods developed in many countries with a view to quantitative investigation of the most appropriate sources of energy. For the purposes of comparison, a forecast of the future situation with respect to electricity services is needed. This in turn implies the application of more complex mathematical methods to the interpretation of an increasing volume of statistical data, by means of which such forecasts can be given validity. The choice between several alternatives also calls for a fairly high degree of approximation as regards the investment costs of the respective projects, and an exact knowledge of their generating capacity. This information is easy to obtain for a thermal plant, but, in the case of a hydroelectric power station, the margins of accuracy at which specific techniques of comparison aim cannot be achieved without a considerable body of hydrological, topographical and geological data which are often unavailable.

It was felt that the foregoing brief historical review and general discussion of methods of comparison might be useful. There is too marked a tendency to forget that the results of economic methods of analysis are liable to show a wider margin of error than the original data concerned, and that in countries like those of Latin America, where all such data are less reliable than those available in European countries or in the United States and Canada, the degree of accuracy of the comparative figures obtained can only be very relative. It should be borne in mind, for example, that in a classification of possible sites for hydroelectric power stations by "coefficients of worth" 13/ made in France about eight years ago, there was a probable margin of error estimated at approximately 20 per cent, mainly deriving from mistakes in the evaluation of inventoried projects based on very preliminary studies and, of course, from those errors of assessment which affect the elements of comparison (i.e., the constants) figuring in the "coefficient of worth" (31).

It is therefore not surprising that at the present stage of development of electric power in many of the Latin American countries, the problem of the choice between alternatives assumes a relatively simple form. If

13/ The "coefficient of worth" is a standard of economic comparison for hydroelectric alternatives with reference to a thermal plant.

/plentiful hydroelectric

plentiful hydroelectric resources exist at an economically reasonable distance from the consumer centres, the choice will light, almost a priori, on a hydroelectric alternative which, because of the amount of information available and because the characteristics of the draft project are more outstanding than those of other possible hydraulic developments, appears the most favourable in the light of a largely qualitative evaluation of the principal factors involved. The hydroelectric project selected as the most desirable will usually be much more carefully compared with the thermoelectric alternative, on the basis of more exact quantitative estimates. Here it would be possible to apply a statement made by Leontiev, who remarks that "the use of concise methods of quantitative analysis has still not gained favour with the majority of professional economists. Leaving aside the understandable suspicious attitude towards the intricacies of the unfamiliar mathematical language, the principal reason for this reserve seems to lie in the fact that exact quantitative procedures have failed yet to produce factual results uncontestably and obviously superior to those arrived at in conventional discursiveness supported by so-called sound judgement and intuitive insight." 14/

Since countries in process of development seldom have enough technically qualified personnel to grapple simultaneously with the manifold problems arising out of the development of electricity systems, it seems preferable to concentrate effort on the most correct and complete project and on the subsequent construction of hydroelectric works selected in accordance with the criterion set forth above, instead of applying more complex methods to determine the best combination of plants or the optimum size of each. In any event, the necessary precautions will have to be taken to safeguard these new countries from the initial errors, committed years ago by more advanced countries in Europe, which have led to the premature dismantling of ill-conceived plants or the inefficient utilization of under-equipped river reaches.15/ Every effort will therefore be made to ensure that the civil engineering works undertaken do not affect the possibility of integrated use

14/ Quoted in (23).

15/ The reason for such mistakes was the lack of previous experience in economic projections and analysis of the profitability of projects, questions which are familiar ground today.

/of the

of the river and leave the way open for increased equipment of the power station at a later stage, should this be warranted by improved hydrological information, expansion of the consumer market or combination with other plants.

The foregoing remarks are not intended to imply an a priori preference for the development of hydraulic resources.16/ Clearly, in many of the Latin American countries, water is one of the most advantageous natural sources of electricity production, but it is considered that the development of a hydroelectric project must always be compared at least with the best thermal alternative conceivable in the given conditions. In countries where low-cost fuels are available, the economic advantages of the hydroelectric alternative may be very much open to question.

This thermo-hydroelectric duality in fact also constitutes a transient phase, which, although it may last for a few decades in new countries rich in water resources, will not take long to change its character completely, given the present rate of growth of consumption. Such a situation has already arisen in the six countries of the European Coal and Steel Community, where a steady trend towards increased thermal production is observable. It can hardly be otherwise, since by 1975 many of the European countries will have harnessed almost 100 per cent of the water resources which it is at present considered economic to develop.17/

While it is true that the form assumed by the problem of choosing between alternatives is quite different in Latin America from that in more advanced countries, and that decisions can and must be based on a much simpler quantitative analysis, it is no less undeniable that there are large systems in the region - the most important if their share in each national

---

16/ On this point, the author shares the opinion of Mr. Leo A. Penna to the effect that in principle, the general public takes a favourable view of the development of water resources, at least in countries well supplied with reserves (32). The a priori position must either be endorsed by studies, or abandoned.

17/ France: 96 per cent; Italy and Switzerland: 100 per cent; Federal Republic of Germany, Portugal and Sweden: 88 per cent (see (33), table 18). The idea of what can be economically developed is relative and contingent upon certain hypotheses with respect to evaluation and economic development (see also (34)).

/total is

total is taken into account - in which the problem under discussion is becoming steadily more complex and will shortly call for the use of complete methods of analysis.

Consequently, in the following pages attention will mainly be concentrated on the study of alternatives within large systems, where several power stations are in operation and which can, in turn, draw upon various new alternative sources, thermal or hydraulic. For the moment, however, consideration will not be given to the possibility of the system's purchasing its power from another neighbouring system - a typical interconnexion problem which will be discussed later.[18/] So will nuclear power stations, which for that reason will also be excluded here, although they could be dealt with in the same way as the classic types of plant (hydraulic, steam-driven, etc.). Lastly, by virtue of the considerations set forth above, more complex selection criteria should not be applied to problems relating to the electricity service in new areas or to small isolated electricity services. As such cases are common in Latin America, although their economic importance is much less than that of the large systems, their special aspects will also be examined at a later stage. Broadly speaking, in these instances decisions will be determined by strictly local conditions and qualitative evaluation criteria based on the experience and good judgment of those responsible for adopting them.

(b) Statement of the problem

A given electricity system is characterized by a certain rate of expansion. Basically, this is dependent upon three factors, each of which is of great importance in countries in process of development: (i) industrialization; (ii) electrification; and (iii) extent of area served.[19/] As

---

18/ A case in point is that of the Compañía Chilena de Electricidad (American and Foreign Power), which obtains increasing proportions of the power its system needs from the State-owned Empresa Nacional de Electricidad (ENDESA).

19/ The development of electricity consumption is usually said to depend upon "industrial production" and "electrification". The notion of "extent of area served", which up to a point merges with that of electrification, has been added here to indicate the special case of countries in process of development where the new areas reached by electricity still represent a very significant proportion of the increase in customers and consumption - a situation which is found only on a much smaller scale in countries at an advanced stage of economic development.

/electrification advances

electrification advances, in the sense that its benefits are extended to a larger percentage of the population in the areas served and that its possible applications become more numerous, and as it spreads so that the services provided cover the whole of the territory, the growth of power consumption becomes almost entirely dependent upon changes in industrial production. This commonly happens in the more advanced countries, where close correlations can be established between industrial production indices and consumption of electricity. But it is important to bear in mind that the reasons for a high rate of growth of electric power are stronger in developing than in advanced countries. At all events, the new sources of power which must be incorporated annually into a system represent a substantial percentage of those already in existence.

As the installation of a new power station, from the moment when it is decided to start work on the final project to the time when the plant enters operation, usually takes from four to six months, during this period the load carried by the system will have considerably increased - by between 32 and 52 per cent, for example, if demand doubles in ten years (i.e., at a cumulative rate of 7.2 per cent). In a large system, such abrupt leaps in its installed capacity are technically very unlikely to be possible and certainly will not be an economic proposition. The process of adding new capacity, then, becomes a continuous phenomenon. Consequently, it is not a matter of deciding upon the construction of one power station, but of programming a whole co-ordinated set of plants to cover new requirements over a specific period. Such programmes, whose approximate duration is ten years,[20] are in practice rigid for the first five, for the precise reason that this is the minimum period required for the execution of the projects. If the satisfaction of the systems' future demand were not provided for so far ahead, it would obviously be necessary, in order to cope with consumer pressures, to choose between alternatives on the basis of the shorter time it would take to execute the project and not on that of greater technical and economic value. Such a situation arose in France in consequence

20/ Programmes are formulated for longer terms, but in the shape of preliminary outlines.

/of the

of the Second World War, when, owing to the urgent need to generate electricity to meet the requirements of the Premier Plan de Modernisation, a power station programme had to be selected without the prior establishment of an estimate of profitability. At that moment it was essential to produce as much as possible in order to set the country's economic activity in motion, since any bottleneck in one of the basic sectors was considered to be more prejudicial to the interests of the national economy than production, however costly (17).

In practice, therefore, when alternatives are compared, it is not a matter of choosing between two or more isolated power stations, but of making a selection from among different programmes made up of various plants, or of the same plants developed in different sizes or in a different chronological order within the period covered by the programme. The aim is to hit upon the plan which, while meeting all consumer requirements, will maximize the benefits obtained without exceeding the available funds, or, if possible, minimize the aggregate investment. The difficulty of ensuring the fulfilment of these conditions lies in the fact that the benefits in question depend not only upon the plants already in existence, but also upon those included in the programme, as well as upon subsequent projects of which the details are as yet outside the scope of the plan established.

The advantages of having a programme, apart from that already indicated - avoidance of the need to select alternatives under the pressure of power shortages - are manifold. It permits the systematized collection of basic data on the possible projects included in the variable part of the programme before the need to adopt final decisions becomes pressing; this will obviate or reduce the risk of deciding in favour of electricity projects likely to militate against integrated use of the course of a river, owing to an over-localized study. At the same time, when a power station is projected as part of a whole formed by others already existing or programmed, the conception evolved can be much more complete. This is often the case with run-of-river plants, which, if designed in conjunction with others whose river régime is different, or with storage plants on the same river or in other catchment areas, have far more extensive possibilities.

/Clearly, the

Clearly, the study of alternative programmes for periods of about ten years, and the analysis of the advantages which they offer when extended to longer periods, necessarily calls for satisfactory medium- and long-term forecasts of consumption. It has already been pointed out, in connexion with the determination of priorities, that this topic is outside the scope of the present study.

A reasonable programme for the installation of generating plant cannot, however, be formulated without approximately accurate knowledge of the characteristics of future consumption. Reliable statistics on the development of electricity in the past are essential, but other useful background data are those relating to consumption of alternative forms of energy and its probable future trends. Broadly speaking, studies of this second type are decidedly scarce in Latin America, and few electricity companies and public agencies have been at pains to promote them.

While estimates based on annual cumulative growth percentages can be used for long-term forecasts relating to periods of more than ten years, short-term projections call for much more meticulous investigation. Techniques for the analysis of demand are based on the hypothesis that the said demand depends upon other magnitudes (determinant variables), either known or susceptible of reasonably exact calculation. " For making an electricity forecast the most important determinant variables are: the size of the population and age grouping, the volume of industrial production (possibly determined in its turn by other variables), the number of households, the prices of electricity and other forms of energy" (35). The foregoing list was made for a highly developed country, but it can also be taken as applicable in the case of the major Latin American systems. In order to establish correct relationships between the different determinant variables and demand for electricity a great deal of statistical material is needed, which is largely unavailable.21/ Hence it is that forecasts in the Latin American countries must be based on simpler methods, taking into account the study of the main electricity consumer groups (residential, transport, industry, street lighting, agriculture) and probable future short- and medium-term trends (over periods of 5 and 10 years).

21/ Such relationships are equivalent to the establishment of an input-output grid determining the correlations between the various sectors of economic activity (35).

Such a study will be conducive to that knowledge of consumption and of its main characteristics which is an essential requisite for determining the best way of satisfying it.

(c) Characteristics of consumption and of the power stations intended to satisfy it

If, as was pointed out above, electricity once produced must be utilized, consumption and production must coincide exactly. When variations occur in the characteristics of consumption apart from the annual growth of load and power, the plant installation programme must make special allowance for such changes.

It is common knowledge that the consumption of electricity in a system, apart from its growth, undergoes three other types of variation: (i) seasonal, i.e., during the course of the year, its level being generally higher in winter than in summer; 22/ (ii) daily, i.e., during the course of the week, consumption being higher on working days than on Sundays and holidays; and (iii) hourly, i.e., during the course of the day, when consumption is very low during the small hours and demand is subsequently variable, with two peak-load periods, one in the morning and another in the evening.23/

At different times of year and different hours of the day the value of power is also different. During the night-time periods of low consumption, for example, if there is hydroelectric energy available in a run-of-river plant, it costs the company concerned practically nothing. On the other hand, a fresh demand for power during the peak-load period of a winter working-day necessitates an additional increase in the capacity of a generating plant which will be utilized for only a very small part of the year, so that, as a result, the cost of the power produced will be high. Consequently,

---

22/ This variation is a function of climatic changes (temperature and light) and depends on the countries concerned. There are parts of the United States today where the use of air conditioning has altered the direction of the seasonal variation, making consumption higher in summer.

23/ In under-developed areas, and sometimes on Sundays and holidays, there is only one peak-load period a day.

the requisite plant installation programme will consist in a combination of power stations capable of supplying these different energy requirements as economically as possible.

Broadly speaking, the basic characteristic of a thermal power station is its installed capacity. This capacity is firm or, in other words, available at any time throughout the year; the power that can be generated is a direct function of the installed capacity.

In the case of hydroelectric plants, the situation is different. The installed capacity does not constitute an adequate basis for classification of the power station, since the available flow varies during the year in accordance with climatic conditions, and differs, for the same reason, from one year to another. Consequently, from the standpoint of consumption, firm power is only that which can be generated with the minimum flow, or at least with the flow available for a very high percentage of the time. The amount of capacity that can be used for generating varies with the available flow, and so, in consequence, does the output of power.

Only if the power station is equipped for a minimum discharge - as was characteristic of the first hydraulic plants to be constructed - does a situation analogous to that of the thermal power stations arise. But it was recognized many years ago that in harnessing water resources allowance should be made for a flow exceeding the minimum run-off. Suffice it to recall that in one and the same system thermal power stations are inter-connected with hydroelectric plants whose characteristics are entirely different and whose low-water periods do not coincide, so that in combination they are capable, for that very reason, of providing dependable capacity and power much more satisfactorily than could the sum total of the minimum values of the various feeder rivers. The position is clearer still in countries where there is a shortage of high-cost fuels and every effert has to be made to use them as economically as possible. In Latin America, a typical case in point is that of Uruguay (36). Japan furnishes a highly representative example of the way in which ideas have changed with regard to the proportion of the time for which firm power should be available in hydroelectric plant

/projects. Up

projects. Up to 1910, designs were based on the flow that was exceeded on 355 days in the year - virtually, that is, on an absolute minimum. Today, the principle applied is that of the flow exceeded during only 95 days in the year (37).[24/] As a general rule, the most suitable flow is determined by means of a technico-economic study in which use can be made of the same methods of comparison as will be referred to later in connexion with the determination of the most appropriate plant installation programme. In practice, designing the same power station on the basis of availability of firm power for different percentages of time is equivalent to comparing several different plant projects.

Again, hydroelectric power stations are of various types: run-of-river plants, with no regulating capacity at all; plants with pondage;[25/] and storage plants (weekly, seasonal, yearly and carry-over regulation). Clearly, the introduction of these regulatory elements opens up new possibilities for the hydroelectric power station, enabling it to use the water at the most valuable times of day.

A power station or a group of power stations can satisfactorily meet a given system's consumer requirements when it is in a position to supply the capacity and power needed at any time. Setting aside the reserve installations necessary both as stopgaps during the periodical withdrawal of machinery for maintenance purposes and in order to cover emergencies,[26/] the

---

24/ This important topic is not specifically covered by the Latin American Electric Power Seminar. Some reference to it is made, however, in many of the papers (see, for example, (2) and (39)).

25/ Definitions of pondage vary a good deal. The French apply the term when the period of regulation is from 2 to 24 hours. Plants with less than 2 hours of regulation are classified as run-of-river power stations.

26/ In a small system, an acceptable reserve is one unit equivalent to the largest in service. As the system expands, the proportion represented by the reserve dwindles to a minimum of 10 per cent. In countries like those of Latin America, where means of access are difficult, climatic and high-cordillera conditions are severe, and there are volcanoes and earthquakes to be reckoned with, no single power station ought to represent a considerable percentage of the system - over 25 per cent, for instance. Generally speaking, these reserve requisites are not fulfilled in the Latin American countries.

/whole group

whole group of power stations, if it is to meet consumer demand satisfactorily, must fulfil certain minimum requisites.

Where the system is purely thermal, it will be sufficient for the peak load available[27/] to match maximum bus-bar demand in the power stations. Or, again, if a major part of the system (90 per cent of installed capacity, for example) is thermal, adequate service will be ensured so long as the available peak load is equivalent to maximum demand.

But, as the proportion of hydroelectricity increases, the requisites for ensuring the reliability of the service increase. The following at least must be established:

(i) The system must be capable of satisfying maximum demand in a dry year. (In Europe the year taken is that beginning on 1 October 1948 and ending on 30 September 1949; in the view of the present writer, a certain percentage of time for which firm power should be available, representative of the interconnected system, might be established - for example, 90 per cent);

(ii) The system must be capable of supplying the whole of the power required annually.

Furthermore, there is always a period in the course of the year in which the supply of water in the rivers and reservoirs reaches a "critical" level as regards the satisfaction of consumer demand. For example, in a country like Chile, in the thousand kilometres that stretch from La Serena to Concepción, maximum demand occurs in winter simultaneously with a considerable reduction of the flow of rivers; this is the "critical" period. In France

27/ Problems of definition arise in connexion with all aspects of the electricity economy. It would be extremely desirable to adopt a standard system for all the Latin American countries, which might well be that established by the Union Internationale des Producteurs et Distributeurs d'Energie Electrique (UNIPEDE) which, generally speaking, is accepted by OEEC. "The available peak load for thermal plants", for example, is defined "as the load that can be obtained in real operating conditions, i.e., taking into account reductions deriving from systematic suspensions of the service, damage and other accidental losses, irrespective of the state of the machinery" (see (40)).

/this period

this period is defined as the 1,200 winter working-day hours when the peak load has to be carried, and it is stipulated that the system must be capable of satisfying power consumption during this difficult period,28/ even in a dry winter. A definition of the "critical" period will have to be worked out for each electricity system, on the basis of hydrological and consumption conditions.

Thus, a plant installation programme must necessarily satisfy certain technical conditions, and can be evaluated accordingly. These requisites are as follows: the system must generate all the power required annually; it must be able to cope with critical periods in critical years; and it must satisfy maximum demand in a dry year. These technical conditions can of course be fulfilled by means of many combinations of power stations. The most favourable programme will be that requiring investment within the financial possibilities of the enterprise or the country and producing the maximum benefits. As has already been pointed out, the measure of the benefits will differ according to whether the enterprise is privately or publicly owned; in the latter case, the indirect benefits must be duly taken into account, in the proportion determined by the socio-economic principles governing the country's overall policy.

In practice, the programme must include other necessary features. For example, it might be stipulated that the proportions of thermoelectricity and hydroelectricity should conform to a predetermined figure, so that requirements of domestic or imported fuels may not exceed an established limit; deadlines could also be fixed for the entry into service of specific capacities, etc. The introduction of these or other parameters restricts the number of alternative programmes among which a choice can be made, and therefore narrows the field of economic comparisons.

The methods of comparison adopted must be applied on specific price and time bases which must be clarified beforehand.

28/ This is what in France is improperly termed "guaranteed power", since, in reality, it is the energy that is guaranteed. Guaranteed power is the average figure for the 1,200 hours under consideration.

/(d) Price

(d) Price and duration criteria

The programmes are carried out over a period of time that we have estimated as being from five to ten years. The advantages are of much longer duration. A programme may be highly desirable in present-day conditions, but become distincdly unfavourable with the passage of time. For instance, a thermal plant which is used at full capacity for a few hours a year only, but is nevertheless advantageous because of its low capital costs, may become a heavy burden when an increase in consumption necessitates the use of the plant for 4,000 hours or more yearly at a high operating cost, thereby wiping out the benefits of the small investment requirements.

It is therefore essential to know how the programme works out over a certain period of time. In industry this is done by the time-honoured method of representing investment by a yearly sum calculated on the basis of the usual formulae that take into account the number of years during which the capital should be returned at a specified rate of interest.29/ If the annual operating costs and receipts are known, the difference between the two constitutes the net profit, which should be compared with the yearly sum destined for amortization in order to ascertain whether there would still be a margin of profit or a deficit. In this way, the results can be determined for any year within the period chosen for comparison.

This method, which is sometimes known as the annual standard cost equivalent, has, however, been sharply criticized, since it is based on the idea that the annual payment for obsolete plant is the same as that originally made for the plant when new. Financially speaking, this is correct, but in practice it is untenable since obsolete plant cannot be expected to function with the same efficiency as it had when first installed.

The concept of present worth, to which reference has been made earlier, is generally accepted today.30/ As already explained, it consists in

29/ $a = \frac{C\, i\, (1+i)^n}{(1+i)^n - 1}$ n = Number of years
i = Interest expressed at so much per unit
C = Capital invested.

30/ This concept is also used in one way or another in a number of the papers submitted to the Latin American Electric Power Seminar (see (53), (42) and (43)).

/expressing any

expressing any amount, receipt or expenditure in a year n in terms of its value at the present time, which is chosen as the base period, and then dividing the said amount by $(1 + i)^n$. This is equivalent to replacing expenditure or income in year n by a capital sum which, at interest rate i at the present moment, would produce the same amount in year n. Thus, initial investment, expenditure and future income are represented by their capital equivalents at the present moment, which, taken in conjunction, will provide the basis for an assessment of the project during the whole period of comparison chosen. The original investment and present expenditure signify outlay and present income implies receipts. The profit obtained during the period of comparison is expressed as the balance of present income after the other two amounts have been subtracted.[31/]

The present worth method clearly offers considerable advantages over the standard cost equivalent method. The main difficulty in its application is, however, the choice of an appropriate "rate of discounting" i. In this respect, it is best to abide by what has already been said concerning the economic cost of money.[32/] Rate i is not the value at which the enterprise is able to obtain the financing of its investment nor is it the private capital market rate; it is an intermediate figure which is virtually impossible to determine exactly in a free economy, where there should be a balance between supply and demand with respect to capital in the economy as a whole. The difficulty of deciding on the rate of discounting is further aggravated by the fact that the rate has to be applied over a number of years during which its value may fluctuate widely. For instance, several years ago, Electricité de France chose the rate of 4 per cent as the average between the prevailing rate of interest - 7 per cent - and that foreseen for the next ten to fifteen years, which is much lower. Recently, however, the enterprise changed its former criterion for a constant long-term rate of discounting of 7 per cent,

---

31/ It is tacitly indicated that the period of comparison corresponds to the useful life of the project which reaches 0 at the end. If the interval is shorter, the initial investment retains a real value which is naturally not deducted.

32/ See pp. 20 et seq.

in view of the unlikelihood of a drop in capital cost since, although savings should increase, investment requirements are also bound to rise (44).[33/]

It should be assumed that the rate of interest on money tends to drop in countries that are developing. It is probable that the propensity to save also increases more rapidly there, and that they receive larger amounts of external savings. For both reasons, interest may be expected to drop to about 7 per cent in the case of France and to 5.5 per cent in the case of the United States, this being the current estimate of "opportunity cost" there. Hence, it is desirable not to adopt unduly high rates of present worth, which may be appropriate to actual conditions but cannot be projected for very long periods.[34/]

It should be remembered that the proportion of present worth represented by expenditure or revenue in the more distant years steadily dwindles. This fact is the more marked the higher the rate of discounting i, as may be seen from the following figures:

i (Percentage)	5th year	10th year	20th year
2.5 a/	0.88	0.79	0.61
8	0.68	0.46	0.21
12	0.60	0.32	0.10

a/ Rate of discounting used for Federal projects in the United States. It is not a representative measurement of the best use of national capital.

From the results given, it may be concluded that with a relatively high rate such as that considered to be representative of the situation of the Latin American countries in the next fifteen years, developments after the

33/ There are studies aimed at demonstrating that the average rate of interest in the major financial centres of the western world has stayed between 6 and 7 per cent for long periods since before the First World War.

34/ No mention has been made of inflation, on the grounds that its effects on a public enterprise ought not to modify the criteria governing that enterprise's choice of alternative. In the case of a private company, however, inflation may largely determine its investment policy.

/tenth year

tenth year will carry very little weight.[35/] If, therefore, enough is known about the electric power programme during the given period, in general no great importance will attach to the mistakes that may be made in estimating revenue and expenditure after the tenth year as a result of the uncertainty with respect to the future use of the plants in question and of those that will enter into operation at a later date in accordance with a so far unspecified programme.

Once a reasonable period of comparison - the useful life of the works or less - has been fixed and either the standard cost or present worth method has been chosen to bring the time factor into play, one difficulty still remains - that of determining the amount of future revenue and expenditure. It is easy to predict the annual production in kWh of the plants contemplated in the period covered by the programme and, with a certain margin of error, the trend of events after that period. More roughly still, the nature and volume of the yearly expenditure required during the period of comparison can also be determined. The problem consists in making a reasonable estimate of the prices at which future income and expenditure should be measured. This problem is basically the same as the former, since it involves forecasting the rate of discounting over a long period. But, in the case of prices, the possible causes of fortuitous variations are far more numerous, since price movements are only partially conditioned by trends and probabilities. The future is essentially governed by new and unforeseeable developments which change the characteristics of the economic and social structures and radically alter the scales of values for the things that are measured by prices. In the last few decades, technology has shown to a striking degree that it can change present conditions by means of new developments. In the case of a problem such as that under consideration, for instance, it is highly important to be able to forecast the price of the fuels to be used by thermal plants. But no one can yet predict with any certainty what effect nuclear energy will have on that price. Electricité de France considers that the increase in

35/ In the case of Chile, for instance, the rate is estimated as between 10 and 12 per cent.

/the known

the known reserves of petroleum in the world will tend to lower the price of the calorie by an estimated 1 per cent annually (44).

If current prices are assumed to be free of such known elements of distortion as are described in this paper, it would be advisable to base future estimates on them. Moreover, even in countries that are well-supplied with economic statistics and a large number of correlations, it is impossible to make a set of parameters for the purpose of progressing with forecasts on long-range prices that is more likely to be applicable in practice than a set of current prices. In the case of some essential prices, their future evolution can be ascertained by varying them in accordance with known trends. This would indicate the limits within which the findings of the studies would range if the conditions actually obtaining differed from those that had been assumed.

In any case, the great uncertainty as regards future prices and the substantial reduction of present worth when there is a high rate of discounting for developments in the distant future justify the choice of a fairly short period for comparing alternatives. Ten to fifteen years is thought to be quite long enough to reflect the real state of affairs as regards the great majority of electric power problems in the Latin American countries.

(e) Methods of comparison

Methods of comparison are many and varied and it is impossible to decide which would be the most suitable in a given case. There is no doubt, however, that the more complicated methods cannot be applied without full and reliable information which is seldom obtainable except in the developed systems for which programming and the choice of alternatives are most necessary. Hence, the smaller and less complex the system the simpler should be the method of comparison, and those methods whose greater precision has real significance only if their background data are equally accurate should be discarded.

Similarly, before the method of comparison is applied, due account should be taken of the importance of what used to be termed the special factors that influence economic criteria with respect to electric power.[36/] Some of these

36/ See pp.18 *et seq.*

factors may take the form of conditions to be fulfilled by the programme, as explained in sub-section (c). For instance, the programme should not be allowed to involve an investment of foreign exchange over and above a specific proportion nor its annual operating cost to absorb a larger amount of foreign currency than the sum stipulated.

In the same way, the indirect profits should be assessed in terms of the extra yearly revenue that could be added to the other receipts of the project in accordance with the appropriate weighting.

The more simple methods used to choose a plant from among a number of possibilities - when no programme proper is involved - include that of comparing the cost of the power to be produced by the new plant with the present cost of power at the generating centres supplying the electricity system. The cost would be calculated for all plants on the same basis.

A similar method, and one frequently used for assessing the desirability of a hydro plant, consists in calculating the sales price of the electric power that the plant could generate with due regard to the relevant provisions in the tariff regulations, and comparing the result with the price of other alternatives as well as with the sales price in force at the moment. When the plants are fairly small in relation to the system as, for example, in the case of Chile, this method involves the assumption that nearly all the energy that can be generated is sold since power is in short supply, thermal generation is expensive and short-term storage capacity is available.

When the plants become larger the methods of comparison should be perfected. What is often done is to compare a hydraulic plant with an equivalent thermal plant that is capable of providing the same service. Generally speaking, the last-named condition can be complied with to a certain extent only since the load curve differs in each type of plant.

The first of these methods consists in making a definitive comparison between each hydroelectric plant and an equivalent thermal plant for the first complete year in which hydroelectric capacity could be used at full load (20). This method was adopted by the advisers to the Argentine Government in their comparative study of the Salto Grande power station

/and a

and a thermal generating plant at Buenos Aires. Admittedly, the investment on lines and sub-stations was also taken into account, and the power was compared at the place of consumption itself.

It has already been stated that a comparison based on the situation during a single year can lead to wrong conclusions. For instance, the findings may be satisfactory in the case of Buenos Aires, where a big thermal system had already been established, but might not give a true picture of the situation over a longer period of years during which the addition of new hydraulic capacity might alter the privileged position of "first in the field" enjoyed by the big hydro plant.

A similar comparison may be made for Uruguay between the hydroelectric plant of Paso del Puerto, which is expected to enter operation in 1964 and might be replaced by additional thermal capacity in the new plant at Punta Yeguas near Montevideo (36). The pertinent study shows that between 1964 and 1970, when the hydro plant will be in a position to dispose of its average annual power production, the advantages in the comparison accumulate on the side of the hydraulic alternative only very gradually.

The time factor is an essential element of consideration. It has been introduced into various methods of comparison in order to perfect them. Let us review the principles of these methods without entering into the refinement of detail suitable to a specialized study.

Let us suppose that a plant involves investment I and that its operating and maintenance costs during the period of comparison will be equivalent to present worth G. The sum of I + G thus represents the total capital outlay required to build the power station and - with the interest on the remaining capital G - operate it. If, in addition, the revenue obtained in any year n during the period of comparison is e_n, this amount may also be represented by its present worth of revenue E.

Therefore, the profit for any plant, also expressed in terms of present worth, will be:

$$U = E - I - G$$

As stated before, a comparison should be made between a hydro plant and another power station chosen as a point of reference. At a given moment,

/all conventional

all conventional thermal plants have similar characteristics and, in particular, the same specific consumption - the lowest attainable. The thermal plant may therefore be taken as a basis of comparison (45). As already pointed out, the difficulty lies in defining a thermal power station that is equivalent to a specific hydroelectric plant. The French base this equivalence on production of the same amount of guaranteed power during the 1,200 hours of maximum load in the year from November to February, and have found it to be a satisfactory criterion in practice. In the case of other systems, the conditions of equivalence may differ, but in general the point of reference will be a thermal plant that is capable of supplying electric power with the same reliability as a hydroelectric plant. Technically speaking, this is tantamount to stating that the revenue of the two plants in question will be the same. This cannot be true in practice because the power supply from the hydro plant will vary according to the amount of water available in the year, and the guaranteed power and peak load correspond to a minimum flow level which is exceeded for a large part of the time. Neverthe-less, the possibilities of the equivalent thermal plant also frequently exceed the flow level on the basis of which it may reasonably be assumed that the real conditions will probably be very close to the theoretical conditions envisaged.

Now let us suppose that it has been decided to compare the hydro-electric alternative with an equivalent thermal plant. The profits of both during the period of comparison will be:

$$U_H = E_H - I_H - G_H; \qquad U_T = E_T - I_T - G_T$$

The difference between the two amounts represents the margin of profit of one alternative over the other or its present relative gains; present because they relate to present worth, and relative because they concern the gains of the hydro plant in relation to those of the equivalent thermal plant. The balance will be:

$$B = U_H - U_T = (E_H - E_T) + (I_T + G_T) - (I_H + G_H)$$

/If the

If the two equivalent solutions are assumed to have the same revenue in theory,[37/] relative present gains may be expressed as follows:

$$B = (I_T + G_T) - (I_H + G_H)$$

In other words, the gains constitute the difference between the total outlay in the thermal and in the hydro plant:

$$B = D_T - D_H$$

These gains have been obtained from investment I_H, but as they are relative to those of the thermal plant, it is more appropriate to say that the surplus gains result from the following difference: $I_H - I_T$.

The term "coefficient of worth" is used to define either of the following two expressions:[38/]

$$W = 1 + \frac{B}{I_H} \qquad (1)$$

$$W = 1 + \frac{B}{I_H - I_T} \qquad (2)$$

The first is a function of gains per unit of investment and the second of gains per unit of investment in excess of the reference investment. In the great majority of cases, the equivalent thermal plant represents the minimum investment required to provide a specific supply. Hence, instead of calculating the average gains from hydraulic investment, it seems more desirable to determine the gains produced by the additional investment, i.e., formula (2). The greater the coefficient of worth the more advisable it becomes to invest in that plant. With value 1, the thermal reference plant and the hydraulic plant offer equal advantages. With a value of less than 1, the thermal alternative is more favourable.

37/ In a more complete calculation, the term $(E_H - E_T)$ could perfectly well be maintained.

38/ See, for instance, (17), (31) and (45).

The first use to be made of the coefficient of worth is precisely in the classification of possible hydroelectric projects in decreasing order according to their coefficient. This classification undoubtedly depends on the rate of discounting adopted; the lower the rate, the higher, in general, will be the coefficient of worth and therefore the greater the number of hydroelectric possibilities that will be more economic than their thermal equivalents. The probable margin of error is naturally fairly large, deriving chiefly from the estimates of the characteristics and costs of the projects under consideration, which are mainly based on preliminary studies. The determination of the costs of power stations in terms of a small number of parameters, which has been done in a number of studies, is particularly useful for this type of systematic arrangement.[39/] In order to prepare an inventory of power stations by coefficients of worth, it is necessary to be familiar with the basic characteristics of the plants classified, such as peak load, firm power in winter, regulating capacity, etc. Hence, at a given moment, all the data on these characteristics would be available, arranged in decreasing order by coefficient of worth.

On the lines of this or similar methods, surveys of the same kind have been carried out which are essential for the formulation of large-scale electricity programmes. It would be advisable for all the Latin American countries that have recently begun basic geo-hydrological surveys to adopt standard methods of classifying their water resources.

In France, surveys of this kind are renewed and revised periodically. The findings of some pieces of research were presented at the Sectional Meeting of the World Power Conference at Rio de Janeiro in 1954 (31).

In Russia, inventories of resources and their economic classification are not based on the same principles. The different sources of hydraulic energy are classified according to quality, which depends on three main factors:

"(1) The extent of natural non-uniformity in the water power resources, which is connected to changes in river-flow in the given region.

39/ See (38) and (39).

/(2) The

"(2) The possibility of reducing the non-uniformity by creating regulating storage basins. This possibility depends on the terrain of the river valley, flood conditions, etc.

(3) Conditions for the utilization of hydroelectric stations in power systems " (46).

These studies, which are based on indices that reflect the characteristics described, constitute, in conjunction with studies of investment cost indices per kWh generated at the plant, an important source of background data for choosing the most appropriate solution.

Nevertheless, when making their final choice, the Russians also use the system of comparing the most desirable hydroelectric alternative, determined on the basis of studies such as those just described, with a conventional thermal plant. The method of comparison adopted consists in "determining the so-called period for recompensating the extra capital investment in the hydro station (as compared to the steam station). Recompensation is obtained by economy in the power production costs" (46).

The formula used to determine the period of recompensation is simply:

$$T = \frac{Kh - Ks}{Is - Ih}$$

T = necessary period of recompensation
Kh = investment in the hydroelectric plant
Ks = investment required in the thermal plant, including capital investment needed to extract and transport fuel
Is = annual production cost of the thermal station
Ih = annual production cost of the hydro plant.

At the present stage of development, a ten-year period of recompensation is regarded as the maximum. Numerous hydroelectric possibilities exist which have less than that figure.

If the Russian method is analysed a little more extensively, it will be found to bear a close resemblance to the coefficient of worth method. The equivalent thermal plant is of course chosen in such a way as to have the same volume of useful production. The interest or rate of discounting appears in the detailed calculation of the Russian method as $\frac{1}{Tm}$, Tm being the normal period of recovery (ten years, as indicated above). If the project covers a certain period of time, the figures comprised in the

/formula become

formula become summatory and include the term $(1 + \frac{1}{Tm})$ as a corrective factor. The main differences between the two methods are as follows:

(a) The comparison is made when the longer-term development alternative is in full use. There is no projection towards a more distant future as in the case of the coefficient of worth. The entry into operation of the plant in less time than its equivalent carries greater weight in the Russian formula.

(b) In the Russian formula, the capital needed to produce and transport the fuel appears as part of the thermal investment. In the coefficient of worth system, this factor is included in the price of the fuel. From the standpoint of national programming, the Russian formula is more suitable. But from the standpoint of electric power programming alone, the coefficient of worth is more logical since it gives the price of the fuel, as it is produced and makes the formula independent of the origin of the fuel, i.e., whether it is national or imported.[40]

(c) The term $\frac{D_T - D_H}{I_H - I_T}$ in the coefficient of worth is the inverse of the term $\frac{Kh - Ks}{Is - Ih}$ in the Russian formula. But the difference is always $I_H - I_T > Kh - Ks$. Owing to the inclusion of different elements, it cannot be decided *a priori* whether the difference in expenditure $D_T - D_H$ is greater or less than Is - Ih, but in principle it may be stated that the first will be greater since it corresponds to a difference accumulated over a large number of years of operation. This enables us to estimate that the period of recovery T will tend to vary similarly to the inverse ratio of the relative returns per unit invested in excess of the reference investment. If it were exactly equal to the inverse ratio, it would be tantamount to saying that the coefficient of minimum worth for acceptance of the hydraulic alternative would have to be higher than 1.1.[41]

40/ These differences resemble to a certain extent what in "operational research" are termed the optimum and suboptimum decisions. The first is best for the whole and the second best for a part of the whole.

41/ For some details of the Russian method see (47).

/Before entering

Before entering into the practical use of these methods of comparison, we wish to refer briefly to another type of approach to the problem of choosing the most suitable solution. It is based on the principles used in establishing tariffs where it is recognized that the cost of producing power will vary during the different hours of the year. The most suitable solution may be found by seeking to ensure that new additional generating stations should produce power at minimum cost. Mr. Friedmann and Mr. Schkolnik,[42] for example, have proposed a method for calculating the hourly cost of electricity service when detailed development requires thorough computation of figures for the various hydrological characteristics of a complex system embracing large numbers of hydroelectric power stations. Briefly, the method consists of dividing the variable cost of hydraulic and base thermal kWh into the total of base kWh for the period under consideration, and the cost of the thermal kWh generated to meet peak load into the peak load kWh only.

As to fixed costs, on the hypothesis that power stations are arranged in their logical order of operation, it is proposed to divide fixed costs corresponding to each load step by the number of kWh actually generated in that load step.

If this procedure is accepted, it could be used for establishing the tariff system. It could also be used "to compare total power costs of various possible combinations of different types of generating facility and could thus serve as a guide for determining which is the most suitable" (43).

Another method of establishing tariffs which has a certain degree of similarity with the foregoing, although it is simpler, is that proposed by Mr. Brelih at the Madrid Sectional Meeting of the World Power Conference (48). In this case, annual costs (including fixed costs) of run-of-river plants, of base thermal plants and of ensuring reserve capacity are distributed uniformly by day or month throughout the year. The annual costs of storage plants and thermal stations with variable generating capacity are divided respectively by the number of kWh generated by them during the year, and to each day or month of the year a total cost is attributed equal to the average

42/ Document submitted to the Latin American Electric Power Seminar (43).

/number of

number of kWh generated, multiplied by the number of storage or thermal kWh produced during the day or month côncerned. By adding both cost figures together it is possible to obtain a figure for the cost of power each day or month of the year and this latter figure divided by the number of kWh produced on the day or during the month concerned, will give an average cost figure. To determine the varying cost of power at different hours of the day, the load curve is divided horizontally into three sections which are those usually employed in the economics of electricity, namely base, off-peak and peak (absolute minimum, daily minimum and peak). Daily or monthly cost is split up in accordance with the load that has to be carried daily or monthly in each of the horizontal sections and is distributed in accordance with the amount of power sold in each horizontal section. This method can be used in dealing with a new generating station which by its inclusión in the foregoing system of calculation, will alter the general price structure in one direction or another. By repeating this operation for the various plants, the different price alterations which occur may serve as a guide to determine which is the most suitable plant.

The two methods of establishing tariffs described above provide an opportunity for recalling that the cost of power will very in accordance with the circumstances in which it can be produced. In other words, in calculating the revenue which a generating station may earn, serious account must be taken of the very variable cost of the different kinds of power which it can produce.

Apart from these methods, based on systems of establishing tariffs, there has also been large-scale development of techniques for calculating probabilities and of statistical methods. Such systems are however, more suitable as instruments of analysis than as methods of comparision.[43]

(f) Methods of programming

The methods set forth in the preceding paragraphs can be used in comparing one power station with another or sets or groups of power stations with other alternative groups. But no systematic procedure for the formulation

43/ See, for example, a case of the application of sequential analysis in (49).

/of a

of a programme has been indicated. If, as is often the case with many Latin American systems, all that is involved is the addition of a single plant to the system within the period dovered by the short-term programme, the methods described above can be directly applied. But where developed systems like the major Latin American networks are concerned, recourse must be had to different procedures.

One conceivable method is that of trial and error or a series of approximations. Its implicit application, up to a point, is very common. The Hydro-Electric Commission of Tasmania has systematized a method of this kind. The practice followed "in the economic investigation of nuclear developments has been to determine the minimum gross unit cost for each of a number of competitive schemes. The gross unit cost is defined as the annual cost of a scheme divided by the available average output, in kW, during a selected period. For any particular scheme there will be a size and layout that will give a minimum gross unit cost. Each alternative scheme of comparable economic merit is then considered in relation with the system in which it is required to operate and modified as necessary to meet the forecast load requirements, due weight being given to system load factor and spare plant requirements.

"Any deficiency in either peak or average output from a proposed development must be made up elsewhere in the system. However, the cost of the scheme must include the cost of providing the necessary firm capacity corresponding to the average output from the proposal and the system load factor. If only hydro plants are considered, such deficiency must be made up by subsequent hydro developments. The economic limit to which a proposed scheme may be developed is therefore the point at which the incremental cost equals the estimated cost of subsequent developments" (51).

The method described is not, however, applicable to large systems, where a great number of generating plants must be satisfactorily combined. This smooth co-ordination of various types of power stations should be effected in line with practicable methods of programming and comparision of alternatives. Linear programming and the use of computers have enabled remarkable progress to be made in this direction during recent years.

The problem consists in minimizing total current disbursements, that is, the sum of investments plus operating expenses in the period to which the comparison relates, both groups of outlays being converted to their "present worth". It is assumed that investments are linear functions of the unknown quantities which, in this case, are the characteristics of the power stations to be constructed and the future output of energy in each plant comprised in the programme. The unknown quantities must at the same time meet the requisites imposed on the programme by the characteristics of consumption or by decisions of another kind, as was explained in sub-section (c) of the present section. These requisites are expressed as linear equalities or inequalities of the unknowns. Acceptable solutions of the unknowns must be positive or nil.

If the number of plants which must be incorporated in the programme is fairly large, the number of equations or inequalities and of unknown quantities considerably increases, and entails calculations for which very big computers are required. In such cases, therefore, it is generally considered preferable to simplify the problem by grouping the plants in categories or sub-categories with common characteristics, such as run-of-river plants, storage plants, plants with pondage, thermal power stations, etc. It is thus relatively easy to work out an overall programme which will show what is required to achieve optimum results. During a second phase, the most suitable plants within each category will be determined.

In this second phase, it is perfectly possible to apply some of the methods of comparison previously described, such as the Russian system or the "coefficient of worth" method. It is sufficient, for example, to choose, for the various types of plant required by the programme, those with the highest "coefficient of worth", and gradually to complete the programme by introducing new power stations in declining order. In practice, the rule of the declining coefficient cannot be strictly applied, since adaptability to the needs of the programme is essential and may not be most satisfactorily achieved by means of the plant with the highest "coefficient of worth". The selection procedure described is, of course, only applicable to those known projects for which the "coefficient of worth" has been determined with sufficient precision. In countries that are only

/just beginning

just beginning to make inventories of this type, the choice is considerably limited by the amount of data available.

The method will, in all likelihood, call for adjustments or repeated trials before the final solution can be reached. The current programme must be projected over a future term in order to ascertain what will be its relative contribution to supply throughout the whole of the period to which the comparison relates. In order to formulate such a projection, one or two programmes subsequent to that already under way must be established on overall lines, so that a general picture may be formed of future generating capacities and of the way in which production will be distributed in the future among the existing power stations, those contemplated in the programme under study and the plants that will be constructed at a later date.

Another reason for approaching the problem by means of a series of approximations lies in the fact that different power stations affect one another, not only physically, as, for example, in the case of a storage plant constructed upstream from an existing run-of-river plant, but from the operational standpoint pure and simple. A familiar instance is that of a more efficient power station or one with a higher base load, which supersedes other plants already in existence and makes their operating conditions different from those originally planned for.

It is understandable that when a method like that described is applied in the French national system, which in 1959 had an installed capacity of 20,737,000 kW, and in the course of that year brought into service an additional capacity of 1,500,000 kW distributed among 21 conventional thermal, nuclear and hydroelectric plants, the matter becomes decidedly complex.44/

In Latin America the problem is different. The largest systems in the Latin American countries barely exceed one million kW. Cases in point are the Greater Buenos Aires and Littoral area, with an installed capacity of 1,427,000 kW (20), the central part of Mexico (the old combined system of the Federal Commission and the Mexican Light and Power Company), with a capacity slightly exceeding one million kW, and the São Paulo system, whose capacity is 1,700,000 kW. In these circumstances, final five-year

44/ See (50).

programmes do not comprise more than five or six major projects which can be fairly easily analysed in accordance with the principles explained above, with some simplification of the methods as regards the conditions and parameters influencing the result, which are less familiar in Latin America.

(g) Determination of the dimensions of the essential elements of a hydroelectric power station 45/

The problem of determining the dimensions of the various engineering works included in a power station is definitely outside the scope of the present study. Once the power stations constituting a programme have been selected, with their main characteristics in the shape of installed capacity, flow harnessed, regulating capacity, etc., the next step must be the final project for each individual plant. The dimensions of the basic works - intake structures, storage or pondage, penstocks, machine-room, etc. - may undergo substantial changes designed to improve or perfect the economic advantages which in the draft project sufficed to justify the inclusion of the power station concerned in the programme of works under way.

Tradition and logic alike assign responsibility for this aspect of the programme to the project-maker. There is a vast body of literature on how to calculate the economic gradient of the channels, the economic diameter of the penstocks, the most suitable cross-section area for the galleries, the size of the generating units, etc. Of course, the changes introduced into the draft project are not so fundamental as to alter its significance, since that would be equivalent to considering an alternative different from the one adopted in the programme, and therefore needing to be justified by the method described in the foregoing paragraphs.

The studies mentioned imply slight changes, amounting only to a few per cent, in the maximum power obtainable or the energy that can be generated during the year. These variations signify increases or decreases in the amount of capital invested. In practice, the purpose of the economic study is to minimize investment per unit of energy produced. 46/ Current project

45/ The problem discussed in this paragraph assumes a much simpler form in the case of thermal power stations.

46/ In other words, the greater investment required to produce the additional amount of power divided by the additional kWh gives a quotient lower than the average of total investment divided by total kWh.

/techniques assume

techniques assume that such marginal energy will be used in the same conditions as the base energy. In other words, if the installed capacity of the power station is such that it will take several years to reach the point of total utilization, the marginal energy will not acquire economic signficance until the end of the period in question. This is equivalent to introducing into the formulae used by the project-makers the notion of "present worth", the importance of which is generally underrated.

A second consideration which should be stressed is that when a high proportion of a system is thermoelectric, the marginal energy obtained through a hydroelectric project finds an immediate sale, at least during some months of the year, and its real worth is easy to estimate. But if the system is predominantly hydroelectric, the sale of the marginal kWh is highly precarious, owing to the fact that every hydroelectric project, whatever the probability of flow for which it was planned, has possibilities of producing additional energy in certain years. In other words, only the marginal energy obtained from flows available for a very high percentage of the time has a definite sales value. From the standpoint of the present discussion, this means that in the study of minimum cost the project-maker must take into account only a part of the kWh obtained in theory, when they correspond to flows available for less than 90 or 95 per cent of the time.

Lastly, it will be recalled that in earlier pages emphasis was laid on the importance of not designing projects on the basis of criteria too closely adjusted to immediate circumstances, which might hinder or prevent subsequent expansions based on the natural change brought about by the progressive depletion of hydroelectric reserves and the joint operation of systems in which a greater part will be played by other generating media - thermal or electro-nuclear power stations, for example. It also frequently happens that a possible hydroelectric project of which the dimensions are too large for the consumption situation in the immediate future may be developed in clearly demarcated phases. Broadly speaking, a project of this kind will mean giving chronological priority to investment in all those construction works which cannot be divided into stages, and the benefits of which will only be obtained in so far as the project is

/completed. In

completed. In all such cases, the "rate of discounting" plays a preponderant role. Given the high rates that must, in the opinion of the present writer, be adopted in Latin America, the weighting of these benefits to come will be very low, and they will consequently make it more difficult to find an economic justification for investment in future projects which a policy of wise conservation of natural resources would nevertheless dictate. In this sense, the low "rates of discounting" applicable in North America and Europe allow much more latitude. The writer therefore feels constrained to recommend that when the stage of final design is reached, the dimensions of the project be planned as far as possible with a view to leaving the way open for fuller subsequent harnessing of the resource in question at minimum cost.

6. Combined use of thermal and hydraulic resources and the position with respect to nuclear energy

(a) Co-operation between hydraulic and thermal plants

As previously stated, there is a widespread preconceived idea that hydraulic exploitation is to be preferred to thermal plants. This strongly entrenched view appears to be based not only on the usual argument that waterfalls are an obvious resource, constantly renewed by nature, but also on the historical fact that water has provided motive force from the remotest times. The great industrial centres inevitably grew up on the margins of the rivers that constituted the only resource capable of producing several tens of horsepower on a single driving shaft.

The problem has been viewed in the light of competition between hydraulic and thermal power, instead of in its proper light as a question of two methods that are to a high degree complementary. This is partly due to the methods used in the study of alternatives referred to in the preceding chapter, whereby hydroelectric plants are compared with reference thermal plants and thus hydraulic methods are worked out that are superior to the thermal equivalent.

/This involves

This involves an unconscious distortion of the real meaning of the evaluation. With reference to these methods of comparison the Russians state:

"It should be emphasized that the comparison with steam is only of design value and should not be considered as an attempt to contrast the different sources of energy one against another. The power industry in the Soviet Union is fundamentally based on the harmonious combination of various types of power plants connected in large power systems, which ensure most favourable conditions of reducing the self cost of energy for the entire system." (46)

This harmonious combination is undoubtely due largely to the programming studies referred to in the previous chapter. It is obvious that if there is a given level of consumption, and a given water resource which can fully meet all power demand and requirements during the period of maximum flow but cannot do so when the water is low, the resource in question can be combined either with another hydroelectric plant or with a thermal plant. In such a case the study would include a comparison between the appropriate thermal reference plant and, firstly, the hydroelectric plant; secondly, the two hydraulic plants in combination, and lastly, the first hydraulic plant (presumably chosen for its high coefficient of value) plus a thermal plant.

It can be seen that there is a logical connexion between this problem and that referred to previously. In view of the vital importance of this subject, some qualitative aspects will be dealt with below.

As previously indicated, there are wide variations in power consumption levels, both throughout the year and during the course of a single day, resulting from climatic factors and the seasonal, weekly and daily rhythms of human activities. At the same time there are variations, following an entirely different pattern, in the abundance of the water resources, directly related to the flow of the rivers, which varies in accordance with climatic conditions. Although the variations in stream flow follow a more or less regular seasonal rhythm, the changes from year to year, floods, flow during the rainy season, etc., cannot be forecast far enough ahead or with enough reliability to provide a basis, for example, for a full year of operation.47/

47/ In certain individual cases moderately acceptable results can be obtained. Moreover the above statement does not apply to the results obtained by means of data from snowfall measurement stations, which provide a basis for forecasting the probable runoff during the period of thaw.

/Hydrological and

Hydrological and hydrometric studies provide data that can be used to forecast with a given degree of probability what will happen over a long period, but not what will happen in a given year or series of years.

Consequently it is a complex problem, when a plant is installed at a stretch of river to make use of a given difference in elevation, to determine what will be the maximum flow that is to pass through the turbines. Unless the level selected is the absolute minimum for the river, the plant's installed capacity cannot be continuously available or relied upon. The building of daily, seasonal or carryover storage on the river, and the connecting in one system of regions with different climatic - and hence different hydrologic - conditions, can undoubtedly greatly improve the situation and make it possible to increase the guaranteed capacity of the hydroelectric plants thus combined to a level far above the sum of the individual minimum capacities guaranteed by the natural stream flow. This is one of the benefits of interconnexion, about which more will be said subsequently.

Storage is one of the most effective methods of increasing hydroelectric potential, but it is limited by physical and economic conditions, and despite the efforts being made in all the advanced countries, it cannot provide a sufficient degree of regulation. France has carried out an extensive programme of reservoir construction since 1945, and has raised its annual accumulated power capacity in the last 15 years from 884 million kWh to 4,114 million kWh (in 1960); that is, it now amounts to only 6.5 per cent of the total power generated during the year. In Italy and Switzerland storage capacity is in the neighbourhood of 15 per cent.48/

In Latin America one of the principal hydroelectric systems, that of the Rio Negro in Uruguay, has a carryover storage capacity of approximately 520 million kWh,49/ but it is not in a position to make use of the whole of its installed capacity.

48/ The reason for this higher capacity is obvious, since the ratio of hydraulic power to total power is much higher in these two countries. With respect to hydraulic production alone, France has a storage capacity of 12.6 per cent (1959). See (52).

49/ Not including the Paso del Puerto plant (in the project stage) downstream from Rincón de Baigorria.

/Hence the

Hence the economic advantage of combining hydroelectric exploitation with thermal plants. As the latter can call on the whole of their available energy at all times, they are particularly well placed to supply the deficiencies due to unfavourable hydrologic conditions. Thus the power that was formerly of a secondary nature at hydraulic plants, that is, the power that could be generated with the water in excess of the estimated from flow and that could not be stored in regulating reservoirs, can nevertheless be guaranteed to the consumer during dry years, when the extra margin of flow decreases or disappears, by means of a thermal plant. This supplementary function of thermal plants is one of their most essential functions in the combination of the two sources of power. This is the explanation of the fact, referred to previously, that the Japanese have been able to design their hydroelectric plants for flow levels that are exceeded on only 95 days in the year.

Canada, traditionally regarded as a country with a large hydraulic potential, in some areas is facing the problem of the limitation in the near future of the sites that can be economically exploited. Studies indicate that by designing hydraulic plants with a view to present or future thermal boosting, it is possible to justify "substantially higher installed capacities than would be the case if future system hydraulic capacity is unlimited and no thermal generation is developed" (53).[50] The same study shows that with the installation of thermal plants the installed capacity of storage plants can be raised economically without any increase in the storage volume, thus obviating or considerably reducing overflow.

In passing it should be pointed out that the flow level on which the development of a given water resource is based is closely linked with the conception of the future system, and that even if at first the design must be for a level close to the minimum flow, because of the lack of safeguards against dry periods or years (such as reservoirs, thermal plants or interconnexions), an effort should be made to foresee what the economic limit might be, and to design the civil engineering works, as far as can be justified, so as to allow of the necessary subsequent expansion.

50/ The systems referred to are those of Manitoba and north west Ontario.

The question of selecting the flow level is by no means only a matter of economics. As water has so many possible uses, bydroelectric exploitation is particularly desirable in the case of multiple purpose projects.[51/] On the other hand, the need to use the water for purposes other than the generation of electricity introduces restrictions that limit or modify the extent to which the water resource can be used as a source of power. In each country local circumstances determine what are the most important uses for water, such as to meet the needs of urban and rural living, irrigation, industrial requirements, navigation, log floating, etc. Links are established between such uses and the development of electricity plants, and these links must be considered in the study of the water courses that are to be used for these plants. In any case, some of these uses alter the character of certain available supplies of energy, reducing them from the category of a constant supply to that of a supply liable to interruptions, or from a source of power throughout the year to one only seasonably available, etc. In such cases the supplementary use of thermal power will also have the advantages indicated above.

There are other advantages in the combination of hydraulic and thermal power. To allow for non-hydrologic factors affecting reliability, such as the condition of the civil engineering works or equipment, failures in the long-distance transmission lines, etc., systems must have an installed

51/ Multiple purpose projects give rise to a special type of economic study of great importance, dealt with in various papers presented at the Latin American Electric Power Seminar; see (47), for example. Although it is not possible to go into the details of this special case here, the study of the energy aspects is in principle analogous to the study of an electricity plant, but the problem is to make an equitable allocation of the investment and expenditure for the project that are common to all the purposes it serves. There are a number of criteria for making this allocation, such as justifiable alternative expenditure, relation to sales, etc. Multiple purpose development usually results in a satisfactory hydroelectric formula. In Chile multiple purpose projects have been carried out, and others are under study, for drinking water (Santiago, Iquique and Antofagasta), and irrigation, of which there are a large number because of the nature of Chilean agriculture. A large multiple purpose project is the Chocón plant in Argentina, which would be capable of producing about 900,000 kW, and in addition would perform regulating and flood control functions and functions relating to irrigation and navigation.

/capacity exceeding

capacity exceeding the maximum actual demand. In addition there must be the normal margin of reserve for the proper maintenance of equipment. Since this margin is only for use in emergencies and for short periods, it should be provided for the minimum capital investment, which of course means that thermal plants are to be preferred, since their installation costs are much lower than those of hydraulic plants. This argument is further strengthened by the fact that for reasons of security and to avoid dependence on long-distance transmission lines, the reserve capacity should be situated near the large consumer centres. The advantages of the thermal plant include a considerable latitude with respect to location. However, this does not always apply to large base thermal plants, whose location is restricted by the water available for cooling during the dry season, and by their atmospheric pollution, which now more or less prohibits building such plants in the immediate neighbourhood of great urban centres. Consequently the statement that thermal plants do not have extensive transmission systems is often untrue.

Despite the unquestionable advantages of combining thermal and hydraulic plants,[52/] in some countries local fuels are so lacking that development is based essentially on water resources, and the small amount of thermal installed capacity is used only as a minimal supplement in day-to-day operations and as the normal and emergency reserve capacity. This is true of Portugal and Tasmania, for example. In Latin America a good example of this situation is Brazil, where there are large hydroelectric resources throughout a considerable area of the country, but where thus far there is a lack of known deposits of good quality coal, and of large petroleum deposits.[53/] In these cases, the emphasis in development is essentially on hydroelectric resources, but it would be a mistake to overlook the possibility of the combination with thermal plants in future plans. However abundant hydroelectric reserves may appear at present, they will be used up to the economic level within a comparatively short

---

52/ The paper presented by Mr. Pett at the Latin American Electric Power Seminar illustrates the results than can be obtained with this combination (42).

53/ See (54).

time, not only because of expansion of consumption, but also because of the gradual reduction in the cost of thermal power, due to the steady rise in the efficiency of new machinery.

Italy is a good example of this situation. Being short of fuel resources, it led Europe for many years in hydraulic production. In 1951 90.1 per cent of its production was hydroelectric, the balance being thermal or geothermic. By 1958 the situation had already changed to the extent that only 79 per cent of production was hydroelectric. Studies indicate that in the near future, in 1965, hydraulic production will represent no more than 60 per cent of the total, and that by 1975 the proportion will be only 40 per cent (55). It should be pointed out that this trend has an immediate significance for hydraulic projects, which within less than 15 years will come to constitute the smaller proportion of the total supply. That is, not only must hydraulic plants be thought of as combined with a large proportion of thermal plants, but they will have to be used more and more as modulating plants capable of dealing with the daily load fluctuations, a task for which they are particularly well equipped. Hydraulic machinery is noted for its great flexibility of operation, enabling it to be brought into service from zero to full load in a matter of minutes; in addition, because of its low speed and great inertia it is highly stable and able to withstand changes of load. Because of these characteristics storage plants are particularly suitable for supplying power during the day when there are rather sudden changes in the load.

Uruguay is a typical example of proper use of the thermal-hydraulic combination. There is a lack of local fuels, and water resources are not abundant. At present, during a normal year for hydraulic generation, the thermal:hydraulic ratio is about 28:72. The estimated ratio for 1970 is 43:57, despite the development of the Paso del Puerto hydroelectric plant (31).

When a country has no fuel resources the use of its water resources, even if their development is costly, has the considerable advantage of economizing foreign exchange. This aspect is particularly important in countries where foreign exchange is an essential requirement for obtaining the capital goods needed for development. This is another advantage of hydro-electric plants, for which the total foreign exchange needed per kW of

/installed capacity

installed capacity is much lower than for a thermal plant. In Chile the proportion as between thermal and hydraulic is 2:1, and for many projects in Latin America the proportion has been established as between 1.5:1 and 2:1.

In brief, for reasons beyond those of an economic nature that can be assessed by quantitative methods, the development of hydroelectric resources will have to be conceived on the basis that they must in the fairly near future be exploited in combination with thermal plants, either conventional or nuclear.

(b) Operating a combined thermal-hydraulic system

The operation of a combined thermal-hydraulic system constitutes a rather complex problem, when the thermal capacity plays a major role and is not confined to supplying the system's reserve power and functioning only for short periods in the year during temporary water shortages.

The operation has two main aims: first, to ensure the service required for consumption, and second, to provide this service in the most economical form.

In a purely thermal system, this second aim is attained by conducting the daily operations on the most economical basis; that is, the first thermal units to be brought into service are always the most efficient - generally the most modern. In a combined system the question must be dealt with not on a day-to-day basis, but in relation to fairly long periods determined by the regulating storage capacity used in the inter-connected system. If this storage is only daily or weekly, the most economic operation must be calculated on that basis; if storage is seasonal, economic operation must be for periods of several months or for the whole year, and if the regulating capacity is very large, with annual or carry-over storage, the planning must be for a period of more than one year.

In order to ensure service, it is perfectly possible that during a certain period of the year more costly thermal power may be generated to permit the storing of hydraulic energy and ensure that consumption requirements can be met during the critical period.

Most of the essential rules for operating a combined system can be deduced from the foregoing. Run-of-river plants will always provide the base

/load. They

load. They will generate as much power as can be sold, since the marginal cost of production is practically nil. When the plants are also provided with pondage, the resultant power and energy is used during just those hours when there is maximum demand. The number of hours during which this peak power is distributed will depend on individual conditions, but generally speaking such pondage is provided for the purpose of providing extra load and consequently there will be a tendency to use it to maximum capacity for the minimum number of hours.

Thermal and storage plants provide the best combination for operating purposes. They have some common features: both can stock potential power in the form of fuel or stored water. However, the reservoirs have only a limited storage capacity, since the water they contain has to be so regulated as not to become exhausted before the critical periods. Economy in the use of storage water is governed by a series of operational techniques that depend on the characteristics of the group of plants that constitute the system.[54] It is quite possible to establish the extent to which it is economical to store water for use during the critical period by generating thermal power to replace the power that would otherwise have been generated by the stored water. It is equally possible to determine the additional cost of reserving hydraulic kWh for various possible hydrologic conditions, and whether this reserve power would be economic or not, if it is assumed that the decision to store energy is immaterial from the standpoint of ensuring the service.

The general rules governing the operation of the combined system must be adapted for each system, but they will have much the same form in all cases. If the daily load curve cannot be met from the available hydraulic power (including the amount that can be allocated daily from seasonal or carryover storage a certain quota of thermal power must be generated. If this is only a small proportion of the total, as would be the case for a predominantly hydraulic system, or for a normal system during periods, or years of abundant flow, the thermal plants would probably operate at a level on the load diagram above the regulating storage plants, but below the pondage. This situation is not particularly favourable for the thermal plants, since they have to modulate a part of the load, and in addition they are in continuous use for only a few hours during the day.[55]

54/ See (32) and (56).

55/ This is the situation in Sweden; it is very exceptional for a thermal plant to operate at the lower levels of the load diagram.

If the year or period in question is normal or dry, a higher proportion of thermal power must be generated. The thermal plants would then operate at a level between the run-of-river plants and the storage plants, and would take on a part of the load curve for many hours during the day. Lastly, if the run-of-river plants cannot generate all the base power, the most efficient thermal plants would make up the base load.

As the thermal plants displace the storage plants to a higher level on the load curve it is advisable to increase the installed capacity in the latter, since the plant factor at which they would normally operate decreases and they can make better use of any additional volume that they can provide at maximum flow periods. Something similar happens in Europe as a whole, where the coefficient of the hydraulic power that can be produced in a normal year and the power required for consumption on the base load was 1.57 in 1955, and will be 1.09 in 1957 (58).

If the Rio Negro-Montevideo system, which lacks run-of-river plants, is examined in the light of the foregoing considerations, it can be seen that the storage plants' main function is to ensure the load required for consumption, while the thermal plants are responsible for providing the power. However, in an average year the bulk of the power is delivered by the hydraulic plants that provide the base load, and the responsibility for modulating the load is left to the thermal plants installed near the centres of consumption. In a below-average year the situation is reversed; the base load is provided by the thermal plants, and the modulation is undertaken by the hydraulic plants (36).

The main Brazilian system, in São Paulo, presents a different picture. The supply is mainly hydraulic, with a very large storage capacity. The reservoir of the Cubatao plant alone can store the equivalent of 1,900 million kWh, more than 25 per cent of the system's present annual consumption. In this case the characteristic function of the thermal plants is to deliver peak power, but in abnormally dry years they also have to supply a part of the base power.[56]

56/ Although no very recent information is available, this apparently is still the case; see (59).

/The electrification

The electfication plan for Venezuela involves a well-balanced development with respect to hydraulic and thermal resources, but it is a country with the great advantage of both abundant hydroelectric resources and large deposits of cheap fuel. For normal operation the base load is to be provided by the thermal plants during the dry season and the hydraulic plants in maximum flow periods. At intermediate times it is expected that these functions will be shared.

In Chile the interconnected system is distinguished by a high proportion of run-of-river plants, daily pondage at almost all plants, rather low seasonal storage capacity 57/ and thermal centres run on costly fuel. In these circumstances the main responsibility for supply lies with the hydraulic plants. The position of the thermal plants is just as described above: when the water is low they are used as peaking capacity below the pondage level, while in dry years and during the critical months they have the base position, displacing even run-of-river plants to facilitate pondage at those plants.

These descriptions of different types of operation indicate that in countries or areas with abundant water resources where hydroelectric generation is economically preferable, the base load should as far as possible be provided by run-of-river plants. In a country like Austria, for instance, the proportion of run-of-river plants is so determined as to be able to provide the base load in summer.

A number of conclusions can also be drawn about thermal plants. These provide two basic services: (i) reserve power, and supplemental and peak service, which means use for a small number of hours during the year, and (ii) base power with a high annual level of use. The first case calls for conventional plants with low fixed costs (low investment per kW) and high operating costs. The second calls for high-efficiency units and consequently high investment. For the first category medium pressure units and gas turbines can be considered. Gas turbines have two advantages that should be taken into account.

57/ A considerable increase in regulating capacity is being provided for the near future.

/Firstly, they

Firstly, they can be brought into service very quickly, since they can carry a full load within 20 minutes of the unit's being cold, an operation which normally required from 4 to 6 hours for a conventional turbine. Secondly, the investment per kW is low compared with conventional units, although the limited experience to date rules out final confirmation of this advantage. However, yield is lower than for a conventional thermal plant (61). Thermal plants in group (ii) above include both conventional high-pressure steam plants, and nuclear plants, which are dealt with in the following paragraph.

(c) Combination of conventional plants with nuclear plants

This question has received a great deal of attention from experts in the economics of electricity, and the Madrid Sectional Meeting of the World Power Conference (1960) was largely devoted to analysing the question.

The situation was described in the following general terms. Investment per kW of installed capacity is much higher than for a conventional thermal plant (according to some 2.5 times as much).58/ The amount increases sharply with the decrease in the size of the reactors; hence the present trend towards the installation of very large units (62). The present cost of nuclear fuel is lower, although not much so, than the cost of fuel for a coal plant.59/ The cost is a direct function of the useful life of the fuel inside the reactor, which might be considerably extended by new metallurgical and irradiation methods now under intensive study. Considerable progress in this field appears possible, but in view of the many existing problems some reserve is called for. The general paper on the functional relationship between traditional and nuclear production states that "although replacement of boilers by nuclear reactors can be envisaged and is the subject of large-scale research, in view of the many problems induced it would be rash to attempt to forecast the future" (63). With respect to continental Europe the Armand-Estzel-Giordani report makes what seems rather an optimistic estimate of the economic possibilities of

58/ See (44).

59/ The English estimate that the cost of fuel in their reactors that use graphite-moderated natural uranium, is about half the present cost of the best coal plants in operation (64).

/installing such

installing such plants in the area of the six countries of the Euratom group, since experience shows, at least with respect to Italy, that installation would certainly be less rapid (55).60/

The foregoing shows that at present nuclear plants can be considered from the economic standpoint only in very large units and to provide base loads with 90 per cent annual use.61/ A typical example is provided by the principles applied in Scotland for the development of electricity, according to which "nuclear generation should be located where alternative resources are not available, but at present cost development should not proceed beyond what may be necessary for base load operation, unless in conjunction with pumped storage" (65).62/

The author of this paper believes that at the present time countries undertake the development of nuclear power for one or more of the three following reasons.

(i) Because of the lack of other thermal or hydraulic resources capable of economic exploitation. This is true in the United Kingdom, which estimates that it will not be able to produce enough coal to meet the growing demand, and in Italy, which is coming to the end of its hydroelectric resources. In Latin America this might also happen in Brazil, which thus far has no local fuels available, and where it is considered necessary to install a large amount of generating capacity near the consumer centres (54).

(ii) Because of the requirements of industrial development, in order to be able to compete in market for nuclear equipment.

60/ Even those responsible for the English programme, which is undoubtedly one of the most ambitious plans for commercial development, appear to entertain some doubts about the rapidity of future development (64).

61/ Even in these circumstances it is estimated by the Italians that the cost of nuclear power is between 30 and 40 per cent higher than the cost of production at a conventional thermal plant with the same load diagram (55).

62/ Another way of increasing the load factor of nuclear plants is the intensive use of heat accumulators (75).

/This applies

This applies to the United States, the Soviet Union and France.[63/]

(iii) As a preliminary stage with a view to eventual development on an economic basis, after the solution of initial difficulties, when experience has been gained, staff trained, and the technical, legal, social and other conditions required for nuclear power development have been established. This applies to many European countries, such as Spain and Portugal, and to some Latin American countries that are considering embarking on this state.

In the circumstances, given that the present economic unit size is a reactor with a capacity of not less than 200,000 kW, the interconnected system required to ensure a utilization factor of the order of 90 per cent would represent a maximum demand of at least 800,000 kW. Few Latin American systems now represent figures higher than this. Those that do, already have run-of-river plants installed that provide all or most of the base load, quite apart from promising sites not yet developed but with priority for development. Consequently there does not at present seem to be any possible combination in which nuclear power could be used economically in Latin America, except perhaps in the case of Buenos Aires and Litoral. This Argentine system will in fact represent an estimated maximum demand of 2,249,000 kW (20) in 1969, which implies a continuous minimum base load of not less than 500,000 kW. Nevertheless, the programme of new plants drawn up by government advisers does not recommend installing any equipment of this nature, undoubtedly for economic reasons, since it could not possibly compete in the near future with the fuel oil and natural gas from the Campo Durán and Comodoro Rivadavia deposits. Mention should also be made of the São Paulo-Rio de Janeiro area, where the construction of a nuclear power plant of the order of 150,000 kW is under consideration.

63/ Although nuclear power is related to the peaceful uses of atomic energy, technical advances are unquestionably of military value in this field as in others.

Chile has considered the possibility of installing a base nuclear power plant in the northern desert, to meet the needs of the industrial complex constituted by the copper mines and refineries and the nitrate processing plants in the neighbourhood of the towns of Tocopilla and Antofagasta, in view of the lack of hydroelectric resources in the area and the high cost of local and imported fuels (between 3.60 and 4.50 dollars per million kilocalories). At present this area is served by a group of power stations representing a total of 227,000 kW, of which 167,000 represent steam plants and the rest diesel plants, except for 1,500 kW supplied by hydraulic plants. The base load is relatively high because of the high level of industrial demand, especially for electrolytic copper refining. A study has been carried out on the possibility of installing a base nuclear power station of 50 MW operating with a plant factor of 80 per cent. Despite specially favourable conditions justifying the construction of such a station, the theoretical study indicates that the advantages would be slight compared with a conventional station (66).64/

One last point is that to the foregoing considerations relating to criteria for evaluating programmes should be added the question of what view should be taken of the future effect of nuclear power stations.

The present author believes that at present the question is one of only academic interest for Latin America, except perhaps for Brazil and Argentina, since it is not now possible to envisage a situation in which the installation of a nuclear station would be considered on economic grounds. However, a few years hence advances with respect to economic size and fuel cost may be such that the question should be reconsidered. In that case, the method of study should be similar to those described above, except that in this special case the parameters determining the cost should have a range extending from an optimistic lower limit to a pessimistic upper limit, and the latter would of course correspond to the present situation. In this respect the nuclear power stations are distinguished

---

64/ Obviously the small size of the plant is one of the factors that make it difficult to justify it on economic grounds, despite the exceptionally high conventional calory cost.

/by a

by a feature which is not found in conventional thermal plants. Apart from the minor modifications that can be made while the station is operating, the yield of a thermal plant throughout its life remains essentially what is was when it was first designed. In nuclear power stations, on the other hand, advances may be made in fuel efficiency that are independent of the reactor installed, and there is thus a considerable possibility that in future years a higher kWh yield will be obtained from the same load of fissionable material at a lower cost. The future operating conditions of a nuclear plant will be determined by such considerations. In practice the matter is less one of judging the possibilities than of judging the time that they will take to materialize. This is one of the new factors that will arise in the future, and that will have to be estimated or approached without reference to established rules or trends.

7. The interconnexion of systems and its advantages. Possibilities in Latin America

(a) Aims

"Though the term 'Power Pool' may seem relatively modern in Electric Utility Operations, in principle the pooling or interconnected or grid operation of electric energy producing resources is practically as old as the industry itself" (67). It is clear that any electricity system involves all the problems arising from the use of different and separate sources of energy to satisfy consumption. The combined use of such sources, however, makes for greater efficiency by facilitating operational flexibility. In principle any system combines all the advantages which can foreseeably derive from the interconnexion of systems.

As independently developed systems have grown, it has become possible to make links between them. It is then advantageous to proceed with development for the "parallel operation" of systems. This is only the first step towards subsequent interconnexion, as at this early stage the junction units needed to bring about effective interconnexion will not have yet been constructed. For parallel development, however, both systems will have to ensure exactly similar conditions at points of contact as the essential conditions for later interconnexion will include identity of

/frequency, voltage

frequency, voltage and direction in which the magnetic field rotates.

Only a joint decision affecting the two systems, however, to provide suitable means for the interchange of load and power in appreciable quantities will bring about a full measure of interconnexion with all the benefits that may be expected from it

The foregoing shows that the interconnexion of two systems can be distinguished from a single integrated system not for technical reasons - since the scale of operation simply increases - but for reasons of interest, organization, etc.[65/] The systems will have developed separately in the past. They will have belonged to different owners and will have been developed along different lines in accordance with the natural resources of the area and the consumption characteristics of the system. It is these differing interests which become integrated into a power pool when two separate systems are interconnected; each of the systems will, however, continue to enjoy a large degree of freedom as regards its own decisions because the two organizations concerned are in fact independent.

Interconnexion has in some cases led to the integration of the various regional systems into a broad national system. This is what happened in the United Kingdom. The establishment many years ago of the British Grid - originally a publicly owned network for the interconnexion of private systems - gave rise in 1947 to the nationalized industry.[66/] This is not what occurred in France where measures for overall interconnexion were taken at a later stage, that is, after the creation of the single publicly owned system of Electricité de France.[67/]

65/ It is true that larger scale creates more complicated problems but they are fundamentally of the same kind. For example, short circuits may be considerably larger and require special equipment.

66/ In 1926 the Central Electricity Board was set up. Its purpose was the more efficient co-ordination of electricity generation. This was the first step towards the establishment of the grid which interconnected the most efficient plants. The 1947 Act set up the British Electricity Authority which acquired existing municipal and private owned facilities.

67/ In France there is interconnexion between the single publicly owned system of Electricité de France and self-suppliers who account for about 20 per cent of the total of power produced. Private production is about 95 per cent thermal (52).

The interconnexion of different systems has two main purposes of a very different kind: (a) to ensure a market for the large amounts of power available in certain areas which can be economically transported only in the form of electricity; (b) to take advantage of the many and various advantages deriving from the diversity of interconnected systems. The same basic reasons justify the ever more complete integration of a single system.

The first purpose itself contains two different aims which have been the principal reasons for interconnexion in various countries. In some cases, the question is one of exchanging large quantities of hydraulic and thermal power. Germany is a typical example. The systems of the southern area which are very largely hydraulic are harmoniously combined with the large thermal resources resulting from the use of light Rhineland coal. The second case has to do with the seasonal variations in hydroelectric resources, so that power can be exchanged in one direction or the other according to the season of the year. Italy provides one example of this, but the most typical case is without doubt Sweden,[68] where all national, municipal and private concerns of any size co-operate voluntarily through the Central Electricity Operations Office (Centrala Driftledningen). In Sweden, interconnexion makes it possible to combine the use of the large hydroelectric resources accumulating in summer in the extreme north with the operations of the power stations in the south whose capacity is regulated by natural lakes and reservoirs into which there is a fairly constant flow of water throughout the year. Interconnexion is particularly important on 380 kW and 230 kW lines (69).

The problem of transporting power in the form of electricity has very clearly defined limitations. In France, for example, where the railway network is dense and there are numerous navigable internal waterways, the transport of good quality coal over almost any distance is less expensive than for the electric power that could be produced with the same amount of coal. This is a problem of great importance. Public opinion has tended

68/ Another interesting example, where development is not yet, however, complete, is in the Eastern and Dinaric Alps in Yugoslavia where the river systems have a typically complementary character (68).

/to jump

to jump to the conclusion that it is more economical to transport electricity. Numerous surveys have contradicted such a view.

A paper of some length submitted to the Canadian Sectional Meeting of the World Power Conference (1958) contains a comparative study on the one hand of the establishment of power stations at the place of production of the fuel or its port of entry, the generated electricity being transported to the centre of consumption, and on the other the transport of fuels to the consumption centre, with generation on the spot. The paper analyzes discontinuous means of transport (rail - road - internal waterways), continuous means of transport (gas and oil pipelines) and the transport of electricity. "Results favour the transport of electric power in the case of heavy mineral oil, natural gas delivered under atmospheric pressure and coal for capacities exceeding 50 MW, when utilization is 8,000 hours per year, and for capacities exceeding 100 MW and distances shorter than 125 kms, when utilization is 4,000 hours per year."

Results are in favour of the transport of fuels, in the case of crude oil and light products conveyed by pipeline (without the assistance of a compressing plant), and in the case of coal supplied by road transport, when utilization is 8,000 hours per year, and supplied by rail transport, when utilization is 4,000 hours per year, in such cases not included above (70).

In a survey of the same kind carried out in the United States with reference to the transport of 500 MW with load factors of 0.5 and 0.8, comparison showed that transport by pipeline was more economical, whatever the distance. The transport of coal by rail for its part also proved more economical for any distance over 100 or 210 miles depending on the case chosen (71).

Lastly, in the USSR, surveys show that "the transport of power by 400 to 500 kV cables is more profitable than the transport of fuels by rail, provided that the calorific power of the latter is less than 3,500-4,000 kg-cal." (72). It is, however, recognized that the combination of the three purposes which electricity lines may serve, namely the transport of power, distribution in intermediate points and interconnexion properly so called (the aim of diversity already referred to) may make the construction

/of electricity

of electricity lines more profitable than the transport of any fuel by rail.

It was thought necessary to draw attention to these examples to stress the need for determining what the situation is in this respect in the countries of South America, where development of the means of communication and in general the cost of transport is higher than in Europe, but where there is also without doubt a clearly defined limit as to the maximum distance suitable for the transmission of electric energy. In Chile, for example, consideration has been given to the possibility of establishing pit-mouth generating stations in the Arauco area with a view to transporting electric power a distance of 500 kilometres to Santiago. This was considered in view of the fact that the interconnected system is very well equipped with hydroelectric power stations and that the load factor is less than 0.6 which certainly does not make it possible to achieve a high hourly rate of utilization of the interconnexion line. The only justification would be the efficient utilization of surpluses of low calorific power which would in no way bear transport. The economic survey which this problem requires still has to be done. At all events, the long distances and the low population density characteristic of large areas of Latin America mean that this problem is one of those that need the most urgent consideration.

However much truth there is in Mr. Ailleret's assertion that "electric power is a product whose cost of transport is somewhat higher than that of petroleum or normal coal" (73) - at least in the less developed countries - it is not any the less true that the transport of electricity on a very large scale is an obligation imposed by the circumstances of geography and by the need for economic development.

There are at all events two energy resources for whose complete utilization large-scale interconnexion is essential: hydro power and coal of low calorific power. Special importance has been given in the large European interconnected system to the possibility of harnessing as yet untapped hydraulic resources which are otherwise likely to remain unused for a number of decades in the country in which they are to be found. This is the case in Yugoslavia whose enormous hydroelectric potential has been harnessed to the extent of a little more than 5 per cent. The United Nations Economic Commission for Europe has carried out a thorough survey of the possibility of making such an interconnexion; it would be justified in view of the exceptionally low construction costs involved (74). A specialized body, Yugelexport, has also been set up on the basis of close co-operation between Yugoslavia, Italy, Austria and Germany to translate the idea into reality.

Another group of interconnected systems, where the transport of power on a very large scale plays an essential part, is in the two major networks of the USSR: the consolidated system of Russia in Europe and the Siberian central consolidated system. Both networks are the result of the interconnexion of large regional systems. The network in Russia in Europe, for example, which is predominantly thermal, includes the system round Moscow which is closely linked to the large hydroelectric power stations of the Volga system (Kuybishev and Stalingrad) and to the Urals system (75).

The natural and logical result of this integration of systems over an ever growing area is the more complete and efficient utilization of hydroelectric resources; this means that the great advantages of combined thermal and hydraulic operation referred to in the previous chapter are even further increased by co-ordination on an even larger scale.

Clearly, the economic advantages deriving from the interconnexion of systems are of the greatest magnitude although they are in fact the same advantages that result from transporting electricity on a very large scale whatever the circumstances.69/

Interconnexion with the aim of taking advantage of the diversity of the interconnected systems is of a very different nature. As to the situation in Europe, the advantages of diversity can be explained in the following manner: "the various sources of energy used in the production of electricity are of a varied nature and may or may not allow for some degree of storage. Furthermore, European electricity power stations have very

---

69/ This is what is at present occurring in extensive systems operating with large thermal power stations (1,000,000 kW) which owing to their size must be set up at some distance from the main consumption centres in order to find the required facilities. Similarly, nuclear power stations which, as has already been stated, must have large capacity and which for reasons of security are built at some distance from centres of population, are faced with the same problem: the generation of large amounts of power and its transport to centres of consumption.

/varied characteristics.

varied characteristics. There is great profit to be derived from operating them in a systematically interconnected way so as to be able at any time to combine their production in the most economic way and also draw benefit from the load diagrams of the distribution networks operating in parallel over a very large area" (76).

In reality, the interconnexion of the European system does not involve very large scale interchanges of power. In 1958 the eight countries of the UCPTE 70/ interchanged only 8,247 GWh or 3.2 per cent of the power produced in the year. If the volume involved is small, the load over short periods is extremely large; in addition, assistance is given during periods of drought to small countries that rely almost exclusively on hydro power (76).

In actual fact all the advantages of interconnexion, apart from the very large-scale transport of electricity for continuing or seasonal reasons, derive specifically from diversity.

(b) Advantages of the interconnexion of systems and problems of operation

Apart from the value of the massive interchange and transport of power mentioned in the previous paragraph, there is a whole range of advantages to be derived from the diversity of interconnected systems. Some of these are obvious and bring about immediately favourable economic results; there are, however, others which are under study in the largest interconnected systems; they are of a kind that may have but slight effect per unit of power exchanged but will be well worth developing in the future as quantities of power exchanged progressively increase (77).

Experience with large-scale interconnexion domestically (as in France, Sweden, United States and USSR) and with the major international interconnexion in Europe gives indications of the benefits which may be obtained. 71/

(i) Diversity in the load diagram. Attention was drawn to this factor

---

70/ Union pour la Coordination de la Production et du Transport de l'Electricité. The countries are: Austria, Belgium, France, Germany, Italy, Luxembourg, Netherlands and Switzerland.

71/ See, inter alia, the paper submitted by UNIPEDE to the Latin American Electric Power Seminar.

/in the

in the previous paragraph. It results essentially from the differences in length of transmission lines in the interconnected area in cases where that area is of the size already referred to above. Clearly, the varying nature of the industrial activities carried on in the different areas also involves advantages. The practical result will be a higher joint load factor or more complete utilization of all the facilities involved in the interconnexion, mainly power stations and high voltage transmission lines. Greater annual utilization is the first rule for reducing the cost of electricity supply.

(ii) Increased efficiency of operation. The classic example in this respect is the British Grid which was set up as a means of interconnexion to achieve greater efficiency of operation. The British Grid was used to ensure operation of all privately-owned power stations in a manner involving the lowest cost for providing service to a given area, taking into account the efficiency of the facilities, the cost of fuel and transmission to the place of consumption. In 1948, when the rationalization of the 300 interconnected power stations became effective, the 143 power stations chosen as the most economical provided 95 per cent of the power supplied to the public service (27).

Naturally, in an interconnected system like the European system where there are thermal plants and hydroelectric generation stations of all kinds, the possibilities for efficient use are greatly multiplied, even though the cost of transport to great distances outside the area of any given country are a factor limiting possible economies. For example, on 21 October 1959 at 11 a.m., Austria exported 306 MW or 22 per cent of its output on the basis mainly of the very valuable reserves of its lakes, and during the night of the same day, Austria imported 161 MW and was thus able to suspend all consumption of stored energy (76).

Similarly, all surpluses in run-of-river plants and any possibility of overflows in reservoirs means that thermal energy could be saved at some point in the interconnected system. It can thus be explained how in 1959 the hydraulic power stations of Electricité de France lost during the daylight hours of working days no more than 0.27 per cent of the energy which could be generated and this loss was due to inadequacy of transmission capacity or consumption (52).

/(iii) Reduction

(iii) Reduction in reserve capacity. It has already been pointed out that the percentage of reserve capacity is in inverse ratio to the size of the system. Interconnexion considerably increases available capacity by joining power stations which by the very fact of having a very much wider area to cover are less exposed to simultaneous limitations arising from adverse climatic conditions, accidents, etc. Interconnexion thereby allows for an additional reduction in the percentage of the reserves required. If it is further realized that a part of the reserve is needed to make it possible to carry out systematic maintenance work, a co-ordinated inspection programme of equipment would bring about an additional reduction in the installed capacity required.

In countries mainly dependent on hydro power, which are subject to critical situations in drought years, interconnexion will involve a substantial reduction in the reserve thermal output required to ensure supply. Switzerland, which lacks local fuels, imports in dry years up to 40 per cent of the power required at night in order to save the water in its seasonal reservoirs.72/

(iv) Technical improvements. Interconnexion imposes need for standardization and the tendency is towards the improvement of standards, for any other course would mean that the most technically advanced system would be prejudiced in its operation and the quality of its service. Interconnexion requires similar frequency and voltage at the points of interconnexion and this means that it is to good advantage to standardize the rules in that respect, so as to avoid having to use frequency converters or transformers that limit load interchange capacity.

In general, interconnexion will help improve voltage and frequency regulation and will ensure stability of service for breakdowns can be dealt with more quickly.

(v) Economics of interconnexion. Some specialists are in the habit of referring to a third stage in interconnexion after parallel operation

---

72/ Switzerland from being an exporter of electricity before the war is now an importer and it is unlikely that the situation will change before 1970 when it is expected that the country's water reserves may well be exhausted (78).

and interconnexion properly so called. This third stage is known as the economics of interconnexion (79); it is based on the idea that the interconnected operation of systems will lead to more rational decisions regarding individual investment programmes which will take into account the fact that, in addition to the consumption which they normally satisfy, there is a second group of consumers, either on a permanent basis or contingent upon circumstances, who will help improve the gains of the undertaking. This may lead to the development of hydro facilities for which demand seems slight, or more frequently in Europe, may bring up the idea of building power stations for joint operation with hydraulic resources situated at the frontier or in the interior of one of the associated countries. The execution of projects on a joint basis (power stations or interconnexion lines) has the advantage, inter alia, that larger power stations can be built at lower unit cost and that the most favourable sites can be chosen, even though they be outside the frontiers of the country concerned or not within the area of a particular concession.

(vi) Development of a spirit of co-operation. However intangible a spirit of co-operation may be it is not for that any the less important. When this spirit develops between two national organizers, it makes it much easier to solve problems of common interest and is of vital importance in dealing with interconnexion between different countries. "The most important problem in international co-operation is achieving better understanding between the scientists and technical experts of different countries" (80). Europeans are righly proud of the results achieved in this respect, for they have made the interconnected electricity service the first and most effective of the economic bodies of a united Europe. The exchange of power goes forward freely, without tax, customs or exchange regulations.

These achievements, however, require the prior solution of important technical, organizational, communications and economic problems.

Interconnexion creates technical difficulties as a result of the growing size of the facilities and loads involved (as for instance by the increased size of short circuits). The automatic regulation of loads and frequencies and highly selective protection are among the problems which have had to be solved.

/The organization

The organization responsible for administering the interconnected systems must have complete information regarding all the facilities which may be included in the interconnected system. The UCPTE, for example, gives information weekly to all interested parties concerning "the position of seasonal reservoirs and the utilization of their power stations, the level of production in thermal power stations (or an approximate figure for the marginal expenditure of calories per kWh), the risks to which hydroelectric reservoirs are subject, transport capacity available over the main interconnexion lines, etc." (76). All the relevant specialized bodies in Europe take part in the necessary co-ordination work.73/

Naturally, in addition to providing the information which each system requires for its more efficient operation as part of the whole, the organization must co-ordinate maintenance programmes and other matters likely to be of interest to all.

The operation of two or more interconnected systems requires a first-class communications service, based partly on the public systems and also, to a very significant extent, on radio and carrier systems of its own.

Lastly, the exchange of energy involves economic problems which are usually solved by means of bilateral agreements between neighbouring systems. As a general rule, the principle applied in operating the exchange of energy will be that known as the "differential incremental cost rate". The incremental cost is the cost of production of one additional kWh. The theory shows "that the optimum load distribution is obtained - i.e., the cost of supplying energy is lowest - when the incremental costs of all the sources of energy in service in the interconnected network, due allowance being made for network losses, are at all times equal; it is assumed that only those plants will be in service which are required for optimum coverage of demand in the network" (81).

In a run-of-river plant the "incremental cost" 74/ is nil, and in a

---

73/ UCPTE - UNIPEDE - FIPACE (Fédération Internationale des Producteurs autoconsommateurs industriels d'electricité) CILPE (Conférence Internationale de liaison entre Producteurs d'Energie Electrique).

74/ The "incremental cost" implies the increase in costs in a power station in service; the "marginal cost" involves the costs of new generating plants that have to be brought into service.

/thermal power

thermal power station it is equivalent to the marginal cost in terms of calories per kWh. It is indubitably more difficult to establish the "incremental cost" of a storage plant, which is determined by the "incremental cost" of the thermal plants in service at the time when the stored energy is used. Hence the policy of drawing upon the reservoirs, during the periods or times of day when the power shortage in relation to consumer demand is greatest, after recourse has been had to the other possible sources, even those with the highest "incremental cost", with the result that the stored energy also acquires the same high values.

It seems desirable to elucidate one last question here. It was stated at the beginning of the comparative study of the various possible alternatives for supplying a system's power requirements that at a later stage consideration would be given to the special case of interconnexion of systems. Obviously, a system can obtain the power it needs from another neighbouring system, and this may constitute a more economic alternative than production on the basis of its own resources. A case in point is that of the Compañía Chilena de Electricidad, a subsidiary of American and Foreign Power, which purchases increasing proportions of the electricity it requires from the systems of the Empresa Nacional de Electricidad (ENDESA), a State agency responsible for the development of the National Electrification Plan (Plan Nacional de Electrificación). A similar situation existed in Mexico up to 1960 between the Mexican Light and Power Company and the Comisión Federal de Electricidad, until the merger of the former with the latter.

The methods of studying alternatives described in chapter 5 are perfectly applicable to the case of power obtained through interconnexion. The statement may probably be hazarded that in general, and given Latin American conditions in particular, the solution consisting in purchasing electricity from a neighbouring system is the best. Almost certainly, in fact, the investment required for making the interconnexion will be a good deal less than that needed for the direct installation of a new generating plant. Again, the enterprise selling the power probably does so at an attractive price, since it has no immediate use for the electricity in question in its own system. Lastly, for the buyer system the purchase

/of power

of power is a future event, and the formula used in conversion to "present worth" will signify a substantial reduction, owing to the high "rate of discounting" which has to be adopted in Latin America. Consequently, the total disbursement will be considerably less than in the case of an equivalent thermal plant. But, at the same time, investment will also be less, an exceptional circumstance which is not taken into account in the "coefficient of worth", but which is indubitably the greatest advantage of all.

The situation described arises where there is a seller system and a buyer system. If seasonal exchange takes place, the economic estimate must undergo the modifications deriving from the dual situation.

(c) Interconnected systems currently in operation: experience and possibilities in Latin America

Numerous power pools exist in the United States (79). The most important is that known as the Central Power Pool, which groups together enterprises in 20 different States in the South-West, with an aggregate output of approximately 75 million kW. The interconnexion of all the systems and companies combined in this Pool is weaker than that existing in the interconnected system of the UCPTE in Europe.

The European system, owing to the complexity deriving from the number of countries interconnected, the differences of language, legislation, tax currencies and customs, the wide variety of equipment and the very large number of integrated plants, presents particularly interesting problems. It is undoubtedly the example of interconnexion in which the greatest number of technical difficulties have been overcome and operational problems solved.75/ The European system represents an output of 50 million kW. This interconnexion was effected regardless of the ownership of the national systems interconnected, among which some, like the French, are completely nationalized, while others include both private and public enterprises.

Apart from the interconnected system represented by the UCPTE group, the States members of this Pool maintain direct contractual arrangements

---

75/ UNIPEDE has submitted a report to the Latin American Electric Power Seminar on some experiences relating to the European integrated system (82).

/for bilateral

for bilateral interconnexion with neighbouring countries not belonging to the Pool. A future case in point will be the agreement between France and England to lay a submarine interconnexion cable across the Channel.

One type of bilateral agreement is that existing between Austria (an important member of the Pool because it is an exporter of peak-load hydroelectric power) and Czechoslovakia. The structures of the electricity systems of these two countries are diametrically opposed, a situation which always constitutes an interesting factor in interconnexion for the exchange of surplus power. In Austria 30 per cent of the power generated is thermal and in Czechoslovakia 90 per cent; in the rivers of the Alps, high water is registered between April and September, and in those of Czechoslovakia in spring and autumn, i.e., in March and November. Thus, Austria has engaged to supply hydroelectric power uninterruptedly between May and August, while Czechoslovakia in its turn provides thermal energy from October to May (83).

Austria's privileged geographical situation, inasmuch as it is adjacent to countries like Germany and Czechoslovakia whose hydroelectric potentials are relatively small, enables it to tackle with success the development of its water resources on the Danube; once these are fully harnessed, they will produce large quantities of surplus power which it will be easy to sell to the neighbouring countries (84).

In the USSR, in view of the considerable size of the consolidated systems previously referred to, the results of a reliable interconnexion, with transmission capacity guaranteed by a large network of very high tension lines, are particularly successful. Thanks to the interconnexion of the Moscow system and that of the Urals with the hydroelectric system of the Volga (Consolidated System of Russia in Europe), it was possible to design the plants on the latter river with much higher installed capacity than would have been economically justifiable if the Volga system had been operating on its own. Comparative studies revealed the existence of the following relative advantages: (a) an expansion of capacity in the hydroelectric power stations represents the investment of 350 million roubles less 76/ than would the installation of the same capacity in a

76/ The official exchange rate, adopted for the purposes of this study, is 4 roubles to the dollar.

/thermoelectric plant;

thermoelectric plant; (b) the investment saved on the extraction and transport of fuel may be estimated at 840 million roubles, owing to more efficient utilization and increased generation of hydroelectricity in the Consolidated System; (c) the annual saving on production costs through the reduction of fuel consumption amounts to 200 million roubles. Similar findings apply to the Siberian central consolidated system. The interconnexion of two relatively small systems, one - that of Krasnoyarsk - hydroelectric, and another - that of Kuzbass - thermal, warrants an increase of 700 MW in the installed capacity of the former and the corresponding reduction of thermoelectric capacity in the latter, investment in plants representing savings greater than the cost of interconnexion, and annual production costs decreasing by 36 million roubles (75).

What are the prospects for interconnexion in Latin America? To begin with, it has already been pointed out that the large consumer centres which form the original nuclei of the independent systems are too far apart for close interconnexion between them to be readily conceivable. Moreover, if international interconnexions are considered, the problem becomes even more complicated, because, as a rule, the topography of the frontier territories concerned is extremely broken. However, consideration should be given to three interconnexion possibilities: international development projects, local power stations in frontier areas when geography permits and, lastly, integration projects proper.

The first of these possibilities is natural and logical. International hydroelectric development is of interest to two (or more) countries and involves natural and financial resources belonging to both. Broadly speaking, a project of this kind, will be developed with a view to serving, from one and the same source of power (one or several plants), established consumer demand in both countries.

This possibility would be interestingly exemplified in Salto Grande on the River Uruguay.77/ If a power station were constructed here, it would be connected with the Greater Buenos Aires-Littoral System (440 km, 380 kV), but would also be linked with the Rio Negro-Montevideo System.

77/ Salto Grande is a multiple-use project designed mainly with a view to navigation and power.

/Even if

Even if the amounts of power exchanged would perhaps not be very large (although it is quite conceivable that the Uruguayan power station might supply energy quotas to the Argentine side on a large scale), the consolidation of these two major systems would offer all the advantages attaching to diversification.

A similar possibility is the international harnessing of the waters of Lake Titicaca. Various ways of doing this have been considered, all of which involve the interconnexion of major regional systems in Peru, Bolivia and Chile.78/

The interconnexion of small frontier systems at points where the terrain is suitable is unquestionably highly advantageous to all concerned, since the formation of large integrated blocks to supply local consumer markets reduces investment and production costs to a striking degree. As the right conditions for interconnexion often exist, it would be desirable to promote simple international agreements authorizing this type of interconnexion. Any advances made in this respect would provide a sound basis for subsequent interconnexion on a larger scale. A recognized case of possible frontier integration is that of Golfito (Costa Rica) and Chiriquí (Panama), which involves the establishment, in one of the two countries, of a hydroelectric plant to supply neighbouring low-consumption zones in both countries (88).

The Central American countries also constitute an ideal group for testing an international interconnexion programme. It has been proposed that the central system in Guatemala should be integrated with that in El Salvador and with the Costa Norte - Lake Yojoa - Tegucigalpa system in Honduras. The principal consumer centres would not be more than 180 km away (88).

The problem of interconnexion is of more immediate interest and offers

78/ The two principal projects are the Angel Forti project, prepared in 1953, which contemplates a diversion of 100 m^3 towards the Tambo gorge with 3,300 metres head separated into five power stations (85). The second is known as the Chilean project (86); it was prepared in 1945 and submitted to the Fourth World Power Conference at London (1950) and the Sectional Meeting at Rio de Janeiro (87). The water is channelled down the Lluta gorge and falls 2,900 metres in three steps. Both projects include irrigation.

/better prospects

better prospects when there are two or more systems in the same country. For interconnexion proper, the systems must either belong to different agencies or, if they are part of the same enterprise, have developed on separate lines for historical or geographico-economic reasons and are generally regarded as having distinct areas of coverage for purposes of investment and operation. For instance, Río Negro-Montevideo should be regarded as a single integrated system instead of two (hydraulic and thermal) interconnected systems, since the decisions to build the hydroelectric works of Rincón del Bonete and Rincón de Baigorria and their operation are related to consumption in Montevideo.

In the case of large countries, the first stage of development involves the consideration of regional systems. This is true of Chile, where for the purposes of the National Electrification Plan drawn up in 1942, the country was thought of as divided into seven geographical zones, of which the three extreme zones (one in the north and two in the south) have only isolated plants to satisfy local consumption, owing to the great distances involved and the extremely low population density. The other four zones, which form the main nucleus of the country, have regional systems planned in accordance with the requirements of the principal consumer centres and the varying types of natural resources available. Similar plans have been made in a number of countries. In Argentina, the report by governmental advisers (20) covered six market zones 79/ which differ widely in area, population, current and future electricity demand and economic development. These zones have their own systems which are all integrated on a regional scale to one degree or another. Venezuela's National Electrification Plan deals with eleven distinct areas.80/ In the case of Brazil, the enormous size of the country makes it necessary to devise regional systems that

---

79/ Greater Buenos Aires - Litoral, Córdoba, Mendoza, Tucumán, upper valley of the Río Negro, Resistencia - Corrientes.

80/ The Venezuelan Plan, which was prepared with the help of Electricité de France is based on the same system as that used in France to divide up producer and consumer areas. The Plan envisages four major producer areas (western, central, eastern and the Guiana Shield) and eleven consumer zones, and excludes all the areas with very low population density (25).

/might be

might be grouped together in the major river basins.[81] In Colombia, the geography of the country is such as to create zones whose economic development is highly individual and naturally propitious to the concept of regional systems.

The possibility of large-scale interconnexion is an economic problem which may be solved in very different ways. With respect to Argentina, for example, the relevant report states that the cost of interconnecting the market zones is out of proportion to the advantages to be derived therefrom during the period 1960-69, but that it may be worth while to make certain interconnexions after the period considered in the study (20). By contract, in the case of Venezuela the authors of the Plan regard interconnexion as virtually an accomplished fact. The development of requirements, area by area, and the inventory of known or probable sources of energy led to plans for the establishment of a system in 1965, to extend from Los Andes and Maracaibo in the west towards the eastern zone and the Guiana Shield, and link up zones 1 to 7 among themselves (25).

In Brazil, the most important interconnexion is probably that tying up the two systems of the Brazilian Traction, Light and Power Company at Rio de Janeiro and São Paulo, respectively. Unfortunately, the difference in frequency between the two systems (50 and 60 cycles) restricts the exchange of power to the capacity of the converters. In the case of the State of Rio de Janeiro, the power is supplied by the Companhia Brasileira de Energia Eletrica [82] at a frequency of 60 cycles, which further limits possibilities of interconnexion with the immediately adjacent enterprise in the city of Rio de Janeiro. This illustrates the desirability of standardizing criteria as soon as possible while electric power is still at a relatively early stage of development in the Latin American countries.

The Peruvian National Electrification Plan provides for the setting up of numerous transmission lines with tensions ranging from 60 to 380 kV.

81/ Mr. Jacy Pinto's study (54) covers eight big basins: Amazonas, Noreste, San Francisco, Este, Paraguay, Panama, Norte and Río Grande.

82/ Subsidiary of the American and Foreign Power Company.

/Most of

Most of these lines are for purposes of transmission rather than interconnexion. But the cable of 220 kW which is to tie up the Cerro de Pasco system with the Lima system will constitute a true case of interconnexion (89).

Examples have already been given of interconnexion among nationalized and private enterprises in Mexico and Chile. In both countries, the importance of interconnexion consists more in selling large blocks of power from a generating system to a consumer system than in taking advantage of the benefits of diversification that derive from interconnexion. In the case of Chile, in particular, the system of the Compañía Chilena de Electricidad is interconnected not only with that belonging to ENDESA (the State enterprise) but also with numerous self-supplying companies and with the system belonging to the other public utility enterprise, CONAFE. In this group of systems, the factors of mutual assistance, diversification and so on play an important part.

The different systems run by ENDESA itself, which stretch from 1,600 km from the second to the fifth geographical zone are interconnected in the way which we have termed the first stage or "parallel operation". Current methods of integration enable energy exchanges of high economic value to be made. Once interconnexion proper has been effected by means of ad hoc transmission lines, such exchanges can be made on a larger scale.

There is very considerable justification for interconnexion in Chile, because of the diversity of the river systems which change appreciably from north to south, ranging from a régime that depends specifically on snow melt in summer and is dry in winter, to a mixed system of snow melt and rain, and finally to rivers with a fairly uniform flow throughout the year, that are and can be regulated by a number of natural lakes. Despite these obvious possibilities of interconnexion, it has been thought best for the time being to construct separate power stations to supply their own areas because of the heavy cost of high-voltage transmission lines. "Parallel operation" is the product of contact between the transmission lines belonging to each system for the purpose of supplying the corresponding consumer area. Up to now, only two short lines have been set up precisely to interconnect geographical areas and enable a certain amount of power to be exchanged. One of the lines, of 110 kV (105 km), ties up the small system in the

/second zone

second zone with the third zone, and another, of 154 kV (242 km), connects the third with the fourth zone.

In Chile, it is thought preferable to establish power stations throughout the country rather than to build a few generating centres with long transmission lines for economic reasons and to guarantee supplies. The economic reasons are based on the fact that the big power stations are far from the main consumer centres, and that sufficient experience to run some of them has only just been acquired. The need for a reliable supply is self-evident in a country like Chile where the terrain offers so many difficulties. In any case, the question of which alternative is preferable should be decided after due consideration, since, in our opinion, it is not sufficient to base a decision simply on the grounds of the economic benefits (direct and indirect) to be derived. Another element is the proper assessment of imponderables which may tip the balance in favour of a new plant rather than an interconnexion line. This statement is relative, and if the Chilean electricity service is to develop in a more complete way, the initial stage of "parallel operation" should definitely be superseded by one of interconnexion.

8. Electricity development in areas where service is non-existent or in its initial phase

In our study of the economic criteria used in choosing between two different alternatives, we made express exception of new areas and of small isolated service areas. Such areas cannot and must not be studied in the same way as the integrated systems with large-scale facilities.

In this section we wish to deal simultaneously with two types of problem. The first is to do with isolated areas where there is as yet either no electricity, or else only a precarious and deficient service. Such areas could be supplied either by extending the existing electricity system to make them an integral part of it or else from separate power stations which might or might not within a foreseeable lapse of time be integrated into a growing system. The second problem is connected with large areas with common characteristics where there are no large consumption centres and where it is thought desirable that the establishment of means of communication should be accompanied by the provision of electric power before demand arises,

/both developments

both developments being used to stimulate new economic activities. Both of these economic problems have one feature in common, and that is the absence of supply or initial short supply of electricity.

If considered strictly from the point of view of public service undertakings, the two problems are of slight importance. They will represent only a small percentage of present supply and accordingly will exert no direct influence over the economic position of the concern or its investment decisions. But from a national point of view, power and in particular electric power is of far greater importance as a result of the indirect benefits which it provides. If private capital fails to take an interest in the matter, the State should step in to solve these problems which involve only some remote possibility of making a profit and that in the medium term. One case of such State intervention is the Tennessee Valley Authority plan - today a classic example of State action in a country whose economy is essentially privately owned.

The problems referred to above are those occurring with the greatest frequency in Latin America. The size and number of areas without electric power is considerable and is naturally greater in countries of smaller economic potential. ECLA has contributed greatly to determining where such situations exist thus making it possible to group the countries of Latin America according to their different degrees of development in this respect. It should, however, be realized that even a classification by countries is only slightly representative of the real situation, in view of the fact that large countries like Mexico and Brazil have very varying economic conditions in different areas within their borders.[83/]

In an area without electricity service or where electricity service is in its initial stages and where supply must come from the extension of a more or less developed system, the determination of potential demand and growth in consumption will exert only a slight influence over decisions taken by the system, provided that it can be reasonably supposed that the area so far without service will, when connected, represent only a small percentage of the whole. The situation will appear in a different light if reasons are sought for justifying the economic value of the investment that will be

83/ See, inter alia, (90).

made in the newly supplied area, or if that area is of a particularly isolated nature and will be supplied by its own source of generation.

In such cases, evaluation of demand will involve the preparation of approximate estimates which can be worked out only by comparison with other similar areas where supply already exists and where the levels of economic activity and personal income are similar. Given such conditions and on the assumption that the cost of power will be similar to that supplied in areas used for comparison, it will be possible to conclude that present and future estimated demand in the area under study will follow the same curve as in other similar areas already developed. Surveys on the subject for different countries would be valuable and could be used as a source of information for other countries where the small degree of development of the electricity service means that no comparative information is available.

Electricity service in poor areas can only be justified for social reasons. In such cases, the provision of power should be limited to lighting and motive power needs, as it will always be possible to find more economical means than electricity for cooking and domestic heating. Research into the situation with respect to present means of lighting and the activities which might advantageously be provided with electric motive power would also be useful as a means for estimating the level of initial electricity consumption.84/

It is important to realize that in isolated areas where development is in its initial stages, the establishment of any productive activity connected with the public electricity service will lead to substantial alterations in the estimates of future demand. This means that growth forecasts are significant only when dealing with areas where the economy has characteristics that do not seem subject to change. In any other circumstances, the sources of supply which are established will be subject to possible basic variations or - and this is more probable - any new activity which is brought into the isolated area will have to ensure self-supply of electricity in the early stages. This could be the first step towards an interconnected system if the public service system was joined up with the self-supplying

84/ An example of market research of the kind described is to be found in a paper submitted to the Latin American Electric Power Seminar (91).

/industry. This

industry. This means that uniform technical standards should be established at the outset; they should be respected both by the public and the private service so as to avoid any difficulties that might later arise from differences in methods of producing power.

The foregoing does not amount to a recommendation that the quality of service in an area where the development of electricity service is in its initial stages must be of a standard equivalent to that provided in fully developed systems. In the latter, service is considered by the public to be compulsory and inescapable in nature. In practice, interruption of supply, rationing or poor quality may have considerable economic consequences. To achieve an equal degree of efficiency in an area undergoing electricity development is, however, out of all proportion. This fact should be remembered, as there is a certain tendency in nationalized undertakings to apply the same yardstick to all the services provided on the basis of a uniform technical standard of quality, without attaching due importance to foregoing differences of degree. Only after a certain minimum consumption figure has been exceeded, can the provision of high standard service be justified.

The foregoing considerations imply that if electricity development in isolated areas does not involve the participation of a large undertaking supplying other systems, there is good reason to provide a State technical assistance service to enable local concessionnaires in the area concerned to solve the many problems that they will have to face. Some official body will of course have to standardize the frequency and voltage characteristics of the service, so as to avoid the classic mistake which has occurred in all countries, namely, establishing electricity service with a wide variety of facilities designed to suit the desires and possibilities of each local entrepreneur. The later modification of such facilities to conform to a common standard during the integration period into a single electricity system has always been costly. In addition, the isolated concern cannot in its initial stages command the necessary technical staff for it to be able to determine the most suitable means of electricity generation. Technical assistance by a specialized department would be very useful in dealing with this and other similar problems, even after operation has begun.

/It has

It has already been pointed out that isolated service areas and those where service is in its initial stages could either be integrated into an existing system or else become self-suppliers. The former has occurred frequently in the Chilean electrification programme. The extension of 13.2 kV and 23 kV lines has been used as a means for connecting towns and even cities with poor or no electricity service to the main electricity network. Our sole purpose here is to draw attention to the good results achieved in Chile with rural electrification, which apart from bringing electricity to the countryside has helped solve the problem of supply to many towns and villages far removed from the main network.85/ Chile's experience in this matter will certainly be of interest to other Latin American countries.

A typical case is the isolated area which must supply its own electricity. The usual solution is to produce electricity with resources available locally, particularly if, as is often the case, means of communication and transport are not good. The basis used for determining what initial facilities shall be set up, must include consideration both of demand at the outset - for the sake of argument during the first two years - and of the probable rate of growth. Furthermore, there will be reason for considering the possibility of interconnexion with other neighbouring isolated electricity services, in a not too distant future, thereby creating the nucleus of an expanding system. If prospects seem promising, care should be taken to avoid proceeding along lines that involve the use of very rudimentary local resources, as these might very quickly prove obsolete if expansion was to occur in the manner described. We are referring, for example, to the use of movable wood-burning traction engines which drive small generators or other larger capacity means of generation which could not be brought into parallel operation with other facilities.

Today the ideal solution for this type of electricity supply problem would seem to be the diesel generating unit whose installation costs are relatively modest; it can provide a whole range of different loads, thereby meeting the initial problem of any isolated area. The adoption of such

85/ Rural co-operative networks have an approximate extension of 3,500 km.

a solution will not involve risks as a result of expansion of service or integration with other neighbouring isolated areas. If the problem of supply to isolated areas - small agricultural, fishing or mining communities, etc. - occurs frequently and if capacities are fairly similar, there is good reason to standardize the makes and types of generators used particularly if a single concern is responsible for the whole matter. This allows of better maintenance and repair service and also makes for greater flexibility in future growth, for in this way generating plants can be grouped in a single locality bringing them from other areas where it has been decided to employ better machines or bring about integration into a regional system. This course of action has been adopted to a certain extent in the isolated areas served by ENDESA (Chile).

If there are possibilities of hydroelectric development near an "isolated" area, the development of one of them may very probably be the best way of ensuring initial supply. The disadvantage of this procedure is that it is not economical for a small-scale hydroelectric plant to install really safe intake structures, and consequently service may be subject to some considerable risk; if accidents occur, they may be followed by prolonged interruption of service. The hydroelectric power stations at present in normal operation are, however, very far from being large scale.

The average installed capacity of all classified hydroelectric generating stations in Mexico in 1955 was 2,750 kW; the figure was, however, as high as 6,000 kW in public service hydroelectric stations (92). In Chile (1960), the general average has reached 9,800 kW as a result of fairly advanced integration of the public networks which has made it possible to dismantle a large number of very small generating stations which gave poor service.86/ It should not, however, be believed that this characteristic is confined to new countries. In a number of large countries, the average installed capacity of hydroelectric generating stations of more than 1,000 kVA, was in

86/ See (93) and other documents.

/1952 as

1952 as follows (94):

Italy	14,400 kW	Norway	14,100 kW
France	15,300 kW	Sweden	17,800 kW
Switzerland	19,700 kW	United States	23,900 kW
Spain	10,300 kW		

It must not, however, be believed that small generating stations are of no interest economically for the future. In a preliminary survey dealing with France, it is estimated that economic generating stations of less than 2,000 kW capacity could provide 12,000 million kWh or approximately 15 per cent of the total capacity that could be installed (31). The survey recognizes that "the functional role of small hydroelectric power stations in the structure of a network consists, apart from the extra power they represent, in reducing the cost of developing transmission and distribution networks; this they can do as a result of the fact that they are usually situated at the extreme limits of electricity lines". We wish to stress this point, for it means that a well-designed small-scale hydroelectric power station is not an investment which will be lost if it is later interconnected with a highly developed system. Clearly, the position of similar diesel electric or thermal plants would be different, for their direct operating costs are considerable and it is therefore doubtful whether they could be kept in service.

The foregoing shows that when an isolated area grows and it is decided to establish larger power stations of, for example, more than 1,000 kW (to take a reference figure), all kinds of generating facilities may be considered.[87/] If hydro works are to be integrated in the future into a broader system, there might be reason to make them larger than required initially with a view to their full-scale use at some not too far distant date in the future. The fact to which attention has already been drawn that the "rate of discounting" is high in Latin America means that it is not possible to carry out anticipated capital development except for a rather

87/ In Chile, for example, thermal power stations of less than 5,000 kW cannot compete with diesel or hydroelectric power stations.

/brief period

brief period ahead. If there is no certainty that full use can be made of a proposed generating station in a given lapse of time, it would be better to adopt an alternative solution, by constructing a smaller hydro-electric power station even if economic studies show it to be less attractive in the long run.

We have no detailed information available regarding the programme which the Government of Peru has recently decided to put into effect, but it seems to us that it must take account in part of the considerations set forth here. The Peruvian plan provides for the construction of 16 hydroelectric and two thermal generating stations in addition to the establishment of a number of transmission lines and distribution networks to promote supply to a total population of 400,000 people living in thirteen different departments.

At the beginning of the present chapter, passing reference was made to the question of areas with a deficient electricity service, where for reasons of overall policy, it is decided to provide an ample supply of electric energy, far in excess of current and foreseeable demand. This attitude is based not on economic criteria, like those analysed in the present study, but on economic policy decisions which presuppose the existence of means of communication and the availability of electric energy as essential requisites for development. It is customary to adduce certain examples which justify such a policy. In Latin America, the case of São Paulo is regarded as typical. "From the development of São Paulo we can see two possibilities which could have great influence on future planning for energy production and transmission. The first is the possibility that load will develop where energy becomes available. It must be considered, therefore, that any new energy sources developed will attract industry, as has been the case of São Paulo. This consideration must be given more weight of course, if there is a general shortage of power facilities existing over the whole country."

"A second and firmer point to consider is that once an industrial centre is established, with its attendant transportation network, skilled labour pool and feeder industries, the advantages of continued growth of the industrial centre will be so great that there will be no decrease in its rate of growth despite an increase in the real cost of energy" (95).

From the standpoint of the present study, the problem is not as simple as it appears in the description given above. Electricity is indispensable for industrial development. "Its presence is essential wherever industrial development is possible and desirable because all the other factors of industrialization are assembled" (96). But how far is this factor in itself a determinant? No satisfactory reply can be given. Electricity represents a small proportion of the cost of any given product, except in the case of a few major basic industries such as steel making, the electro-chemical and pulp and paper industries and the production of certain building materials. In these instances, low-cost electric energy must be available, but still greater weight will be carried by the costs of raw materials and the geographical situation of the industry in relation to its consumer market.

The establishment of labour-intensive manufacturing industries is of the greatest importance for the development of any area. But in these, energy costs constitute only a small percentage of the total, so that a decision as to site will not be greatly affected by the price or even by the availability of electricity, since, if other factors - raw materials, manpower, housing, transport, market - are favourable, the industry will probably solve its own electricity supply problem independently of the public service.

Nevertheless, in new areas where the appropriate raw materials are to be found, a development programme based on transport and power may provide the indispensable spur to industrialization. Such a policy has been adopted in Africa in some of the non-self-governing territories. In British Uganda, for example, power requirements were extremely low; four thermal plants, with a total capacity of 15,000 kW, sufficed to meet the demand of the whole vast territory. It was decided, however, to construct a big hydroelectric power station at the Owen Falls on the White Nile, with initial and final production capacities of 90,000 kW (1956) and 150,000 kW (1960), respectively. The power was to be used in the manufacture of

/cotton goods,

cotton goods, cement and paper and for the exploitation of certain mineral resources[88/] (96).

The United States T.V.A. programme referred to above has been cited as a typical example of what can be achieved by means of the intensive development of energy resources. This programme, however, included the simultaneous promotion of other factors which also made an efficacious contribution to its success.

In Latin America, one of the large-scale experiments is that undertaken in the north-east of Brazil. In this vast tract of over 500,000 km^2, the population is very unevenly distributed, the main concentrations being found along the coast and in a few large towns (Salvador and Recife). It was decided to construct a large hydroelectric power station at the Paulo Alfonso falls on the River San Francisco, in several stages, with a final installed capacity totalling 900,000 kW. It would be extremely interesting for all the Latin American countries to be informed of the results of this programme, from the standpoint of the influence which an assured supply of large quantities of low-cost electric energy may have exerted on the economic progress of the area (97).

9. Conclusions

It is not the present writer's intention to deduce a set of recommendations, much less a definite thesis, from the present study. All that has been attempted is to set forth in orderly fashion a few ideas which might be useful as economic criteria on the basis of which to approach the systematic selection of sources of electric energy from among various alternatives and, in general, to determine the lines along which electricity systems should be developed. The author fully recognizes that many of the topics dealt with should be analysed by experts whose knowledge and experience is greater than his own. This, in fact, is precisely the objective aimed at, - that the study may serve as a point of departure for the elucidation

---

88/ No recent data on the success of this project are to hand.

of ideas and the establishment of criteria adapted to the conditions prevailing in the different Latin American countries, where a variety of situations is to be found.

In the list of conclusions drawn up below, the essential ideas discussed in the present study are summarized under a number of heads, in the same order as in the body of the work.

(a) The basic importance attaching to the availability of a satisfactory quantity and quality of power, the volume of investment required for the attainment of this target and the preponderant role played by electricity in the energy sector establish a close relationship between a country's overall conception of development, the policy adopted in the energy sector and economic criteria for the selection and development of power stations and electricity systems.

(b) Owing to the increasing interdependence of the various sources of energy, it is advisable that the responsibility for formulating an energy policy which takes into account the country's own natural resources and its future requirements should be assigned to a single authority. The policy must have continuity; it must not be influenced by occasional economic distortions, and its aim should be to obtain the maximum amount of power at the lowest possible price and the highest possible level of dependability.

(c) The economic analysis of electricity development alternatives is influenced by factors alien to the project under discussion. In the case of private enterprise, the essential criterion on which the company concerned bases its decisions will be that of obtaining the maximum return on its investment. But a publicly-owned concern will have to maximize the sum total of the direct benefits plus those social or indirect benefits most immediately adjacent to the project.

(d) The decisions adopted by private concerns are strictly commercial; such companies determine the advantages of their investment in relation to the cost of money on the market where they can obtain it. In the case of publicly-owned enterprises, it is suggested that investment should be studied on the basis of a variable cost of money, the minimum being the cost at which money is obtainable from the public sector and the maximum an intermediate figure between the legal rate of return on capital and the cost of money on the private capital market.

(e) For the purposes of more rational establishment of tariffs, not only should the criterion of a rigid rate of return on capital be reconsidered, but it would also be interesting if in some Latin American countries studies were undertaken on "demand elasticity", an essential factor in the more efficient utilization of the generating capacity of the plants installed.

(f) It is essential that an immediate beginning be made on studies calculated to augment the basic data available on the energy resources of the Latin American countries and the market for the various types of energy.

(g) When, as often happens, very limited resources have to be allocated to different alternative energy projects, it is recommended that priority be given to those which will increase "productivity" rather than to those implying immediate social benefits, on the grounds that an expansion of production is the soundest and most lasting way of improving social conditions.

(h) The use of elaborate methods of comparison will be dependent upon the validity of the data available. Complex methods of comparison should not be applied if the basic information to hand is inadequate.

(i) In view of the fundamental shortage of technical personnel, priority should be given to making a detailed project of the power station which it has been decided to construct, rather than to an unduly protracted study of alternative plants or projects.

(j) In the case of systems of a certain minimum size, the projects to be executed must be programmed for periods of about ten years, so that studies and the collection of basic data can be concentrated on the points of greatest interest. This will obviate the need for over-hasty plant designing, which might militate against the integrated development of a water resource, or for seeking emergency solutions under the pressure of consumer demand.

(k) An electricity system is satisfactory when it can meet maximum demand in a dry year and supply all the power required during the year and during the "critical" period characteristic of the system, with due regard to its hydrology and its consumption.

(l) The application of the "present worth" method is recommended for comparisons through time. It is estimated that high rates of discounting will show a tendency to decrease over long periods. In respect of investment, consumption and future sales, the use of current prices is proposed, except when there are sound reasons for calculating that some important price factor is distorted and is bound to change, in which case consideration should be given to the influence it will have on results if it varies within given limits.

(m) Systems of relative valuation of hydroelectric resources, similar to the "coefficient of worth" method, should be introduced, so that the prospects for programming in the Latin American countries may be improved as time goes by.

(n) The methods of comparison selected, as was stated under point (h), will have to be contingent upon the significance of the problem and the quality of the basic data available. In any event, when power stations and electricity systems increase in importance, alternatives must not be compared with an eye to the initial phase or to a specific date, but taking into consideration a reasonable period for which the operating conditions of the projects under study can be estimated with relative precision.

(o) The process of establishing a programme will have to consist in a series of approximations; when the programme is highly complex, owing to the number of power stations involved, recourse may be

/had to

had to linear programming or some other more systematic method of selection which simplifies the study of the most favourable combinations. The use of modern methods of computation will be essential. In the case of the major Latin American systems, it is urgently necessary to formulate methods of programming which, while less complex than those applied in Europe, will enable decisions to be better justified.

(p) The idea of thermal plants as opposed to hydroelectric power stations is meaningless. The two types of plant should properly be conceived as complementary to each other. A combination of thermal and hydroelectric plants considerably increases the value of hydroelectric energy resources and permits their integrated development at lower levels of hydrologic probability. For countries where there is a shortage of domestically-produced fuels, the development of hydroelectric resources allows a considerable saving of foreign exchange to be effected, which is invaluable in view of the fact that countries in process of development badly need foreign currency to purchase capital goods.

(q) Broadly speaking, the power stations forming a system will be used in ascending order of their marginal production costs. Run-of-river plants will always be found at the base of the load diagram. Storage plants must modulate the load and their operating cost will be determined by that of the thermal power station which they are replacing within the system.

(r) Given the existing situation with respect to technique, nuclear power stations are relatively economic only for large reactors operating with a high annual plant factor. It would seem that circumstances in Latin America do not yet afford commercial justification for the installation of a nuclear plant.

(s) Interconnexion makes it possible to take advantage of seasonal differences between the systems interconnected in respect of the energy available, but it is also justifiable for the mass transport

/of energy

of energy in a given direction. In the relatively difficult transport conditions prevailing in Latin America, it is interesting to investigate how far the transport of energy in the form of electricity is economic.

(t) The interconnected systems must operate in such a way that the incremental costs of all the sources of energy in service are equal at all times.

(u) The decision to meet energy requirements by means of interconnexion with a neighbouring system instead of through the establishment of a new source of generation of the system's own will be reached by methods similar to those applicable when a choice has to be made between various alternative power stations.

(v) From the standpoint of interconnexion among different Latin American countries, international hydroelectric projects are considered to offer the most hopeful prospects. At the national level, it is felt that the "parallel operation" stage should be attained at an early date. As regards interconnexion of systems proper, the general opinion is that only when the systems in question have attained a higher degree of development will it be possible to secure all the benefits justifying interconnexion.

(w) For the study of demand in isolated areas, it is recommended that the procedure adopted be that of comparison with other analogous areas, and the suggestion is made that some of the Latin American countries should issue information on their experience which may serve as a guide to other countries.

(x) Technical assistance must be given to isolated areas so that projects can be developed in line with common technical standards that will allow of future integration should the need arise. Care will be taken to avoid the existing tendency to provide isolated areas not at present electrified with a high-quality initial service that is not economically justifiable.

(y) A previously-assured supply of electric energy considered as a means of encouraging development is felt to constitute a determinant factor when the other conditions justifying

/industrialization are

industrialization are present. It is thought that information on the results obtained in the River San Francisco area in Brazil would be of great interest.

Under the foregoing 25 heads, a summary has been given of some of the conclusions that may perhaps be deduced from the present study, as well as of some aspects on which it would be interesting to obtain valid data for the study and perfecting of the economic criteria applicable in electricity development in the Latin American region. In the text itself a number of other problems are raised which might provide food for discussion.

The author desires to place it on record that, although many of the personal opinions expressed in the present study derive from his experience in the company in which he works, they do not necessarily reflect the views of ENDESA. He also wishes to thank Mr. Renato Salazar, Mr. Carlos Croxatto and Mr. Santiago Astraín, who read his original manuscript and contributed valuable suggestions.

BIBLIOGRAPHY

1. Joseph L. Fisher — Energy in an expanding economy. Public Utilities, June 1960.

2. OECE — L'Europe face à ses besoins croissants en énergie. Paris, May 1956.

3. United Nations — Energy in Latin America. United Nations publication, Sales No: 1957.II-G.2.

4. Corporación Venezolana de Fomento — Programa general de desarrollo económico para el próximo decenio. Santiago, August 1959.

5. United Nations — World energy supplies, 1955-1958. Statistical Papers, Series J-No: 3. United Nations publication, Sales No: 59.XVII.7.

6. Corporación Venezolana de Fomento — El consumo y abastecimiento de energía en Venezuela 1945-1957: 1968. Caracas, 1959.

7. O. Lapie et al — Portée et effets des mesures prises dans le domaine de la politique énergétique dans les six pays de la Communauté. Revue française de l'Energie, No.114.

8. Augusto Cabrera — Movilización del potencial nacional de carbón para solucionar la crisis de combustibles. Electrotecnia. Lima, January/June 1959.

9. Victor Sánchez A. — Utilización y comercio del carbón. Electrotecnia. Lima, January/June 1959.

10. Louis Armand — Quelques aspects du problème européen de l'énergie. OECE, Paris, 1955.

11. Jean Majorelle — Regards sur l'évolution des problèmes énergétiques. Revue française de l'Energie, No.118.

12. John V. Krutilla and Otto Eckstein — Multiple purpose river development. Baltimore, 1958.

13. United Nations (written by Julio Melnick) — Manual de proyectos de desarrollo económico. Mexico, 1958.

/14. Frank

14. Frank L. Weaver — Economic analysis of proposed hydro-electric projects. Latin American Electric Power Seminar, Mexico, 1961.

15. David F. Carvers and James R. Nelson — Electric power regulation in Latin America. Baltimore, 1959.

16. Dr. H. Frewer — Die theoretischen Zusammenhange zwischen dem Energiebedarf und seiner Deckung. Praktische Energiekunde, Vol.4, No.2, Karlsruhe, 1956.

17. Ives Durrieu — La prévision économique en matière d'électricité pour la France. Paris, 1959.

18. H. Frewer and H. Schendekehl — Untersuchungen über die Nachfragestruktur von Tarifabnehmen. Praktische Energiekunde, Vol.4, No.3, Karlsruhe, 1957.

19. Electricité de France — L'expérience dite de Trois Villes. Paris, January 1960.

20. Tippets Abbett, McCarthy Stratton, Kenedy and Donkin — Estudios de problemas eléctricos argentinos. New York, 1960.

21. L. Nonat et al — Rapport économique et commercial (on the problem of coal in Chile). Paris, 1960.

22. R. Sáez — Various unpublished papers on the effects of electricity rationing. Santiago, Chile, 1957.

23. Leopold Schneetterer — Rapport sur les méthodes employées dans la statistique de l'énergie. Fifth World Power Conference, Vienna, 1956.

24. United Nations — Economic development of under-developed countries: (c) sources of energy. Work done and recommendations concerning energy development (E/3212).

25. Corporación Venezolana de Fomento y Electricité de France — Plan nacional de electrificación. Caracas, 1960.

26. Instituto Costarricense de Electricidad — Investigación de recursos hidroeléctricos de Costa Rica. San José, 1959.

/27. Central

27. Central Office of Information — Britain - An official Handbook. London, 1958.

28. D. J. Bolton — Capital investment and government control. Electrical Review, November 1960.

29. Instituto Costarricense de Electricidad — Naturaleza de la electrificación en Costa Rica. San José, 1959.

30. Corporación de Fomento de la Producción — Plan de electrificación del país. Santiago, 1942.

31. M. Rousselier — L'Inventaire total des ressources hydrauliques comme base des plans généraux de développement. World Power Conference, Rio de Janeiro, Sectional Meeting, 1954.

32. Léo A. Penna — Evaluation of potential hydroelectric project as an addition to an existing power system. Latin American Power Conference, Mexico, 1961.

33. OECE — L'Industrie de l'electricité en Europe (1957-1975). Paris, April 1958.

34. OECE — L'Industrie de l'electricité en Europe. Paris, January 1956.

35. Sven Lalander and Matts Bärlund — Energy statistics and load forecasting in Sweden. Fifth World Power Conference, Vienna, 1956.

36. Carlos A. Giavi — Production of electrical energy in Uruguay. Development of the hydraulic-thermal system Río Negro-Montevideo. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

37. Noburu Mitani, Takashi Fujii and Motoharn Ischi — Economic tendency in electric power development in Japan. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

38. M. Bouvard — Les tarifs et les méthodes de choix des équipements hydroélectriques. Latin American Electric Power Seminar, Mexico, 1961.

39. A. Bennett, Luis Court, R. Arteaga and R. Bennewitz — Influencia de la magnitud y características de una central hidroeléctrica en el costo de las obras. Latin American Electric Power Seminar, Mexico, 1961.

40. OECE — Situation de l'industrie de l'électricité dans les pays de l'OECE. Paris, 1954.

41. Arnold B. Taylor — General criteria for the selection of hydroelectric generating plant size at multiple-purpose projects. Latin American Electric Power Seminar, Mexico, 1961.

42. J. F. Pett — Combining hydro and thermal capacity results in maximum economic benefits. Latin American Electric Power Seminar, Mexico, 1961.

43. Efrain Friedmann and Raúl Schkolnik — Costo horario del suministro eléctrico en un sistema interconectado. Latin American Electric Power Seminar, Mexico, 1961.

44. Marcel Boiteux — L'énergie électrique. Données, problèmes et perspectives. Revue Française de l'Energie, No.123.

45. F. Bessiere — La programmation à long terme des investissements d'Electricité de France. Elektrizitätsverwertung. Zürich, December 1960.

46. A. N. Voznesenski and A. A. Bestchinski — A comparative cost estimate and prospects for harnessing the water power resources in the eastern regions of the USSR. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

47. A. Schwefelberg, T. Popovici and A. Cogalniceanu — Méthode pour la détermination de la proportion optima dans l'utilisation des différentes ressources énergétiques pour la production de l'énergie électrique. World Power Conference, Madrid Sectional Meeting, 1960.

48. Milos Brelih — The evaluation of energy from the various power plants in the interconnected system. World Power Conference, Madrid Sectional Meeting, 1960.

49. Tomasz Biernacki — Application of sequential analysis to economic evaluation of installed capacity of hydroelectric plants. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

50. Electricité de France — Travaux d'investissement, 1959. Paris, 1960.

/51. A.W.Knight

51. A. W. Knight — Economic trends of power in Tasmania. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

52. Electricité de France — Statistique de la production et de la consommation. (Année 1959). Paris, 1960.

53. C. G. Mills and H. Teekman — Thermal hydraulic generation integration in Southern Manitoba and Northwestern Ontario. Montreal, 1958.

54. Jacy F. Pinto — A survey of electrical power generation trends in Brazil. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

55. Prof. Fiovanni Padoan, Mario Maniardis, Alessandro Rota and Ettore Verducci — Perspectives d'une insertion de la production nucléothermoélectrique dans la production d'énergie électrique traditionnelle en Italie. World Power Conference, Madrid Sectional Meeting, 1960.

56. R. Brudenell and J. Gilbreath — Economical use of hydropower, steam power and system interconnections. Latin American Electric Power Seminar, Mexico, 1961.

57. Petri and Lars Lingstrand — Steampower as a supplement to water power in Sweden. World Power Conference, Rio de Janeiro Sectional Meeting, 1954.

58. Claudio Marcello — Tendances et perspectives de la production d'énergie hydroélectrique dans l'Europe Occidentale. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

59. G. Strandberg and J. Chapman — Thermal power as a complement to hydro-electric power in regions of large hydraulic potential. World Power Conference, Rio de Janeiro Sectional Meeting, 1954.

60. Dr. O. Vas — Economic aspects of hydro power development on the electricity supply in Austria. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

61. T. Ingledow — Integration of gas turbines in hydroelectric systems. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

62. Jean Andriot — L'énergie atomique. Revue Française de l'énergie, No.119.

/63. D.Suarez C.

63. D. Suarez C. and F. Saleta — *Enlace funcional entre la producción tradicional y la nuclear*. World Power Conference, Madrid Sectional Meeting, 1960.

64. D. Clark, P. Cash and F. Faux — The integration of nuclear power into a large electricity generating system. World Power Conference, Madrid Sectional Meeting, 1960.

65. J. Henderson and C. L. Allan — Economic integration of coal-fired nuclear and hydraulic generation of electricity with special reference to Scotland. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

66. E. Friedmann and R. Salazar — *Perspectivas de la energía nuclear en Chile*. World Power Conference, Madrid Sectional Meeting, 1960.

67. Howard L. Melvin — Power pool operation. Fifth World Power Conference, Vienna, 1956.

68. Vladimir Slebinger — *Possibilités d'intégration des forces hidrauliques des Dinarides et des Alpes Orientales*. Fifth World Power Conference, Vienna, 1956.

69. Kungl. Vattenfallsstyrelsen — Power Supply in Sweden *Energie Heute*. Vienna, 1956.

70. Gastone Falomo — Economic comparison between fuel transportation and electric transmission in Italy with reference to the location of steam electric power station. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

71. J. K. Dillard and Miles Maxwell — Economics of extra high voltage transmission. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

72. F. D. Ivanichtchenko and K. A. Smirnov — *Création du réseau électrique d'interconnexion unique de l'URSS, son rôle dans l'économie nationale et ses indices économiques*. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

73. Pierre Ailleret — *Problèmes énergétiques à long terme et rapidité d'évolution des techniques*. *Soc. des Ingénieurs Civils de France*. Paris, 1957.

74. Milos Brelih — Le potentiel hydraulique yougoslave réserve énergétique de l'Europe. Belgrado, 1958.

75. I. O. Saatchjan and G. N. Lyalik — The role of water power in the formation of large power systems and consolidated systems in the Soviet Union. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

76. G. Bardon — Les échanges d'énergie électrique dans l'Europe Occidentale. Revue Française de l'énergie, No.118.

77. G. Bardon — L'amélioration continue des centrales et réseaux nationaux, source de progrès dans les échanges internationaux d'énergie électrique. Osterreichische Zeitschrift für Elektrizitätswirschaft, Vol.9, No.6.

78. W. Goldsmith — Internationale energiewitschaftliche Zusammenarbeit in schweizerisches Sicht. Osterreichische Zeitschrift für Elektrizitätschaft, Vol.9, No.6.

79. W. Fleischer — Les conditions techniques et économiques déterminant l'évolution de la marche parallèle vers la marche interconnectée et l'économie de l'interconnexism. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

80. Bruno Mengele — Les problèmes techniques de la coopération internationale dans les secteurs de l'économie énergétique. Fifth World Power Conference, Vienna, 1956.

81. L. Wolf — Voraussetzungen und Möglichkeiten der wirtschaftlichen Lastverteilung in zwischenstaatlichen Verbundbetrieb in Europa. Osterreichische Zeitschrift für Elektrizitätswirtschaft. Vol.9, No.6.

82. UNIPEDE — Economical and technical aspects of the interconnection of electric power systems. Latin American Electric Power Seminar, Mexico, 1961.

/83. Josef

83. Josef Kelar — Energiewirtschaftliche Zuzammenarbeit zwischen del Tschechoslowakischen Republik und der Republik Osterreich. Osterreichische Zeitschrift für Elektrizitätswirtschaft, Vol.9, No.6.

84. R. Stahl — Der nationale gewinninternationales Zuzammenarbeit. Osterreichische Zeitschrift für Elektrizitätswirtschaft. Vol.9, No.6.

85. E. Torres Belon — El Lago Titicaca. Proyecto Angel Forti. Lima, 1955.

86. R. Sáez — Estudio del aprovechamiento para riego y generación de las aguas del Lago Titicaca. (Private unpublished paper, June 1945.)

87 R. Harnecker, R. Salazar and D. Santa María — Principios técnicos y económicos del aprovechamiento internacional de las aguas del Lago Titicaca. World Power Conference, Rio de Janeiro Sectional Meeting, 1954.

88. Instituto Costarricense de Electricidad — Aprovechamiento combinado de proyectos de carácter internacional. San José, November 1959.

89. G. Wunenburger — Estado actual de la producción de energía eléctrica en el Perú. Revista Electrotécnica, Nos.27-28. Lima, 1959.

90. T. W. Schultz — El test económico en América Latina (Lecture given at Cornell University). Santiago, 1960.

91. K. Finch — A commercial approach to rural electrification. Latin American Electric Power Seminar. Mexico, 1961.

92. Comisión Federal de Electricidad — Empresas y plantas en la República Mexicana. Mexico, 1955.

93. ENDESA — Producción y consumo de energía eléctrica en Chile. Santiago, 1958.

94. Armando Camponeschi and Umberto Beltrami — Les perspectives du développement de la production d'énergie hidroélectrique en Italie. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

/95. A.W.Huseby

95. A. W. Huseby — Some economic considerations of long distance electric power transmission in Brazil. World Power Conference, Canadian Sectional Meeting, Montreal, 1958.

96. OECE — L'énergie dans les Territoires d'Outre-Mer. Paris, 1953.

97. O. Marcondes Ferraz — L'usine hydroélectrique de Paulo Alfonso sur le São Francisco de la "Companhia Hidro Eléctrica de São Francisco". World Power Conference, Rio de Janeiro Sectional Meeting, 1954.