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Scenario Writing: One Component of a Systems Approach to Energy/Environment Management

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SCENARIO WRITING: ONE COMPONENT OF A SYSTEMS APPROACH TO ENERGY/ENVIRONMENT MANAGEMENT

W.K. Foell

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Preface

This report is one of a series describing a multidisciplinary multinational IIASA research study on Management of Energy/Environment Systems. The primary objective of the research is the development of quantitative tools for energy and environment policy design and analysis--or, in a broader sense, the development of a coherent, realistic approach to energy/environment management. Particular attention is being devoted to the design and use of these tools at the regional level. The outputs of this research program include concepts, applied methodologies, and case studies. During 1975, case studies were emphasized; they focused on three greatly differing regions, namely, the German Democratic Republic, the Rhône-Alpes region in southern France, and the state of Wisconsin in the U.S.A. The IIASA research was conducted within a network of collaborating institutions composed of the Institut für Energetik, Leipzig; the Institut Économique et Juridique de l'Énergie, Grenoble; and the University of Wisconsin, Madison.

Other publications on the management of energy/environment systems are listed in the Appendix at the end of this report.

Wesley K. Foell

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Summary

The primary purpose of this paper is to describe the concept and process of writing alternative energy/environmental futures (scenarios) for the three regions considered in the IIASA research program on Management of Energy/Environment Systems. The paper describes 1) the objective of the writing of the alternative futures, 2) the basis of the organization, 3) the procedures by which components of the futures are chosen and structured, 4) a format for presentation of the results, and 5) a possible procedure by which they can be embedded into a decision or policy framework in a useful and constructive manner. Although the three regions for which the alternative futures have been written are very different in their socio-economic, geographic, and technological nature or structure, an attempt has been made to apply a consistent approach for choosing and writing alternative futures. This paper is meant to provide that framework as a prelude to the actual description of the futures in a subsequent report. It describes only one component of the overall research process of the Energy/Environment study.

Scenario Writing: One Component of a Systems Approach to Energy/Environment Management

The primary purpose of this paper is to describe the concept and process of writing alternative energy/environmental futures (scenarios) for the three regions considered in the IIASA research program on Management of Energy/Environment Systems[1]. The regions are Bezirk X, a composite region in the German Democratic Republic; Rhone Alpes (France); and the state of Wisconsin (U.S.A.). The paper describes: 1) the objective of writing the alternative futures; 2) the basis of the organization; 3) the procedures by which components of the futures are chosen and structured; 4) a format for presentation of the results; and 5) a possible procedure by which they can be embedded into a decision or policy framework in a useful and constructive manner. Although the three regions for which the alternative futures have been written are very different in their socio-economic, geographic, and technological nature or structure, an attempt has been made to apply a consistent approach for choosing and writing alternative futures. This paper is meant to provide that framework as a prelude to the actual description of the futures[2].

I. OBJECTIVES OF WRITING OF ALTERNATIVE ENERGY/ENVIRONMENT FUTURES

In their simplest form, the alternative futures written for the IIASA research project on Energy/Environmental Management may be considered the result of the sustained efforts of a multidisciplinary and multinational group of individuals trying their best to imagine what the energy/environmental characteristics of three regions in the world could be like during the next fifty years. To express this process in more sophisticated terminology, (that warmly espoused by the proponents of such endeavours as "technology assessment", "technology forecasting", "applied systems analysis", and others), the process is one of "scenario writing" with the aid of the construction of "alternative futures" for generating additional scenarios. These methodological devices have been chosen here because of their particular value in the study and evaluation of the interaction of complex and/or uncertain factors.

In a strict sense, the term "alternative futures" better describes the products of our writing efforts than does the term "scenarios". Scenarios are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points. In general they answer two types of questions: (1) "Precisely how might some hypothetical situations come about, step by step?", and (2) "What alternatives exist for each actor at each step for preventing, diverting, or facilitating the process?". Scenarios are much closer in nature to the plot of a stage play. Alternative futures place much more emphasis on setting forth and discussing criteria for the systematic comparison of various alternative policies or alternative combinations of assumptions and objectives. They place less emphasis on the study of the evolution of a system. Nevertheless, for the remainder of this paper and in our work in general, we shall use the generally accepted term "scenarios" to describe our work.

Broadly described, both scenario building and the writing of alternative futures are a detailed examination of the likelihood and consequences of alternative assumptions about the future. With these sets of futures, one may see better what is to be avoided or facilitated and hopefully may derive a useful perspective on the kinds of decisions that may be necessary and the points in time after which various decision branches will also have been passed.

In more explicit terms, the primary objectives of our scenario writing are:

(1) To illuminate significant structural differences or similarities between the energy/environmental characteristics of the three regions.

(2) To describe the sensitivity of energy usage and environmental impact to the natural, socio-economic, and technical infrastructure of a region.

(3) To identify and investigate energy-related limits of the development or evolution of the human enterprise in the regions.

(4) To describe and analyze the consequences of a specific energy/environmental policy option.

The greatest value of writing these alternative futures may be their catalytic contribution toward stretching the imagination and inducing fresh thinking. The required effort will be worthwhile if it simply serves to pose previously unconsidered questions and leads to a searching review of established assumptions and interpretations, or alternatively, if the process points towards unexplored opportunities. It must be stressed that these futures should in no way be considered as forecasts.

II. THE CHOICE OF POLICY ISSUES FOR STUDY

A. Time Horizon of Alternative Futures

A key consideration in any scenario writing effort is the time period under consideration. The objectives of this research project are related primarily to strategic rather than tactical or operational considerations in energy/environmental system management. In this sense the research does not have as its goal improved methods for scheduling of power plant operations, on-line monitoring of pollution concentrations, allocation of energy resources during periods of temporary shortage (e.g. during the winter fuel oil scare in the U.S.A.), description of detailed fuel distribution patterns through a marketing system, etc. The primary goal can perhaps best be described as one of mid- to long-range planning and policy analysis, spanning a time period covering approximately 5-50 years in the future. By avoiding the next five years, we have spared ourselves the necessity of worrying about detailed operations of the system today and in the immediate future, but yet have chosen a time period close enough that today's decision makers and institutions are focusing on it explicitly and intently. Thus our scenarios should not be a completely academic exercise, divorced from relevant policy considerations. At the other limit, the choice of a 50 year time horizon allows our more speculative brain cells some room for maneuvering; it also allows for some major changes in technology as well as the possibility of significant restructuring or evolution of the infrastructure of socio-economic activities.

We are completely aware of our courage (or foolhardiness) in writing scenarios which claim to have some relevance in the near term (a time point at which we must satisfy the hard-nosed operations-oriented analyst or engineer) but also over the period of several decades into the future (when we open ourselves to the rhetorical attacks of the dreamy or wild-eyed futurist who shames us for our lack of vision).

B. Criteria and Procedures for Choosing the Policy Issues

The policy issues were chosen on the basis of two criteria: (1) the issue had to be of special interest to at least one of the regions and of at least general interest to the other two regions; and (2) the issue had to have sufficient focus and data that it could be approached in at least a semi-quantitative manner through the use of methodologies available to the IIASA research team.

The procedure for choosing policy issues satisfying the above criteria was an iterative one beginning with discussions with the collaborating institutes in each of the three regions. After identification of several issues, these were explored by the core research team at IIASA to see if they could be approached within the time-frame of the research project and by individuals who would be participating in that effort. After general decisions were made regarding these policy issues and what types and classes of scenarios would help illuminate some of the important questions within these specific policy frameworks, some months were spent gathering data and developing relationships with which to describe the alternative futures. In the last stages of research, it must be admitted that limitations of time and resources were the most important factors in the process of converging to the small number of policy issues and alternative futures finally studied.

The policy areas chosen for study as a result of the process described above are described in the following section. They are organized according to that part of the energy/environment system with which they have the closest relationship, although it is obvious that in reality many of the policy issues cut across several parts or all of the system. However for purposes of discussion and organization it is convenient to link them to one component as a starting point.

C. The Issues

1. Urban Settlements

The structure of the human settlement and, in particular, of urban settlements, plays a major role in determining man's use of energy and the nature of its influence upon both the man - made and the natural environment. Urbanization, as a by-product of and in combination with industrialization, is to a large part responsible in the industrialized countries for excessive concentrations of wastes with which man must cope. Many of these wastes are directly or indirectly energy-related. The environmental impacts which accompany man's use of energy would appear to be a function of the design of human areas, of their locations and sizes within a region, and of the embedding of energy production and consumption devices within them. Each of the three regions studied showed a strong interest in investigating these interrelationships, with the goal of improving their design and planning of human settlements. The following areas of interest can be specifically named:

(i) How is energy use and environmental impact related to urban density, urban size, types of housing, and energy supply technology and type? In all three regions the answers to these questions are useful for policy discussions relating to land use planning, zoning, building codes, etc. It is also tightly linked to energy use and environmental impact associated with transportation systems. In the German Democratic Republic, significant portions of the populace are in large housing districts, explicitly planned in connection with central district heating systems[3]. Such district heating systems are under discussion and in some cases being implemented in Rhône-Alpes; clearly however their feasibility depends upon urban patterns of size and density. In the GDR, there is particular interest in assessing the tradeoffs between district heating, direct burning of lignite or lignite briquettes, and electric space heating. In Rhône-Alpes there is considerable discussion of new population centers being constructed; in the Lyon and Grenoble areas new compact cities are being planned--the so-called cite dortoir. In addition there is considerable interest in France[4] and Wisconsin on assessing the compatibility of solar energy systems with various urban patterns.

In Wisconsin, land use planning is now a major issue, and the State Planning Office has under study several alternative strategies for development patterns[5]. This is particularly important in Wisconsin because of the multiple objectives espoused by various segments of the Wisconsin population with a desire to maintain high environmental quality as well as continued industrial development of the state.

2. Transportation Systems

In each of the three regions, transportation is responsible for a major portion of energy consumption, particularly in Wisconsin and Rhône-Alpes where it accounts for between 17-25% of the end use energy consumption. In addition, as urban concentrations of people and automobiles continue to grow, the effects of the automobile upon the environment are becoming increasingly evident. Consequently an examination of issues associated with the transportation components of energy systems was of interest to all three regions, particularly as it was integrated with urban considerations. The following issues are of particular interest:

i) What are the energy and environmental implications of continuing present trends of evolution of inter- and intracity passenger transportation? How are these modified by the introduction of significant fractions of alternative modes, including mass transit systems? These are of special interest in the Rhône-Alpes region where there is already underway some experimentation with increased mass transit in the larger cities, as well as a major plan moving into the implementation stage for a large system of high speed trains ("train grande vitesse") running between Paris and the major cities of Rhône-Alpes, i.e. Grenoble and Lyon. In Wisconsin the state government has major legislation prepared and is aggressively pushing a complete reorganization of the administration of the state transportation system, a reorganization which would give much higher priority to mass transit systems and attempt to put a larger fraction of the automobiles' social costs on the shoulders of the auto users. Interestingly enough the GDR already is in the position of providing a large fraction of its passenger transportation from non-automobile modes[6], but is moving toward a greater reliance on the automobile.

ii) What will be the energy and environmental implications of higher efficiency automobiles? This question is very closely linked with the fact that each of the three regions is strongly reliant on imported petroleum in the transportation sector. Again in Wisconsin this is a major policy issue, and is now being addressed in the form of proposed legislation which would increase the license fees for autos of low energy-efficiency.

3. Energy Supply

With the recent worldwide increases of the price of petroleum, questions of the reliability of a region's energy supply and its economic viability have increased in importance. For example Wisconsin, being at the "end of the pipeline" in the United States, having no energy sources of its own except for bright sunshine (usually), has very great concern about the future availability and prices of the current forms of energy which it uses. Although Rhône-Alpes and the GDR obtain significant fractions of their energy from within their borders, these sources are relatively limited in terms of the customary forecasts of increasing demand for the mid- and long-term. New technologies either just being implemented or on the horizon, could play major roles over the next fifty year time period, but great uncertainties exist about the costs, as well as their advantages and disadvantages within the infrastructure of society.

There are several policy issues and questions related to energy supply:

i) What are the implications of satisfying future energy demand for the spectrum of alternative fuel categories? These potential fuels vary from region to region, i.e. in Rhône-Alpes coal appears to play a minor role and the major potential fuels are hydroelectric, nuclear, conventional (petroleum and gas), and possibly solar and geothermal. In the GDR, lignite currently plays a major role, nuclear may have potential for the mid- and long-term, and solar, fusion, etc, to a lesser degree in the long-term. In Wisconsin the fuel mix is very diverse at the present time, and all fuels currently in use would appear to be major contenders for strong future roles; gas could continue in high use if coal gasification were technically and economically feasible within the time period under consideration. Solar energy also is currently provoking considerable discussion in Wisconsin, and various proposals are being studied for legislation which would help it achieve economic viability. One of the most significant aspects of supply issues is the question of substitution of electricity for other fuels as an end-use energy form.

ii) What is the feasibility of the extension of heating technologies, e.g. district heating, combined thermal-electric plants, or use of waste heat? These supply or energy conversion strategies are of interest in all three regions. Some of them have already been implemented in the GDR and therefore, from a comparative point of view, form an interesting subject for study in the other two regions.

4. The Structure of Economic Growth

A topic common to all three regions is the interrelationship between energy use and supply and the rate and infrastructure of economic growth. Such questions as i) the fractional contributions of light and heavy industry in the future, and ii) a potential increase of the fraction of the service sector in regional economic activity, are of considerable interest. Although these may not be explicit policy issues in each of the regions, the question of government intervention or lack of intervention to bring about certain shifts in the economic patterns is of primary interest. Patterns of economic growth are clearly very basic to the overall evolution of the energy systems.

5. Environmental Protection and Resource Conservation

Energy-related environmental issues are of major importance in the three regions, albeit in different specific versions in each. It appears that in each of the regions, energy problems and environmental problems are viewed as inextricably linked. Environmental considerations appear to be a common thread that links together the issues regarding urban settlement, economic growth, transportation, and energy supply systems. In the design of our scenario writing we adopted this philosophy and organized the components within the scenarios in a way that facilitated painting a comprehensive environmental picture. Several specific environmental issues were identified:

i) What are the possible environmental limits associated with various patterns of energy demand and supply within each of the regions? What is the impact of these energy futures on the man-made and the natural environment?

ii) What would be the effects of various pollution control policies on the environmental impact associated with alternative energy system strategies? Would these control measures be sufficiently effective to make possible the implementation of otherwise infeasible energy systems? In Wisconsin this issue is related in part to the problem of meeting air pollution standards as specified by Federal regulations. An analagous situation exists in the other two regions. Independent of the standards applicable in each of the regions, there are questions of tradeoffs between the benefits of the energy and the costs of the impact. In the GDR, cooling water ranks as one of the most important resources which is in scarce supply. Within the Rhône-Alpes region, the Rhône River is under major environmental scrutiny because of the plans of Electricité de France to locate a major fraction of their future nuclear capacity on it[4].

iii) What are the major environmental tradeoffs associated with alternative fuels for the production of electricity and for the substitution of electricity as an end-use form of energy? Of particular interest in both Rhône-Alpes and

Wisconsin is a broad look at the relative impacts of nuclear power.

iv) A specific question of the environmental advantages or disadvantages associated with district heat was enunciated in the GDR and the Rhône-Alpes region. In particular the air pollution and fuel conservation aspects of this question are important issues.

Because of the complex manner in which environmental quality is related to a large number of physical variables as well as to human values and the perceived quality of life, the environmental issues received prime attention in the scenarios and the associated studies within this research program.

III. ORGANIZATION AND STRUCTURE OF THE SCENARIOS

A. Conceptual Approach

The methodology employed in the writing of the alternative energy/environmental futures assumes that the regions under study can be described as a system comprised of socio-economic, technological, and environmental components or subsystems, either tightly or loosely coupled to each other. Examples of these components are population, economic activity, energy demand, energy supply, environmental systems, etc.; clearly most of these components are in themselves comprised of subcomponents so that the total picture is one of a hierarchy of subsystems. For example, energy demand can be further divided or disaggregated according to the economic sector, e.g. residential, industrial, etc. or according to the process of energy use, (e.g. heating, transport, etc).

The writing process was one of imposing given policies on the systems within the framework of the existing initial conditions and the constraints characteristic of the region, and then evaluating the resulting development and evolution of the region. In more specific terms this process can be divided into four steps:

(1) The identification and description of general broadly

based policies or norms regarding the development in a region from a socio-economic and technological point of view, and the description of the general relationships between this development and past history. This requires the identification of a certain number of hypothetical sequences of events and of the corresponding causal processes and decision points.

(2) The development of a description or methodology for forecasting (or at least postulating) what effect these policies, decisions, and development patterns will have on each of the elements of the energy/environment system.

(3) The quantification over time of the dynamic development of these components.

(4) A retrospective evaluation of the alternative futures that resulted from steps (1) - (3), with particular attention devoted to an examination of the internal consistency of the dynamic evolution of the components of the system. In addition for internal consistency it is important to re-evaluate the key decision and branch points in the overall scenarios.

In some cases, certain components of the total system appear to be only very weakly coupled at the most, and policies may be evaluated by studying only selected components. However in many cases there is a tight linkage, e.g. between urban design and energy use in transportation; the policies which were applied to these components of the system had to be treated carefully to ensure consistency. It is this phase of the scenario writing that comprises one aspect of the integrated approach to regional management of energy/environment systems. One of the greatest difficulties in the scenario writing approach was to quantify the interrelationships (technical, economic, ecological) between the components of the system.

B. Specification of the Scenarios

Although the general philosophy of the scenarios approach is to integrate as many considerations as possible, in practice in the writing process the policies and norms being imposed must be applied to components of the system as described in step (3) of the previous section. In other words, at some point in the overall scenario writing process, the strategy can best be described as "divide and conquer". To achieve this, we have chosen to specify or describe the nature of a given scenario according to a discrete number of "properties" which can later be explicitly expressed and evaluated by appropriate models and information systems. Within this framework, a given Scenario, S, was expressed in a functional form as:

$$S = f\left\{ [POP],\ [GRO],\ [URB],\ [TEC],\ [TRN],\ [HEA],\ [SUP],\ [ENV] \right\} \quad (1)$$

where

[POP] = POPULATION
[GRO] = ECONOMIC GROWTH AND STRUCTURE
[URB] = HUMAN (URBAN) SETTLEMENT LOCATION AND FORM
[TEC] = TECHNOLOGIES OF ENERGY USE
[TRN] = TRANSPORT SYSTEMS FOR PEOPLE AND GOODS
[HEA] = HEAT SUPPLY SYSTEMS
[SUP] = PRIMARY ENERGY CONVERSION AND SUPPLY TECHNOLOGY (INCLUDING ELECTRICITY GENERATION)
[ENV] = ENVIRONMENTAL CONTROL AND PROTECTION

This notation has proven to be useful for *describing* the overall rationale of a given scenario for a region. This rationale is then applied explicitly to the evaluation over time of these components in the energy/environment system which are related explicitly to the properties of S.

Within this framework, the general policy issues discussed in Section II.C were approached through two paths:

1) The specification of three primary scenarios, each applied, where appropriate, to each of the three regions.

2) The development of "sensitivity studies" which evaluate the effects of variations in one of the properties of S while holding some or all of the other properties constant. (This might be viewed in one sense as a partial derivative of the

scenarios with respect to that property).

The three scenarios can be described as follows:

S1: The "Base Case"
This represents a best estimate of a combination of extrapolations of trends or of "the plan". However it should not be considered as the "most likely".

S2: A high-energy future in which electricity plays a major role.

S3: A low-energy resource conserving future in which solar energy is emphasized, and in which alternative energy technologies are postulated to play a major role.

The above are clearly "energy scenarios", and are written from that perspective. However because of the complex manner in which energy is intertwined into the very fabric of society, they require a comprehensive description of the broad range of properties of Equation 1. As an example of the characteristics of the scenarios, Table 1 presents the basic assumptions for the three Wisconsin scenarios.

The sensitivities were studied by changing individual characteristics such as urban form, supply technologies, environmental control, etc. It is recognized that in many cases it may be unrealistic to assume that the characteristics could change independently; however these sensitivities can provide considerable insight into the relative importance of various components within the hierarchical system.

IV. STRUCTURE OF THE COMPONENTS OF THE ENERGY/ENVIRONMENT SYSTEM

A. Conceptual Approach

Because the three regions under study had very different infrastructures, it was necessary to develop an energy/environment systems structure that allowed us to provide descriptions of a spectrum of components, varying from region to region.
In view of our plans to evaluate the suitability of this approach for regions with even more widely varying characteristics, it was decided to strive for maximum freedom in the descriptive analysis. Specific goals associated with this desire for flexibility were:

	Scenario Number		
	S1	S2	S3
Population	• Declining growth rate	• Same as S1	• Same as S1
Economic	• Continued expansion of service in relation to industry	• Same as S1	• Same as S1
Urban Form	• Suburban extension • 25% apartments	• Exurban dispersal • 50% apartments	• Small compact cities • 50% apartments
Technology	• Almost constant energy use per unit value-added in service and industry	• Increasing energy use per unit value-added • Emphasis on electricity	• Declining energy use per unit value-added • Conservation measures
Transportation	• Auto efficiency gain	• No auto efficiency gain	• Large auto efficiency gain
Heating	• Mostly gas	• Emphasis on electricity	• Solar • Conservation measures
Energy Supply	• Synthetic fuel from coal • Mix of coal and nuclear for electricity	• Synthetic fuel from coal • Mostly nuclear for electricity	• Solar for electricity • No new nuclear • Synthetic fuel from coal
Environmental	• Present trends of increasing controls for SO_2 and particulates	• Low controls of SO_2 and particulates	• Stringent controls of SO_2 and particulates

Table 1: Basic Assumptions for Three Wisconsin Scenarios for the Period 1970 to 2025.

1) The ability to focus either on specific areas of the energy system or on the entire system,

2) Ease in modifying only selected components of the system, without necessitating change in the overall framework, and

3) The capability of adding to the scenarios as additional policy questions arose during the research efforts.

There are many ways to aggregate and display the characteristics of the energy/environment system of a region. This can be done from an economic perspective, from an energy flow perspective, with material-economic flows (input-output), as a complex technical-economic system, and in many other ways. Because a large number of submodels of the Wisconsin Energy Model (WISE) were available at IIASA, and because this model was originally structured in a flexible hierarchical manner, the structure and subcomponents chosen for our scenario writing were organized in a manner somewhat similar to that in the WISE model[7]. Figure 1 gives an overview of the overall Energy/Environment System used in the IIASA research. The major components are:

1) socio-economic activities
2) energy demand
3) energy conversion and supply
4) primary energy, and
5) environment.

The hierarchical structure within each of these larger components is extremely complex and no attempt will be made to describe it within the space limitations of this paper. However, Figure 2 gives an example of the complex of considerations which arise when the scenario transportation property (TRN in the notation of Equation 1) is explicitly evaluated for the system of Figure 1. In actuality, much more detailed structure than shown in that figure was considered in the process of describing alternative futures. In some cases these fine structure components were represented by simple models; in other cases they were treated by judgement or assumptions of the IIASA research team.

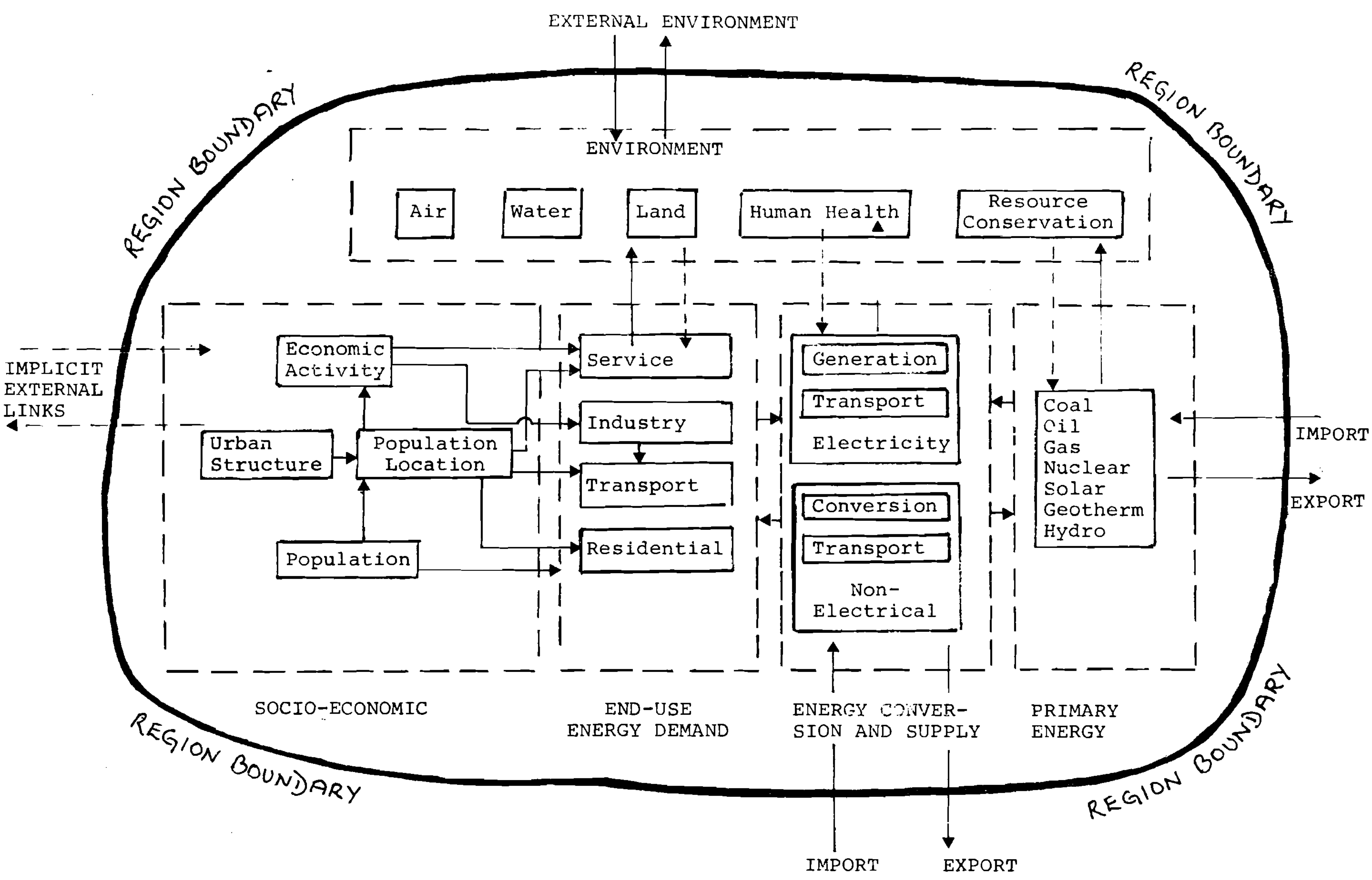

Figure 1: Structure of Energy/Environment System for Scenario Development

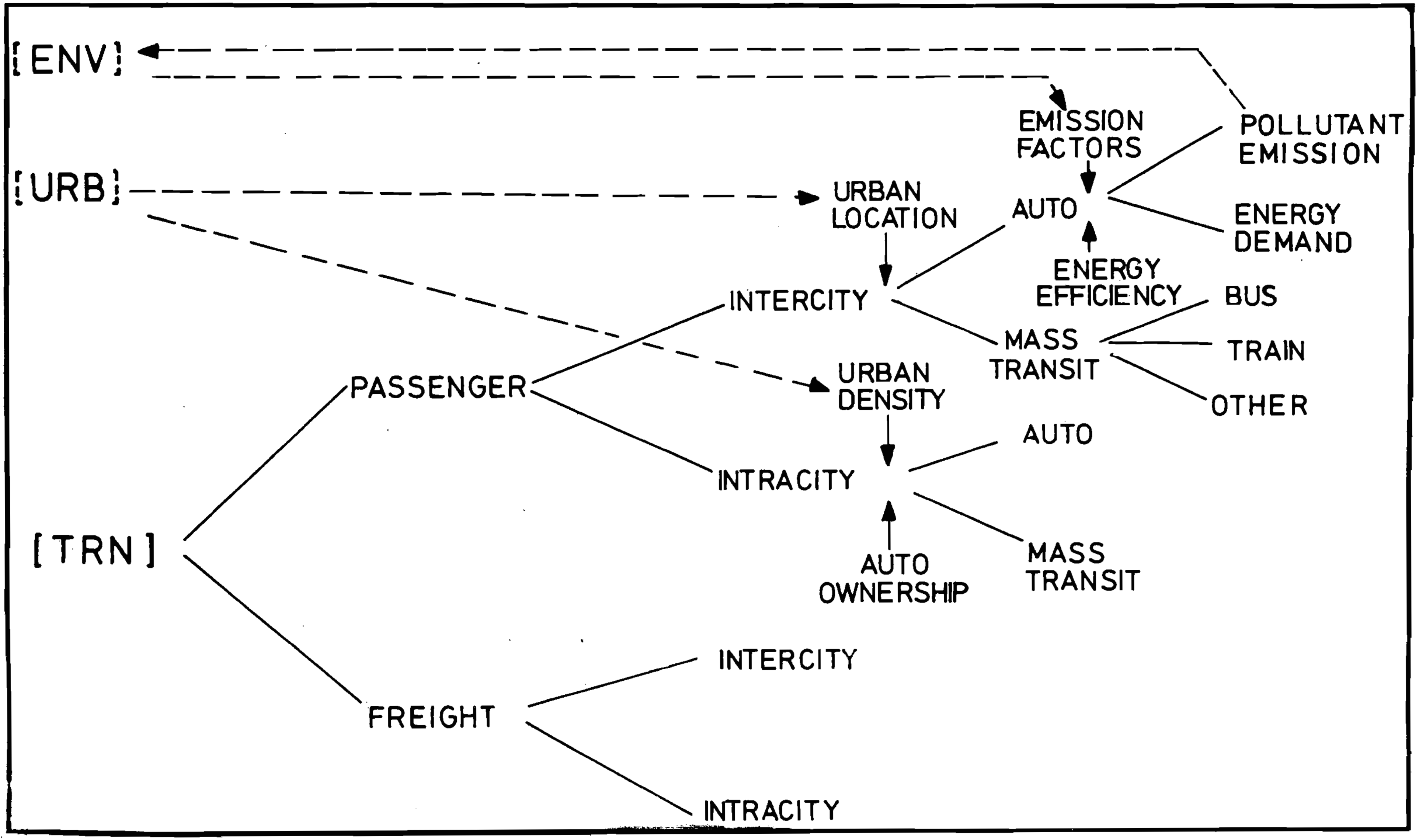

Figure 2: Partial Description of Evaluation of the System Consequences of a Specific Transportation Property in Scenario S.

B. Description of the Components

This section give a brief description of each component for the energy/environment system as depicted in Figure 1 and enumerated in Table 2 for the regions. It also introduces the general procedures for deriving the time evolution of each component. More detailed descriptions of the assumptions and values of many of the parameters used are given in the scenario descriptions for each of the three regions.

Socio-Economic	Energy Conversion and Supply
1) Population	9) Non-Electrical Energy
2) Urban Form	10) Electricity
3) Population Location	11) Import
4) Economic Activity	12) Export
End-Use	**Primary Energy**
5) Industry Sector	13) Primary Fuels
6) Service Sector	14) Import
7) Residential Sector	15) Export
8) Transport Sector	**Environment**
	16) Air
	17) Water
	18) Land
	19) Human Health and Safety
	20) Resource Conservation

Table 2 : Major Components in Scenario Writing

The initial regional data bases, trends, and projections supplied by the three collaborating institutes were very different in nature. For Bezirk X (GDR), a very large quantity of data was supplied for the Base Case Scenario through the year 2025. In other words, a considerable part of the variables in the

Base Scenario was defined by personnel at the Institut für Energetik in Leipzig. In the case of Rhône-Alpes and Wisconsin, many of the key variables in the scenarios were evaluated by the use of trends, empirical relationships, various subcomponents of the Wisconsin model, or other tools. These are described in more detail in the following section and also in the scenario descriptions.

1. Socio-Economic Components

1) Population

Population changes were essentially the same for all scenarios in a given region. Since much of the modelling was done on a per-capita basis, it would be a relatively simple matter to revise the scenarios, if at some time other population scenarios were of interest. It is interesting to note that in Bezirk X, the population is approximately constant through the entire period of the study. The significance of this is that there can be very little restructuring of the population location patterns. For all three regions, population projections for the next few decades were deduced from official projections; for the first quarter of the 21st century, growth rates were postulated by the IIASA Research Team.

2) Urban Form

The size, population density, and location of human settlements were treated as a major determinant in the scenario writing process. These characteristics are tightly linked to transportation systems, to the provision of energy-consuming public services, to the emission, distribution and health impacts of energy-related pollution, and to many other characteristics of the energy/environment system.

The sensitivity of the scenarios to urban characteristics was studied through the use of four different versions of future urban development and evolution in the regions, namely:

1) *Suburban Extension*, i.e. a continuation of what might be called "sprawl".
2) *Small Compact Cities*, in which a significant fraction of the population will live in small compact cities.

3) *Large Compact Cities*, which might be called the "urban containment" scenario, where present large cities grow in density but not in area, and
4) *Exurban Dispersal*, where growth takes place on the far wings of cities.

These development patterns were constrained by the initial conditions within each of the three regions and by the population growth rates that were used in the scenarios. In Bezirk X, because zero population growth was assumed to preclude any drastic restructuring of the urban centers, only one urban form was studied.

3) Population Location

The actual location of population in the scenarios was determined in part by the population projections associated with each of the major subregions in each of the three regions, and in part by the specific urban form scenarios used above in Section B. In all three of the regions, some population location projections were available for the period up through the late 20th century; judgement of the IIASA team was then used to extend these trends through the 2020 - 2025 period.

4) Economic Activity

The description and specification of economic activity in each of the three regions was one of the most important aspects of the scenario-writing procedure. In analogy to the treatment of population, an attempt was made to explicitly identify and isolate the role of economic growth and structure in the evolution of the energy/environment system. However it is recognized that economic activity, like energy, is inextricably bound to all parts of the system, and to separate out its influence is an extremely difficult task. For all three regions economic growth was specified according to 1) the industrial sector, and 2) the so-called "service sector" of the economy. Because of differences in data and in methods of national and regional accounting, an identical definition of these sectors could not be applied to all of the regions. As will be seen in the later scenario descriptions, however, a reasonably consistent approach was taken.

For a given region, economic growth was specified exogenously in a manner such that its total evolution was identical for all scenarios although the infrastructure was allowed to vary between the scenarios. In addition to financial indicators of economic activity, employment was also modelled or specified according to relationships determined from historical patterns in the regions.

2. End-Use Energy Demand

5) Industrial Sector

Industrial energy demand was classified according to a disaggregation into subsectors. Twenty subsectors were used in Wisconsin, seven in Rhône-Alpes, and six in Bezirk X. Various means were used to specify value-added or material product in these sectors; energy intensities (e.g. calories per Mark) were specified according to trends, judgement, or assessment of industrial technology. Specific technological processes were not described explicitly in the model but were treated implicitly through the energy intensity coefficients. The results of this form of modelling were annual energy use in each industrial subsector, disaggregated according to fuels.

6) Service Sector

The service sector included all other activity not included in the industrial, transporation, or energy supply and conversion sectors. It is well known by energy researchers throughout the world that this sector provides one of the greatest challenges. In our scenario-writing process, available data necessitated using a different approach in each of the three regions. In Bezirk X, the Leipzig Institut provided forecasts of employment in the service sector; these projections, combined with an energy intensity (calories per employee) permitted a calculation of annual energy use. In Rhône-Alpes and Wisconsin, the service-related energy was based on projections of floor area in buildings which were responsible for the majority of the energy use in the sector. A technological model which included energy use in heating, cooling, lighting and other processes was then used to provide annual energy use. The coefficients describing these technological processes were varied in some of the scenarios to study the effects of energy conservation.

7) Residential Sector

This part of the system describes energy use within residences. It includes energy used in heating and cooling the residents, and in the operation of home-appliances such as water heating, television, cooking appliances, etc. It is disaggregated according to single-family and multi-family homes, and according to the specific purpose for which energy is used. The scenarios studied for the region included the effects of technological changes in energy consuming devices.

8) Transportation Systems

The transportation component of the system covers both passenger and freight transport on an intracity and intercity basis. The characteristics of this part of the system are closely linked to the urban component; in particular urban density played a major role in the detailed characteristics of the transportation system. In addition the transportation component is linked to economic activity through the specification of freight demands for the industrial sector. The modelling techniques for this component varied from region to region. In Bezirk X, the passenger-kilometers were specified by the Leipzig Institut; for Wisconsin and Rhône-Alpes they were forecast through the use of a trip-generation model related to household density and cars per household. Included in the models were varying specifications for technical efficiencies of each transport mode, related to various policies introduces into the scenarios.

3. Energy Conversion and Supply

The energy conversion and supply component includes that part of the system which converts primary fuels into intermediate or final forms of energy for end use in the demand sector. Examples of this are the electricity generation and the petroleum refining facilities. In addition that part of the system which transports energy for end use is also included, e.g. electricity transmission. The overall component is divided into two parts:

9) Non-Electrical Energy

This component is comprised of very different facilities in each of the three regions. In Wisconsin it consists only of the non-electrical distribution systems, since there are no transformation or conversion facilities in Wisconsin except for one small refinery. In Bezirk X and Rhône-Alpes, there are major facilities described in this part of the system, including petroleum refineries, coal processing facilities, and others. In general these are not described explicitly in the scenarios but are treated by means of efficiency coefficients for the supply and distribution systems. This implicit treatment of the conversion and transport plays a strong role in describing the overall efficiency of the energy system.

10) Electricity

This component includes electricity generation and transmission. The modelling procedures convert kilowatt-hour demands, (provided by end-use demand models) to required generating capacity. If a modal mix of fuels is then specified for generating plants, the model calculates appropriate efficiencies and system characteristics, and provides a basis for input to the environmental models. Although the capability exists at IIASA for calculating costs associated with these facilities, time did not permit their inclusion in the generation and transmission system description. Differing electricity parameters were applied to the models from each of the three regions, as appropriate for a given scenario. Included in this part of the system are alternative supply technologies including solar-produced electricity (solar heating and cooling was treated in the end-use demand component). These alternative supply technologies must be consistent with the characteristics of the urban and demand characteristics, e.g. urban density.

It should be emphasized that in the modelling done in these components, the share of the energy market between fuels and between electricity was specified in the scenarios; it was not feasible to model the market mechanism or a detailed allocation system within the constraints of the data available and the time permitted for the research.

4. Imports and Exports of Secondary Energy

11) Import and 12) Export

Electricity export plays an important role in the Bezirk X and Rhône-Alpes scenarios. They are specified exogenously from available plans postulated according to the overall policy structure of the scenario.

5. Primary Energy

13) Primary Fuels

The primary fuels considered in this component of the system were coal, petroleum, gas, nuclear, hydro, solar, and geothermal. In each of the three regions, the primary fuels were described and specified according to their energy content, method of extraction, etc. as well as by point of origin, i.e. internal or external to the region. An energy trajectory (or "chain") was described which followed the fuel from its origin to the appropriate conversion or end-use subsystem. Where possible, specific regional characteristics were associated with each of these primary fuels, e.g. energy content and impurities of lignite in Bezirk X, and of bituminous coal in Rhône-Alpes.

14) and 15) Import and Export of Primary Energy

These components are explicitly included in the total system to indicate that import and export of primary energy is treated. These are modelled in the scenarios according to specified time-series.

6. Environment

The environmental component comprises a highly interactive part of the system. It interacts with the primary energy sources, with energy conversion and supply sectors, with end-use demand, and with the environment external to the region as well. Environmental impacts are broadly defined to include effects on land, air, water, structures, and living things. Included in this definition are not only the health and safety of the general public, but also the health and safety of those people employed throughout the energy system. In general, environmental impact as used here treats explicitly all phases of the energy flow system, starting with the fuel extraction phase, (e.g. at the oil well) up through the end uses, (e.g. emissions from autos). Thus an important distinction between the environmental component and others in the system is that this component includes effects both <u>within</u> and <u>outside</u> the region's boundary. Clearly enough, this is an open-ended component of the model since it is extremely difficult to provide a precise definition of the boundaries of "the environment".

16) <u>Air</u>

This component of the system focuses primarily on emissions and concentrations of pollutants in the air. It includes emissions from conversion facilities (e.g. power plants) as well as from end-use (e.g. autos). Major pollutants included are SO_2, particulates, CO and CO_2, hydrocarbons, nitrogen oxides, trace elements and radioactive releases.

17) <u>Water</u>

The focus is primarily upon water use and emissions of pollutants into water. The major pollutants treated are heat, radioactivity, and mining-related wastes. Special attention is devoted to discharge-heating of rivers.

18) <u>Land</u>

This component includes land disturbed or somehow removed from use throughout the entire fuel trajectory. Included are such activities as surface mining, subsidence, and solid waste disposal.

19) <u>Human Health and Safety</u>

This is an important category which covers a wide range of impact to humans. Included are occupational and public accidents, and pollution-induced impacts to the occupational and public sectors, both within and outside of the regions. These impacts are expressed in varying degrees of severity, ranging from person-days lost to fatalities.

20) Resource Conservation

Region- and worldwide there is a strong interest in the issue of energy system efficiency and energy conservation. This component of the system takes into account energy inputs needed throughout the fuel chain to produce a calorie of end-use energy. The system boundary is defined in this study to include the fuel system inputs but not the energy used to construct buildings or mining equipment. Thus the energy in the fuel used to drive a coal train is included, but the energy required to fabricate the coal car is not included. Furthermore the potential energy lost because some coal is left in the ground in the mining process is not considered an energy input to the full system and therefore does not affect the fuel chain efficiency.

V. THE SCENARIOS

A. Current Status

The scenarios were written according to the general procedures described in the previous sections, and were discussed and evaluated at the IIASA Workshop on Management of Regional Energy/Environment System in November[2]. The fourth step of the scenario-writing process is still underway, namely, a retrospective evaluation of the scenarios with particular attention to an examination of the internal consistency of the dynamic evolution of the energy/environment system.

Because of time constraints, not all components of the energy/environment system were evaluated in identical detail across the three regions or across the scenarios. The approach chosen was to evaluate some of the scenarios as completely as time allowed so as to illustrate the methodology; other scenarios were then only evaluated in coarse form. The scenarios written for the three regions and a cross-regional comparison will be presented in a forthcoming publication[2].

B. Scenario Applications to Energy/Environmental System Management

It has been pointed out several times in this paper that these scenario writing activities do not in any way represent a forecasting or prediction procedure. The scenarios are meant to stimulate discussion and to provide a better basis for evaluating alternative futures. The success of their use in the design or management process depends on feedback between the scenario writers and the designers and managers of the energy/environmental systems. The scenario writing process is never completed. The feedback process in scenario writing takes a form similar to that mechanism by which man's knowledge grows. In that sense, the cycling is a continuous process that rarely stops for long; new knowledge evolves continuously. Time also affects the feedback system to the extent that hypothetical future events as laid out in the scenarios either do or do not occur.

From the methodological description in this paper, it is obvious that no formal method has been applied for including uncertainty in the procedure. Rather, the uncertainties must be judged in a subjective manner by means of scrutiny of the scenarios and the sensitivity studies. Clearly there is ample opportunity to exclude major components and events which can completely change the evolution of the energy/environment system. This is a well-known hazard of scenario writing.

The scenario writing process is descriptive. To explicitly transform the output of these scenarios into prescriptive forms, additional steps and research are obviously required. One of these steps is the embedding of the scenarios into an institutional and decision-framework where preferences and values must be applied to the results. This is clearly a very complex task and would differ considerably across the three regions studied in the project. Each of the three regions has very different social and institutional structures. However, a general framework by which some steps can be made in this direction is described in another publication[8]. This paper describes the application of multiattribute decision analysis to the evaluation of alternative futures for energy/environmental systems.

Even if the system can be described and if objectives, preferences, and values are known, there still remains the task of choosing the strategy which achieves the objectives in a manner that somehow maximizes benefits. It is quite obvious that the application of conventional optimization techniques to an entire system of the complexity described in the scenarios is a monumental task, to say the least. However we have begun to take some initial steps in that direction on simplified versions of the energy/environmental systems and with simplified descriptions of preference structures. The first phase of this work, to be described in a later publication[9], has as its goal the synthesis of scenario writing, preference assessments, and conventional optimization procedures. Such a synthesis of systems analysis techniques, if successful, would be an extremely valuable tool for the management of energy/environmental systems.

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APPENDIX

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