EXPERIENCE WITH THE OPERATION OF AN ENERGY MODEL SET

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PREFACE

The Energy Group of the International Institute for Applied Systems Analysis (IIASA) has developed a set of models to describe the global energy system. This was first used in the late seventies to formulate two scenarios for global energy demand and supply for the period 1980-2030. The original model set consists of individual models and blocks of assumptions that are arranged in the form of a loop. The information flow between the elements of the set is deliberately not fully automated, so as to enhance human control of the modeling process. The model set operates iteratively, i.e., tentative assumptions made in one part of the set are subsequently modified in the light of results in other parts of the set until satisfactory consistency over the set as a whole is achieved. This paper reports on the conclusions arrived at by the author during his participation in the work of formulating the IIASA scenarios and subsequent applications of the model set. The main methodological conclusion is that there is an important trade-off between model detail and model usability, which calls for great care in the do not leave the terminal without writing, etc. design of both the model and the analysis to be undertaken.

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INTRODUCTION AND SUMMARY

Three years ago, IIASA's Energy Systems Program published the book *Energy in a Finite World* (Häfele et al., 1981). A major part of the book dealt with the description of a set of energy models and its application, i.e., the formulation of two scenarios for the development of the global energy system over the period 1980-2030. The models themselves and their input data have been extensively documented (see, e.g., Schrattenholzer (ed.), 1982) and the global scenarios have been presented on a number of occasions. The emphasis in those presentations was usually on various aspects of the model results. In contrast, this paper sets out to report on the experiences and conclusions arrived at by the author during his participation in the work formulating the IIASA scenarios and later on. Although the global scenarios were the result of a team effort, responsibility for the conclusions presented here rests solely with the author.

The paper begins by describing some of the deliberations that took place at the beginning of IIASA's global energy modeling activities and outlining a number of perspectives in which the work was seen as the results matured. The model set is then described with an emphasis on methodological aspects, taking

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into account both the purpose of the modeling and conclusions drawn from the modeling process. This is followed by some remarks on the operation of the model set and experience of applying it to other problems involving various geographical areas.

DESIGN CRITERIA FOR IIASA'S GLOBAL ENERGY MODEL

The main idea behind the development of the IIASA model set was to construct a tool with which plausible and consistent lines of development (scenarios) of the global energy system could be investigated and displayed. The size of the model was to be chosen in such a way as to allow just enough room for the formulation of the plausibility arguments for scenarios described. This meant, in practical terms, that the model set was to be comprehensive enough to provide for the formulation of a wide variety of scenarios, whilst at the same time being small enough to be comprehensible to a single person.

A few words about the variety of scenarios are necessary here. Clearly, the two main scenarios (High and Low) described in *Energy in a Finite World* did not fully exhaust the range of possible future developments. Rather, they were intended to span a range which covers what appeared to be a "maximum plausibility" path in the judgment of the IIASA group and a significant number of outside advisors. There was not too much concern about representing all or most possible future developments, first because it seemed impossible to make "everybody happy" and, second, because it was believed that the scenarios would also be useful for anyone in disagreement with some of the numbers contained therein, since the High and Low scenarios could be used as reference cases against which disagreements could be formulated and quantified. As expected, criticisms were raised of having considered too narrow a range of scenarios, but it is worth noting that no critique has gone so far as to present an alternative to the IIASA scenarios in any comparable form.

One important point that is crucial for an understanding of the IIASA study (and misconceptions here appear to be a continuing source of criticism) is the distinction between a scenario and a forecast. The difference between the two that is important here is that the global energy scenarios are very much the result of expert judgment. Thus, the dynamics relevant in the global modeling process are the changes of the outputs as a function of changes of the input assumptions. In contrast, the relevant part of a forecasting model mimics the dynamics of the real-world system. Therefore, the "art" of forecasting is to capture the system's dynamics as accurately as possible (this may involve a huge mathematical apparatus) whereas the "art" of scenario writing consists more of finding a good selection of variables in terms of which the scenario can be defined. In addition to be obvious qualitative criteria (such as comprehensiveness in spite of having only a small number of variables, logical consistency in the combination of variables, transparency, etc.), I want to stress the importance of one that might be called uniform comprehensiveness. Meeting this last objective should prevent, figuratively speaking, the third decimal place being provided in one part of the scenario when at the same time the very position of the decimal point is a variable controlled by a different part. Expressed in this way, the argument should sound convincing even to the most casual reader, but in its application to modeling it takes so many forms that it is both difficult to apply and easy to overlook.

One practical consideration in the design of the IIASA model set was that time and manpower constraints favored the use of existing, albeit modified models. This turned out to imply no particular shortcomings – since the models selected were adaptable enough to serve the purpose – but it explains some of the differences in style of the various parts of the model set.

THE IIASA MODEL SET

A schematic description of the model set and the logical connections between its parts is given in Figure 1. The basic structure of the model set is that of a loop. Accordingly, the model set was operated iteratively, i.e., preliminary assumptions made in one place were later changed as consequence of model results in other parts of the loop. This process was continued until satisfactory consistency within the whole model set was achieved.

The model set was applied to seven world regions (see Figure 2), the major part of the set (those elements above the dashed line in Figure 1) being applied to each region. The seven regions were linked by a procedure that established a global balance between primary energy flows (represented by the box below the dashed line in Figure 1).

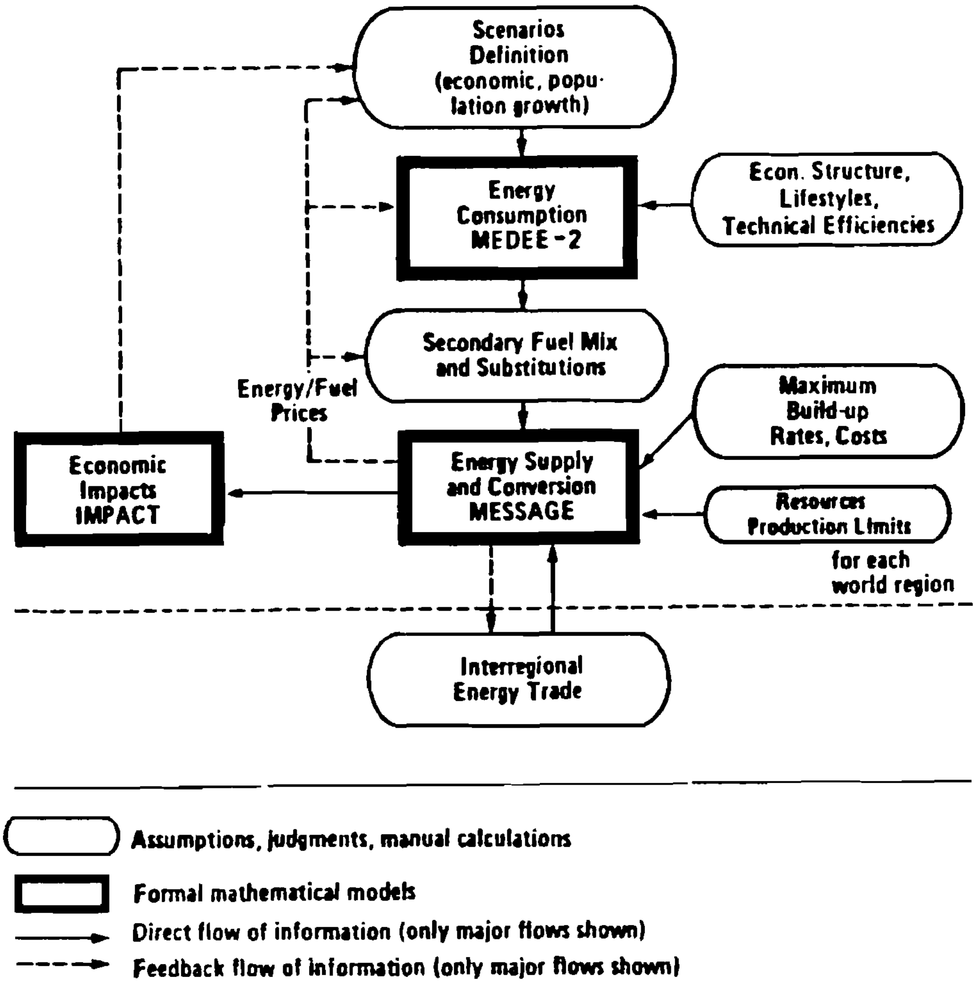
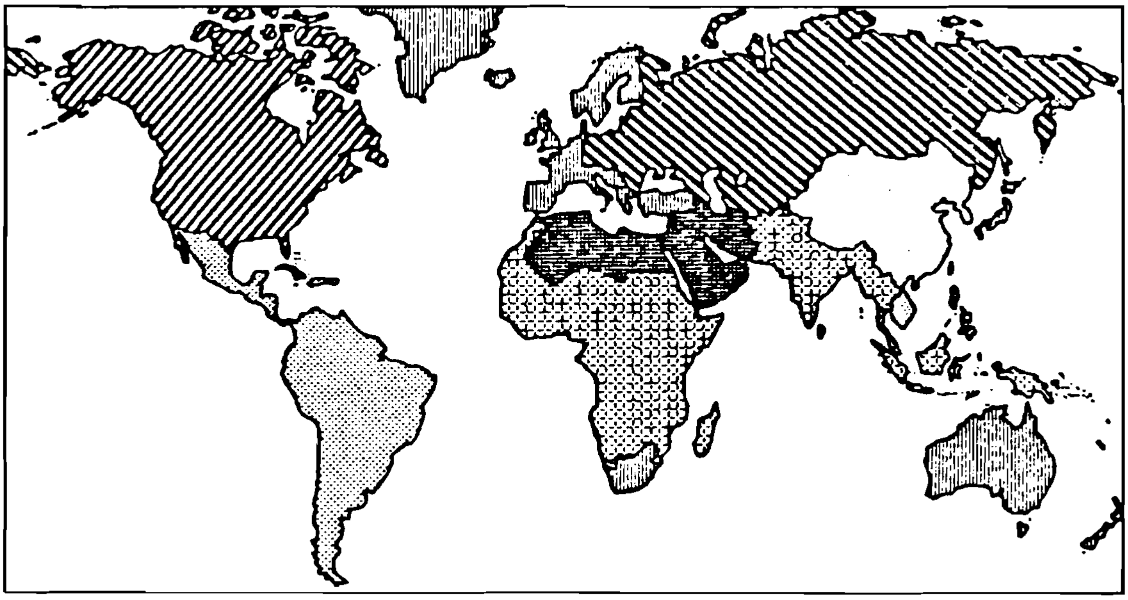


Figure 1. Schematic Description of the Model Set.



▨	Region I	(NA) North America
▧	Region II	(SU/EE) Soviet Union and Eastern Europe
▥	Region III	(WE/JANZ) Western Europe, Japan, Australia, New Zealand, S. Africa, and Israel
░	Region IV	(LA) Latin America
▦	Region V	(Af/SEA) Africa (except Northern Africa and S. Africa), South and Southeast Asia
▩	Region VI	(ME/NAf) Middle East and Northern Africa
□	Region VII	(C/CPA) China and Centrally Planned Asian Economies

Figure 2. The IIASA World Regions.

The operational starting point of the model loop was the definition of economic scenarios (see the top box in Figure 1). The outputs of this procedure are economic activity (represented by GDP) and population development for all seven world regions for the year 1980-2030. These results are very much judgmental, but the degree of arbitrariness was constrained by qualitative rules, e.g., restricting the differences between economic growth rates in the different world regions, requiring judgmental consistency with historical developments and with model results for the whole set, etc.

The economic growth projections are a major input to the energy consumption model MEDEE-2. Other groups of input data for this model define, e.g., the structure of the economy (the disaggregation of GDP into economic sectors), lifestyle (amount of dwelling space, room temperature, average daily traveling distance, etc.), and energy intensities of production processes. Thus MEDEE-2 is a model of physical energy flows – in contrast to an econometric demand model, which calculates demand as a function of GDP, prices, and elasticities. The reason for choosing this particular approach was again the specific purpose of the modeling, which involved a time horizon that was considered too long for the more "conventional" approach. A general argument may serve to support this point. If one wants to know the position of some particle p at a given time t in the future, there are two distinctly different ways of proceeding. The first is to take the initial position and velocity of p and make a straightforward extrapolation. The second possible approach starts with the assumption that time t is too far in the future for the initial position and velocity to be of much predictive help. This problem description is simple enough, and one can easily think of real-world problems that clearly fall into one or other of the categories. A much more tricky problem is to decide where to separate the two situations if one is given an initial location of p and asked to estimate the new positions at several points of time in the future. For the specific problem of projecting future energy demand, the method chosen by the IIASA groups follows essentially the second approach, i.e., physical factors other than current energy demand and elasticities (corresponding to the particle's velocity in the illustration above) were used to derive future energy demand. This procedure certainly did not go unquestioned by those who favored the first approach. Consequently (and this was more than a mere compromise), elasticities were calculated *a posteriori* , thus serving as another consistency check and maintaining a means of communication with the adherents of the "classical" approach.

The results of MEDEE-2, which are final energy projections for the period studied, are subsequently converted into time series of secondary energy demands. Since some of the final energy demand is calculated in terms of substitutable fuels, various assumptions on the fuel mix and on the dynamics of interfuel substitution were required in order to perform the conversions.

Secondary energy projections, in turn, are major inputs to the energy supply model MESSAGE-I, a dynamic linear programming model that minimizes total costs of energy supply for each world region over the given period. Although future costs are somewhat easier to project than future prices, one may ask why the role of prices was neglected in one place (viz., the demand model) when at the same time costs were allowed to play a crucial role in another place (the supply model). There are several answers to this question. The most important one is that the determination of a feasible solution for the supply model was more important for the scenarios than the exact location of the optimal solution within the set of feasible points. This is readily understandable when one looks at the setting in which the IIASA study was initiated. At that time (around 1977) serious questions were raised (see, e.g., the Workshop on Alternative Energy Stragegies' report on global energy prospects, 1985-2000) as to whether the global energy demand could be met at all in the decades to come. Accordingly, many contemporary expectations – about both supply and demand – had to be stretched in order to arrive at a solution at all. Thus, constraints on the buildup of new technologies and on the rates of utilization of primary energy sources were just pushed up high enough to overlap with pushed-down demand projections, leaving very little room for optimization. Another argument for using a linear programming model was the relative familiarity of analysts with this method worldwide, which made it easier for the IIASA group to disseminate the model results.

The box labeled "Interregional Energy Trade" in Figure 1 refers to a procedure which, at that time (around 1979), had not yet been developed into a formal model. It consisted of a set of rules for standardized hand calculations, with the largest part dealing with a global balance in oil trade. Thus it was connected with all seven world regional supply models. This connection was two-way: information about a region's oil import requirements (or export potential) went into the balancing procedure, and information on the availability of (or demand for) crude oil went into the seven regional supply models. The scenario variables determining the outcome of the balancing procedure in terms of prices and quantities traded between regions are the short-term and long-term export strategies of the oil-exporting countries as well as assumptions about quantities and costs of oil substitution in the importing regions.

The IMPACT model of the economic impact of energy supply strategies is fed by the output of the supply model. It is a dynamic input-output model with particular emphasis on energy activities. It calculates direct investments in the energy sector and indirect investments in other industrial sectors that deliver products to the energy sector, as well as the requirements for other principal resources like water, land, and manpower. One aim in applying the IMPACT model was to use its results to judge whether the increased overall costs of energy could be carried by the economies in question in the future. It turned out, however, that the results were less conclusive than expected because the energy system is a significant but still relatively small part of the whole economy, so that the feedback from the small energy sector is much harder to assess than the direct impact that goes the other way. Nonetheless, the IMPACT results on the magnitude and structure of direct and indirect investments in the energy sector remain an important part of the global energy scenarios.

OPERATING EXPERIENCE WITH THE MODEL SET

The most important feature of the operation of the model loop was the frequent human interaction with the model, which controlled each information flow between the elements of the model set. Although this lack of complete automation was considered a shortcoming to begin with, it was felt later that such a setup was actually more appropriate for the desired goal, the generation of plausible scenarios. A once-through operation would certainly have led more smoothly to results but often at the expense of blurring the path between inputs and outputs, whereas the presence of a larger number of check points made it easier to assess the validity of the results and to gain insights into the dynamics of the system.

Further experience with the IIASA model set was gained during its application to other energy systems, each of which included at least one of two different ways of using the model set. The first was to use the model set or some of its parts as a tool to be applied to a new problem. The second approach used the global scenarios to provide a consistency check on energy scenarios for geographical regions or countries (that lie within a particular IIASA world region), by trying to fit such energy scenarios plausibly into the result for a world region that is, in turn, a part of a globally consistent picture. Both types of application were combined in a study for the European Community (Sassin et al., 1983) and in the development of an energy supply model for Austria (Schrattenholzer, 1979).

The general problem in applying a model that has been developed for one specific purpose for a different one is that the new problem usually has peculiarities that need individual treatment. Building an "all-purpose" model to begin with is no solution, first, for fairly obvious economic reasons and, second, because a model can in fact be too big for a given purpose – as I will argue now.

The eventual size of any model is necessarily a compromise between accuracy on the one hand and clarity on the other, the first objective calling for larger models and the second for smaller ones. Unfortunately, the second objective seems to be frequently neglected by modelers. This is somewhat surprising in view of the sheer practicality of at least starting small. In my view, the correct answer to questions about model size should be "as small as possible", i.e., one should construct the smallest possible version that still gives a reliable and relevant answer to the problem modeled. My preferred way of proceeding is to divide the original problem into parts and then to start with a simpler subproblem and the simplest model form that will yield results for the subproblems. Adding one subproblem at a time, the model should then be expanded step by step. Clearly, this procedure presupposes that there *is* a problem or a question to begin with. (Frequently there is no such starting point – at least none that is visible in the model description.)

The recommended stepwise procedure is particularly useful if the problem to be modeled is posed by a decision maker or if policy recommendations are to be derived from model results. In this case it is usually unrealistic to expect final model runs to be understood in isolation by the "customers" (and thus to have any impact). Rather, the decision makers should be permanently involved and clearly understand each stage of the modeling process in an active sense; in other words they should know *why* the model yields particular results. (preemptive answers to the question "why?" are rarely found in published descriptions of model results.)

How does the IIASA modeling process look in the light of these recommendations? I have described the underlying purpose of the modeling in some detail, but how about the questions posed by the decision makers? There were (and still are) no decision makers at the global level. On the one hand this is somewhat unfortunate because a variety of assumptions (such as a certain degree of international cooperation) had to replace decisions. On the other hand, it was perhaps lucky because it was impossible to make a mistake in this regard. Since I attribute so much importance to the interaction with decision makers, I conclude that the absence of this deficiency contributed significantly to the success of the IIASA scenarios.

CONCLUDING REMARKS

Although I have used the IIASA model set to illustrate some methodological and procedural ideas about modeling, my conclusions have been influenced by a significantly larger number of encounters with modeling activities. My most general conclusion is that it is vital to clearly specify the modeling aim before starting the process. I am convinced that adherence to this principle can preempt several questions that would otherwise arise during the modeling exercise. These questions primarily concern the eventual shape of the model, and most importantly its size. An important side effect of proceeding in this way could be better communication between the modelers and the "outside world", including decision makers, peer groups, and the interested public. All of these audiences would have an easier time trying to understand the modeler's concerns if the models and their results were described as answers to the specific questions raised in the statement of modeling aims.

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