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METHODOLOGY FOR FORECASTING ELECTRIC POWER DEMAND

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CONTENTS

/Introduction

Introduction

WHY DEMAND PROJECTIONS SHOULD BE PREPARED

The demand for electricity should be forecast far enough in advance for an estimate to be worked out carefully. This has to be done because the supply of electric energy, both as a final consumer product and as a production factor, must keep ahead of demand and because of the interval which must necessarily elapse between the decision to build a power plant and the date on which it actually begins to function.

The problem can of course be solved simply by providing more additional capacity than is actually needed to meet the increase in demand. However, this solution is not recommended because the power plants would always be operating at less than maximum capacity and the solution would therefore lead in practice to a building up of excessive reserves and a depletion of investment funds.

An estimate of demand is thus an essential feature of investment programming in the electricity sector as in other branches of the economy. It is even more important in the case of electricity, not only because of the considerable investment of time and capital required to provide additional output capacity but also because of a peculiar characteristic of electric power, namely that it cannot be stored. It therefore lacks the flexibility - inherent in virtually every other industry - which allows seasonal or cyclical changes to be absorbed while additional investments based on long-term demand trends are planned.

Demand projection provides data essential to the formulation of investment programmes and it therefore follows that the risks and costs involved in these programmes have a direct and significant bearing on the projection methods to be applied.

This point should be stressed, the more so as it is often ignored when projection techniques are analysed and selected.

It is essentially a general problem which has all the earmarks of what is known as decision-making theory in conditions of uncertainty or lack of data. The main problem with respect to investment programming

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in the field of electricity is the element of uncertainty involved in estimating the future conditions of a specific market.

As is known, the formulation of optimum decisions under these conditions is essentially based on an analysis of the following factors: (1) the distribution of the element of probability with respect to possible errors; (2) the cost of these errors. The former is basically related to an analysis of projection methods whereas the latter derives essentially from a study of investment programmes.

No attempt is being made here to analyse the problem as a whole, in view of its extreme complexity and the fact that its solution may not be feasible in practice; the aim is simply to emphasize the close interdependence between the demand projection phase and the programming stage of an electricity plan.

An electric power expansion or investment programme calls essentially for a decision to be made concerning: (a) the projects to be selected from a large available portfolio; (b) the optimum size of the projects concerned; (c) the time sequence of construction. All these aspects are decisively influenced by the analysis of demand projections. Assuming that the analysis reveals considerable uncertainty as to the future trend of electricity consumption, preference will be shown for expansion programmes with a greater measure of flexibility, e.g., those providing for a more careful staggering of increases in existing capacity.

Generally speaking, the economic value that should be attached to the element of flexibility in an expansion programme may be said to be in direct proportion to the degree of uncertainty in the estimate of future demand. If the estimate leaves nothing to chance, provision for flexibility in the programme or for possible future programme changes would serve no purpose.

As a further example of the interdependence between projection methods and programming machinery, the relative margin of error in estimates, a most important aspect which will be dealt with in greater detail later in this paper, should be mentioned. If the demand for electricity is under-estimated, the cost of the error can be measured by the loss of goodwill on the part

/of the

of the customer whose needs have not been met, plus the drop in industrial output (or the loss occasioned by the structural changes in industrial production which have to be effected). If, on the other hand, demand is over-estimated, the cost of the error may be measured by the amount of funds unnecessarily invested in plants compelled to operate at less than capacity. Where the distribution of these costs is balanced, a reasonable target to adopt for expanding the electricity sector is the average or most probably value resulting from the analysis of projections, particularly if the distribution of errors is deemed to follow a normal or Gaussian curve.

There is nevertheless reason to believe, as will be argued later, that the average cost of an under-estimate is higher than that of an over-estimate. If so, a value higher than the average would be the best target for programme expansion.

The interdependence referred to earlier applies not only to projection methods but to the very subject of programming. In fact, the main purpose of an electricity expansion programme is adequately to meet consumer demand as expressed by the load diagram, i.e., the curve of power demand in terms of time, the integral of which is the total energy consumed in a given period.

This can only be achieved if consistency is ensured between certain parameters or critical characteristics of the load diagram and the system producing electric energy. Therefore - and this must be stressed here - the projection or estimate of some elements of the diagram is much more important than that of others, depending upon the characteristics of the generating park. The best example of this is the difference between a predominantly hydro system and a predominantly thermal system.

In the first case, the critical parameter of the load diagram will be its area and, in the second, its maximum ordinate. The programmer will have to exercise the greatest care in making a proper estimate of the respective parameter because errors committed with regard to other aspects will be far less significant and costly.

/Lastly, the

Lastly, the fact should be borne in mind that demand for electric energy, as for any other product, is not a fixed value but a function of a number of variables, including the volume and conditions of supply.

In other words, this demand is not entirely beyond the control of the person responsible for programming an expansion of energy output capacity. On the contrary, the policy applied with a view to expanding and promoting the use of electricity, as well as the price at which it is sold, will have a direct bearing on the volume of demand. Demand is, of course, affected by other variables over which the programmer has no control whatsoever, particularly if he acts only at the level of the electricity enterprise.

The relationship between the two parameters is given by the load factor, the values of which have a considerable influence on the profit margin of electric power sales. An increase in this profit margin implies a more satisfactory use of the fixed investment and therefore a higher net income. This is so because the sales price, even if it fails to cover the total cost of production (including amortization and the interest on the capital invested) is nearly always higher than marginal costs which, for hydro-electric generation, are virtually nil and, in the case of thermal generation, barely exceed the equivalent cost of fuel per unit of energy.

Most electricity systems are, of course, neither completely thermal nor purely hydro-electric but a combination of both in varying degree, depending upon the energy resources available, the demand pattern and the results of the economic estimates aimed at optimum use of the resources within the limits of the problem under consideration. Under these conditions, both the area and the maximum ordinate of the load diagram are important. For instance, while in the case of a mainly hydro-electric system the periods of low water are a limiting factor from the point of view of energy supply, the maximum demand shown in the diagram (and, more broadly, the general shape of the curve) will also have an important bearing on decisions to install peaking units. Thus, supply must not only adequately meet demand but must do so as economically as possible. Assuming, for example, that a choice is to be made between a gas turbine and a steam

/plant to

plant to meet demand over a certain power value, the unit cost of the gas turbine will be lower than that of the steam plant but its operating cost will be higher (i.e., the same relative position as exists between the steam plant and a hydro-electric plant). Under these conditions, as is well known, the relative economic advisability of one or the other depends essentially upon the hours of operation. Thus, a major error in estimating the shape and height of the diagram in the peak area may cause a decision taken in either sense subsequently to prove uneconomical.

Stress should be laid here on the importance of introducing the element of probability in analysing the behaviour of these variables because, while a maximum demand trend line can be worked out with a measure of confidence, the maximum demand will in practice - as in the case of the real points of the regression curve - oscillate above and below the trend line. These deviations are essentially an unpredictable element whose behaviour ought to be studied. This also applies to the shutting down of generating units, which cannot be accurately estimated and must therefore be calculated on the basis of probability. By combining a large number of possibilities with respect to each of these unpredictable variables (by means of the so-called Monte Carlo processes) a histogram or frequency curve may be drawn of the reserve margins available for alternative schemes of installed capacity expansion and the information used to formulate decisions in the matter.

In view of the large number of alternatives that must be analyzed and the attendant arithmetical calculations required for each of them, electronic computers will have to be used. By resorting to a mathematical model "simulating" the actual system, the computers will, in accordance with the instructions they receive from the operator, give results for the various alternatives from which one must be selected.

On the other hand - and reverting to the more general aspects of the problem - it is a fact that economic development calls for changes in a country's economic and social structure inherent in the very essence of the process. Hence, in order to achieve accelerated development, economic policy is aimed at creating conditions conducive to these changes.

/An attempt

An attempt will now be made to deal briefly but more specifically with the influence of the changes in a country's economic and social structure on electric power demand and supply.

The principal changes are: (a) an increase in general manpower output; (b) a change in population distribution (process of urbanization); (c) a change in the formation of the gross product; (d) a change in income distribution.

It should be made clear, at the outset, that the structural changes, far from being independent, are closely interrelated. Thus, an increase in welfare and a production structure weighted in favour of secondary and tertiary rather than primary activities may be viewed as the final results produced by a combination of all these changes.

A rise in manpower output can be achieved by a better organization of labour and an increase in capital equipment per employed person. This is particularly the case in industry where highly capitalized productive units replace artisan production.

This increase in productivity is logically linked to a change in the composition of the installed capital. It should be noted that in every country moving swiftly towards industrialization, productive equipment takes precedence over other elements of renewable capital, and in the more advanced economies may constitute as much as one-fourth or more of the total.

Moreover, the relative importance of the economic sectors in gross product formation varies with a country's development.

Growing emphasis is placed on industry, particularly light industry, at the expense of agriculture in the early stages of the process, and on heavy industry and services in subsequent stages.

The development process brings with it a concentration of population in the urban areas. This phenomemon does not seem wholly related to the process itself, although it may be accelerated to the extent that additional employment is made available in the industrial and services sectors and agricultural output increases. Similarly, an increase in the per capita income level is generally related to a downward redistribution of income which broadens demand for food and essential items and subsequently for services and goods which might be considered "convenience" items.

/I. CLASSIFICATION

I. CLASSIFICATION OF DEMAND ESTIMATE METHODS

To simplify an overall analysis of the problem and without prejudice to a detailed consideration of some of the methods applied, the latter may conveniently be classified into three separate groups:

(a) methods of extrapolation in time;

(b) methods in which variations in electricity consumption are related to one or more macroeconomic variables, in addition to time, by means of single or multiple correlation procedures;

(c) direct and research methods.

The first group consists of a typical case of simple or first-stage forecast in which, from data based on previous experience, a functional relationship is determined between the variable whose future behaviour is to be predicted and time.

The methods in the second group, on the other hand, are designed for second-stage forecasts where, after a functional relationship between the variable to be forecast and other first-stage macroeconomic variables has been determined, the behaviour of these first-stage variables has to be predicted. Hence the number of conditional or second-stage forecasts for this type of projection.

1. Methods of extrapolation in time

This group includes all the procedures in which a specific curve selected from the components of a body of functions is adjusted to data based on past experience. This adjustment is generally effected by means of normal equations derived from the assumption that the sum of the squares of the deviations should be minimized with respect to the function sought. These equations make it possible to calculate the values of the parameters which separate this function within the group of functions selected a priori.

If consideration is limited to the Gaussian hypothesis of minimum squares, the area of discretion for these methods of simple extrapolation in time basically includes:

(a) selection of the functional form or body of functions, with one or more parameters, from which a function will be chosen on the basis of the calculations resulting from the system of normal equations;

/(b) the

(b) the time interval, particularly the moment at which use of the data provided by past experience is first made, i.e., the interval of variation of the independent variable in the problem.

With regard to the first point, it is well known that the simple exponential with a single parameter, i.e., with a constant annual growth rate, is the functional form most often used in practice.

Some observers have noted that the annual consumption growth rate of an electricity system is relatively high early in its life span but declines as the system ages. The function of the simple exponential type is inadequate to describe this evolution and Robinson and Daniel have therefore suggested, for the United Kingdom, a formula in which the annual growth rate decreases with time. (See Annex I.)

It should be noted, in this connexion, that the above finding by the observers would be true only in the case of "closed" systems - those to which no new consumers are added. But even for these systems, relatively few in actual fact, the Robinson-Daniel formula has a serious disadvantage in that the relative annual growth rate tends asymptotically towards one. This is theoretically unacceptable since it would mean total stagnation of a system's electricity consumption, which is not found in even the most developed economies of the northern hemisphere.

In order to overcome this objection, a functional form (see Annex I) of the potential-exponential in time type, which depends upon four parameters, has been developed. The special - and desirable - feature of this group of functions is that the relative annual growth rate of the dependent variable decreases with time but instead of tending asymptotically towards one, as in the case of the Robinson-Daniel functions, it tends towards a "normal" value higher than one, thus representing the mature stage in the life of the electricity system.

The above is of interest as a concept rather than anything else and should in no way be interpreted as a recommendation that this method of projection should be applied in Latin America. On the contrary, the experience of the more developed countries indicates that there has so far been no trend towards a decrease in electricity consumption, even though such a decrease may have been announced or assumed on various

/occasions. Thus,

occasions. Thus, for instance, both the Federal Power Commission and the publication Electric World implicitly assume this hypothesis in their estimates of electricity demand in the United States up to 1980. The FPC estimates that the growth rate will be about 7 per cent in the 1960-65 period, gradually dropping to 4 per cent in 1975-80, while the corresponding figures in the Electric World estimates are 8.5 and 5.75 per cent respectively. It should be noted that neither believes that the 1946-59 annual growth rate, which was slightly above 9 per cent, can be maintained.

Adoption of this type of hypothesis in the past has invariably led to an under-estimate of future demand. Estimates made by the FPC in 1954, 1956, 1958 and 1959 were all below the actual figures subsequently reached.

It seems logical to assume that the reason for such systematic under-estimates, which are also a feature of other forecasts in the United States, is to be found in the refusal to envisage the possibility that electricity demand may grow over a reasonably long term at a rate many times higher than that of the economy as a whole. This point will be dealt with in more detail in the chapter on indirect or second-stage projection methods, where the relationship between the electricity sector and national income is discussed.

These extrapolation methods can be more effective if the "interval" instead of the "peak" type of projection is used. The change in the theoretical hypothesis consists of introducing an unpredictable element in the functional form assumed for the extrapolation. In other words, the assumption is that for every value of the time variable there is a distribution of electricity demand values based on a specific law of probability. The average value of this distribution will usually be the one given by the function itself, e.g., the exponential curve. This curve thus becomes a curve of mean values and if, in addition, a specific law is assumed for the unpredictable element - e.g., the normal or Gaussian distribution - a position is reached where not only the mean values curve but also the extreme values curve corresponding to a specific degree of safety, perhaps 95 per cent, can be determined.

/Besides the

Besides the "trend" indicated by the mean values function, these curves make it possible to visualize the probable maximum and minimum levels of consumption and to compare them both with plans to expand generating capacity and with the cost of possible over-estimates ane under-estimates.

It should be noted that introduction of the terminology and methods of calculating the element of probability in electricity demand projections serves a real purpose and is not a purely theoretical refinement. The characteristics of consumption include variables - e.g., meteorological conditions - which are typically unpredictable and have a substantial bearing on the basic parameters of the load diagram, in other words the maximum power demand and the annual consumption of energy.

Selection of the time interval and therefore the starting point for determining the functional form best adapted to the data based on past experience, is a most important factor and one which present the greatest difficulty in the application of extrapolation methods.

What is involved is essentially a compromise between two factors that have opposite effects. On the one hand, it would be more accurate to take the whole period for which data was consistently available because it is a cardinal principle of statistics that the size of the sample should be increased in order to obtain more reliable results. It should be noted, however, that this principle is based on one assumption - uniformity of the population statistics from which the respective samples are drawn. This uniformity, however, is clearly lacking. On the contrary, it is precisely the change in the economic structure that alters the relative evolution between electricity demand and the development of other sectors of the system.

In view of the above, the most logical course would seem to be to reduce the size of the sample by taking only recent, relatively short, periods in order to ensure that their economic structure is as representative as possible of the conditions likely to obtain in the immediate future.

This is so important a consideration that it affects not only the election of the time interval for determining the functional relationship given by electricity consumption but also the selection - or relative value -

/of the

of the extrapolation method in demand projection. The extrapolation will be of little value if there is good reason to believe that future conditions will be rather different from those which have prevailed in the past. This would be the case, for example, if substantial changes in the industrial production structure are envisaged which have not occurred in recent years. This last condition warrants emphasizing in view of the often mistaken impression that extrapolation necessarily implies the assumption of a static hypothesis with respect to the development of the economic machinery, particularly the electrification of demand sectors. This is obviously not the case. The difficulty arises only if there is reason to believe that the rate of electrification in the next few years will be very different from that of the recent past. In other words, the method of extrapolation in time makes it possible to include the dynamic factors inherent in the development of electricity. On the other hand - and this is only logical - the method does not allow any forecast to be made of the effect of changes in these dynamic factors.

Future conditions may also differ substantially from those of the past if use of electric energy has been restricted, a common occurrence in Latin American countries during the post-war period. If the lifting of these restrictions is envisaged, the extrapolation of past demand will obviously serve at best to fix a reasonable minimum for an estimate of future consumption.

2. Conditional or second-stage projection methods

This group includes those methods in which variations in electricity consumption are linked to one or more macroeconomic variables - as well as time - by means of various functional forms. As in the previous case, selection of the function is usually made within a family of functions depending upon one or more parameters. Calculation of the latter is effected by the method of least squares.

A fundamental distinction to be made at the outset within this group relates to the procedures which specifically include the time variable and those which do not. The analysis undertaken in the present work

/leads inevitably

leads inevitably to the conclusion that the only methods worth considering are those which specifically introduce time as an independent variable affecting the demand for electricity. This point will be dealt with in more detail later in connexion with the interdependence between the demand for electricity and the process of innovations and technological progress both in industry and the domestic sector.

The best known and most used form of dependence between electricity demand and specific macroeconomic variables is the one which relates demand to the gross product or real income, as the case may be. To this end, two different types of correlation have been applied: the first, between the annual growth rates of both variables; the second, between their absolute - total or per capita - levels. In both cases a specific number of countries has been taken. It should be noted at the outset that notwithstanding a pronounced similarity or complementarity in the scope of their application, there is a difference between the two types of correlation: the first takes account of the dynamic evolution of electricity consumption over the years - apart from what might be termed "normal" or "vegetative" growth related to the product -, while the second is tantamount to a statistical analysis - a photograph, so to speak -, of the relationship between electricity consumption and income for a group of countries at a given moment.

It should be borne in mind, however, that notwithstanding this distinction, the second type of correlation implicitly includes dynamic elements in the form of income growth in the more developed countries.

To give an example, the first type of correlation was applied by International Bank experts in a study on electricity consumption development in which data on twenty-eight countries was used and the following ration corresponding to the regression curve obtained was reached: the average annual electricity consumption growth rate was equal to 2.6 per cent plus 1.3 times the growth rate of real income. It should be noted that by taking this linear relationship between the two rates, the rate of increase

/of electricity

of electricity demand corresponding to a 100 per cent increase every ten years - or 7.2 per cent each year - would be consistent with a 3.5 per cent annual rate of increase in real income.

Table 1 shows the rate of increase of electricity demand and the gross product in the Latin American countries during the period 1949-1958. It will be noted that the conventional correlation coefficient corresponding to the simple regression analysis is extremely low, whereas the rank correlation coefficients are both significant. In other words, while there is a marked relationship between the ranking of the two columns, the simple regression curve is not a very suitable procedure for formulating electricity demand projections, even if the future rate of expansion of the economic system can be fairly accurately gauged.

The second type of correlation has been generally used in ECLA studies on energy, together with the projection of specific consumption by production sectors and branches and, where available or significant, with data based on past experience. It should be pointed out that in another paper prepared by the secretariat for this Seminar[1/] additional elements were included when comparing the regression curves corresponding to a single group of countries for two separate time periods. The result was highly significant in that both the degree of correlation and the coefficient of the two right angles a coefficient equal to the electricity consumption - real income elasticity, proved to be practically equal. On the other hand, the regression curve relating to the most recent period was above that of the previous one, with a vertical displacement of about 60 per cent of the ordinates. The interesting point about this comparison is that the vertical displacement of the regression curve in the seven-year period considered can be taken as an indication of the rate of electrification of the economy, i.e., the average rate at which electricity consumption

1/ The electric power industry in Latin America: present status and recent developments (ST/ECLA/CONF.7/L.1.01).

/Table 1

Table 1

GROSS PRODUCT AND ELECTRIC ENERGY GENERATION

(Average growth rates for the period 1949-58)

Country	Gross product	Electricity generation
Bolivia	0.75	4.7
Argentina	1.6	6.3
Paraguay	2.5	11.4
Chile	2.8	8.0
Uruguay	2.8	9.1
Cuba	3.4	8.7
Honduras	3.6	5.6
Panama	3.9	9.5
Guatemala	4.0	8.5
Colombia	4.2	11.4
Brazil	5.0	11.0
Ecuador	5.0	12.5
El Salvador	5.8	11.7
Costa Rica	5.8	12.5
Mexico	7.1	8.5
Nicaragua	7.9	6.8
Venezuela	8.1	19.4

Correlation coefficient......................0.56

Rank correlation signficant according to both Spearman and Kendall coefficients.

/increased for

increased for a particular income level. In other words, the vertical displacement of the regression curve reflects the dynamic element inherent in the electrification process itself.

On the basis of this analysis and in terms of the electricity consumption - real income diagram, the increase in a country's electricity demand may be described as the result of two concurrent movements through time or, in geometrical terms, the sum of two vectors: first, a movement along the consumption - income regression curve corresponding to the very beginning of the period considered and to the increase in income; secondly, a vertical displacement of the regression curve itself, related to technological progress and to the substitution of electricity for less advanced forms of energy.

This obviously does not mean that both movements are independent. On the contrary, the innovations and technological progress which largely explain the growing rate of electrification per unit of product and income, are in their turn one of the chief dynamic forces of investment and the general process of economic development.

Another example of the inadequate results achieved by using a simple linear relationship between electricity consumption and gross product for the short-term projection of the former is provided by the inertia of consumption even during periods of acute economic recession. Thus, the gross product dropped by 40 per cent in the United States between 1929 and 1933 while electricity consumption declined by only 10 per cent. During the 1959 recession in Europe and North America, electricity consumption increased in countries like Belgium and the United States in which the lowest point in the downward phase of the cycle was represented by a 7 per cent drop in industrial production. As for Latin America, the generation of electricity in Argentina and Chile between 1955 and 1959 increased at an annual rate of 9.1 per cent and 4.6 per cent respectively, while the gross per capita product declined during the same period.

Reference has been made in earlier paragraphs to the fact that time should be included as one of the variables to be considered in indirect

/or second-stage

or second-stage projections. Apart from this, there is the problem arising out of every conditional projection which is that, in addition to determining the functional relationship between the endogenous and exogenous variables of the system, the behaviour of the latter must be predicted. It is not at all clear that prediction of the exogenous variables is simpler than the forecasting of the endogenous variables or that it can be made with a greater degree of confidence. Errors in projections of the gross product are in many cases more serious than mistakes in projections of electricity consumption. This has happened even when the latter was based on the former and is a clear indication of serious flaws with respect to the validity of the assumptions made regarding the functional or structural relationship between the two.

The extent to which electricity demand projections can be improved with respect to a single extrapolation in time where there is no structural change, e.g., through the inclusion of specific macroeconomic variables in the analysis, thus depends essentially on the degree of confidence with which the future behaviour of these variables, such as real income, industrial production and urbanization, can be predicted.

The requirements in this connexion must nevertheless not be exaggerated. Even if the degree of uncertainty surrounding the future development of the gross product is considerable, inclusion of this variable in the analysis of electricity demand ensures a certain consistency between the targets of the electricity expansion scheme and the development programme in other sectors of the economy. In other words, an optimum distribution of investment resources must be rationally sought through previous analysis of the relationship between electricity demand and the growth of product and income, particularly, during a period in which structural changes are envisaged.

Generally speaking, the two types of electricity demand may be projected in terms of gross product growth by sectors and of the urban population's available personal income. However, a few problems relating to these forms of projection should be stressed.

In so far as the provision of electric energy is an essential and relatively specific technological requirement for the operation of capital goods, the projection is a virtually mathematical operation to the extent that the industrial production growth rate and the corresponding electricity input coefficients are known.

/Demand deriving

Demand deriving from convenience items which can at a first approximation be estimated in terms of the urban population's personal income growth, present a much greater degree of flexibility than the above.

During the early stages of the development process the personal income available is used to increase the level of food and clothing, whereas in subsequent stages demand increases for durable household appliances requiring substantial consumption of electric energy over and above the cost of lighting.

This process may nevertheless be substantially accelerated by the demonstration effect of the more developed countries and because industrial growth is largely dedicated to the production of durable goods, first as a substitute for imports and later to meet the new demand arising from income growth.

As a result an appreciable part of the demand deriving from increased welfare will be closely linked to the production of durable household goods and to the capacity to purchase such goods.

Growth in urban population plays an independent role in the formation of demand for electricity and is not very closely linked to income levels. Population growth implies an increase in the area covered by towns and as a result will lead to an increase in supply, quite apart from greater household demand for power.

These factors - increases in available personal income, urban population growth and a more equitable distribution of income - are those which mainly influence the demand for electric power, defined here as dependent of the level of welfare.

Generally speaking, the forecasting of electric power requirements resulting from increased welfare bears no mathematical relationship to economic growth, or at least this can be said to be true within certain limits. Power supply for this type of consumption depends in practice on policy decisions; this is also the case with other urban services such as drinking water supply, sewage, education services, etc.

The problem can better be considered as a study of compatibility between "productive" and "social" investments in relation to a given rate of growth, a particular social policy, the greater or lesser deficiency in supply of such services and a given amount of resources.

/The group

The group of methods being analysed includes those which contain variables that are macro-economic, but have a lesser degree of aggregation than gross product or national income. An example of this is to be found in the formulae of the mixed kind with a potential factor with respect to the index of the output of manufactured goods (the index usually being between 0.3 and 0.5) and another factor of the exponential type in time. In other words, a specific dynamic trend related to the expansion of the manufacturing sector of the economy is incorporated into the formulae of simple extrapolation in time.

Various statistical surveys - for instance, those carried out by Electricité de France - have shown to what extent the irregularities of the electricity consumption curve in relation to time, C(t), are attenuated if reference is made to the quotient $C/I^{0.4}$. Accordingly, while the dispersion of relative annual increases on the curve is 5 per cent, the dispersion for the quotient mentioned above is almost as low as 2 per cent.[2/]

In the Netherlands use has been made of the formula:

$$E_i = P^3/L^2$$

where:

- E_i represents industrial consumption of electricity
- P is the index of industrial production
- L is the index of use

the base year 1 being 1938. This formula is based on the principle that the industrial consumption of electricity varies in direct ratio to the level of industrial production and to the square of labour productivity.

This type of formula, which introduces the notion of productivity, has also been used in the United States at the level of the enterprise.

One of the advantages of explicity introducing the index of industrial production into the methodology of projecting electricity demand for the countries of Latin America, is that it is less unpredictible and erratic than the index for gross output or income, because the latter variables are subject to strong fluctuations in the volume and prices of primary production.

2/ These results correspond to a sample taken in France. Use has also been made, particularly in the case of centrally planned economies, of specific consumption figures expressed in kWh per physical unit of product, for the various branches of manufacturing and mining.

/The share

The share of the industrial and mining sectors in the total of electricity consumption varies considerably as may be seen from table 2; the figure for Latin America as a whole is in the neighbourhood of 55 per cent.

Apart from the direct influence of industrialization on the growth of demand for electricity, there is also an indirect influence of importance resulting from the growth of urban areas, and this is due to the close relationship existing between the industrial development process and the growth of urban areas.

Broadly speaking, in both the more and the less developed countries, the industrial sector is a greater consumer of electric power than a provider of income. This is particularly true in countries where income levels are low as this leads to a low degree of electrification in the household sector. Consequently, the expansion of electricity demand in low-income countries is absorbed to a large extent by development and electrification in the industrial sector.

It should be pointed out that the use of binary formulae using two factors, one of which is potential with respect to the index of industrial production and the other is exponential through time, does not give grounds for assuming stagnation in the specific consumption (kWh per unit of product) of the manufacturing sector. The upward trend of the quotient for specific consumption in the manufacturing sector and the increase in specific consumption per household service connected are included within the term of growth which contains the time variable.

In countries where satisfactory statistics exist, it is possible to introduce a greater degree of disaggregation into the methods of projecting electricity demand, with special study of the behaviour of the two main consumption sectors: industry and households. This has the advantage of allowing for careful analysis of trends in both kinds of electricity consumption, namely, as a final consumer good and as a production factor.

Electricity consumption as a final consumer good depends basically on the level of available personal income, its distribution and breakdown and also on the degree of urban development and the relative prices of electric appliances. Demand for electricity as a production factor

/Table 2

Table 2

LATIN AMERICA: SHARE OF CONSUMPTION OF THE INDUSTRIAL AND MINING SECTORS IN TOTAL ELECTRICITY CONSUMPTION

(Percentages)

	1938	1949	1955	1959
First group				
Argentina	53.1	56.3	54.5	(57.9)
Chile	83.4 a/	80.3	75.3	74.5
Cuba	...	53.5	45.6	44.8
Uruguay	...	(52.0)	48.7	(45.4)
Venezuela	(78.9)	(75.6)	(71.1)	(64.3)
Second group				
Brazil b/	...	...	42.1	46.8
Colombia	33.4	39.7	43.8	43.9
Costa Rica	...	24.6 c/	19.6	14.0
Mexico	(62.4)	58.0	57.3	(56.5)
Panama d/	...	26.2	32.7	30.6
Peru	76.8 a/	78.8 e/	80.6 f/	(79.9)
Third group				
Bolivia	(86.8)	77.9	74.5	(66.6)
Ecuador	...	21.4 e/	36.0	(41.1)
El Salvador	...	52.7 c/	37.5	37.1
Guatemala	...	49.0 c/	47.9	45.5
Honduras	...	83.0 c/	76.4	67.1
Nicaragua	...	83.3 c/	79.5	65.4
Paraguay	...	58.6	51.0	46.5
America Latina	65.6 g/	62.0 h/	54.0	54.9

a/ 1940.
b/ See note p/ of Statistical Annex I.
c/ 1950.
d/ Does not include the Canal Zone for lack of information.
e/ 1951.
f/ 1954.
g/ Includes Argentina, Chile, Venezuela, Colombia, Mexico, Peru and Bolivia.
h/ Excluding Brazil.

/depends on

depends on the volume of industrial production, its degree of electrification in each sector and the structure of existing industrial plant.

Clearly, there is close interdependence between the variables conditioning the two types of electricity demand. The level of electricity input is one of the determining factors of productivity in manufacturing and this in its turn exerts an influence over the <u>per capita</u> level of income in the community. It is interesting to note that the experience of some industrialized countries in the European continent and also of the United States would seem to indicate that increased productivity in the manufacturing sector - physical production per man hour worked - occurs in a proportion similar to the increase in specific consumption of electric power in that sector. The importance of this observation stems from the fact that the greatest percentage of future growth in income must derive - as experience in the post-war period showed - not so much from increases in the labour force but from a growth of productivity per person employed.

(a) <u>Industrial sector</u>

Increases in electricity consumption as a production factor, or in other words, demand in the industrial sector occurs as a result of the combined effect of three different causes which should be clearly distinguished. These are:

(i) Increases in industrial production which, even for a constant value of the coefficient of intensity of electricity consumption (kWh per dollar of aggregate value) in the sector, will lead to a parallel increase in the consumption of electricity;

(ii) The process of electrification in each one of the industrial sectors; this tends to increase the coefficient of intensity of electricity consumption either by a higher degree of mechanization of the industrial process concerned or else as a result of the use of electric furnaces in the place of conventional furnaces (as for example in the iron industry), etc.;

(iii) Changes in the industrial sector which usually lead to an increase in the relative participation of industries with high coefficients of intensity of electricity consumption as, for example, the electro-metallurgical and electro-chemical industries or heavy industry in general.

/The importance

The importance of structural changes with regard to specific consumption or the average coefficient of the industrial sector may be seen in the significant differences between the coefficients for different industries. Thus, electricity consumption per unit of value added in some electro-metallurgical industries is from 50 to as much as 100 times higher than in the food or textiles industries. In general, it is particularly the "dynamic" industries - or those which are established and grow at a faster rate during the process of economic development - which have the highest coefficients of electricity input.

This means that the average coefficient of intensity of electricity consumption industrially is considerably higher in the more advanced countries than in the less developed countries and that a large part of such electricity consumption is accounted for by the metallurgical and chemical industries.

The major part of the most usual industrial processes in the less developed countries, namely, light industry, requires less than one kWh per dollar of value added, while in the chemical, petrochemical and steel industries the equivalent figure is usually higher and may sometimes be as much as from 5 to 10 kWh per dollar in the case of processes using electric furnaces.

The foregoing considerations reveal the importance of structural changes in total electricity consumption in the industrial sector - particularly when industrial consumption in its turn accounts for a preponderant part of total consumption - and demonstrate the need to take this fact into account in preparing forecasts for each country, when industries are established with high intensity of electricity consumption.

In addition it is particularly for these mass consumers of electricity that the sales prices of power are of importance, for its cost will represent a large percentage of value added per manufactured article. For this reason, the price elasticity of demand will be much greater than for other consumers, either industrial or domestic, and any person responsible for preparing electricity development programmes cannot fail to take account of rates policies when considering demand projections. This point will be further considered when an analysis is made of the interdependence of supply and demand for electricity.

/(b) Domestic

(b) Domestic sector

Demand analysis and projections for the domestic sector give rise to far less difficulties, owing to the greater statistical homogeneity of this sector in comparison to the industrial sector. The two basic parameters which determine total consumption - or the number of connected services and average consumption per service - are closely linked to the level of income and its distribution.

In the absence of restrictions on supply, the increase envisaged in the number of services will be closely linked to the number of building permits granted in the immediate past within the area served by the electricity undertaking concerned. Trends in average consumption per connected service will perhaps be harder to determine; one of the decisive indices in this connexion, will be the rate of sale of electric household appliances, for it should not be forgotten that in this respect demand for electric power is a form of "derived" demand which requires preliminary investment by the purchaser.

For the purposes of analysis of electricity consumption in the domestic sector, a distinction should be drawn between its use for (i) lighting, (ii) the provision of heat (cooking, water, heating), and (iii) mechanical uses (radio, television, refrigeration, cleaning).

As is natural, these three components of electricity demand in the domestic sector have different income and price elasticities. In this respect, it should be noted that while for (i) and (iii) there are practically no substitutes for electricity, for the uses combined under (ii), electric power has to compete with other forms of power such as gas and fuel oil and even in many instances in Latin America with paraffin, wood and charcoal.

As regards the price elasticity of electricity demand, it has proved very difficult, even for statistical organizations as efficient as the Central Planning Office of the Netherlands, to determine the relationship between electricity consumption and its sales price. As consumption has increased and the real price for electric power has fallen constantly, there is a natural inverse correlation that does

/exist; that

exist; that does not neccesarily mean however, that such a relationship can be identified with the demand curve at any given moment.

There are, however, reasons for believing that price elasticity is relatively high, particularly for consumption under group (ii) where competitive sources of power exist. For example, average household consumption in the area served by the Tennessee Valley Authority in the United States during the 1960 fiscal year was 8,800 kWh at an average price of 0.99 cents of a dollar per kWh, while the average figures for the country as a whole during the same period were 3,700 kWh and 2.5 cents of a dollar.

This very considerable difference between average rates of consumption per connected domestic service even in a country where the use of electric household appliances is as widespread as in the United States demonstrates the wide margin that exists for an increase in per capita electricity consumption and is one of the reasons why no relative saturation in these figures is foreseen.

It should not be forgotten that intensification of the rate of electrification in the domestic sector depends not so much on the rate of increase of income as on the absolute level and distribution of income; this is true mainly because electrification involves relatively high initial costs in relation to the available income of the medium and low income groups. This means that no spectacular progress in per capita domestic electricity consumption should be expected even in the less advanced countries which are growing very fast, at least until such time as a relatively satisfactory average income level has been reached.

If a comparison is made of trends in total electricity consumption and electricity consumption in the industrial sector, it can be concluded that both in the United States and in Europe non-industrial electricity consumption - which in addition to household consumption includes commercial, agricultural, municipal and transport consumption - has increased faster than industrial consumption. The same has occurred in Latin America where the percentage share of industrial consumption has

/declined from

declined from 65 per cent in 1938 to 55 per cent in 1959. In the United States, it is thought that this trend will continue; accordingly, while household consumption of electricity at present represents 28 per cent of the total, it is estimated that the equivalent in 1980 will be 40 per cent owing to the fact that the rhythm of household electrification is overtaking the rate of industrial electrification. Part of the explanation of this phenomenon must be found in the fact that a certain number of the advances made in industrial productivity - automation through the use of automatically controlled machines, for example - have been obtained as a result of relatively slight additional electricity consumption in relation to savings in labour, and this is a reason for expecting that in the future, unlike the past, productivity in the manufacturing sector will increase proportionately to a greater extent than specific consumption of electric power.

Another type of projection of a secondary order is the use of the input-output model for a given economic system, as was done for example in the case of Italy. Once the coefficients of direct and indirect requirements have been obtained by inversion of the matrix (I-A), it will be possible to obtain individual production values - including the value for electricity - by multiplying the respective lines of the inverted matrix by the vector of final demands forecast for the year for which the projection is being made. Thus, in the case of Italy a predicted increase over five years of 65 per cent in electricity consumption was obtained and this corresponded to an increase over the same period of 25 per cent in gross product.

Unquestionably, the application of the input-output model means much more rational utilization of economic data than by using simple correlation between electricity consumption and gross product. The very serious difficulties which may arise in the latter case should not be forgotten, for they may distort the results obtained. Firstly, the problem of second-stage projections again arises here; even if accurate knowledge is available regarding the matrix of coefficients of direct and indirect requirements, an estimate will have to be made or a figure

/found not

found not only for the total volume of final demand but also for its distribution by sectors or to state it in geometrical terms for the module and direction of the vector of final demand. To make an estimate of this kind is a matter of some very considerable difficulty.

But there also arises the problem of changes in technological coefficients including both those resulting from changes or improvements in manufacturing processes which as a result affect the number of kWh consumed per unit of product, and those deriving from changes in the relationship of unit prices in the electricity sector and various manufacturing sectors, since such changes will also affect the coefficients of the Leontief matrix.

These difficulties added to the scarcity of statisfactory statistics in the greater part of Latin America make it necessary to set aside the input-output model in analysing projections of electricity demand in the countries of Latin America.

3. Direct and research methods

These methods include mainly procedures of direct consultation with industrial undertakings - at least with all important undertakings and a selected sample of other undertakings - and a sample survey of probable trends in household consumption.

Although these direct methods in many cases supplement the indirect methods already analysed, which employ mathematical formulae, they are used in some countries as the basis for projecting electricity demand. Such is the case in the United States where, apart from the existence of an excellent basis of statistical data, this work is greatly facilitated by the fact that the major part of the electricity generating industry is in the hands of undertakings which supply relatively restricted and homogeneous geographical areas and are in a position to analyse the situation in their own area of operation and have fairly reliable information about it.

Normally a group of companies - including both privately and publicly-owned companies - whose generating stations are within a given geographical area interconnect such stations, thereby forming a pool

/generating and

generating and distributing electricity in such a way as to benefit all members. In these circumstances, each member of the pool is responsible for supplying the co-ordinating group with information regarding the characteristics of its present load diagram and a forecast for the immediate future in its own consumer sector. The data are later brought together to determine the overall diagram and the maximum load forecast for the integrated system, the latter being the most important parameter, since generation in the United States is predominantly thermal. The forecasts of the various pools are in their turn integrated for the whole country at the sixth monthly meetings of the Electric Power Survey Committee of the Edison Electric Institute.3/

Within the statistical sampling carried out by each company in its consumer sector, attention should be drawn to the following characteristics as being of special importance: (a) the number of houses under construction; and (b) builders' plans regarding the installation of electric appliances, electric heating and air conditioning. As to electric household appliances, a careful distinction is made between normal rate of growth of installation and fast growth resulting from special sales programmes, incentives of various kinds, etc. These are a factor of great importance in the economic system of the United States. Large numbers of the private and public electricity companies carry out their own promotions programmes for specific electric appliances with the deliberate purpose of taking up the slack in the load diagrams, thereby improving the load factor and as a result the profitability of the undertaking. It is considered, for example, that in some cases an increase of one per cent in the load factor of a system will increase the net profits from generation by up to 6 per cent.

Within this same group, although of a completely different kind, it is possible to include the procedures used in countries with a centrally planned economy, and in particular the USSR, where projection of electric power consumption is part of the electricity "Plan". For

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3/ See "Problems of load forecasting and the generating capacity to meet these loads" (ST/ECLA/CONF.7/L.1.15).

/this purpose,

this purpose, use is made of what are known as consumption "norms" or specific consumption per industry in kWh per unit of product, expressed not only in current terms but also forecast for the future, account being taken of technological developments.

It might be thought that projection work would be greatly complicated, even in countries with a completely planned economic system, if account is taken of the independent private consumer sector for which it is more difficult to fix consumption norms. As in those countries, however, potential demand for the majority of consumer goods has not yet been satisfied, the problems arising from possible saturation of supply do not usually arise. Furthermore, it is only in recent years that the standard of living has increased to any noticeable extent in those countries, and that the problem of determining volumes of production and price policies in consumer goods sectors is, as a result, likely to become very much more complicated.

/II. INTERDEPENDENCE

II. INTERDEPENDENCE BETWEEN ELECTRIC ENERGY SUPPLY AND DEMAND

There is a close relationship between the two terms of the electric energy equilibrium equation, which the stress laid on the aspects relating to the projection of demand tends to obscure. Thus, it has sometimes happened that a projection has been almost exactly borne out by reality even when the bases on which it was constructed were entirely false. And the reason is not that the projection concerned was satisfactory, but that the company or companies responsible for the provision of electricity adapted their expansion and price policy to the projection and demand in turn adjusted itself to supply.

Such is clearly the case with those countries - and there are many of them in Latin America - where restrictions on electric energy consumption are in force, both as regards the connexion of new services and the utilization of existing connexions. Demand is thus artificially constricted, and confines itself to making immediate use of any expansions of installed capacity. Little can therefore be deduced from the behaviour of demand in such circumstances, except the conclusion that it at all times exceeds the supply that generating capacity can offer. In cases of this kind, up to the time when the unsatisfied potential demand is covered, an analysis of the projection of total demand is of little help in establishing a policy for the expansion of installed generating capacity. It should be noted that in these instances future installed capacity cannot be correctly determined by adding to the estimated amount of the existing deficit an extrapolation of the growth of demand in recent years, since, in relation to its future behaviour once it is freed from its direct dependence on supply, demand may have been abnormally low or abnormally high.

Another aspect of this interdependence is constituted by price policy in the electricity sector. This is a question of the greatest importance, which is specially and more thoroughly discussed in another secretariat document to be presented at the Seminar.[4] It is the more significant, inasmuch as in some Latin American countries radical changes

4/ See ST/ECLA/CONF.7/L.1.30.

/have taken

have taken place in this field during recent years - changes which may affect the future behaviour of demand in relation to more recent experience.

It is a well-known fact that electricity tariffs in the Latin American countries have lagged far behind the overall inflationary process; that is, in real terms, the cost of electric energy has fallen. In qualitative terms, this is in no wise exceptional, since the electricity industry in general constitutes a typical example of those sectors of industry in which productivity increases faster than in the rest of the economy - particularly the manufacturing sector -, which means that tariffs may rise at a relatively slower rate than the overall price index without greatly affecting the profit levels of the undertakings concerned.

In some Latin American countries, however, this lag has been more considerable than was to be expected, especially as at the same time the productivity of the sector, and, in particular, specific consumption of fuel in thermal generating plants, has remained stationary or improved very slightly.

Broadly speaking, this situation has been made possible by means of fuel subsidies; for example, through a multiple exchange rates policy, or through direct subsidizing or decapitalization of the companies producing electric energy.

Of particular interest for the purposes of the present study is the relation between the volume of energy sales and the price policy of the public utility company. The price-elasticity of demand is especially important in the case of those mass consumers for whom the high level of electricity demand per unit of value added makes the price of electricity an important item within the aggregate costs structure. Consequently, the study of special tariffs is of great interest in the case of these consumers, especially when they accept the condition of restriction of demand during critical periods, thereby enabling the supplier company to take up the slack in the load diagram. This aspect is particularly useful when the replacement of a conventional manufacturing process by one implying more intensive consumption of electricity is under study, as in the case of electric furnaces for pig iron or steel in the steel making industry. The

/social profitability

social profitability of a substitution of this kind may well be conditional upon tariff and consumption arrangements, since otherwise the rate of return on profits offered to the steel making firm (to pursue the same example) by the process involving more intensive consumption of electricity may be more than offset by the additional investment required of the electricity sector in order to cover the increment in the peak demand of the industrial sector.

III. METHODS OF PROJECTION OF DEMAND USED IN LATIN AMERICA

In a separate secretariat document on projections of demand for electric power in Latin America,[5] the projections formulated in the leading consumer countries of the region are analysed in detail. Some of the conclusions which can be drawn from this analysis may usefully be summed up here.

Broadly speaking, the three types of methods indicated in the foregoing chapters are seen to be applied, sometimes eclectically and not always in such a way as to be clearly distinguishable. An extrapolation of recent experience is used as a basic datum for forecasts of the future, but with the necessary adjustments. Thus, for example, owing to a variety of factors - but essentially in view of the need to cover the installed capacity deficits existing in most countries -, projections frequently postulate a twofold hypothesis with respect to the rate of growth of electricity capacity and demand. A preliminary figure, a good deal higher than the average for the past five or ten years - in the neighbourhood of 12 or 13 per cent yearly, for instance, - is assumed for the next few years, or, in other words, for the period needed to make up the deficit; and a second an lower figure, generally about 9 or 10 per cent, for the second half of the 1960-70 decade, when the demand which at present cannot be covered for want of equipment had been satisfied. In other words, the future is divided into two phases - one of accelerated growth during the transitional period and another of growth which might be termed normal or balanced. Examples of this type are afforded by Argentina, Chile and other countries. In many cases, too, the different regional growth rates are taken into account, in accordance with the different conditions prevailing.

5/ See ST/ECLA/CONF.7/L.1.11.

/The projections

The projections which have been described here as "second-stage", and in which electricity consumption is related to specific macro-economic variables, have also been employed with considerable frequency. Among them, as can be seen in the study cited, the projections embodied in plans formulated round about 1955 have generally proved over-optimistic, partly because the assumption adopted as to the rate of growth of the product was far from being borne out by experience, and, in consequence, neither were the resources contemplated in the programmes allocated to the electricity sector.

Stress should be laid on the differing degrees to which the methods analysed can be adapted to the economic structure of the country concerned. If, as is the case in Chile and Peru, industrial consumption accounts for three fourths of total electricity consumption, a much more detailed estimate must obviously be made of the realtion between demand in the electricity sector, the expansion of the manufacturing sector and the interdependence of this and the growth of the product. Such observations acquire special importance in cases like those of Argentina and Brazil, for example, where the countries in question intend to introduce considerable changes in their industrial structure, especially in the basic branches of heavy industry, over the short or medium term.

It is also important to emphasize the need to exclude both first - and second-stage projections those sectors of electricity demand whose growth depends upon extremely unpredictable external factors beyond the programmer's control. This applies to copper in Chile and to Cuba's sugar mills. Such a procedure is necessitated not only by methodological rationality but by economic facts. From the standpoint of the expansion of public utility capacity, an increase in demand for electricity on the part of producers in these branches of industry is not of direct importance (although it does indirectly bear upon the question because of its influence on the overall rate of development), since this additional demand will be satisfactorily covered by the producers themselves, on the basis of their own resources. Only when the generating and/or consumer centres concerned are interconnected with the public utility networks must the programmer of the latter take into account the direct impact of the expansion of these sectors of demand.

/In this

In this case, as in that of big industrial undertakings which do not generate their own power and are entirely or preponderantly dependent upon the public utility supply, a direct inquiry among these consumers must be recommended.

Lastly, it should be pointed out that in some Latin American countries methodological problems relating to projections of demand are of purely theoretical interest, since the voracity of demand is so disproportionate to the hopelessly inadequate supply that only restriction of the resources that can be allocated to investment (both as a whole and for the electricity sector) will effectively curb the expansion of the demand in question.

It is equally difficult and hazardous to attempt a reasonably realiable prediction of future demand in areas to which an electricity service is being carried for the first time or whose supply has been dependent in the past on inadequate installations.

The relative weight which must be given to the various results obtained for one and the same country by the application of the different methods of projecting demand for electricity obviously depends upon the special characteristics of the case under consideration. If the said demand has been repressed in the recent past by supply restrictions or by stagnation of the development process, or by a combination of both, little relative importance can attach to extrapolation of the historical trend. This would apply to Argentina and Chile, for example.

Second-stage methods, and especially those which relate demand for electricity to the development of manufacturing industry and the rise in the level of disposable income, must be the more carefully considered, the more radical is the structural change foreseen in the economic system and the more intensive the estimated future rate of industrialization. Argentina, Brazil and Venezuela constitute cases in point.

Direct or inquiry methods, in their turn, are the more necessary the greater the degree of aggregation of the industrial plant, especially in industries with a high input of electricity per unit of output. It is a well-known fact that statistical methods using a regression analysis are satisfactory when a numerous and homogeneous group or universe has to be dealt with. Such is not the case in Venezuela, as regards the demand for

/electricity of

electricity of the Caroní industrial complex, and therefore, in this as in other similar instances, a direct estimate of the probable consumption concerned, based on consultation of the interested companies, becomes necessary.

For a similar reason, in projections based on a regression analysis - as is the case with most of the type (a) and (b) methods - it is as well to exclude sectors of demand which are of great importance, but whose rates of expansion and/or electrification may be considered likely to differ from those of the rest of the economy. This procedure was followed, for example, in the projections of demand for electric power embodied in the official plans of Cuba (sugar), Chile (copper) and Venezuela (petroleum). It is the more justifiable inasmuch as these demands do not influence public utility expansion programmes, since the industries concerned generate their own electricity and interconnexion with public utility services is slight or non-existent.

When satisfactory statistical data are available, the analysis of demand should be carried out by geographical areas, in order, among other reasons, to furnish material that can be used in planning area development, apart from the reduction of probable margins of error which can be achieved by lowering the degree of aggregation of the base for the projection. This was done in the Argentina electricity study and in the expansion programme of ENDESA, in Chile.

In some programmes - especially those prepared by Electricité de France - two rates of increase of demand are generally adopted. The first and higher is assumed for the early years of the programme in view of the need to make up existing deficits, while the second and lower is postulated for the subsequent period. These figures are in the neighbourhood of 13 and 10 per cent respectively.

IV. ANALYSIS OF CHANGES IN THE LOAD FACTOR

The load factor is the most important of the parameters which help to characterize - although of course they do not unequivocally determine - the load diagram or demand function through time in a centre with a certain

/level of

level of consumption. The energy consumed over a specific period of time, which is the variable generally used in the different methods of projection, is the integral of the said demand function in the interval under consideration, and the load factor may be defined as the quotient of this integral and the product of the maximum value of the function multiplied by the given period of time, usually one year or 8 760 hours. Geometrically, it measures the ratio between the area contained by the demand curve and the time axis and the rectangle demarcated by the maximum value of the said demand curve and the time interval considered. If the time interval is excluded from this quotient, the result will give, instead of the load factor, what is generally termed operating or utilization time. Care must be taken that no ambiguity exists in respect of coefficients that are similar but relate to installed generating capacity instead of to maximum demand.

As has already been stated, projections as a rule are concerned with the figures for total energy consumption in the course of a year. Expansion plans, however, have to be formulated in terms of the capacity to be installed. Thus, it is necessary to assume a specific load factor and, subsequently a margin of reserve between the system's maximum demand and installed capacity, in order to formulate the corresponding plan for the expansion of generating plant and its distribution among the various sources of energy (thermal, hydroelectric, nuclear, etc.).

One possible hypothesis is to adopt a load factor for the near future equal to that existing at the moment when the projection is made. This procedure would seem to be quite reasonable, save in exceptional cases, since changes in the load factor come about fairly slowly, and very great variations cannot therefore be expected in the course of more or less short periods like those under consideration. Again, in the case of the Latin American countries, the assumption that for the next five or ten years the load factor will be much the same as at present or similar to the average for the last few years has the advantage of introducing some degree of reliability into the projections, since the trend is towards a slow increase in the load factor, mainly attributable to the progressive industrialization of their economies.

/Tables 3

Tables 3 and 4 include data on average values, standard deviations and coefficients of variation of the load factor for some Latin American electricity systems during the last twenty years. It will be seen that the changes take place relatively slowly and the coefficients of variation are comparatively low.

In the formulation of a hypothesis on the behaviour of the load factor during a future period of time, care must be taken to avoid the mistake of extrapolating results deriving from abnormal circumstances, if the aim is to eliminate the causes of that very abnormality. Thus, in the case of Greater Buenos Aires it would be erroneous to assume a load factor equal to or slightly greater than the present one, the relatively high value of which is due to restrictions of the service which result in the taking-up of slack in the load diagram and consequently in an increase in the value of the load factor. If the considerable installed capacity deficit were successfully eliminated in the course of the next few years by means of a high rate of investment, the load factor would in all likelihood substantially decrease.

Another factor of vital importance is the degree of interconnexion characterizing the system and the prospects for the incorporation of new networks in the future.

An electricity system has already been defined as a set of generating and consumer centres such that each of them has at least one link (transmission line) with the rest of the set. Each consumer centre, in its turn, is characterized by its own demand function and will therefore have its own specific load factor. It is an easy and intuitive process to prove mathematically that the demand function resulting from the sum of a finite number of individual functions - that is, what will ultimately be the load curve and/or diagram of the interconnected system - has a load factor which is always higher than the minimum individual factor and lower than the maximum and which is relatively nearer to the values for the consumer centres whose weight or importance within the system is greatest.

One way of measuring the advantages of interconnexion from the standpoint of consumption consists in determining the so-called coefficient of diversity between several load diagrams. This coefficient can be defined as the quotient

/Table 3

Table 3

AVERAGE VALUES AND COEFFICIENTS OF VARIATION OF THE LOAD FACTOR, 1937-58

System	Average value	Dispersion	Coefficient of variation %
Buenos Aires	0.528	0.0034	11.04
Córdoba	0.455	0.00186	9.48
Caràcas	0.506	0.0019	8.6
La Paz-Oruro	0.555	0.0009	5.4
Guayaquil	0.533	0.0016	7.5
Santiago	0.530	0.0004	3.77

Table 4

ENERGY AND DEMAND: AVERAGE VALUES AND DISPERSIONS OF THEIR RATES OF GROWTH, 1937-58

(Values in terms of annual percentages)

	Average value		Standard deviation	
	Energy a/	Maximum demand	Energy	Maximum demand
Montevideo	8.94	9.34	2.15	4.83
Buenos Aires	5.47	5.18	3.71	4.51
Santiago	4.58	4.23	2.70	4.91

a/ The "energy" values correspond to annual generation.

/of the

of the sum of the maximum demand of the various centres and the maximum value of the sum function. Intuitively, it measures the dispersion through time of the maximum loads of the individual centres.

It is usually assumed that the development of industry tends to increase the load factor owing to the greater regularity of electricity consumption in the manufacturing sector, which, moreover, uses power at times when household consumption is lower. A somewhat different opinion was expressed by the Netherlands Planning Office in its reply to the ECE's questionnaire in 1956. According to this source, an analysis of the data for 20 years leads to the conclusion that the operating time - that is apart from a constant of proportionality, the load factor - is approximately proportional to the fourth root of the number of consumers, which thus appears as the principal determinant variable. On the other hand, the effect of the volume of industrial production on the said parameter could not be precisely established.

/V. PROJECTIONS

V. PROJECTIONS AND PROGRAMMING FOR THE ELECTRICITY SECTOR AS PART OF OVERALL ECONOMIC DEVELOPMENT PROGRAMMING

It is clearly apparent from both the present study and other documents submitted by the secretariat to this Seminar that there should be a close relationship on the one hand, between projections of demand and programming of the expansion of supply within the electricity sector itself, in view of their interdependence, and, on the other, between both these activities and overall development programming.

Although no attempt will be made to enter upon an exhaustive analysis of the question, some aspects of that relationship should be pointed out which are of interest to those responsible for taking decisions in respect to the expansion of the electricity sector.

The allotment of resources is conditioned by the order of priority in an integrated economic development programme, within whose context the electricity sector should be placed.

Studies that make a general analysis of the economy and sectoral growth requirements in relation to a particular rate of increase for the gross product show the amount of capital that should be assigned to the individual sectors in accordance with technological capital productivity relations.

In this way a rough idea can be obtained of the definitive figures for capital formation in the different sectors, since these should be modified in accordance with technical production alternatives, practical possibilities of implementation, the time required for investments to mature, the resources needed to bring to completion investments in projects that are being executed, etc.

The projection of demand is the first step towards assessing the amount of resources required for electric power development, this being a preliminary estimate for comparing with the total resources of the economy and determining the possibility of obtaining funds.

In this respect, it should be pointed out that there are some structural relations between a country's total capital formation and the amount assigned for investment in the electricity sector. These relations should be carefully reviewed because they need to be adapted to the particular conditions

/prevailing in

prevailing in each country as regards, on the one hand, the current electricity deficit, the magnitude and period of the projection and the changes in production sites and, on the other, the national aggregate of possible sources of energy.

In his study, The Design of Development, Mr. Tinbergen refers to energy and transport as being the two most typical cases of the pehnomenon of complementarity in investment, which leaves the planner little room for making hard-and-fast decisions. In the case of transport and communications, the author points out that the relevant sectoral coefficient, i.e. investment in the sector as a proportion of total gross investment, has remained fairly constant, varying from 20 to 25 per cent in countries with both differing structures of production and consumption and different levels of development. For instance, the order of magnitude of the coefficient for the energy sector to judge by the experience of Latin America which is analysed in this paper and is corroborated by that of a number of European countries and of the United States, fluctuates between 10 and 15 per cent, electric energy usually constituting about two thirds of the total, i.e. 7 to 10 per cent.

However useful it may be for planners to possess some knowledge of these orders of magnitude, they should not be observed so strictly as to militate against the flexibility with which a programme should be prepared by the person responsible. Thus, in the particular case of electric energy, it should be remembered that its utilization as an intermediate good in the form of an input in the manufacturing and mining sectors constitutes little more than half total consumption. The remainder forms part of the vector of final demand, and its rate of growth is largely conditioned by decisions on the part of the energy supplier as regards supply and price. In other words, although the role of the income-elasticity of electric energy demand should not be overlooked, due consideration should also be given to the role of the price-elasticity, not only of energy, but of demand for the durable consumer goods with whose inventory and sales levels domestic energy consumption is so closely connected.

Even in the case of industrial consumption, complementarity has its limitations, particularly in the case of the technical processes that are

/intensive electricity

intensive electricity consumers - the intensiveness being generally measured by the number of kWh required per unit of weight or of value added - since they are often replaceable by processes that use other sources of energy. The price-elasticities of such processes are obviously high; this, apart from being a sign of the relative lack of inflexibility in the sectoral coefficient of investment, demonstrates the need for a rational policy, i.e. for tariff differentiation and analysis of demand curves with respect to the sale of energy to the industrial sector, in order to ensure optimum utilization of national resources by that sector.

It has already been pointed out that the allotment of resources for energy production should be proportionate not only to the corresponding allotment for industrial production but also to the estimates of foreseeable expenditure in those durable consumer goods or capital goods (housing) that are related to the welfare of the people.

This type of study is not common in Latin America, but is nonetheless urgently needed. It may happen, for instance, that production of durable household goods is expanded by means of different economic measures at a time when there is an acute energy deficit. The expansion aggravates the deficit, leads to an even greater shortage of energy for other activities and ties up savings in an activity of doubtful priority.

Another highly important aspect to bear in mind is that, given the relative amount of investment in the electricity sector, the selection of the best programme of projects and the establishment of an order of priority for these projects within the sector cannot be independent of general decisions on the amount and distribution of investment required for income to attain a certain rate of growth.

As regards this aspect, two very important problems have to be dealt with in programming the expansion of the electricity sector; one concerns the relationship between the hydroelectric and thermal capacities to be installed, and the second, the distribution of total expenditure among generating equipment, transmission and interconnexion lines and primary and secondary distribution networks.

The two technical alternatives for electric energy production which are important for adjusting the allotment of resources are thermal and

/hydraulic plants.

The method of financing may also play a part in determining the type of generation chosen. If a project can be financed by external resources on favourable terms as regards the rate of interest and amortization periods, it might be worth while to pay more at the outset, on the understanding that the saving in annual costs will offset the servicing of the loan, particularly if the fuel for operating the thermal plant has to be imported.

It is very difficult to explore possibilities in the abstract without reference to specific cases. But there is no doubt that for programming electric energy development, it is necessary to have a clear idea of the variables that affect each of the two systems and adopt a generating policy that would combine the different factors and thus lower the social costs.

The implementation period is occasionally a decisive factor in the choice of production techniques. From the economic standpoint, the longer it takes to carry out a project, the longer it will be before there are any returns on the capital invested in the different stages. This raises the cost, if the interest not produced by the capital during the period of execution is computed as part of the cost. Nonetheless, the operational economies that result from hydroelectric generation may compensate for the fact that the capital takes longer to yield returns, and clinch the question of the desirability of this type of generation.

It should be pointed out that when an electric energy development programme is in full process of execution, the supply of power will increase in the form of a discontinuous curve, but with minor jumps, since the project is implemented and the plant made ready for operation in such a way as to invalidate the objection concerning the waiting periods for electricity supplies, although it may still prevail in specific areas. Of course, if these comments are to be applicable, a programme must exist in which the successive projects and the various stages of the preliminary studies - draft project, project and execution - are combined clearly and effectively within the stipulated time-limits.

The establishment of the respective proportion of hydraulic and thermal generation in a programme for electric energy expansion naturally has its

/technical limitations.

technical limitations. The most obvious limitation is of course the lack of water. Conversely, even when there is an abundant supply of draft projects for hydroelectric plants that are easy of access and have a low unit cost, the need to guarantee the respective power generally entail a certain supplement of thermal power.

But even within these limitations there is scope for choice on the basis of purely economic considerations. The possibility of choice plays an important part in determining the total amount of investment in the sector, and therefore, the sectoral coefficient, owing to the difference between the capital intensity of each type of plant and the length of time needed for construction. Although the relation between the two intensities varies appreciably in accordance with specific circumstances, its distribution is asymmetrical, the cases in which the capital cost of a thermal plant exceeds that of a hydro plant being exceptional. Hydroelectric works, on the other hand, are characterized by practically no inputs of fuel at all and a level of labour productivity that is slightly higher than that in a thermal plant. Hence, this is a typical example of a choice between two techniques, one of which requires a larger unit input of capital but smaller inputs of all the other production factors.

Economic development theorists have repeatedly argued that, in the case of under-developed countries, there is an undue tendency, in dealing with this type of problem to decide in favour of the process that involves more capital formation. This is mainly because the structural disequilibria affecting the economic systems of such countries tend to widen the gap between market prices and intrinsic or equilibrium values, i.e. those whose consideration would lead to rational decisions and the best possible distribution and use of resources. Thus, for instance, it may be concluded from an analysis of these economies that so long as the rate of interest that prevails in the capital market for reproductive investment is lower than the assumed level of equilibrium, the level of wages - largely because of the political and social pressure of the trade unions - is higher than equilibrium value.[6/]

6/ With respect to the last point, the ravages of inflation in some Latin American countries may have led to a decline in the level of real wages which has brought them closer to equilibrium value.

/Both disequilibria

Both disequilibria have a coincident or cumulative effect on the above-mentioned problem of choice i.e. they tend to tip the balance in favour of the alternative with higher capital intensity and less current inputs. Hence, many economists believe that fictitious or book values should be used, since they would represent the intrinsic values of the different production factors in the economic system more adequately.

This point must be emphasized because it is of the greatest importance for Latin America, a region in which the disequilibrium in the level and structure of the whole gamut of rates of interest in certain economies affected by inflation has reached a point where the bank rate has often been many times lower than the rate of increase of prices, which means that the real rate of interest had a negative value.

Again, in some calculations relating to public investment the error is aggravated, since the rate adopted, instead of being that of bank interest on the capital market - which in itself would be lower than the equilibrium value -, is that at which international financing agencies lend funds, and which is still lower than the former. This error was pointed out in a study by the International Bank for Reconstruction and Development.7/

There is, however, a third distortion of the calculation which, in the case under discussion - that of the choice between hydroelectric and thermal power stations -, sometimes tends to offset, although only in part, the errors involved in the two disequilibria mentioned above. Reference is made to the foreign exchange rate adopted for the calculations in question, which is usually that in force in the financial markets. The rate in question is lower than the equilibrium value which would have to be taken for the purposes of analysing the impact of alternative programmes, and this on several accounts. From the macro-economic standpoint, it is common knowledge that the capacity to import constitutes one of the bottlenecks apt to be inherent in development programmes, for two fundamental reasons: in the first place, because of the disparity between the rates of growth of income and of the capacity to import; in the second place, because the flow of investment needed for the attainment of the desired

7/ See Cost of capital in the choice between hydro and thermal power, 1957.

/rate of

rate of growth necessitates an increase in the investment coefficient, with the consequent pressure on the capacity for external payment, since the import content of investment is higher than that of consumption even in those Latin American countries which have made most progress in the domestic manufacture of capital goods.

In contrast with this relative shortage of foreign exchange for development purposes, a tendency is observable on the part of Latin American Governments and central banks to stabilize the exchange rates for foreign currencies as far as possible even during periods of internal inflation, and this practice causes the disequilibrium referred to above.

In such circumstances, as the generation and transmission equipment for the provision of hydro power generally has a relatively lower import content[8/] than that of thermal projects, owing to the preponderance of the civil engineering works in the total expenditure, the third distortion just analysed helps to make the thermal project more attractive. Thus, the effect of the other two disequilibria on the rate of interest and the level of wages is partly counteracted.

Brief mention must now be made of the second problem noted above, i.e., that relating to the distribution of investment among the phases of generation, transmission and distribution of electric energy in a system.

Firstly, it should be pointed out that the thermal, hydroelectric and nuclear alternatives - and, within the first of these, the wide range of possibilities afforded by the use of different machinery according to the breadth and characteristics of the market, the supply and price of fuels, the available water supply, local conditions, etc. - differ from one another

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8/ It is difficult to give precise values in this connexion, although it could safely be stated in general terms that while the import content in thermal plants is a good deal higher than 50 per cent, it is below this level in hydroelectric projects. It must be borne in mind, however, that given the greater unit cost of the hydroelectric kilowatt, the absolute values of the respective foreign exchange requirements may often be similar for the two alternatives under consideration. What is more, the exchange rate which is lower than the equilibrium or intrinsic value may give rise to an unwarranted preference for foreign capital goods in cases where domestic production could compete with imports, by placing the former at a disadvantage as regards prices. This in its turn would help to aggravate the position with regard to the foreign exchange balance.

/only as

only as regards the generation of electricity. Once the electricity is fed into the network, its transmission and distribution display no distinctive features in relation to its origin. This means that the cost of transmission lines, given equal distances from the consumer centres, and that of distribution, given similar conditions in those centres, would be the same in every case.

In reality, it is preferable to include the costs of transmitting electricity with those of generating it, so that a clearly differentiated segment of investment may cover the whole of that required to despatch the high-tension power in question to the vicinity of the consumer areas, and enable the relative advantages of several solutions to be considered on more comparable bases.

This point was touched upon in the foregoing pages. As regards the electricity distribution system, it should be recalled that the investment required is by no means negligible. For densely populated urban centres it may represent amounts equivalent to those needed for the despatch of high tension power, while in rural districts - which have a low demographic, industrial and consumption density - its cost per kilowatt is raised by the length of the secondary transmission lines.

In this connexion it is most important to decide upon technical standards that, without of course affecting the safety of the service or of the consumers, will make possible lower investment through the judicious use of materials, tensions, etc.

It will have been noted that the allocation of resources is bound up with both the alternative forms of generation and the possibilities with respect to financing. The latter is one of the factors that most strongly influences electricity development, since the rapid growth of this sector's activity means that in Latin America as a whole installed capacity will need to be doubled within a few years (5 to 8), while at the same time, because electric power is a widely used input, its sale price will be a cost component in nearly all economic activities, and will consequently affect the general price level.

These and other considerations have led the governments in most countries to lay down regulations establishing rates which, even when they

/provide some

provide some return with respect to operation, do not permit an accumulation of profits sufficient to provide any appreciable contribution to the investment required to double generating capacity within a relatively short period. Consequently capital growth in the electricity sector is largely financed by funds from other sectors or from national savings as a whole.

This transfer of investment funds to the electricity sector is usually made by means of government budgets through direct state participation in the provision of the service.

However, experience has shown that domestic savings are insufficient to provide the capital formation of a country that wishes to develop at a rate faster than in the past, even though modest by comparison with the aspirations of the community; consequently foreign credit must be used for this purpose.

From a technical standpoint the electricity sector is well placed to finance part of its capital formation with external funds, which can be devoted mainly, in a direct or indirect form, to financing the proportion of investment required for imports (heavy machinery and equipment), while national savings can provide construction and other costs for domestically produced items.

However, it may also become necessary for foreign credit to pay for at least some of the local currency investment costs of electricity, especially in those countries where the deficit of installed capacity is so large that the expenditure required to eliminate it would endanger investment in other sectors.

Another basic aspect of the interdependence between programming in the electricity sector and general programming relates to the institutional and legal framework within which the expansion of the sector is planned, and to the rates policy governing the public electricity service. Although this question is analysed in greater detail in another secretariat study on sources of finance for electricity development,[9/] some comments are appropriate here.

9/ See ST/ECLA/CONF.7/L.1.30

/In order

In order to increase the rate of economic development the coefficient of investment must be increased without affecting the rational sectoral distribution of the total available resources. To attain this aim without restricting the population's levels of consumption, and to establish the necessary conditions for a gradual and steady increase in the coefficient of internal savings, it is usually assumed in development programmes that the contribution of foreign capital will provide the balance that cannot be financed internally during the transition period, until a level of internal savings has been reached that will alone suffice to maintain the required rate of development.[10/]

Consequently, within this framework, the size of the contribution in foreign capital depends on the rate of growth of the coefficient of domestic savings during this transition period. In this field, as in others, proper programming for the sector obviously requires that there will be no inconsistencies with the general assumptions of the programme.

For example, it would be illogical to establish, within the general economy of a development programme, premisses in the macroeconomic part with respect to the volume and form of the contribution of foreign capital or domestic private capital[11/] without at the same time ensuring means of access for such capital through administrative and legal provisions.

Thus it is necessary to adopt a definite policy with respect to the participation of private capital in electricity expansion within the framework of overall financing, taking into account both its present level and the level postulated for the future. If the decision is against using such sources for electricity expansion, steps must be taken to verify that the state enterprises or the organizations concerned can provide the funds required to carry the whole weight of the programme. This evaluation, in

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10/ This does not of course rule out the continuation of external financing to the extent considered desirable, even after this aim has been achieved, since to do so would make it possible to raise the target rate.

11/ It is hardly necessary to point out that there is no reason why these overall macroeconomic coefficients of investment should be attained in each sector, since they are based on averages of values that vary, sometimes considerably, between different sectors or different branches of the economy.

/turn, should

turn, should be in relation to the percentage of the national income represented by government expenditure (which in the western world is usually between 10 per cent and 33 per cent), and to the relevant items of investment and expenditure in the government budget.

It is particularly important to ensure an adequate flow of funds into such sectors of the economy as the electricity sector, in which demand increases much faster than revenue. In such cases, even if it is assumed that the net profit rate is reasonably high - and this is notoriously not the usual situation in electricity enterprises, whether state or private -, and that the coefficient of reinvestment on these profits is also high, it is highly unlikely that the resources produced within the sector in the way of net profits and amortization funds will be sufficient to ensure the expansion required for the balanced growth of the economy. In this connexion it should be noted that excessive autofinancing by means of a specific tax on the sale of power, for example, affects marginal costs, and consequently distorts the price structure and the process of selection by the consumer, and thus leads to a less than optimum use of resources.

Another way in which the structure of the electricity programme is closely linked with that of the general development programme relates to the scale of the engineering works and the order in which they are carried out. It has been rightly said that the programming of economic development basically implies the selection of a system of priorities through time. In other words, in the electricity sector, as in the rest of the economy, once a suitable portfolio of workable projects is available, the question is not to give any of them up, but rather to postpone some in favour of others.12/

With respect to scale, although there are many important aspects to consider, this paper can do no more than indicate the need to achieve the right balance between economies of scale on the one hand, and the flexibility

12/ Obviously the postponement for a long time of certain projects may well mean their eventual abandonment if technical advances or subsequent economic conditions give rise to new projects that can with advantage replace the original projects.

/of the

of the expansion programme, on the other. Like any other form of strategy adopted to deal with a comparatively uncertain future situation, a programme of this kind should be flexible enough to allow of changes in decisions taken with respect to the future if the behaviour of external factors is substantially different from the prospects on which the programme was based. This argument obviously militates against the execution of large-scale projects, whereas modern technology favours them in view of the considerable economies of scale.

The instability of Latin American economies makes it necessary to give due attention to this flexibility in programmes. Experience shows the close relationship between investments and the capacity for external payments, and the strong influence on the latter of variations in the terms of trade, particularly as a result of fluctuations in the prices of primary commodities on the world market.

If, for example, the capacity for external payments is restricted in order to maintain a balanced expansion of the economic system, there must be a reduction in investments with a relatively high import coefficient, such as electricity plants. If on the contrary total investment is reduced, and thus the rate of growth, maintaining the increase in the capacity to supply electricity at the rate originally planned would lead to an availability of means of production in excess of the demand.

The foregoing observation naturally does not apply when the capacity for external payments is reduced within the framework of intensive economic growth, or when by means of adequate supplementary financing of external requirements the additional payments can be made without noticeably affecting the medium-term balance of payments. In such cases there is no reason why an adverse balance on current account should slow down either the economy's growth rate or, consequently, the growth rate of the electricity service.

Thus far attention has been concentrated on the investments required to ensure the electricity supply and the effect of these investments on total national capital formation. But it is undeniable that in order to bring about the postulated demand, which as has been shown requires such large capital expenditure in equipment for the electricity industry, it is also necessary to ensure that the economy will be in a position to

/produce the

produce the necessary savings in those production or consumption sectors, other than the electricity sector, where the demand originates, and that the investments are made that will transform this potential demand into effective demand.

The reference here is not to ensuring consistency between investment in the electricity sector and investment in each of the other sectors, and in the economy as a whole. That is a matter of the general programming of investments and is beyond the scope of the present study. The specific question here is that portion of investment outside the electricity sector which conditions the consumption of electricity. It should be stressed that such investment is not automatically ensured once the sectoral allocation of funds has been made. Thus for the purposes under discussion, it will not suffice to see that the planned investment in railways, for example, is carried out, unless at the same time steps are taken to ensure that the electrification of the railway system will meet the postulated demand as planned with respect to volume, place and time. Similarly, it is of prime importance that the industrial inputs of electricity should become available, either through plant modernization or through the installation of the new processes and activities that have been planned. In the domestic consumption sector what is perhaps the basic strategic factor is the investment in housing including, in particular, electrical appliances for the home, that could result from a proper distribution of income.

Thus it may be useful to indicate an order of magnitude for ancillary or supplementary investments required for such purposes in sectors other than the electricity sector. Without entering into details that would be out of place here, it may be stated that in order to use the power generated by each kilowatt of installed capacity with a normal average degree of utilization, the investment in other industrial sectors will have to be twice, three times or even four times as much as that required in the electricity sector itself, and higher still in houses well equipped with the fruits of modern electrical advances.

Consequently it is appropriate to draw attention to the question of the distribution of the investments that might be described as "directed" and that are of great practical importance in the final stages of economic programming.

/As the

As the supply of electric power is an indispensible requirement for production, it can constitute an effective means of inducing desirable changes in the siting of industry. This question acquires special importance when it is necessary to deal with situations resulting from large concentrations of economic activity that result in imbalances and may result in high social costs for the community, although decentralization usually means a high initial investment in services.

Examples illustrating this are to be found in most Latin American countries, where there are a few thickly populated areas with a relatively high degree of industrial development and large areas whose links with the economic activity of the rest of the country are weak or non-existent.

One way of establishing the proper conditions for decentralization or the incorporation of new areas is to provide these areas with the basic social capital that produces cost economies and thus constitutes an attraction for the establishment of production. Investment in electric power is a typical example of such basic social capital which, if conditions are favourable and there is a potential demand, will make possible the expansion of associated secondary and tertiary activities.

In dealing with a problem of this nature two main determining factors are to be considered. The first is the decision to incorporate additional areas or to reduce the difference in the level of economic activity as between the various areas of a country; the second relates to the pressure on demand resulting from the existing localization of production, a pressure which for many reasons tends to strengthen the existing structure and thus to lead to the need for more public services in proportion to its growth.

These two factors compete for the funds intended for capital formation in the electric power sector, and since the second represents needs that are obvious because of their urgency, it usually has the most influence on the decisions taken. Thus long-distance transmission lines are provided to supply the industrialized centres, or else, when these centres are far from any hydroelectric source, thermal generation is installed, sometimes without regard to a general policy aimed at making the most profitable use of existing resources.

/Consequently, as

Consequently, as in transport programming, the programming of a country's electricity development should take account of the fact that the service is an effective means of bringing about a change in the geographical structure of production, and in this sense is an autonomous element; that is, within certain limits it can be independent of the projection of needs according to the present structure of production.

Another way of approaching this question relates to the period of the projection of electricity production requirements. If the basic considerations underlying the projection are of a short-term nature, the projection will certainly not contribute to structural change, whereas if the problem is studied from a long-term standpoint, and possible changes of the siting of production are considered, the projection of the capitalization requirements in the electricity sector may be completely different.

/Annex I

Annex I

PROJECTION FUNCTIONS FOR ELECTRICITY DEMAND

A suitable origin is taken for time n, and an endeavour is made to establish for electric energy demand E a projection formula of the type $E = f(n)$ that would be valid for a given system.

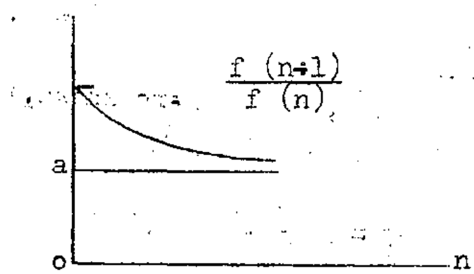
Formulas of the purely exponential type $E - E_o a^n$ have a constant rate of growth, and are therefore inadequate for describing those situations in which the rate of growth of demand is high to begin with - owing, for instance, to the removal of restrictions on supply or because the service in question is new and covers hitherto non-electrified areas - and then gradually diminishes until it reaches a certain level and remains fairly constant.

Potential formulas, such as that of Robinson and Daniel, $E = E_o \left(\frac{n}{a} + 1\right)^b$, make some allowance for this objection, since the rate of growth $f(n + 1)/f(n)$ is a decreasing function of n. There is, however, the grave drawback that the quotient in question tends to one, i.e. theoretically it would bring electricity demand to saturation point, a hypothesis which is hardly acceptable.

The ideal would be to find a formula $E = f(n)$ that would combine the virtues of both formulas:

a) $\frac{f(n+1)}{f(n)}$ should decrease with n

b) $\frac{f(n+1)}{f(n)}$ should tend towards a "normal" a for $n \to \infty$, i.e., for n in the "normal" period, f (n) should act as the exponent (constant annual cumulative growth).



/A formula

A formula with these properties would best describe the whole life of the system.

A mixed formula such as the following is therefore considered to be the most appropriate:

$$\boxed{E = A \left(\frac{n}{k} + 1\right)^x \quad a^n}$$

The starting point for the formula would be termed year 0.

It should be ascertained whether this formula complies with the requisite conditions as follows:

a) $\frac{f(n+1)}{f(n)} = \left(\frac{n+1+k}{n+k}\right)^x$. a decreases with $\underline{n}$. In fact, if x is positive:

$$\frac{dy}{dn} = x \cdot \left(\frac{n+1+k}{n+k}\right)^{x-1} x \frac{-1}{(n+k)^2} a < 0$$

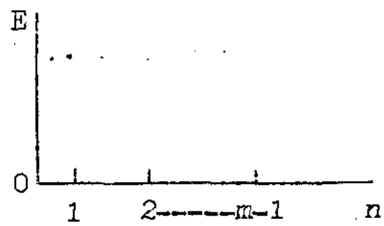
b) $$\lim_{n \to \infty} \frac{f(n+1)}{f(n)} = a$$

Both conditions are thus fulfilled.

Determination of parameters A, K, x, a:

The most rational way of determining the parameters of the formula is to take the points for energy demand obtained in previous years (known statistical data).

It may be assumed that one point is known and that the first known year is taken as the origin:



Value E_i is therefore known for

$i = 0, 1, \ldots\ldots, \quad m-1$

On the assumption that A, K, x and a are known, there will be a difference (residue) between the value calculated:

$$E_i^1 = A \left(\frac{i}{K} + 1\right)^x \cdot a^i$$

/and the

and the known value E_i:

$$E_i - E_i^1 = z_i$$

The principle of least squares requires that:

$$\sum_{i=o}^{m-1} z_i^2 \qquad (1)$$

shall be the minimum.

It is assumed that the values A_o, K_o, x_o and a_o have been found to be more or less satisfactory. On the basis of the data for a recent period, the principle of least squares will be used to revise these rough figures by quantities

$A = A_o + \alpha \qquad K = K_o + \beta \qquad x = x_o + \gamma \qquad a = a_o + \delta$

If the partial derivatives of a higher order are disregarded, the difference:

$$f\,(i, A, K, x, a) = A\,(\frac{i}{K} + 1)^x \cdot a^i = E_i - z_i$$

will be written as:

$$f\,(i, A_o, K_o, x_o, a_o) + \alpha \frac{\delta f}{\delta A_o} + \beta \frac{\delta f}{\delta K_o} + \gamma \frac{\delta f}{\delta x_o} + \delta \frac{\delta f}{\delta a_o} = E_i - z_i \qquad (2)$$

The terms of this equation are:

$$f\,(i, A_o, K_o, x_o, a_o) = A_o\,(\frac{i}{K_o} + 1)^{x_o}\, a_o^{\,i}$$

$$\frac{\delta f}{\delta A_o} = (\frac{i}{K_o} + 1)^{x_o}\, a_o^{\,i} = \lambda_i$$

$$\frac{\delta f}{\delta K_o} = A_o\, a_o^{\,i}\, x_o\, (\frac{i}{K_o} - 1)^{x_o - 1}\, (-\frac{i}{K_o^2}) = \Gamma_i$$

$$\frac{\delta f}{\delta x_o} = A_o\, a_o^{\,i}\, (\frac{i}{K_o} + 1)^{x_o}\, L\,(\frac{i}{K_o} + 1) = \nu_i$$

$$\frac{\delta f}{\delta a_o} = A_o\, (\frac{i}{K_o} + 1)^{x_o}\, i\, a_o^{\,i-1} = \pi_i$$

/If the

If the following is also put:

$$E_i - f\,(i,\ A_o,\ K_o,\ x_o,\ a_o) = \phi_i,$$

(2) gives:

$$z_i = \phi_i - \lambda_i \alpha - a - \Gamma_i \beta - \nu_i \gamma - \pi_i \delta$$

Expression (1) then becomes:

$$\sum_{i=0}^{m-1} (\lambda_i \alpha + \Gamma_i \beta + \nu_i \gamma + \pi_i \delta - \phi_i)^2$$

The partial derivatives with respect to
should be eliminated in order to obtain the least squares:

$$\begin{cases} \sum_{i=0}^{m-1} (\lambda_i \alpha + \Gamma_i \beta + \nu_i \gamma + \pi_i \delta - \phi_i)\,\lambda_i = 0 \\ \sum_{i=0}^{m-1} (\qquad\qquad\qquad\qquad)\,\Gamma_i = 0 \\ \sum_{i=0}^{m-1} (\qquad\qquad\qquad\qquad)\,\nu_i = 0 \\ \sum_{i=0}^{m-1} (\qquad\qquad\qquad\qquad)\,\pi_i = 0 \end{cases}$$

This system of normal equations is easily solved after the respective coefficients for $i = 0, 1, \ldots\ldots m-1$ have been tabulated.

Application

This method was used to work out, on the basis of data for 1955-59 the respective formulas for two countries - Uruguay and Venezuela - that differ widely in structure. The following equations were obtained:

Venezuela: $E = 2193\left(\frac{n}{117.3} + 1\right)^{44.47} \times 0.8001^n$

Uruguay : $E = 704\left(\frac{n}{74.37} + 1\right)^{24} \times 0.8047^n$

/Annex II

Annex II

RANK CORRELATION AND NON-PARAMETRIC INFERENCE

A normal (Gaussian) distribution of the population or of the errors is usually assumed in conventional statistical methods. This is undoubtedly a restrictive assumption. In the case of non-parametric inference this restrictive assumption is not made. It may be assumed for example, that the distribution of the error is symmetric but not necessarily normal.

On the whole these tests are not as powerful and a price has to be paid for this generalization.

Among the non-parametric statistical tests, rank correlation is found. It was originally motivated by the fact that some variables are not measurable so that the observations can only be ranked in an ordinal but not cardinal relationship. But it is often used even with measurable variables because the assumptions are not as rigorous and computation is much easier.

In rank correlation the following would, for instance be stated: if income is higher, savings are higher. No linear or exponential or any other particular shape for the functional relationship is assumed. The only conclusion would be that the trend was "upwards". The applicability of such correlations to this particular case is obvious. Consequently, the two methods used will be briefly explained below.

Two different approaches are used in order to measure the extent of rank correlation: Spearman's coefficient and Kendall's coefficient.

Spearman's coefficient

The input data is given in the form of two columns of numbers, each horizontal pair corresponding to one observation or experiment.

Let X_i, Y_i be the ranks (that is the integer numbers denoting their position as to the size of the number) of one of these two pairs. Then

$$d_i = X_i - Y_i$$

is defined and the sum of the squares of these differences between rank

/numbers is

numbers is compared with the expected value of this sum in the case that the variables were not related in any way.

If n is the number of observations (that is to say, the length of each one of the tables of variables that are being compared), the expected value of the sum of squares in the absence of any relationship is proved to be:

$$n(n^2-1)/6$$

It is important, although perhaps rather obvious, to note that this is not the maximum possible value of the sum of squares of rank differences. This maximum value will occur when there is perfect inverse correlation and it will be equal to

$$n(n^2-1)/3$$

If there is perfect direct correlation the sum of squares is nil.

For any given sum of squares of rank differences, Spearman's coefficient is defined by:

$$S = 1 - \frac{\text{Sum of squares of rank differences}}{\text{Expected value of the sum of square rank differences}}$$

substituting by the expression above:

$$S = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

M. G. Kendall has proved that S may be tested in a Student distribution.

$$t = S \cdot \left(\frac{n - 2}{1 - S^2}\right)^{1/2}$$

so that if Probability (t) is small, according to the tables of the Student distribution, independence between the two variables that are being analysed cannot be rejected and the value of S is declared as "not significant" according to the level of significance that has been chosen.

Kendall's coefficient

This coefficient refers to the number of order inversions in one of the variables supposing that the order is ordered. This number of inversions is denoted by s. Then the definition of Kendall's coefficient is:

/K =

$$K = \frac{2s}{n(n-1)}$$

where n, as before, represents the size of the sample, that is, the number of pairs of observations of the variables.

There are different ways of computing the number of order inversions in one variable after the other is ordered. Perhaps the simplest is as follows: consider the first element, that is the one that has rank 1, and its position in the row of elements where the number of order inversions is to be counted. Let D(1) and L(1) denote respectively the number of elements that are to the right and to the left of 1. The element itself is excluded so that, as a verification there must be

$$D(1) - L(1) = (n - 1)$$

The difference

$$h(1) = D(1) - L(1)$$

is taken and the same is done for the element with rank 2 after striking out the first one, so that $D(2) - L(2) = n - 2$.

It can be proved that the total number of order inversions is equal to the sum of all these differences, that is:

$$s = \sum_i h(i)$$

Like Spearman's coefficient, Kendall's is equal to one only if the correspondence between the two rankings is perfect and (-1) if the rankings are inverted.

It can be proved that the distribution of K tends to normality when n tends to infinity.

Although the two coefficients are different in conception and method of calculation they are very closely related. It can be proved that the product-moment correlation between them approaches $1 - n/4$ for large values of n.

Also for large values of the sample size the ratio S/K is in the neighbourhood of 3/2.

References:

M.G. Kendall: "The Advanced Theory of Statistics".

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