FOREWORD

I am convinced that a world policy for sustainable development could not be disjointed from a stronger world cooperation in all fields, economic, social and political, that involve international relations.

I am also convinced that a stronger world cooperation in such fields could not be disjointed from a strengthening of the international and supranational institutions. The United Nations must indeed assume a larger decisional role and proceed towards some kind of world development programming and planning.

However, to implement world development programming and planning, people need analytical tools of knowledge and understanding of the complex interactions at planetary scale.

The science and the technology of planning, based also on forecasting techniques, began - twenty or more years ago - a slow, hard journey towards the provision of instruments of analysis of planetary interactions: the so-called Global Models of development. The Club of Rome played a big role in this beginning.

It is a matter of a very gradual journey, with alternate success and failure, and often contrasted by the inertia, by the mistrusting, by the inevitable mistakes, by the scarce support on behalf of the decision-maker.

After the Brundtland Report, as a member of the Italian Government, I felt the obligation to take that journey again and I have commissioned a team of scholars of the Planning Studies Centre of Rome, directed by Professor Franco Archibugi, to determine the position of the state-of-the-art of world global modelling; and to explore the chances for relaunching with new up-to-date methods and more conscious and "intelligent" equipment the journey to world programming and planning.

The Report of the Centre, coordinated and edited by Professor Roberto Vacca, has just been achieved. And, waiting for an integral publishing, the Ministry has considered it useful to give in this pamphlet some highlights of it on the occasion of the Bergen Conference, promoted by the WCEU. Obviously it is up to Governments and international institutions to provide the institutional and decisional network, capable in the future of using such kinds of instrumentation.

Giorgio Ruffolo
Minister of Environment

OLD GLOBAL MODELS REVISITED AND NEW ONES ENVISAGED

Summary

INTRODUCTION

This paper* presents the main points of a 500 pages study commissioned by the Italian Ministry of Environment to the Planning Studies Centre of Rome (Centro di studi e piani economici, 1989).

The aim of the study was to supply a digest and a review of the mathematical socio-economic models of the world produced between 1971 and 1988; to analyse these models methodologically; to suggest future avenues for the construction of models – hopefully more adequate to forecast the world's future more reliably. (The Table of Contents of the study is given in the Appendix, in order to give a more detailed idea of the models analysed, of the theoretical and practical issues and of their treatment.)

In the past, one of the main obstacles was the scarce availability, quality and disaggregation of the data. Here we will describe briefly the basic features of the models examined. Then we will describe available techniques intended to permit a more rational building of scenarios and a more coherent structure of the mathematical, informational and discursive parts of a model. Substitution models will be discussed in more detail and, finally, we will present a new proposal for future research in the field.

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* This paper has been prepared by Roberto Vacca, coordinator of the "Global Development Models Study" (see Centro di studi e piani economici, 1989). The team was also composed of Valerio Franchina, Riccardo Le Pera, Roberto Nenzi, Carlo Sessa.

I. Global models

Global models – strictly speaking – are systems of mathematical equations used to describe economic, social, industrial, environmental mechanisms of our planet. The systems are introduced in electronic computers in order to check that the variables really behave like the corresponding factors in the real world and, then, to forecast future developments of the latter.

The abstract models, with which we are dealing here, can be described and classified in general terms only with respecL to their mathematical features. In fact, a given physical system can be represented in many different ways depending on which of its aspects we intend to analyse in a given context.

This observation suggests that the very gathering of input data has to be oriented towards the aim we have chosen. It is not reasonable to amass large quantities of data, if we haven't specified plans on how to use them. On the other hand, only if we have adequate data, we can attempt building a model.

Mathematical models, then, are made up of systems of equations apt to describe formally the functional dependences among variables which are relevant to analyse a process or a system.

Dynamic models analyse factors and interactions which vary in time. Static models analyse the dependences among variables in a given moment: as if they took a still photograph of a situation. Some econometric models, as Leontief's input/output matrices, belong to this class.

Models may be linear or non-linear. In the former we assume that the effects of the different factors are superimposed linearly. If a first factor, alone, produces effect E1 and a second factor produces effect E2, the simultaneous application of the two factors will produce the effect E1 + E2. If this is not the case, a linear model cannot be used to represent reality. A non-linear model will have to be used.

In open models some of the variables assume sequences of values predetermined externally. These are called exogenous variables. Their values may have been determined on the basis of the knowledge of deterministic situations in certain sectors, in given periods of time. For example, in certain models the population of an area may be chosen as an exogenous variable, because demographic projections appear to be credible over the span of time considered. It is reasonable to assume a constant development rate over 5 years. It would not be reasonable to assume that rate to be constant over 50 or 500 years.

In closed models, instead, sequences of values are determined from within the model for all variables. They are determined through multiple interactive feedback loops.

The first global model (Forrester, 1971) considered overall aggregated values on the whole world's scale for: population, capital invested in agriculture and in industry, pollution, reserves of non-renewable resources. Other models, instead, are more disaggregated. They subdivide the planet in 10 or 12 regions (sub-continents) and they analyse separately the variations of factors within each region. The values determined in a region may interact with those corresponding to the same or to other factors in other regions. For example, the availability of capital in an advanced country may produce investments in a less developed region geographically quite far removed. Global values then may be re-aggregated by totalling the results obtained in all the regions.

Disaggregated models may be more accurate. The increased accuracy though entails a much greater complexity (and cost) both in the building and in the usage of the model.

Models are useful if they really permit to represent faithfully the world, within limits of space, time and change of the relevant factors. If we prove that a model is faithful to reality, within the limits indicated, we have validated it. If we can show that the validation holds for future periods of time too, then the model has predictive value.

A model may have predictive value only if the environment depicted and the actual factors considered are deterministic. When we deal with complex situations, implicating vast numbers of elements and factors, the fluctuations of final values may depend on multiple mechanisms so that a probabilistic approach becomes necessary.

Stochastic models use the tools of the theory of probability to define future sequences of likely events and to assess the uncertainty affecting forecasts (in Greek stochos means 'conjecture').

Some systems in certain conditions may reach steady states. In other conditions they may reach unstable conditions from which a sudden collapse is experienced. Certain variables, then, undergo large variations which may bring some of them to zero or unleash oscillations of varying amplitude and frequency. It is quite difficult to determine whether the instability conditions presented by a mathematical model mirror instabilities inherent in the physical system – or are present only in the model and not in reality.

Forrester's model was based on the theory of dynamic systems. The more sophisticated model of Mesarovic and Pestel was based on the theory of multilevel hierarchical systems (Mesarovic, Macko, Takahara, 1970). Leontief's models are based on the use of intersectorial dependence matrices (Leontief, 1968 and 1977).

Composite models use simultaneously different procedures to attack different aspects of the analysis or different sectors of the physical system. For example the FUGI system, built at Osaka university, incorporates a section based on the theory of dynamic systems and another based on input/output matrices.

Logistic substitution models, based on the use of Volterra equations, are particularly simple and in certain cases have been found to be quite effective. They are described in the following section 4.

2. Theories, listings, printouts, discursive texts: their coherence

The possibility of constructing global models finds stringent limits in the maximum admissible complexity. The viewpoint according to which any model has to be designed with the scope in mind of supplying one or at most a few answers to well defined questions (Meadows, 1971), implies a fallacy. In fact, we cannot know beforehand which portions or which functional dependences within a large physical system may be ignored or may be postulated in order to supply certain results in a more limited environment.

Another vital question concerns the eventual impossibility of evaluating objectively: the listings of the programmes used by the model, the faithful correspondence of listings to theory, the printouts obtained, the coherence between theory, listings, printouts and discursive-literary description of the results supplied by the model. Clearly it makes no sense to produce models on which it is possible to form an opinion and to pass judgement only after years of full-time work.

So the very concepts and theories at the base of many global models are largely debatable from an epistemologic point of view. In this field we cannot define simple criteria adequate to assign a higher – conceptual or predictive – value to a given theory more than to a competing one.

The Mesarovic-Pestel model has been used to foresee much more accurately than the Marchetti-Nakicenovic (1979) logistic substitution model, at least the apportioning of the world's total energy between coal and natural gas. It would be rash, however, to contend as a consequence that 'the Mesarovic theory on hierarchical multilevel systems is found experimentally confirmed, while the theory at the basis of logistic substitution models is not confirmed. In fact, none of the models introduced so far can boast a massive and uninterrupted record of accurate prediction.

In any case, most global models are presented as structures incorporating:

- a theory defining the correspondence between the real world and the model;
- a computer programme which enables us to apply the theory automatically on a computer, using inputs from data bases and time series, either existing or organised for this purpose;
- the numeric or graphic results supplied by the operation of said programme;
- the explanatory texts or the popularisations intended to explain this process and to suggest interpretations of the results.

A parallel can then be established between a global model and a physical theory accompanied by a sequence of experiments which confirm it. But a marked difference between physical theories and global models is that with the latter we cannot carry out any experiments, we have to wait for certain events to take place (without influencing them) and we judge then how well they match the forecasts. These checks though are difficult and sometimes they are not very significant.

For us to be able to understand adequately the real structure and inner mechanisms of a global model, the connections between the 4 components indicators should be transparent and easy to analyse. This is not always true.

It is well known that it is difficult to fully understand computer programmes written by somebody else and not adequately documented. Hence the following prescriptions, which are to be interpreted as part of the integrated research programme outlined in the following Section 5:

1. the theory and the basic concepts of a global model must be described in a clear and complete fashion;
2. listings have to be published and possibly made available on disks. They should be written in well known languages and well documented;
3. results must be published in adequate detail, but refraining to reach a bulk so massive as to be unreadable;
4. validation must be explained and documented;
5. discursive descriptions must be correlated step by step with the simulation process.

We should watch closely the risk of misrepresenting the relationship between theory, computer programmes, results and the implications of their interpretations. The latter expression refers to statements and claims which are not expressed explicitly, but are implied by the formats and the choices made in presenting the model.

A case in point is the User's Manual for the Mesarovic-Pestel model (Mesarovic, 1975). This manual supplies in 50 pages the notions and procedures a user has to learn in order to employ the Mesarovic-Pestel model or to participate actively in a demonstration of it.

The introductory part of the manual illustrates in a very general way the basic features of the model:

- every policy has to be stated in explicit operational terms;
- a choice has to be made of indicators on which to base future judgement of the success or failure of selected strategies;
- the relationship between strategy and indicators must be clearly defined.

The manual explains, then, that the model will answer questions of the type "if ..., then ...?". The "if" part is defined by means of a scenario. Scenarios can be created using preprinted forms, possibly just considering one sector – as the oil situation or the food problem.

This choice given to the user contradicts the starting assumptions of the model, according to which global mechanisms depend critically on the interactions between levels and, at each level, between sectors.

The scenario relative to the world's oil situation is defined simply by any one among 3 choices offered for each of 10 factors. These are:

- assessment of potential resources;
- decrease of demand as a function of price;
- increase of supply as a function of price;
- yearly percent price increase;
- price upper limit;
- conservation policy;
- ratio between the price of oil and those of: consumer products, investment goods;
- desired rate of economic development;
- demographic policy;
- recycling of financial resources.

The number of possible choices is 3^{10}, that is 59.049. The user can also draw 3 diagrams: oil price variations, maximum export level from the Middle East as a function of time and rate of economic development of industrial countries. The maximum and minimum levels of these 3 diagrams, though, are predetermined.

Clearly the manual implies that users have available limitless choices, since 59,000 is a fairly large number. These choices, though, are not so wide ranging. The maximum price of oil, e.g., can go from 10.50 to 16.50 $/barrel (see the WAES choices in the following Section). Total potential oil reserves may range between 2 and 3 Terabarrels. The economic rate of development may range between 1 and 6%. But even apart from these constraints, there is no easy way to compare two scenarios chosen among the available 59,000.

If the user does not select any of the 3 choices, the model will assume an average value by default. So, even if a user does not understand the plausibility or the meaning of his choices, he can still obtain results employing the model. In other words it is implied that the model works as a previsional tool, even if actually it produces diagrams and tables without giving any indication of their plausibility and real meaning.

Part of the real problem here is that the links between theory, computer programmes, results and write-ups should be presented in different languages, at different levels according to the addressees and to the purpose of presentation.

The public at large should receive a cultural impact apt to spread more constructive habits and to create a public opinion in support of strategic decisions. This can be provided, without technical jargon, by well known and credible authors. The unanimity of the scientific community – which normally validates scientific theory and experiments – is not available for global models, due to the tyranny of time.

Presentation should be made at deeper levels for industrial and governmental decision makers, although quite often they are culturally lacking. So these presentations should be ultimately aimed at the advisors of decision makers.

3. Scenarios

From the above it appears that building large models representing: large systems or the economy, the industry, the society of a country – of a continent or of the globe, meets considerable difficulties:

- in determining which factors are relevant to the analysis
- in quantification, i.e. in determining which measurable variables may be used to evaluate which factors.

The choice of variables is a first important decision. It bears heavily upon the model's structure as well as the ways in which it can be put to use. There can be no formalised procedure to guide this selection: a first step is the formation of a conceptual image of the mechanisms governing the system we want to analyse. The more detailed the model, the harder is quantification.

We meet another considerable difficulty if we decide to examine the impact of international political choices on the economy and, vice versa, if we try to determine the possible impact of major economic events on political choices.

In order to anticipate complex future situations, we have to recur to scenarios. These are stories or tales concerning the future which are formulated on the basis of certain premises. Each scenario is a description of an alternative future, which might really happen in given hypotheses.

In a sense, writing scenarios is a prerequisite for the construction of any quantitative global model. In order to define structure and mechanisms of the model it is also necessary to specify what kind of answers we expect to receive.

The final reports on the results obtained from a quantitative model are also literary texts and, in a sense, they too constitute a scenario. In the previous section we have analysed the problem of coherence between theory, listings and final description.

Scenarios are often prepared by teams of experts. Recourse to probabilistic information processing, in general, is more fruitful than the use of Delphi procedures.

We tend to assume that just reading a scenario enables the reader to pinpoint the incoherent or absurd consequences of given assumptions. These should be discarded, then, and replaced with others hopefully leading to more sensible scenarios. But it is well known that the forecasts of experts frequently fail – especially in economics.

Each scenario should be used to focus on a given problem and to generate new solutions to it. A good scenario should single out one or more discontinuities – deducing from them reasonable outcomes.

Here we must face the problem of the exponential growth of alternatives. It makes no sense to try and deduce the consequences of a single assumption of discontinuity. After having reasoned out the consequences of a first hypothesis, we go on to other dilemmas. Each successive level of uncertainty generates at least two scenarios, corresponding to the two choices. If we assume that each choice may have only 2 outcomes and that we are looking at 10 choices, we should examine 2^{10} = 1,024 different sequences. If at each level we had 3 choices, on 10 levels we would have 3^{10} = 59,049 different sequences. It would be a major endeavor just to list all these sequences in order to decide which appear to be more plausible or interesting and which appear as absurd. An interesting example is WAES (Workshop on Alternate Energy Strategies) – (Wilson 1976, 1977) – published in 1976 by a group of experts from MIT, with the help of experts from industry and economics in all the industrial countries outside of the Communist world (including Iran, Mexico and Venezuela, who are major oil producers).

The aim of WAES was to disaggregate future energy demand, analysing the individual situations of each country as well as the reactions of the national experts to different hypotheses. The hope was to obtain an accurate and credible forecast of global energy demand, so adequate alternative energy strategies could be devised, e.g. to react to a continued oil crisis.

The study concluded that a serious lack of oil would be experienced between 1985 and 1995 with grievous consequences.

Initially, WAES gave the international experts a series of assumptions on the factors which could influence the future of the economy. These were:

1977-1985 FACTORS	VARIABLES		
Economic growth rate high (6%), low (3,5%)	high		low
Oil price high, constant, low (in $/barrel)	17.25	11.50	7.66
National economic policy	strong		timid

1985-2000 FACTORS	VARIABLES	
Economic growth rate high (6%), low (3%)	high	low
Oil price high, constant (in $/barrel)	17.25	11.50
Increase in oil reserves (G barrels/year)	20	10
OPEC production ceiling (M barrels/day)	45	40
Main energy source replacing oil	coal	nuclear

Clearly, the alternatives to be examined would have been 12 (2 x 3 x 2) for the period 1977-85 and 32 (2^5) for the period 1985-2000. The study, instead, considered only 5 for each of the two periods, considering the others not to be significant or realistic.

Consequently the scenarios produced were:

1977-1985	**A**	**B**	**C**	**D**	**E**
Economic growth	high	low	high	low	high
Oil price	17.25	17.25	11.50	11.50	7.66
National policy	strong	strong	strong	timid	timid

1985-2000	**C1**	**C2**	**C3**	**D7**	**D8**
Economic growth	high	high	low	low	low
Oil price	17.25	17.25	17.25	11.50	11.50
Increase of reserves	20	20	20	10	10
Production ceiling	45	45	45	40	40
Substitute source	coal	nuclear	coal	coal	nuclear

If we try to compare one with the other 5 scenarios in each of the two periods considered, we appreciate how difficult it is to form separate conceptual images of each.

Even harder is the task of evaluating for each scenario energy consumption disaggregated by primary source, type of utilisation in industry, transportation and domestic use.

One would tend to conclude that experts should make explicit the criteria and the procedures employed to process conceptually each projection. After these criteria have been discussed, analysed and agreed upon, they can be used mechanically to make explicit the implications of each scenario.

It would be interesting to examine the possibility of creating scenarios with the help of computerised expert systems. In fact, these systems have become available only in recent years. Up to the present there is no indication that they have been used for preparing scenarios, nor as tools to build global models.

Actually, there are past experiences indicating that this may be a fruitful endeavor. In the Seventies the PLATO system, in the form developed at the University of Illinois, supplied to users a vast database with worldwide demographic, socio-economic and industrial data. So the user could determine the outcome of sequences of assumptions, e.g. on different rates of development. The aim was the training of operators to process and evaluate socio-economic data and at the same time to make clear the less credible consequences of unlikely assumptions.

4. Logistic substitution models

Marchetti and Nakicenovic (1979) have suggested an interesting procedure which permits to avoid the considerable mathematical difficulties met if one tries to determine the constant parameters in Volterra equations and to find, then, their solutions.

This procedure generalises the Fisher-Pry Transform. The success in simplifying the elaboration of the model has been reached on the basis of observation of numerous concrete cases of time series describing the growth and the decline of portions of total demand for goods or services supplied by different sources. These processes take place formally according to the same laws according to which two or more biological species compete with each other.

The first case published by Marchetti and Nakicenovic is that of energy sources considered as competitors in the arena of energy production. The same authors have analysed many other similar cases (modes of transportation by road, rail, air, sea; steel production technologies, etc.).

Each competitor goes through three phases. The first is logistic growth, aiming at an asymptote which can be computed from the initial time series. Long before reaching the asymptote, though, growth slows down markedly.

So begins the second phase: a transition from growth to decline. The third phase – decline – follows again a logistic (just like growth) having the Volterra equation

$$N = A/(1 + e^{(Bt+C)})$$

where A is the asymptote, B and C are constants determining the position in time and the time constant of the curve. The values of A, B and C in general have no relationship to those valid in the growth phase.

Nakicenovic's procedure is based on the assumption that only one competitor at a time may be in the transition phase. So declining competitors proceed decreasing their share following the equations already established (on the basis of the time series recorded during the first part of the decline process).

The growth of competitors, which appeared last on the scene, proceeds again following Volterra equations.

The portion attributed to the competitor who is in the transition phase is determined as the difference between 100% and the sum of the other portions. After this competitor goes on from the transition phase to the decline phase and proceeds on it for a certain time, we can determine the formula of the corresponding decreasing logistic. At this point it will be possible to foresee the passage from growth to transition of the competitor who is still growing, but is the oldest of all.

The procedure has been applied successfully to the US and also to the world's energy sources.

Figure 1 shows the diagrams for the world's primary energy. The ordinates represent in a logarithmic scale the values of $F_i/(1-F_i)$, where F is the portion of the total attributed to source i. On the right hand side of the diagram are marked the corresponding values of F_i . Clearly if $F_i = 0.5$, then $F_i /(1-F_i) = 1$.

Notice that in 1850 wood supplied about 70% and coal about 30% of the world's primary energy. Oil reached 1% in 1878 and 10% just after 1920. Coal, after having reached a peak of 70% in 1925, proceeds in its transition to decline. Oil reached a peak of just under 50% in 1975 and begins to decline. According to this model, then, we will stop using oil for energy long before the wells are dry.

Natural gas begins its growth at the turn of the century and, according to the model, should peak at 70% around 2025. This forecast is based on the assumption that nuclear energy, which had reached a few percent in the early Seventies, will grow again following a logistic roughly parallel to those of coal, oil and gas.

Of course the model cannot produce any forecast concerning energy sources which are not yet commercially available. Nakicenovic has tried imaginatively to anticipate the growth of a new logistic which will reach 1% around the third decade of next century. This is shown in the figure to be again parallel to previous ones and is called SOLFUS. This alludes to two plausible new sources: solar photovoltaic (provided efficiency will grow markedly and installation costs will plummet) and nuclear fusion (provided the necessary breakthroughs are reached).

It is important to notice that the model equations can be built on the basis of empirical time series taken from any 30 years period between 1877 and 1977 – and they describe with considerable accuracy the shares of the various energy sources both before and after the period used as a database.

The thin curves in the figure represent actual shares recorded between 1850 and 1975. The thick curves represent the model equations. The differences between the ordinates of pairs of curves of the two types can be interpreted as noise.

We must face now the problem of deciding whether the model equations fit the empirical values adequately or not. Marchetti and Nakicenovic do not supply any discussion on this subject, which represents a shortcoming.

The fit of a curve plotted on the basis of an equation to certain experimental points is expressed by means of the standard error E_S, defined as the square root of the sum of squares of deviations S_i, divided by the number of empirical data and by their average V_m.

$$E_S = \sqrt{\sum s_i} /(n \cdot V_m)$$

In general standard errors larger than a few percent indicate a poor fit, or, perhaps, the presence of large noise. However, even if the standard error is frankly below 1%, we would have no guarantee that the logistic equation we have built is the only one apt to model the empirical data.

In fact, it may happen that infinite logistic curves (with asymptotes varying in a range of many orders of magnitude) fit the same sequence of empirical points with very small standard errors. In these cases it would be rash to contend that an equation has been found, which faithfully represents the process under study.

This difficulty is more serious when we analyse tne logistic growth of a single population instead of a substitution process. In that case, in fact, we can form no opinion on the value of the asymptote and on the time when it will be reached. In order to avoid illusory certainties, it is imperative to develop mathematical tools which allow us to judge whether the logistic equations we find are unique or not (see Vacca and Franchina, 1989).

In the case of substitution processes the difficulty is less severe because typically asymptotes are never reached. The figure shows that in 1920 we could have produced effective forecasts projected to 1970. Today, even admitting that the decline of wood and coal and the growth of natural gas will continue following the equations, we would face considerable uncertainties. It is hardly credible, in fact, that we can determine the growth equation of nuclear energy since worldwide it has reached only a few percent of the total. Consequently we can consider probable that the decline of oil will continue. However, it will proceed on quite different curves – depending on the actual growth curve (if any) of nuclear energy.

The curves of Figure 1 have been built on the basis of data up to 1977.

Figure 2 represents the raw data for the period 1960-1987 (from: "Energia/Economia - dati fattuali di base", ENEA, December 1983 and from "Rapporto sull'Energia, 1988" of ENI).

Notice that the decline of coal and the growth of natural gas have not taken place as foreseen by the substitution model. These 2 sources, instead, have represented almost constant shares starting in 1977. The share of coal has not been surpassed by that of gas, as foreseen for 1979. It does not appear credible that gas will overtake oil in 1990, as indicated in Fig. 1. In fact, in 1987 the share of gas was 20% against 38% of oil. The foreseen decline of oil has taken place, but the logistic curves determined for gas and coal on the basis of data up to 1977 have been found to differ widely from reality.

The weight attributed to minor sources has been too scarce. Adding up hydroelectric, nuclear and geothermal energy we get 12% in 1987, whereas these sources do not appear in Fig. l.

These factual observations indicate a very different general picture.

Finally we cannot rule out that, instead of nuclear, and in advance with respect to the advent of solar plus fusion in 2025, a new primary source will appear on the scene. For example the physical availability exists of exploiting about 1500 GW of hydroelectric power, with stations to be installed mainly in Asia, Africa and South America. Feasibility studies have been completed for these new ventures, but it is almost impossible to foresee whether the necessary investment capitals will be made available or whether the decision processes to implement the new systems will succeed.

In general, it appears to be reasonable to single out the cases of industrial sectors, goods and services which develop according to logistic curves and to incorporate the future time series as exogenous variables in future global models. It will be necessary to check, though, that the forecasts produced in each sector be coherent with those produced in other fields. For example primary energy produced will have to match energy consumption in industry, transportation, agriculture, domestic uses, etc.

As regards the discrepancies between the curves of Fig. 1 and 2, it may be argued that they represent values averaged out worldwide. Aggregation is very high – which could generate artificial regularities in a random fashion.

Let us look, then, at a single country, Italy, so we can appreciate how far the primary energy distribution among various sources differs from the world average in a single case. Figure 3 represents the situation for Italy (data from: S. Pierantoni and S. Piacentini in "ECOS", ENI group, N. 180, 1988, p. 51). We notice from Figure 3:

- the strong dependence on oil which peaked at 75% in 1973 and decreased in 1987 to 58%;
- share of natural gas slightly higher than world average – low share of coal (10% - against a world average of 28%);
- high shares of hydroelectric and geothermal offsetting the scarcity of nuclear.

Notice that recognising straight lines (which are interpreted as logistics when ordinate scale is logarithmic) in the Italian diagram is more difficult than in the world diagram. Even overlooking the incidental drop in the oil share between 1940 and 1945, the decline logistics for coal and hydroelectric (plus geothermal and nuclear) level off from 1973 to 1987. Finally recognizing a straight line in the gas curve would require an excessive dose of good will.

5. Integration of different methods for implementing global models

In general all global models are based on assumptions, have aims and use methodologies which differ markedly from each other. A system which integrates the advantages of different methods may appear as a hopeful device to obtain more reliable forecasts. The mathematical tools and formalisms, however, may not always be amenable to be combined. Moreover, the assumptions at the basis of the different models should also be compatible and coherent with each other. The higher the number of factors considered, the harder it is to check this coherence.

In some cases, when the nature of the interdependence between the different sectors admits it, we can build intersectorial input/output tables. Let us assume, for example, that certain sectors for which we have obtained forecasts by means of other mathematical methods are connected to each other through a production/consumption relationship. This may be the case also when the connection goes through intermediate factors. For example, the man-hours necessary for certain productions may be evaluated in terms of the available workforce, which in turn is related to the results of demographic projections. It will be possible, then, to introduce previsional data in the input/output tables.

If it is not possible to crossfoot the output of production sectors with the input of consumption sectors, it means that the forecasts were not coherent. Therefore, the forecasting methods used should be amended or discarded.

An attempt of this type has been made in France by Bureau d'Informations et de Previsions Economiques (BIPE), in the context of French national economic planning.

The problem attacked by BIPE was the assessment of changes which future technological innovations (still unknown) may produce in economic forecasts based on today's data. The BIPE method is based on two pillars – one of which is mathematical.

The first innovative idea was to reconsider the input/output matrices system. Rearranging the matrices may lead to the recognition of interdependences between technical and productive factors, so that the economic system may be decomposed in partial blocks. Now it becomes possible to produce separate forecasts for each block, which can be treated as a separate system, connected to the other blocks through a sequence, indicated as "chain of production and use".

The prevision of the effects of technological innovations is achieved by means of the introduction in the rows or columns of the matrices of coefficients determined on the basis of the opinion of experts. They should be familiar with the innovations which are in the various stages of research and development. They should also be able to assess their probabilities of success and rates of diffusion in the market. The latter time variable though, is not left completely to the intuition: an attempt is made to correlate it to other phenomena, of which it is easier to evaluate the time dependence. In this way it should be possible to determine the moment in time when the new matrix with the technical coefficients replaces the previous one. In this way a scenario is produced of the technological evolution of a sector.

Another problem which must be closely watched is the limited resolution of global models in space and in time. Global models, in fact, may be successful in forecasting the evolution of factors which change slowly and continuously, but not transient phenomena (which may take place in a very short time or in a small area). In other words, even if quite disaggregated, global models always deal with average values of the socio-economic systems they analyse. There are, however, instantaneous or localised phenomena which may have dire consequences, but are completely missed because of the very structure of the models.

A possible way to face this situation could be to supplement global macroscopic models with smaller dynamic models, which are more sensitive to large instantaneous signals. These lesser models representing large technological systems (the crisis of which may be fatal in high density areas – as energy, communications, transportation, waste removal, etc.) could furnish a useful function also in normal situations. In fact, they could supply running information on the systems efficiency helping to eliminate waste and inconsistencies.

5.1 Programmes for gathering and validating data

Clearly the validity of global models strongly depends on the validity of input data. However, not even in the more advanced nations adequate data are available to provide a sound basis for the analysis of interdependences among relevant socio-economic factors. When these data are indeed available, they are often gathered with non standardised classifications and accounting rules. In less developed countries the situation is much worse and often vital data (on income and on production) do not appear in the national accounts.

To build new and better global models, it is necessary to design and implement new and better programs of data gathering. Clearly, though, we cannot expect governments and international organisations to adopt programmes of this kind just on the behalf of global model builders.

It is certainly possible, however, to initiate actions aimed at improving the situation and linked with some existing international programmes. Over the long term – after a vast analysis and verification of present statistics, their standards and their compatibility – a programme of worldwide normalisation and standardisation of data should be started.

This implies a world census of census bureaus and of databases and an international quest for new solutions. Over the medium term a modest programme can be envisaged to improve quality and interpretation of data bases. It would be useful to include in national accounts also economic data relative to public services. These are overlooked or taken into account according to different rules. A second proposal is to aim towards an integration of economic and financial accounting with record keeping in terms of energy, environment, demography, and human resources (education, training) using a common standard based on physical rather than monetary units.

The task of international standardisation is always a hard one. Problems of cost, sovereignty and basic understanding are not to be belittled. A movement to improve the data situation is absolutely necessary if new attempts at global modelling are considered as desirable.

5.2 Theories, methods, instruments

The problem of mathematical tools will have to be attacked with special attention to innovation: expert systems, artificial intelligence.

Theoretical aspects of methodology will have to be re-thought. This does not entail a mere repetition of classic economic, demographic, financial and social analyses. A working group in charge of feasibility studies for new global models will have to review methodically a number of phenomena overlooked by traditional research. Invariants, positive correlatìons, interdependences, thresholds will have to investigated. Research should not take place at random. A rational conceptual framework will have to be built and its relationship (if not its isomorphism) to the real world should be checked continuously.

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Figures

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Fig. 2: Italian version, vol. 1 p. 88 (2.4)
Fig. 3: Italian version, vol. 1 p. 179 (13.2)

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APPENDIX

"GLOBAL DEVELOPMENT MODELS"
Report to the Italian Ministry for the Environment

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