International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at

The IIASA Research Program on Management of Regional Energy/Environment Systems

Foell, W.

IIASA Research Memorandum
April 1976

RM-76-40

THE IIASA RESEARCH PROGRAM ON MANAGEMENT OF REGIONAL ENERGY/ENVIRONMENT SYSTEMS

W.K. Foell

April 1976

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 focussed on three greatly differing regions, namely, the German Democratic Republic, the Rhone-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 fuer Energetik, Leipzig, the Institut Economique et Juridique de l'Energie, Grenoble; and the University of Wisconsin - Madison.

The research described in this report has resulted from the contributions of many individuals both at IIASA and at the collaborating institutions. More detailed descriptions of some of the individual contributions can be found in the references and in current and forthcoming publications resulting from this research project. Although the entire list of contributors is too great to acknowledge here, the following individuals have been associated in a major way with the research:

IIASA: J. Bigelow, J. Buehring, W. Buehring, J.-P. Charpentier, R. Dennis, W. Foell, A. Hoelzl, K. Ito, R. Keeney, B. Lapillonne, H. Stehfest, J. Weingart, R. Yorque

Institut fuer Energetik, Leipzig, GDR: W. Haetscher, P. Hedrich, W. Kluge, D. Ufer

Institut Economique et Juridique de l'Energie, Grenoble, France: B. Chateau, D. Finon, J.-M. Martin

University of Wisconsin, Madison, Wisconsin, USA: M. Hanson, J. Mitchell, J. Pappas

E. Ampt, J. Dimitrova, L. Hervey, H. Lee, and J. Ray of IIASA also provided substantial and dedicated assistance during the course of the research.

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

TABLE OF CONTENTS

Summary

Late in 1974, a new research study on "Management of Regional Energy/Environment Systems" was initiated at IIASA. It was structured to meet four primary objectives:

1) To describe and analyze existing patterns of regional energy use and supply and to develop an insight into their relationships to socio-economic patterns within the human enterprise.
2) To analyze and compare alternative methodologies for regional energy and environmental forecasting, planning and policy design.
3) To develop new concepts and methodologies for energy/environment system management and policy design.
4) To use the above methodologies to examine alternative energy policies and strategies for test regions, to explore their implications from various perspectives using sets of indicators related to environmental impacts, energy use efficiencies, etc., and to investigate whether these strategies represent a viable choice for the society in which they are being considered.

"Regional" in this context is not defined specifically, but in the current study, it refers to national or subnational areas. The research is organized on a comparative basis, with three distinct regions chosen as the first case studies, namely, the German Democratic Republic, the Rhone-Alpes region in southern France, and the State of Wisconsin in the U.S.A. A core team of IIASA scientists, cutting across several existing IIASA projects is conducting in-house research with research institutions in each of these three regions, namely,

1) The Institut fuer Energetik, Leipzig, GDR
2) Institut Economique et Juridique de l'Energie, Grenoble, France
3) The Energy Systems and Policy Research Group, University of Wisconsin-Madison, U.S.A.

These regions were chosen because of their greatly different planning and policy frameworks in their respective countries; the specific collaborating institutions were chosen because of their active role in the policy design process in their own regions.

The overall research format was strongly influenced by the presumption that it should be structured to ensure interactions between the research team and the primary scientific and policy clients in the respective regions. The ensuing interinstitutional network resulted in a vigorous flow of information and people, coordinated by IIASA.

The research activities within the study are divided into five related components:

1) Description of the Energy/Environment Systems of each region. This included a picture of past and current energy use, energy supply models and flows, environmental quality indices (air, land, water, etc.),

economic activity, demography, human settlement patterns, and so on.

2) Description and comparison of the regional institutional and organizational structures within which energy and environmental planning, management and policy design are conducted.
3) A comparison of energy/environment modelling tools used in each of the three regions; this was done according to methodology, domains of policy and planning applications, relation to the decision-making structure, transferability to other regions, etc.
4) Development of alternative futures (scenarios) for each region as a tool to examine alternate energy and environmental policies and strategies.
5) Development of methods and concepts for communicating and evaluating energy/environment strategies and options.

Among the outputs of the research during 1975 and early 1976 are:

- a multi-regional energy/environment data base for use with a set of planning and forecasting models implemented at IIASA.
- a set of alternative long-term Energy/Environment futures (scenarios) written for the three regions.
- an appraisal and comparison of energy models used in the regions.
- the application of decision analysis techniques as a tool for more effectively embedding systems-analytic tools (e.g. impact models) into the regional energy/environment management and planning institutions.

In late 1975, a workshop held at IIASA brought the IIASA core research team together with scientific experts, policy makers, and members of the public from the regions for a synthesis and appraisal of the research activities.

IIASA and the collaborating institutions will continue to pursue the above questions during 1976, and in addition, IIASA will extend the studies to additional regions.

The IIASA Research Program on Management of Regional Energy/Environment Systems

W.K. Foell

I. Introduction

The Setting and the Problem

Public awareness of the increasing severity of environmental problems and of the growing need for environmental management first grew to significant proportions in the early 1970s. In the United States, for example, the Environmental Movement, beginning in 1970, led rapidly to major legislative actions which not only focused on new laws for protection of resources such as air and water, but also to a completely new procedural requirement to planning - The Environmental Impact Statement. In 1972, the first report commissioned by the Club of Rome, The Limits to Growth by Meadows, et al., burst upon the world scene and generated tremendous attention and debate, not only in academic circles, but in the high levels of the business and government as well as in the eyes of the public in most industrialized countries. Their efforts had two primary initial impacts. First, they increased significantly, on a world-wide basis, the intensity and the focus of the discussions on the long run impacts of environmental degradation and resource shortages and depletion. Secondly, the use of quantitative computer-based models was discussed as an important analysis and communication tool in a surprisingly broad range of disciplines and public circles.

In autumn, 1973, the energy crisis and the cutoff of Mideast oil supplies dramatically demonstrated to the industrialized world the central role which energy plays in our society and the range of interdependencies through which it is linked to the economic and technological fabric of the human enterprise. As a complement to the global picture painted by the Limits to Growth report, it drove home the importance of the regional and distributional aspects of resource availability and utilization. It also brought into clear perspective the explosive nature of the potential conflicts that could arise over questions of sharing the world's resources. With the energy crisis serving as a catalyst which ignited the issue, the uneven distribution of current wealth, resources, and population in the world has become a major theme of discussion, debate, and negotiation in a wide range of world forums.

In most industrialized countries, a greatly intensified concern with energy planning has been emerging at all levels of government. The grass roots public concern about energy and its effect on day-to-day existence has stimulated much greater action on the part of local and regional governments. One major reason for this phenomenon originates with the diverse ways in which each region within a nation or a part of the world depends upon energy. For example, a purely consuming region, which neither extracts nor processes primary fuel, in general employs a distinct set of objectives and values in formulating energy policies; these are in most cases quite different from those in an energy-producing region. In a similar manner, the considerations differ between industry- and tourism-oriented regions, between agricultural and urban regions, etc. The maze of interdependencies between energy and the total human enterprise in each region binds its energy policy objectives quite tightly to the natural and man-made characteristics of that region. The recognition of this bond has made apparent the great need for an improved understanding of energy systems and their embedding in society at the regional level.

It has been convincingly demonstrated many times that over almost any conceivable time period the limitation on man's use of energy will not be due to the amount of energy stored in the earth or the sea or in space. That is, the potential energies from breeder reactors, fusion, and the sun are enormous. Rather, the limit will most probably originate from man's inability to convert this energy into a useful form at acceptable costs, or from his unwillingness to accept some of the consequences which may accompany the conversion of these sources into useful work. These consequences may be in the form of a broad spectrum of environmental effects (with the term environment used here in a very general sense) or in the form of unacceptable risks - many of which will be poorly understood, vaguely perceived, or even hypothetical. Some of these consequences may be primarily global in nature, but a majority of them, although having certain universal characteristics, derive a specific meaning only when related to a given region or human environment.

A more controversial aspect of man's future energy systems is their relationship to economic growth and well being. Are there global or regional limits to our energy systems? If there are limits, how can these systems be designed so as to maximize human welfare? What would be the economic consequences of such limits for the less energy-intensive countries or regions; for the less-developed countries and regions? Will these regions need to consider alternative energy systems, e.g. solar or low-energy technologies? These questions of energy resource management cannot be answered from a purely global perspective.

The above events and realizations during the first half of the decade beginning in 1970, in concert with a number of other resource-related issues, have created the following conditions:

1) Environmental management has been recognized as an important component of the planning process.

2) Society is now beginning to explicitly incorporate energy into many of its decision-making processes.
3) A broadly-based recognition has developed of the major role which energy plays in the determination of environmental quality.
4) Regional and distributional aspects of energy and the environment have emerged as important issues at international, national, and subnational levels.

An IIASA Research Program

Late in 1974, a new research study, Management of Regional Energy/Environment Systems was initiated by the IIASA Ecology Project. The study was specifically structured to address the above issues and to take advantage of IIASA's international and multidisciplinary character. In addition, during 1975 and early 1976, this study served as a rich source of case studies for what has been the dominant objective of IIASA's Ecology Project since its inception -- the development of a coherent science of ecological management which could be applied to a number of similar problems throughout the world (1).

The research was founded upon four key presumptions:

- Energy use limitations will result from unacceptable costs and consequences ... not from resource depletion.
- Strong relationships exist between energy systems and the structure of economic development. Energy and its environmental corollaries will exert an increasingly strong influence on technological, economic and environmental decision-making bodies throughout the world.
- Many significant social and environmental consequences of energy systems arise from embedding the system in a specific region or human environment.
- There is a need to study alternative human patterns and life styles in connection with energy/environment systems.

The study, designed to integrate energy and environmental management considerations from a system's perspective, has four primary objectives:

1) To describe and analyze existing patterns of regional energy use and supply and to develop an insight into their relationships to socio-economic patterns within the human enterprise.
2) To analyze and compare alternative methodologies for regional energy and environmental forecasting, planning and policy design.
3) To develop new concepts and methodologies for energy/environment system management and policy design.
4) To use the above methodologies to examine alternative energy policies and strategies for test regions, to explore their implications from various perspectives using sets of indicators related to environmental impacts, energy use efficiencies, etc., and to investigate whether these strategies represent a viable choice for the society in which they are being considered.

This report describes the research study as it has developed over the past sixteen months, with particular emphasis upon the conceptual framework within which it has been conducted. Many of the detailed results are described in other current or forthcoming publications. Section II of this report presents the overall Research Format of the study. Section III presents a summary description of the three Regional Energy/Environment Systems, including the institutional structures, followed by a brief discussion in Section IV of the regional models. A methodological and illustrative discussion of scenario-building is given in Section V, including a brief example of a representative set of scenarios for Wisconsin. Section VI presents one approach to the evaluation of options and strategies, and concludes with a brief discussion on implementation of research results. A few concluding remarks on plans for the future are made in the final section.

II. The Research Format

The Comparative Case Study Approach

One of IIASA's strengths is its access to research institutions and scientists throughout the world and its mandate to interact with them in applied and policy-oriented research projects. To take advantage of this capability and as a vehicle to sharpen the research, the Energy/Environment study was organized on a comparative basis with three distinct geographical regions chosen as first case studies each having very different structural characteristics. The three regions* are the German Democratic Republic (GDR), the Rhone-Alpes region in southern France, and the state of Wisconsin in the U.S.A. (Figure 1). The regions were chosen in part because of their greatly differing characteristics, including their socio-economic and political structures, their technological base, their geographic and ecological properties, and their institutional approaches to environmental and energy planning management. A second important basis for the choice was the presence in each region of an institution with an active policy-oriented research program, examining energy/environment systems from a broad resource management perspective.

A Research Network

A small core team of IIASA scientists, cutting across several existing research projects, conducted the in-house research in collaboration with the research institutions in the three regions under study, namely,

- The Energy Systems and Policy Research Group of the Institute for Environmental Studies and the College of Engineering, University of Wisconsin-Madison, U.S.A.
- Institut fuer Energetik, Leipzig, German Democratic Republic
- Institut Economique et Juridique de l'Energie (Centre National de la Recherche Scientifique - CNRS), Grenoble, France.

Each of these institutions, in varying degrees and manners, plays an active role in its respective country or region in

---

*Within this context "regional" is ill-defined and refers to to a geographic region appropriately limited in size.

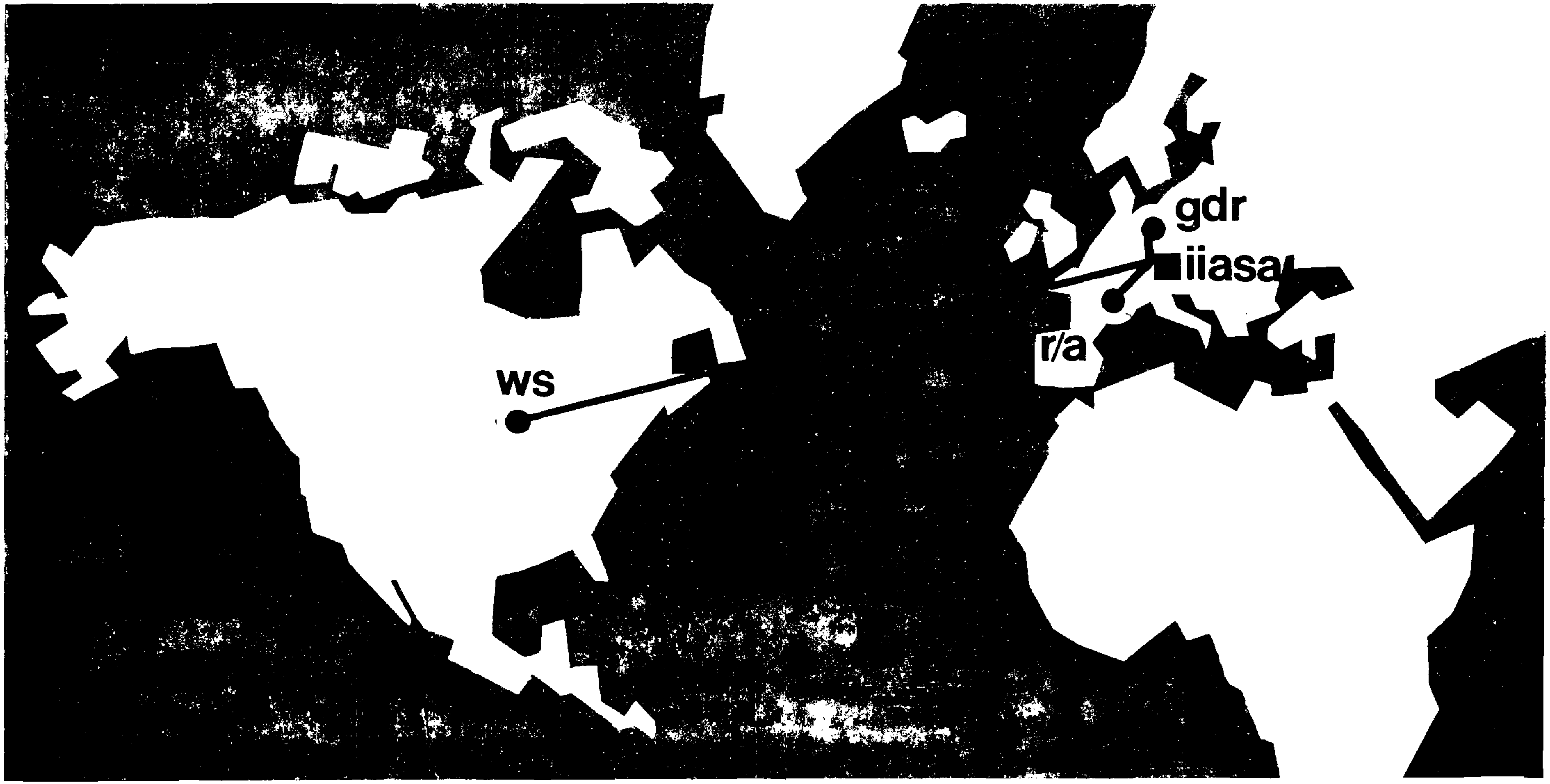


Figure 1: The 1975 International Network of the IIASA Regional Energy/Environment Project

conducting applied policy-oriented energy research and in advising decision and policy makers.

The overall interaction between IIASA and the collaborating institutions is shown in Figure 2. As indicated, there was an interinstitutional flow of models, data and personnel. The vigor of these flows reflected positively upon IIASA's potential coordinating roles in the international scientific community. As represented by the broken square, planning for a follow-up phase was initiated in 1975, with preparations for later participation by an additional country or countries.

Components of the Research

The research activities can be broken down into five related components:

1) Description of the Energy/Environment Systems of each region. This included a picture of past and current energy use, energy supply models and flows, environmental quality indices (air, land, water, etc.), economic activity, demography, human settlement patterns, and so on.
2) Description and comparison of the regional institutional and organizational structures within which energy and environmental planning, management and policy design are conducted.
3) A comparison of energy/environment modelling tools used in each of the three regions, according to methodology, domains of policy and planning applications, relation to the decision making structure, transferability to other regions, etc.
4) Development of alternative futures (scenarios) for each region as a tool to examine alternate energy and environmental policies and strategies.
5) Development of methods and concepts for communicating and evaluating energy/environment strategies and options.

The following five sections of this report describe the above research components and their integration through a workshop held at IIASA in November 1975.

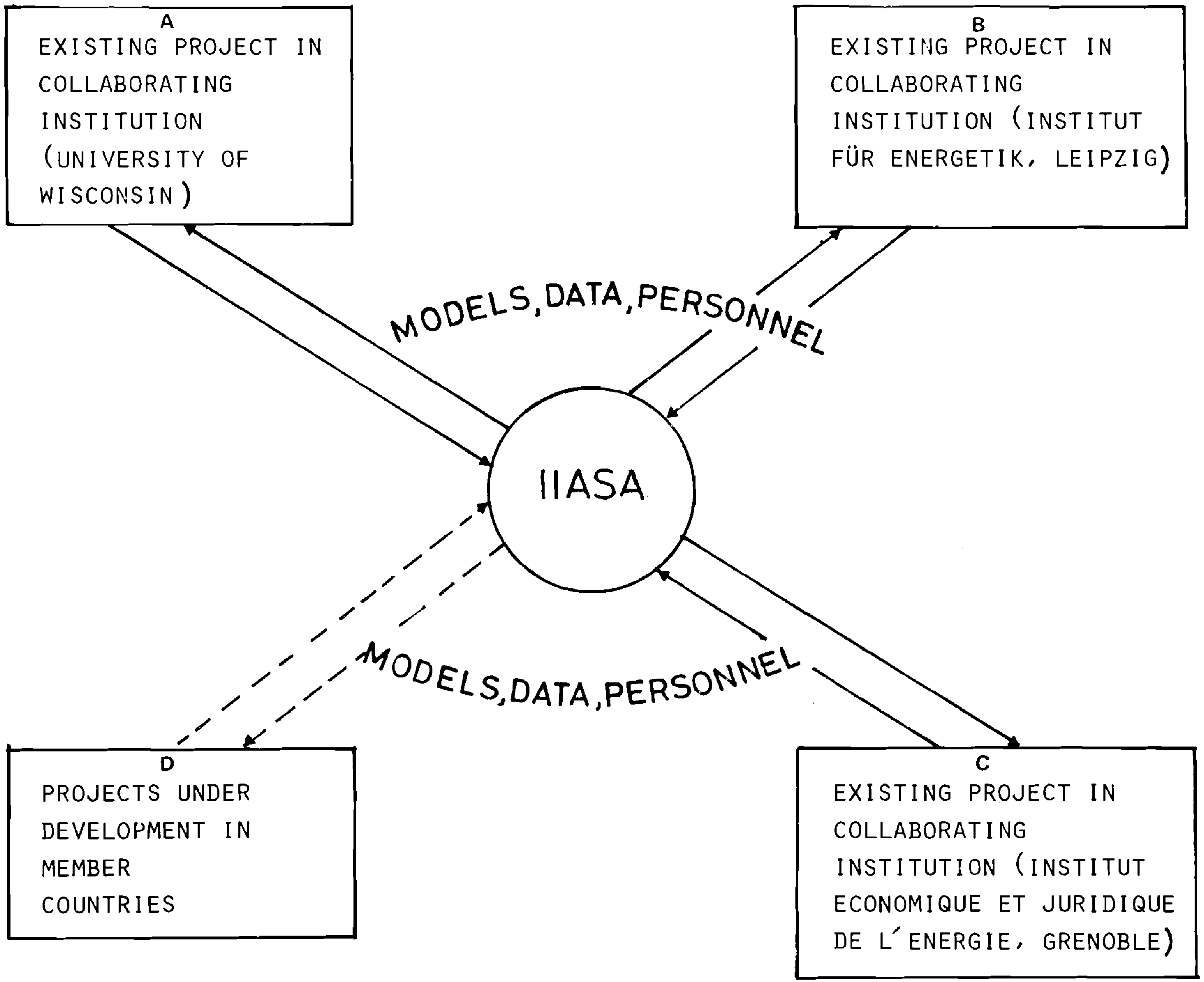


Figure 2: Interinstitutional Relations Within the Energy/Environment System Study

III. Description of the Regional Energy/Environment Systems

A detailed comparative descriptive analysis was developed for the three regions. This analysis focused on relating differences in energy use, supply, and environmental conditions to socio-economic activity and natural geographic characteristics. There are dozens of ways to aggregate and display the characteristics of the energy/environment system of a region. This can be done from an economic perspective, on an energy flow basis, with material-economic flows (input-output), and in many other ways. For the purposes of this study, the overall system structure shown schematically in Figure 3 was used. The major components are:

- Socio-economic activities,
- Energy demand,
- Energy conversion and supply,
- Primary energy, and,
- Environment.

The hierarchical structure within each of these components is complex and no attempt will be made to describe it within the space limitations of this paper. These detailed descriptions will be described in a forthcoming work (2) and only a comparative overview is presented here. Most of the data are for 1972, chosen as a reference year.

Socio-Economic Activities

The general location of the regions is shown in Figures 4 a), b) c). Table 1 provides a comparison of their size, the populations and the population densities. The contrast

Table 1

Comparison of Population & Area 1972

	Population (10^6 people)	Area (km^2)	Density (people/km^2)
GDR	17.0	108,178	157
RHONE-ALPES	4.7	43,634	108
WISCONSIN	4.5	145,370	31

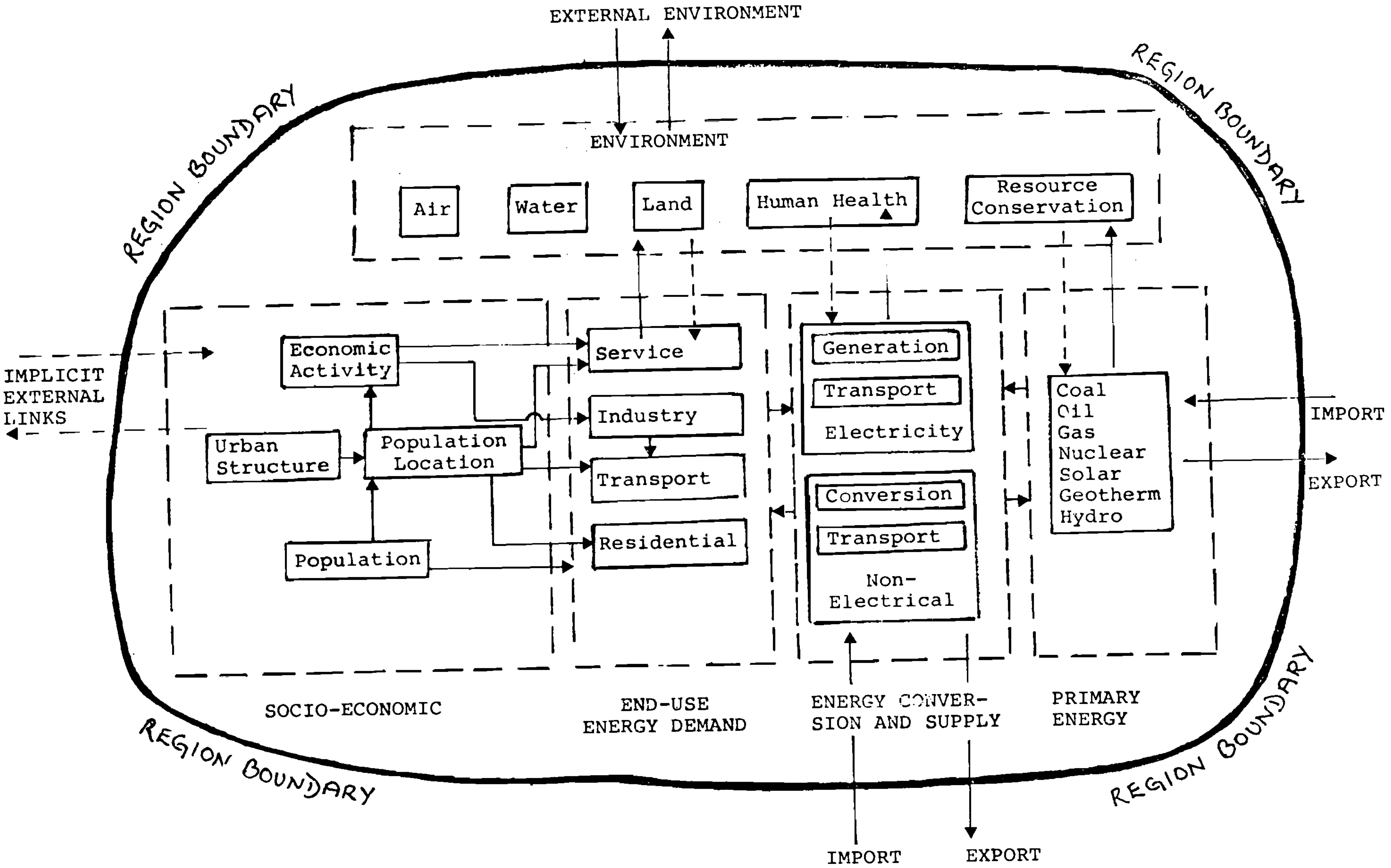


Figure 3: Structure of Energy/Environment System for Scenario Development

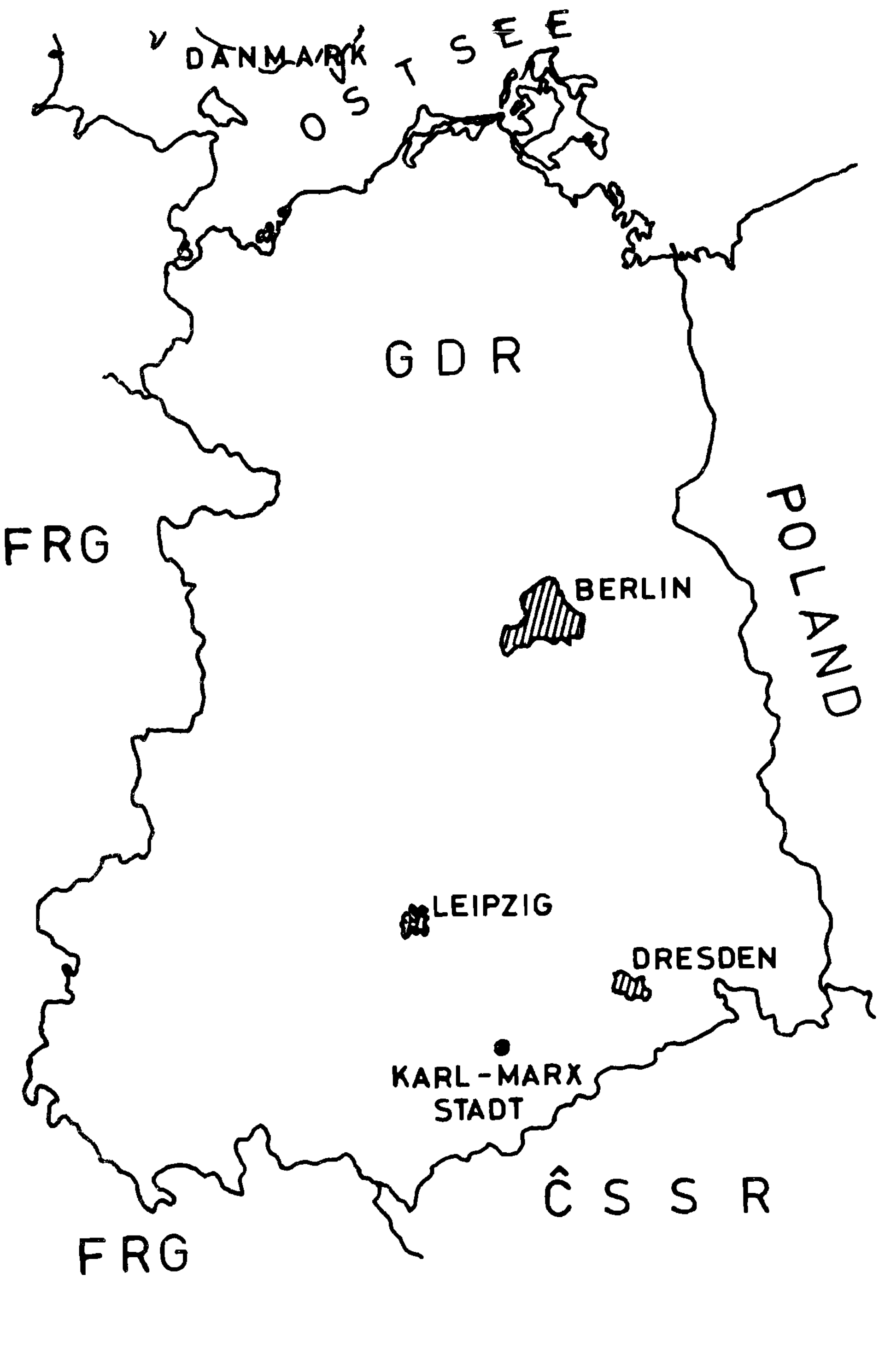


Figure 4 a): The German Democratic Republic and Surrounding Countries

Figure 4 b): The Rhone-Alpes Region, France

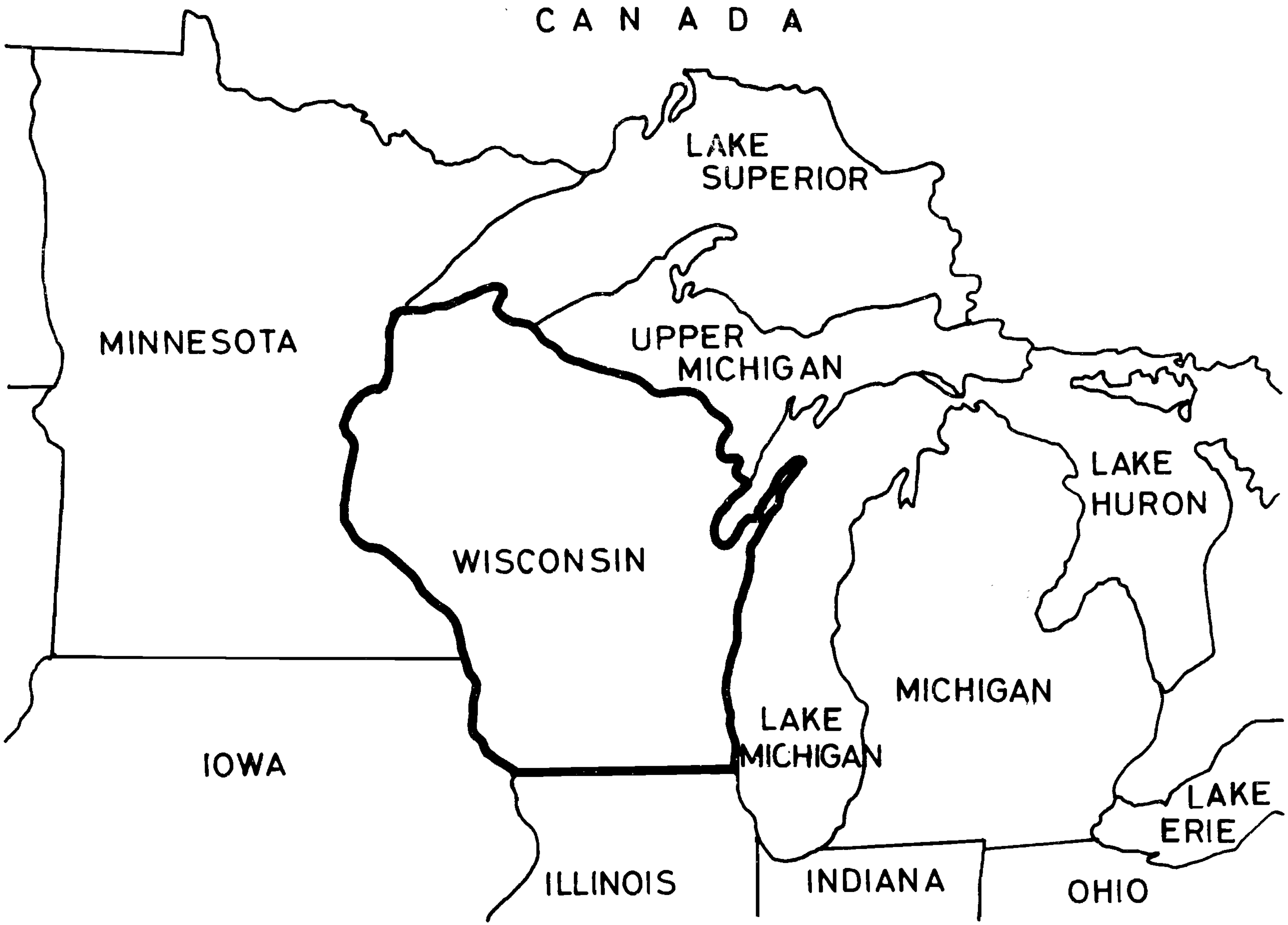


Figure 4 c): Wisconsin, U.S.A. and Bordering States between the overall densities of Wisconsin and the heavily populated GDR is striking. Figure 5, a comparison of recent population figures in the regions, shows the current zero population growth behavior of the GDR, in contrast to continuing although modest growth rates in Rhone-Alpes and Wisconsin (currently approximately 1% and 0.8%, respectively). The contrasting population dynamics had a strong influence on the scenarios written for the regions. A 1972 partial snapshot of the three economies is presented in Tables 2 and 3. Table 2 indicates a greater industrialization in the GDR and Rhone-Alpes, relative to Wisconsin. Table 3 provides some insight into the industrial infrastructure of the regions; the greatest dissimilarities occur in the chemical and food subsectors.

Table 2

Cross-Regional Comparison of
Estimated Fraction of Total Working Population
By Economic Sector (1972)

Economic Sector	GDR (%)	Rhone-Alpes (%)	Wisconsin (%)
Agriculture	11.6	9.0	8.4
Industry	38.5	36.0	25.5
Building, Public Works	7.4	9.3	3.3
Commerce, Services, Administration	42.5	45.7	62.8
	100.0%	100.0%	100.0%
Fraction of Total Population	48.6%	43.4%	40.8%

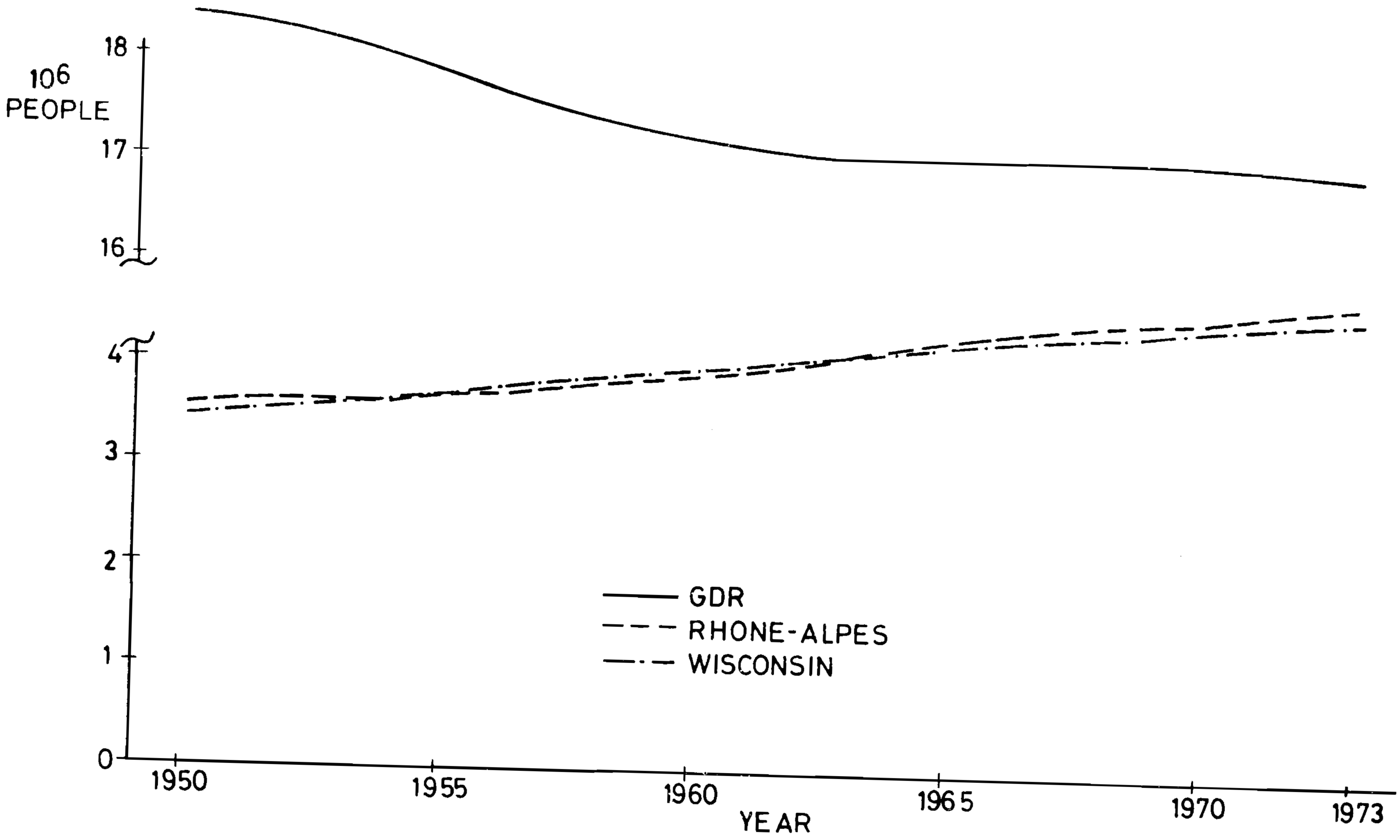


Figure 5: Cross-Regional Comparison of Population (1950-1973)

Table 3

Cross-Regional Comparison of Fractional Industrial Activity by Sector (1972)			
Individual Activity	GDR	RHONE-ALPES	WISCONSIN
	% of Net Industrial Product	% of Industrial Value Added	% of Industrial Value Added
Food	11.6	8.7	15.8
Building Materials	2.1	3.5	1.3
Primary Materials	4.7	5.8	5.6
Machinery, (Mech. Elec., & Transp. Equipment)	42.0	44.5	49.0
Chemicals & Rubber	17.0	14.7	6.0
Light Industry	22.6	22.8	22.3
	100.0	100.0	100.0

Table 4 gives a cross-regional comparison of motor vehicles. The heavy Wisconsin reliance on the automobile is vividly demonstrated by the table; however, time-series studies show that auto ownership in the GDR is increasing at an annual rate of 12% in comparison with a 4% growth in Wisconsin. Also striking is the heavy GDR reliance on mass transit.

Table 4

Cross-Regional Comparison of Motor Vehicles (1972)						
	GDR		RHONE-ALPES		WISCONSIN	
	Total (10^6)	Per Capita	Total (10^6)	Per Capita	Total (10^6)	Per Capita
Autos	1.400	0.082	1.259	0.270	1.969	0.436
Motorcycles	1.373	0.081	0.502	0.106	0.070	0.015
Buses	0.018	0.001	0.007	0.001	0.010	0.002
Trams & Trollies	0.0048	0.00028	0.0003	0.00007		
Trucks	0.256	0.015	0.328	0.069	0.376	0.083
Tractors	0.203	0.012	0.011	0.002	0.230	0.051

Energy Use and Supply

The comparison of primary energy use in Table 5 shows that although the per capita energy use is the greatest in Wisconsin, the density of use is by far the greatest in the GDR. The primary energy sources for the three regions differ

Table 5

A Cross-Regional Comparison of Primary Energy Use (1972-3 Data)

	Annual Energy Use (10^{15} cal/yr)	Annual Energy Use Per Capita (10^{9} cal/p/yr)	Density of Annual Energy Use (10^{9} cal/km^{2})
GDR	749	44	6.9
RHONE-ALPES	168	35.7	3.8
WISCONSIN	319	70.9	2.2

significantly. The GDR relies heavily on coal (mainly lignite--strip-mined in the country) whereas Rhone-Alpes is dependent on petroleum and hydropower (Figure 6). Wisconsin, although having no naturally occurring fuel resources within its boundaries, has a diverse supply mix comprised mainly of petroleum, natural gas, and coal; nuclear is providing a rapidly growing portion of its energy.

The above descriptions provide only a glimpse of the three energy systems, but they already give an indication of the diversity of the three regions. The natural and environmental characteristics are not presented in this report, but are discussed in some detail in a forthcoming publication (2).

Institutional Structures

As indicated earlier, one component of the research program was to describe the institutional and organizational structures associated with planning and policy analysis in the energy and environmental areas in each region. Although this was one of the smaller parts of the overall

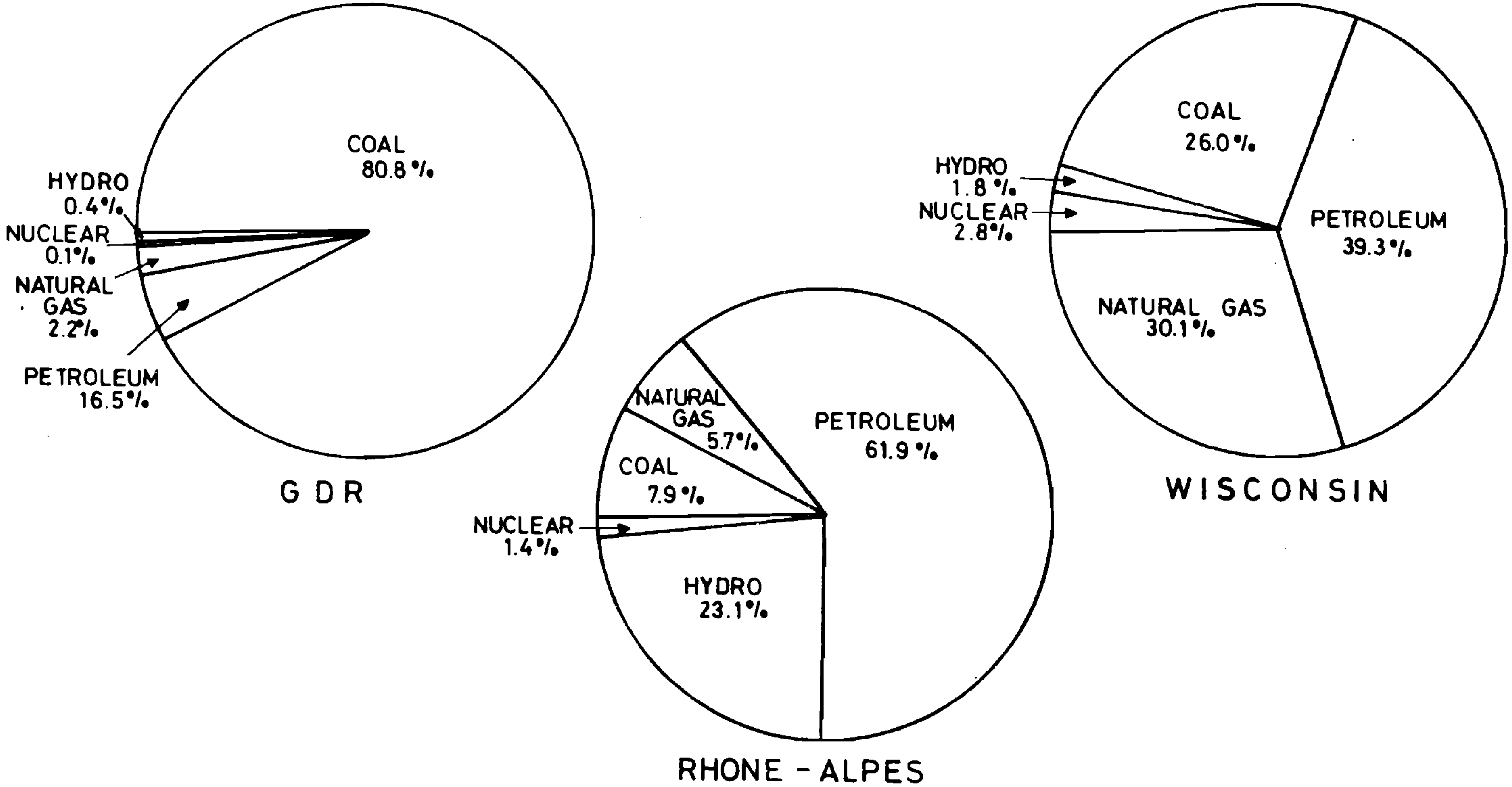


Figure 6: Cross-Regional Comparison of Primary Energy by Source (1972)

research effort, it turned out to be a significant one. As the research progressed, it became apparent that there was a strong relationship between the institutional and decision structures of a region and the formal models and planning tools that were used. This point was demonstrated quite vividly by the contrasts between the structures in the three regions chosen.

The respective institutional structures and their relationships to the models and planning tools are described in several papers written by regional energy experts and policy makers (3). Only a few summary statements are presented here.

The Wisconsin Institutional Structure (4)

Energy and environmental decision making and planning in the United States is highly diffuse; there is no single centralized planning or decision making body. Not only are federal responsibilities widely distributed, but various areas of jurisdiction are either the province of or shared with state and local governments. Only a few states in the United States have been able to consolidate energy-related functions within a relatively few, or even a single agency; examples include Connecticut, California, and Kentucky. Most states, however, have a rather dispersed institutional framework for energy/environmental planning and decision making. Wisconsin is more or less typical. State executive agencies are responsible for planning and administration of state legislative programs. However, many state authorities' actions result from federally-mandated programs and requirements. In Wisconsin, emphasis has been placed on strong functional planning by line agencies such as the Departments of Transportation and Natural Resources. Coordination and independent policy analysis is provided by other offices, including the State Department of Administration and the Office of Emergency Energy Assistance. An overview of the planning and modelling activities of the various components of the institutional structure is shown in Figure 7.

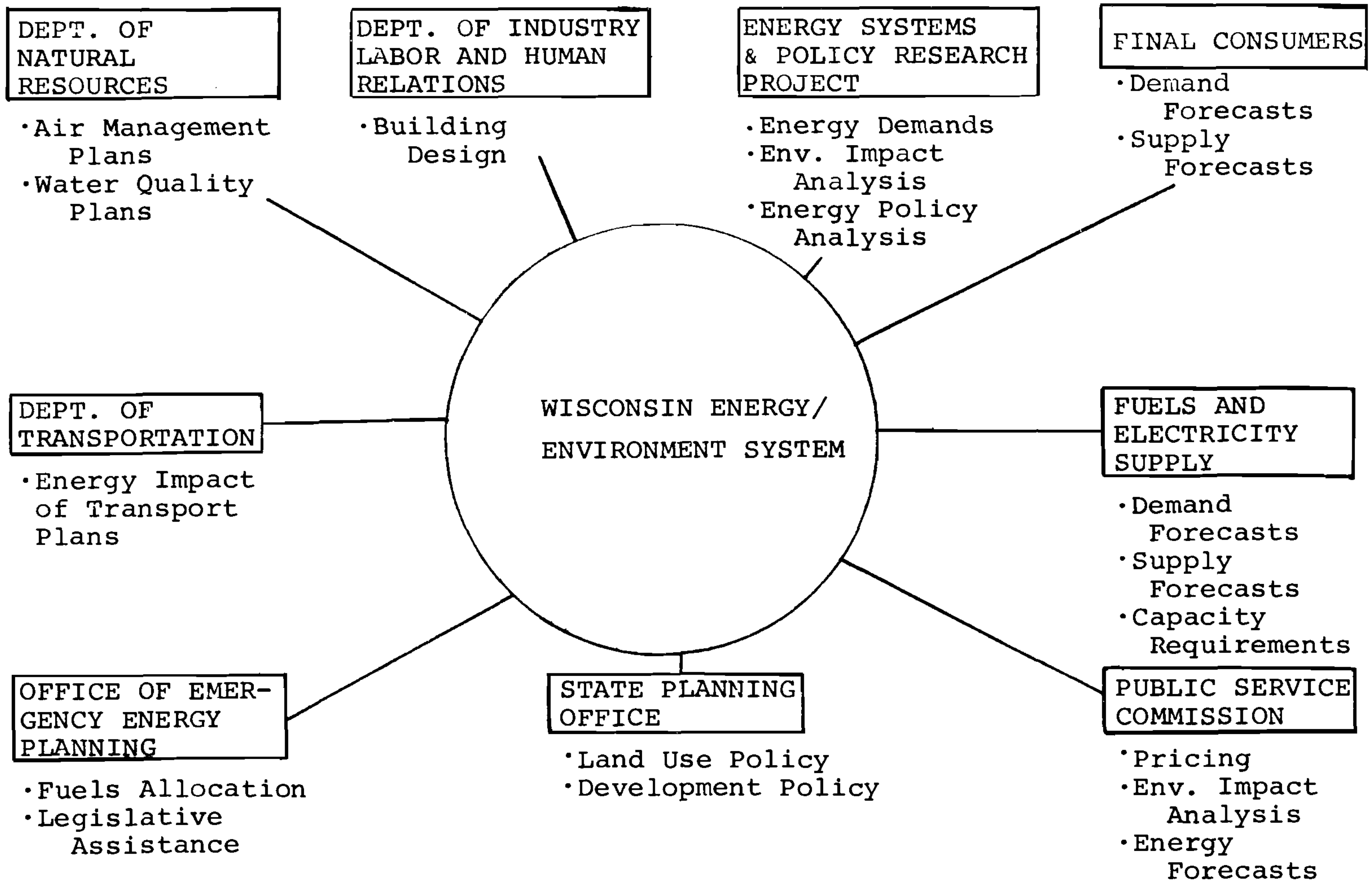


Figure 7: Wisconsin's Energy/Environment System Modelling and Planning Activities

The diffuseness of the illustrated structure points out the fragmentation of energy/environmental planning in Wisconsin and the relatively small amount of centralized effort. In the past few years, however, this situation has been changing rapidly and it is not unlikely that the future will bring about more centralization or coordination.

The Rhone-Alpes Institutional Structure (5)

Two aspects of the French economic and political organization are of importance for an understanding of the energy and environmental decision structure in the Rhone-Alpes region. In the first place, for historical reasons, the entire French decision system is extremely centralized. This accounts for the state apparatus in which all decisions are centralized in the high-level administration (the ministers), geographically concentrated in Paris; it also explains the existence of very important firms in which the power is also centralized in Paris. These two structures, the state and the large firms, could be represented by bodies with greatly expanded heads and atrophied limbs, reduced to executive orders coming from the top. Thus the Rhone-Alpes region has essentially no policy or decision making power of its own in the energy and environmental areas. The "region" was created by the grouping of 8 departments from a total of 94 departments in France. One of the primary activities of this regional level of government at the present time is to collect and supply information for the national level that makes the decisions and policies. In addition, the regional level in one sense also arbitrates between decisions taken by the large firms.

The German Democratic Republic Institutional Structure (6)

In contrast to the other two regions, the German Democratic Republic has a highly centralized and formalized system of energy/environment planning and management. The State Planning Commission, subordinated to the Council of Ministers, is the most important staff organ for providing a strategy of development of national energy industries. The Ministry for Coal and

Industry is responsible for the elaboration and realization of this national energy policy. This ministry is also subordinate to the Council of Ministers. A complex array of factories, associations of nationally owned industries, etc. are subordinate to this Ministry and serve as a major partner in the planning and management process. The most important instrument for realization of energy policy is regarded to be the Plan. An energy plan has been explicitly elaborated for more than ten years by all essential energy consuming factories and institutions, both on an annual and on a five year planning basis. A highly structured and centrally coordinated systems model and data base play a significant role in this planning process as will be described in a later section of this report.

In partial contrast to the energy planning, the environmental planning and management in the GDR is somewhat more decentralized. Although the Council of Ministers is entrusted with central management planning and weighing of fundamental issues, some of the policy making and coordination would appear to be divided among a number of ministries , including the Ministry of Health and the Ministry of Environmental Protection. It should be emphasized however that the structure of the environmental management procedures seems to be evolving rapidly in the GDR and it is difficult at this time to talk in a definitive way about its long-term nature.

IV. Appraisal of Energy/Environment Models

One of the major objectives of this research project was to appraise and compare the energy and environmental models in each of the three regions studied. This appraisal would be valuable to each of the three regions in assessing their potential use of models from other regions. Furthermore, it would reveal how the models are tied to the policy analysis objectives and to the characteristics of each of the regions, including the institutional structure within which the models are used.

In order to emphasize the transferability aspect of the models, the appraisal process was divided into two parts: 1) each of the three collaborating institutions provided a description of its own system of energy/environment models; 2) each collaborating institution wrote an appraisal of the models of each of the two other groups from the perspective of its own energy/environment system and its own methodological requirements for planning and policy analysis. For example the Wisconsin group identified the types of information it desires and discussed whether the French models treat these areas adequately.

Listed below are the general attributes of the models which were suggested for comparison. These were not included in all of the comparisons but in general they covered the important characteristics.

Categories Suggested for Appraisal

1. Objectives of the models, i.e. what general needs do they serve?
   (a) Policy analysis tool

       Environmental policies
       Research and development policies
       Limitation of dependence on imports
       Transport or urban policies
       ......

   (b) Planning model
   (c) Forecasting model

(d) Operational decision making - based on monitoring, etc.

(e) Descriptive or prescriptive? Optimization?

(Tied in with above attributes would be the question of whose needs?)

2. Specific objectives

   (a) Predicting energy demand

   (b) Planning energy supply system

   (c) Environmental impact analysis

3. General characteristics of models

   (a) Time horizon and time intervals, e.g. annual description, 20 year time horizons, etc.

   (b) Spatial attributes, e.g. by Bezirk or on a fixed spatial grid, site-specific

   (c) Economic
   Engineering or physical
   Environmental or ecological

   (d) Boundary conditions; linkage to the world outside of the system

   (e) Means of communication and display to decision and policy makers

4. Input data

   (a) Form

   (b) Quantity

   (c) Availability, i.e. compatibility with existing or obtainable data

5. Output data

   (a) Form

   (b) Quantity

   (c) Compatability with objectives and needs

6. Embedding within a decision framework

   (a) Treatment of multiple objectives

   (b) Treatment of uncertainty

   (c) Treatment of impacts over time

   (d) Treatment of differential impacts on various groups in society

   (e) Adaptability to handle a broader class of problems

   (f) Use of monitoring for purposes of model validation

7. Computer-related attributes

   (a) Flexibility of software

   (b) General computer time requirements

   (c) Ease of transferability; ease of operation

The Models

Although each of the regions uses a broad spectrum of model and information systems, only the broadly-based system planning models were appraised (2).

The GDR models appear to be aimed at long-term planning activities, with emphasis on the economic/energy (as opposed to the energy/environment) relationship (6). As such, they combine demand projections, technological development estimations, and investment planning, in a system which allows for analysis of alternative growth strategies. Although it would appear that there are energy-related environmental modelling activities going on in various institutions and planning organizations in the GDR, these models have not been integrated into the central energy planning models. The highly-integrated GDR energy model appears to be quite advanced in its capability to examine and model the significant interrelations between the various sectors of the economy. An economic objective function, the minimization of social expenditures, forms the basis of the optimization procedure used.

In Wisconsin, the multiplicity of decision-making units means that it is impossible to structure a single model with a unique objective function, or in fact with even a common constraint set, since the various agents in the Wisconsin system are not all constrained by the same array of factors (4). The need is for a comprehensive well-integrated model of the system, but one that explicitly recognizes the fragmentation of decision making. At the present time for Wisconsin, one must talk in terms of a set of energy/environmental models and the means by which they can be integrated. The modelling activity in Wisconsin is comprised of a variety of efforts in both the public and private sectors, some of them coordinated and others carried on simultaneously but uncoordinated. One exception to this is the work of the Energy Systems and Policy Research Group at the University of Wisconsin; the research of this group has resulted in the development of a computerized dynamic simulation model of the entire Wisconsin energy/ environment system. The model has the capability of providing alternative energy/environment futures for the state and of analyzing some of the impacts of alternative policy decisions related to both public and private sector activities. Although the research group and the model are not formally or institutionally linked to Wisconsin's governmental planning and operational decision making, they both play a significant role in providing technical expertise for policy analysis.

Although there is considerable centralization in energy planning in France, the private sector plays a significantly greater role than in the GDR, and hence the energy modelling activities are somewhat more directly akin to those in Wisconsin. However, as has been mentioned earlier, the economic and energy activities of the Rhone-Alpes region do not comprise an autonomous economic system since the institutional and economic structure of France is very centralized. Therefore no energy modelling exists exclusively for the Rhone-Alpes region. Consequently, the model evaluation dealt with models for the nation rather than the region. Particular attention was given to the linear programming model developed at the Grenoble Energy Institute. It provides for an optimization of the total energy system, subject to constraints on availability of particular primary energy fuels. It also provides for the inclusion of environmental constraints, although not at a level of complexity which make them amenable to regional analysis. In addition, the French modelling has included a long and extensive effort related to the French electric system. The resulting investment models for the electric industry are a very useful tool for evaluating alternative options and strategies. However, with the increasing penetration of electricity in the overall energy market, it is expected that greater reliance will have to be placed on the Grenoble model which treats the entire energy sector and less reliance on models which treat the electricity subsector only.

The above discussions touch only the surface of the appraisals of energy models which took place during the year's research. One of the results of this effort has been the establishment of a task force, including scientists from the three regions, which will continue the appraisal of the models and work toward the development of specific improvements and combinations of some of the models. As a start in this direction, work is underway to incorporate more realistic regional environmental constraints into an optimization procedure of the type developed at the Grenoble Institute.

V. Scenario Building

The writing of alternative futures, often referred to as "scenario building", has been chosen as a methodological device in this research because of its particular value in the study and evaluation of the interaction of complex and uncertain factors. Broadly described, scenario building is a detailed examination of the likelihood and consequences of alternative assumptions about the future.

This set of futures may provide a better view of what is to be avoided or facilitated, a useful perspective on the types of decisions which are important, and on the points in time after which various decision branches will have been passed. In more explicit terms, the primary objectives of scenario building in this research were:

(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 specific energy/environmental policy options.

(5) To evaluate the adequacy of a spectrum of models developed for the purpose of energy/environmental policy design and analysis in a region.

The Conceptual Approach

The methodology employed in the writing of the scenarios assumed that the region under study could be described as a system comprised of socio-economic, technological, and environmental components, coupled to each other with various degrees of strength. The system description used for our work is shown schematically in Figure 3, which has components such as population, economic activity, energy demand, energy supply, environmental systems.

The scenario building 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. This process can be divided into four explicit 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.

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. They also had to be relevant to mid- and long-term planning and policy analysis, defined here as spanning a time period covering 5-50 years in the future.

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. Several of the major issues are listed below.

Urban Settlements

- 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 analysis related to land use, building standards, district heating strategies, etc.

Transportation Systems

- What are the energy and environmental implications of continuing present trends and policies for inter-and intra-city passenger transportation? How are these modified by policies favoring alternative transportation modes, including mass transit systems?
- What will be the energy and environmental implications of higher efficiency automobiles?

Energy Supply

- What are the consequences and implications of satisfying future energy demand through alternative energy supply options and strategies?
- What is the potential impact of solar energy?

- What is the feasibility of the introduction or expanded use of alternative heating technologies, including district heating, combined thermal-electric plants, and waste-heat use systems?

Structure of Economic Growth

- How would energy demand and environmental quality be affected by alternative patterns of economic growth?

Environmental Protection and Resource Conservation

- Are there environmental limits associated with various patterns of energy demand and supply within the regions?
- What are the environmental effects of various pollution control policies associated with alternative energy system strategies?
- What are the major environmental trade-offs associated with alternative fuels for the production of electricity? How will a policy encouraging expansion of district heating influence air quality?

It was necessary to develop a notation in order to specify a "policy set" within which a scenario was built. With this notation system, the policy is expressed through the specification of a number of characteristics. In a functional form, the framework for a given scenario is described by the following characteristics:

- POPULATION
- ECONOMIC GROWTH AND STRUCTURE
- HUMAN (URBAN) SETTLEMENT LOCATION AND FORM
- TECHNOLOGIES OF ENERGY USE
- TRANSPORT SYSTEMS FOR PEOPLE AND GOODS
- HEAT SUPPLY SYSTEMS
- PRIMARY ENERGY CONVERSION AND SUPPLY TECHNOLOGY (INCLUDING ELECTRICITY GENERATION)
- ENVIRONMENTAL CONTROL AND PROTECTION

This framework then is used to provide the exogenous functions, boundary conditions, constraints, etc. for the models used to build the scenarios.

The policy issues listed above were addressed by two specific paths:

1) The development of three alternative policy sets, each of which was applied to each of the three regions. In the selection of a limited number of scenarios for study, an attempt was made to choose rationales which were meaningful in all three regions, combined the majority of the policy issues described earlier, and could conveniently be compared.
2) The development of sensitivity studies which evaluate the effects of variations in one policy variable while holding the others constant.

Models and Methodology

The primary quantitative tool used for scenario building is a large-scale simulation model, originally developed at the University of Wisconsin and extended at IIASA to treat regional energy/environment systems with characteristics differing from Wisconsin. In addition, some new models or quantitative approaches were or are being developed at IIASA during the course of this research, e.g. energy/environment preference models(7,8) and air pollution methodology (9,10). The Institut fuer Energetik in the GDR also provided considerable quantitative input based upon their extensive calculations in the preparation of the GDR long-term energy plan.

The WISconsin Regional Energy Model (WISE) is a computerized simulation model designed to describe the technological-economic-environmental interactions in a regional energy system. It is built of a hierarchy of submodels. Its simulation structure provides considerable flexibility in both the modelling process and the application; it enables the modification of selected components of the system without the necessity to rework the entire model, and the focusing of attention on specific areas of the energy/environment system as well as the entire system. Although there are numerous ways to describe the overall structure of the WISE model, one of the more revealing is by component subsystems as illustrated in Figure 8.

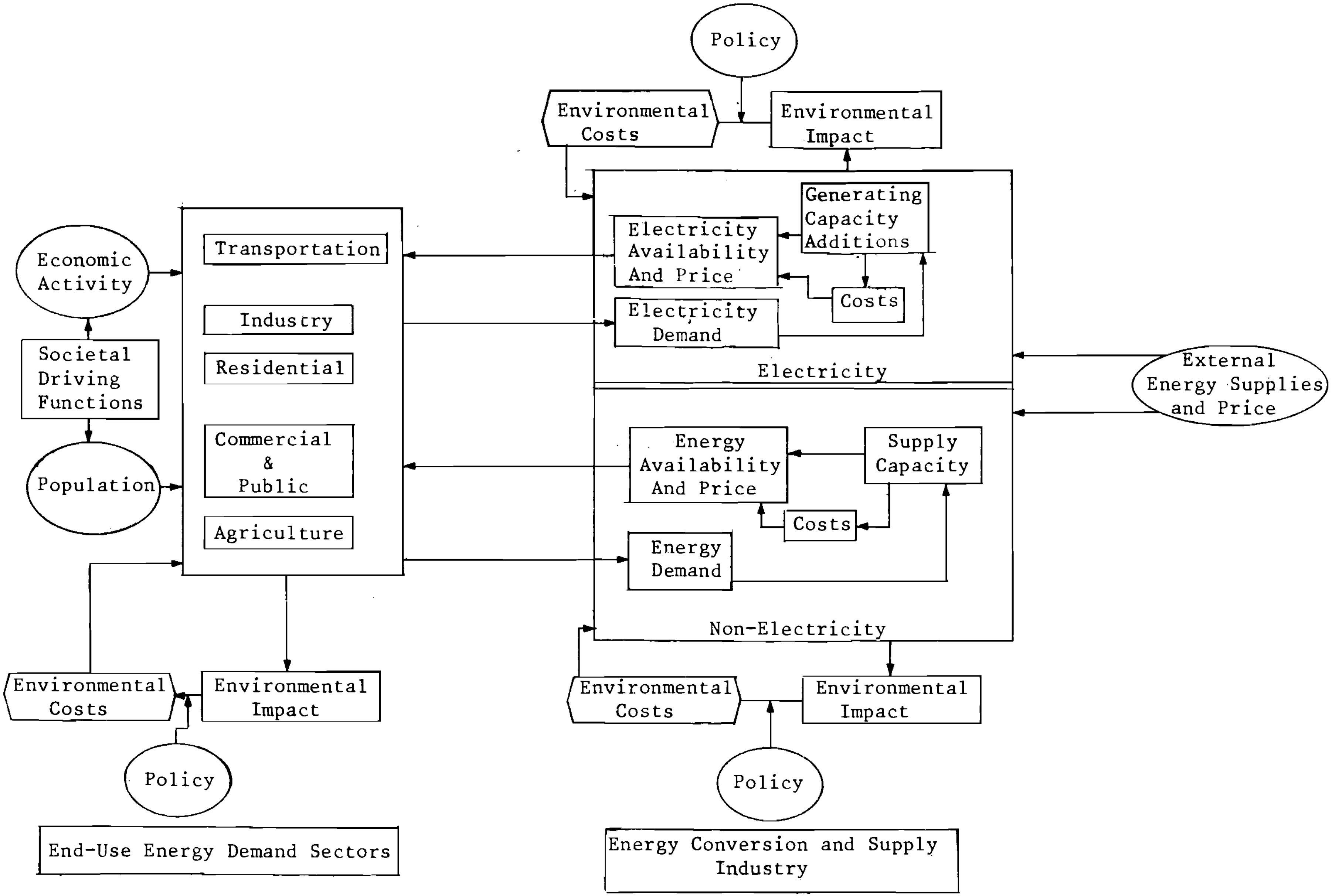


Figure 8: The WISconsin Regional Energy Model (WISE)

The general flow of information in the model begins with the exogenous specification of population, human settlement pattern, and economic activity. These variables provide a basis for the calculation of end-use energy demand. A second group of models calculates characteristics of supply systems necessary to meet that demand, including capacities, primary, etc. The environmental impact models use population and human settlement data, as well as outputs of the energy demand and supply models, to calculate environmental impacts (indicators), including human health and safety. A growing literature exists on the structure and a spectrum of applications of the WISE model (11) and on the IIASA extensions and experiences. Its use in scenario-building is described in more detail in Reference (12).

When a particular submodel or set of submodels was not applicable to a particular region, other alterntives were used. Since a specific energy-use plan exists in the GDR through the year 1990, some of the end-use demand scenarios for the GDR scenario were obtained from the Leipzig Institut fuer Energetik instead of from calculations with the WISE model. In addition, because the Rhone-Alpes region is not a distinct political unit, some types of data were difficult to obtain; in these cases, the models had to be simplified to take advantage of whatever data exist.

The Scenarios

The three scenarios can be briefly characterized as follows:

S1: The "Base Case", representing a continuation of the current socio-economic trends and policies (or the "Plan" in the GDR case).

S2: A scenario resulting from policies encouraging a high-energy future, based on the presumption of low or moderate energy costs and little or no emphasis on improving efficiencies of energy use. Low environmental controls are also assumed.

S3: A low-energy conservation-oriented future, resulting from policies encouraging energy-saving technologies of transport, heating, and industry, and which promote increased environmental quality by means of conservation and stricter pollution controls.

It is recognized that any number of other scenarios could have been chosen for the initial study, perhaps for equally good reasons. However, these three could be applied consistently across each of the regions and seem to focus attention on many important issues.

The above three scenarios have been built at IIASA for Wisconsin, Rhone-Alpes, and for a composite region ("Bezirk X") which is typical of the heavily industrialized southeastern area of the GDR. They were discussed in November 1975 by energy and environmental experts and decision makers from the regions at the IIASA Workshop on Management of Regional Energy/Environment Systems. The final step of the scenario writing process is still underway, namely a retrospective examination of the internal consistency of the dynamic evolution of the energy/environment system.

The scenarios and a cross-regional comparison will be presented in a forthcoming publication (2). As an example of the methodology, a partial description of some Wisconsin results are presented below.

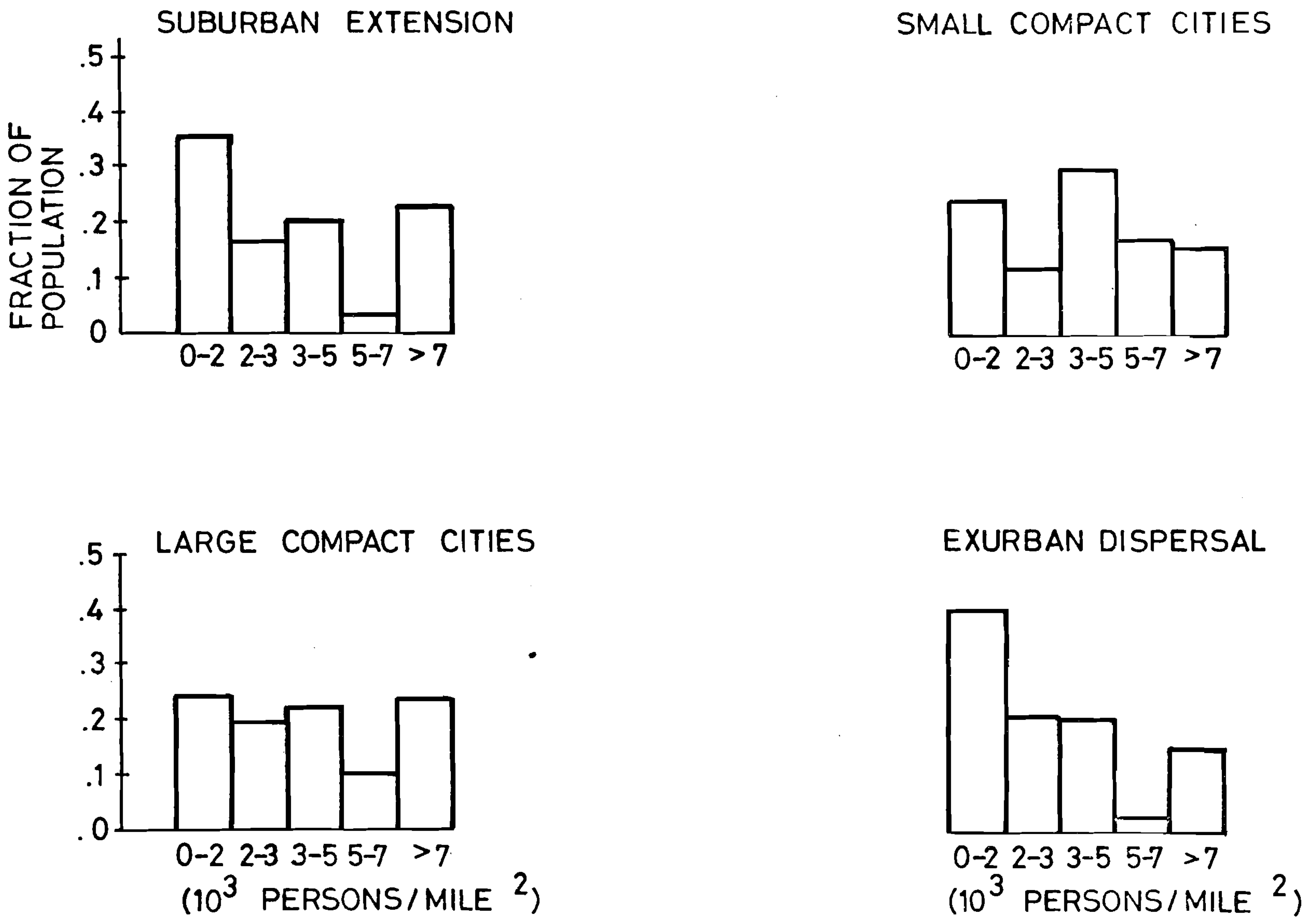
An overview of the three Wisconsin scenarios is shown in Table 5. For purposes of comparison, total population growth and economic activity are not varied among the three scenarios discussed here; the focus is on alternative urban forms and spatial distribution, energy supplies, energy efficiency, and environmental controls. Spatial population distribution affects virtually all parts of the system, e.g. the average trip length for personal transportation is related to city size. Population distribution also affects environmental impacts resulting from energy use in ways other than by modifying energy use. For example, the location of pollution sources relative to population is an important consideration in the estimation of associated health impacts.

Several possible future urban forms for Wisconsin have been postulated and quantified for incorporation in the scenarios. Four of these urban futures with different population density distributions are shown in Figure 9. The Suburban Extension is a continuation of the current density distribution and was used in Scenario S1 (Table 6). The Exurban Dispersal case has more people moving to low population areas and was used in S2. The other two urban forms in Figure 9 have growth in present urban areas, with Small Compact Cities having more growth in less dense urban areas than Large Compact Cities. The Small Compact Cities form was used in S3.

The percentage of total end-use energy in each of the four demand sectors for Scenario S1 is displayed as a function of time in Figure 10. The end-use energy includes only energy consumed in end-use processes; therefore, conversion losses such as in electrical generation, are excluded from the end-use total. The service sector increased its share of total end-use energy from 13 to 31 percent over the 55 year period, while the residential sector's share dropped from 30 to 15 percent. Transportation maintains approximately the same fraction of the total only because freight energy increases in relation to economic activity; personal transportation energy grows at a much lower rate than freight energy in Scenario S1.

	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 electri-	• 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 6: Overview of the Three Wisconsin Scenarios for the Period 1970 to 2025.



FRACTION OF WISCONSIN POPULATION DENSITY IN 2025 BY DENSITY CLASSIFICATION

Figure 9

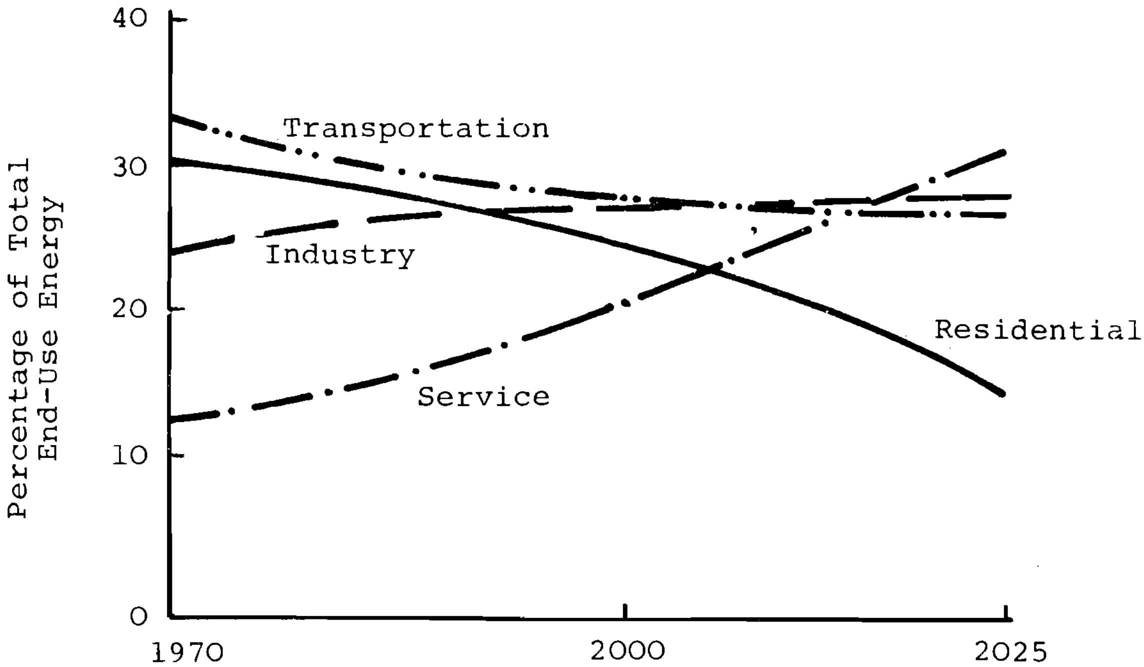


Figure 10: Percentage of Total End-Use Energy By Sector For Wisconsin - Scenario S1

The total emissions of sulfur dioxides, expressed in metric tons of SO_2, for eight districts in Wisconsin, are shown in Figure 11 for the years 1970 and 2025 for Scenario S1. Sulfur emission controls and use of low sulfur coal in coal-fired electrical plants are assumed to reduce the quantity of SO_2 emitted per unit of electrical generation from coal by more than a factor of three over the period shown. The emissions indicated in Figure 11 show a spatial dependence that is based on location of power plants, industries, and population centers. The calculation of expected health impacts depends not on emissions but rather on ground level concentrations. The different release characteristics, e.g., stack height, among the different sources of SO_2 result in ground level concentrations that are not directly proportional to the emissions shown.

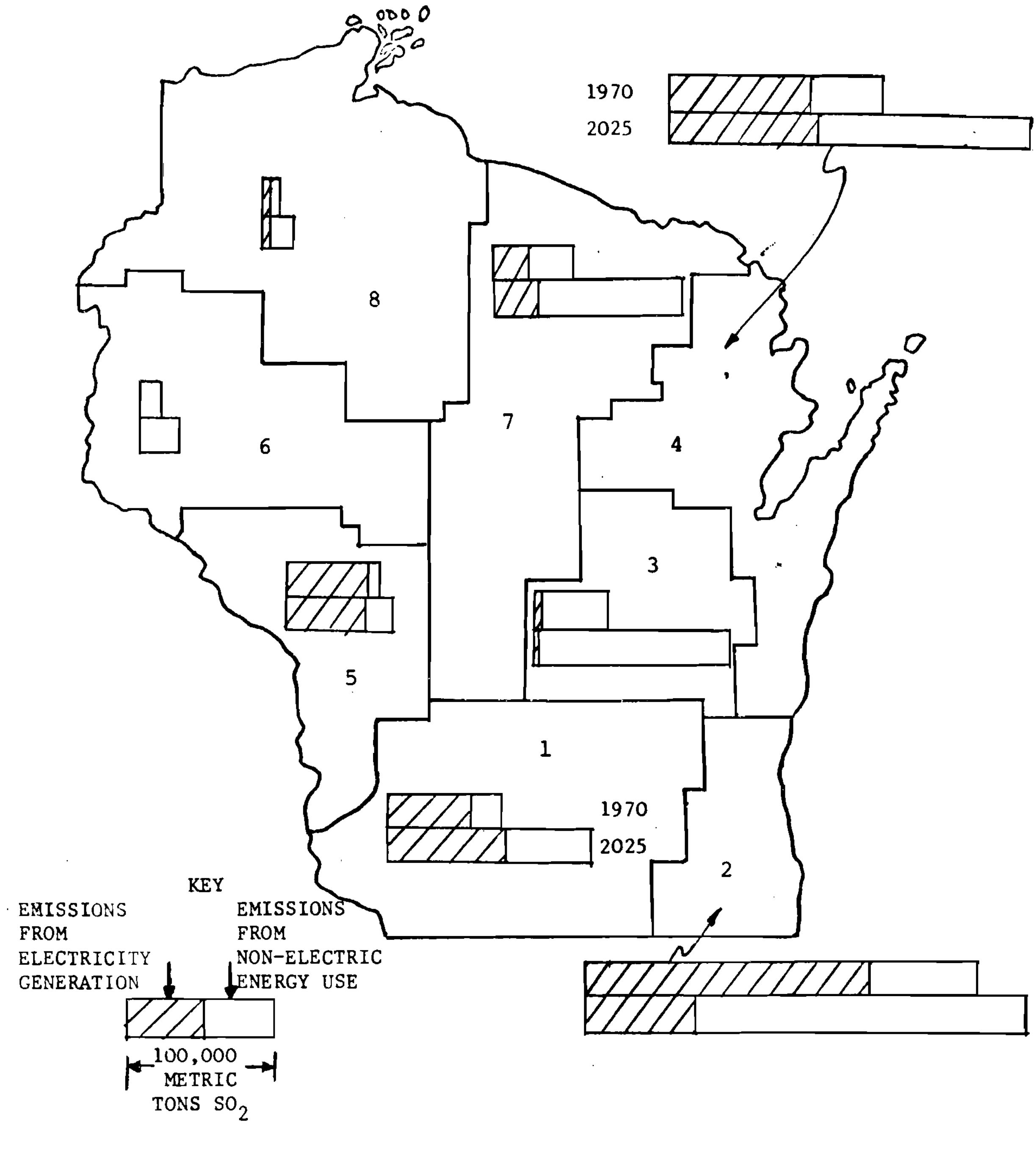


Figure 11: Total Emissions of Sulfur Dioxide in Wisconsin By District for 1970 and 2025 (Scenario S1)

The total primary energy demands, including all conversion and distribution losses for the three scenarios in the years 2000 and 2025, are displayed in Figure 12. All scenarios show a significant expansion in coal use, partially because of the assumption on limited natural gas and petroleum availability by 2025. The low energy scenario, S3, represents about a 1.5 percent per year increase in per capita primary energy. If the conversion losses in producing synthetic fuels from coal could be eliminated, this growth rate would only be about 1.1 per year. Solar energy supplies about 13 percent of the total in 2025 for S3, nuclear supplies nearly half the 2025 energy in S2, and coal supplies about three-fourths of the energy by 2025 in S1. Since each of these primary energy sources have unique sets of environmental effects associated with them, quantified environmental impacts are quite different for the three scenarios. For example, S1 would have the most air pollution, S2 would have the most radiation exposure, and S3 would have highest land use requirements.

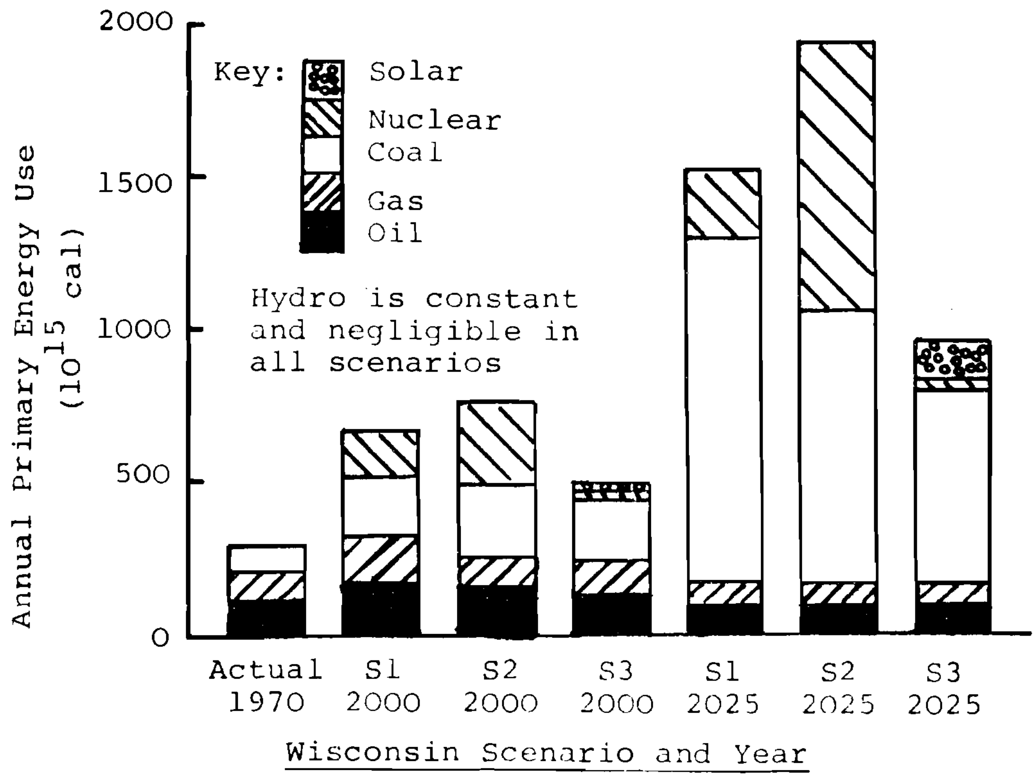


Figure 12: Primary Energy Use for Wisconsin Scenarios

Environmental consequences were one of the major objectives of the scenario building. The SO_2 emissions presented in Figure 11 represent only one of a wide range of indicators used to characterize their environmental implications. Broadly defined, these indicators include effects on land, air, water, structures, and humans, including the health and safety of the general public as well as people employed throughout the energy system. Some of the environmental indicators used were associated with "quantified" human health and safety impact. "Quantified" here refers only to those impacts explicitly included in the Environmental Impact Model used in this research. The choice of this set of impacts clearly has subjectivity associated with it; in addition, some of the calculated impact factors have some degree of uncertainty (and perhaps controversy) associated with them. There are also many impacts which are recognized but remain unquantified; there are others which are unrecognized and unquantified because the impact is not even suspected to exist or considered important. Some initial attempts to cope with uncertainty and subjectivity are described in References (8) and (13).

One of these "quantified" indicators of impact associated with the energy use in each scenario is shown in Figure 13. Person-days-lost (PDL) are used to combine the effects of mortality and morbidity; each fatality is associated with 6000 PDL. The quantified totals shown in the figure include health and accidental impacts on the general public and those people employed throughout the energy system, from resource extraction through waste disposal. The quantified health effects of air pollution from non-electric energy use represent 68, 54, and 18 percent of the PDL in the year 2025 in the scenarios S1, S2, and S3, respectively. One reason the base case (S1) has more PDL than the high energy case (S2), is that residential and service sector air pollution is high in areas of high population in S1. Electricity is used to a large extent in S2, and power plant emissions are well away from population centers and have different dispersion characteristics

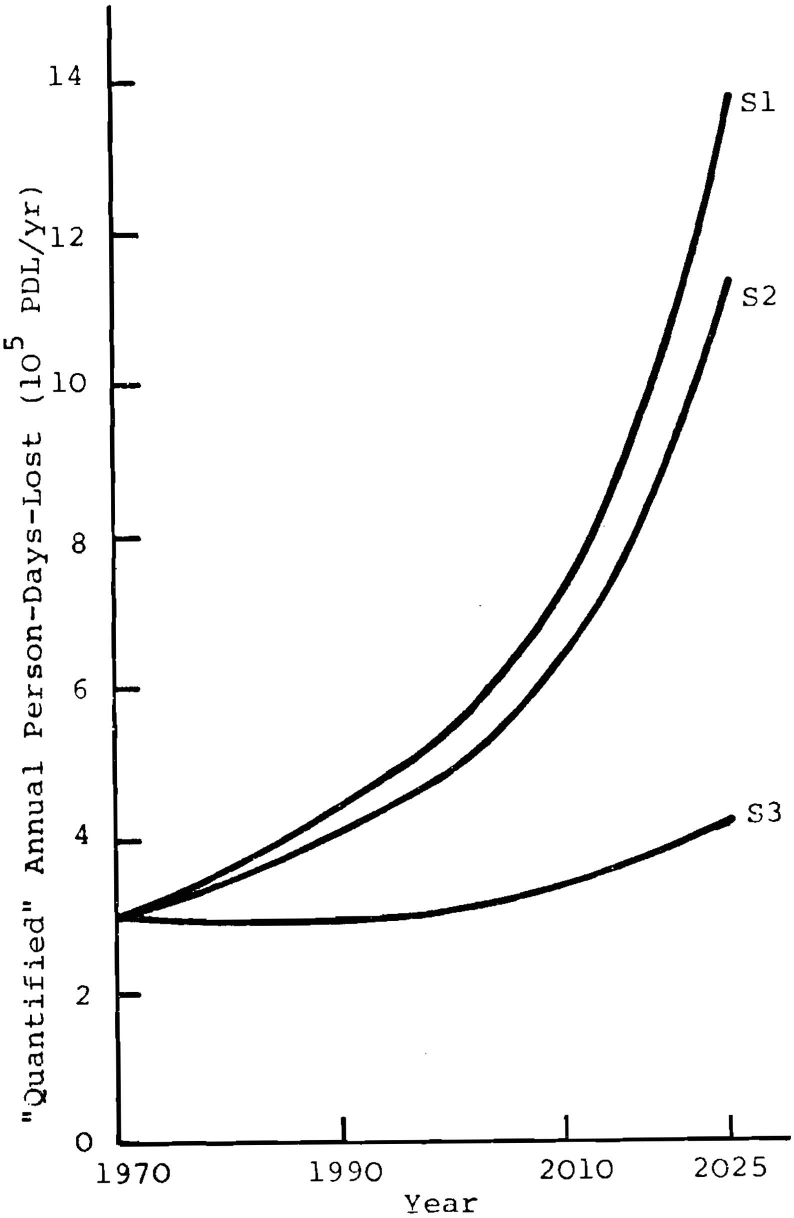


Figure 13: "Quantified" Human Health and Safety Impacts Associated with Energy Use for the Wisconsin Scenarios

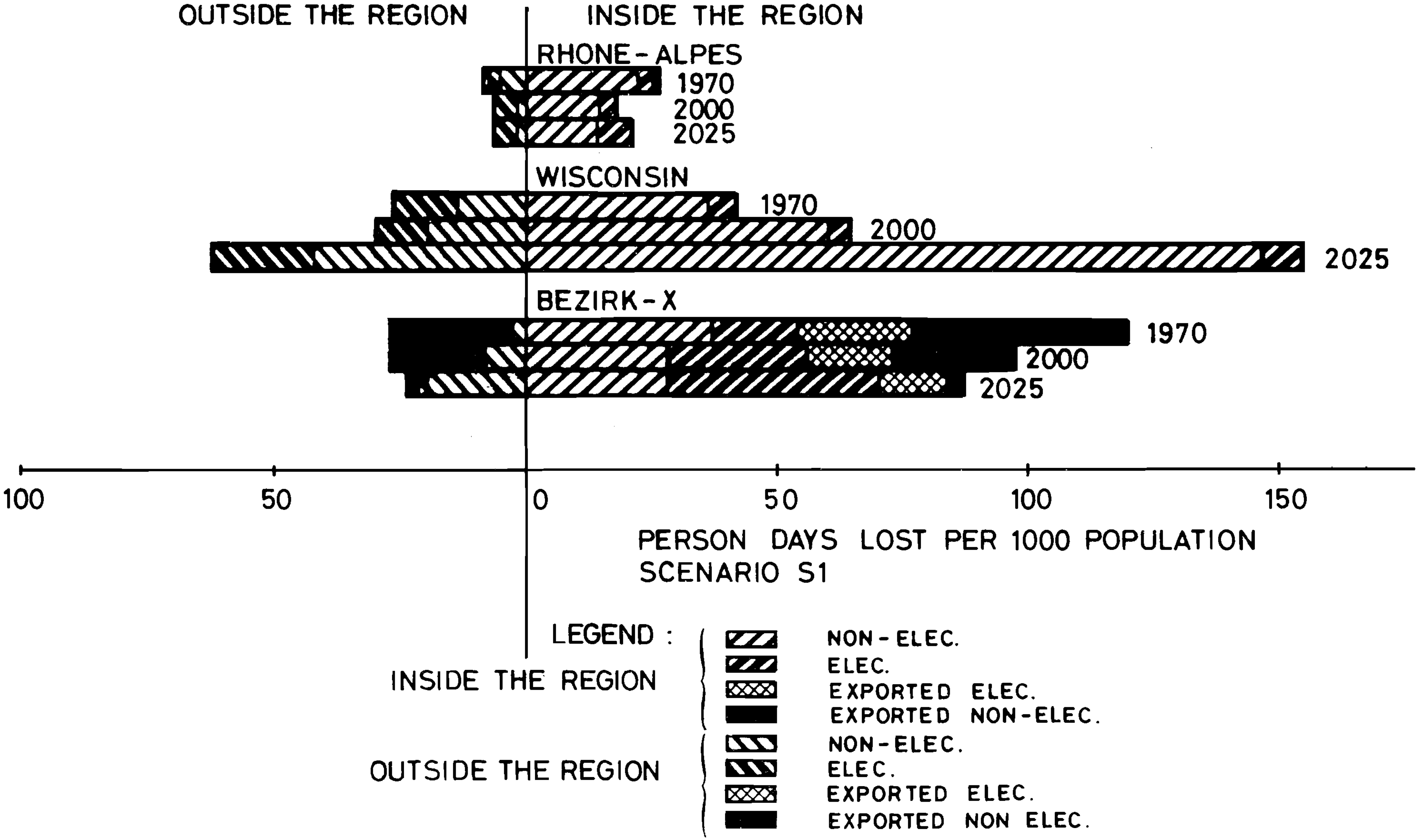
than low level releases, such as from residences. There are many other indicators with which the information shown in Figure 13 can be expressed to give a different perspective, for example on the basis of per capita, per unit land area, per energy use, etc.

The comparison among the three regions is proving useful in evaluating the potential of a range of indicators in policy analysis. As an example of cross-regional comparison, Figure 14 displays the total "quantified" human health and safety impact, in terms of person-days lost, for Scenario S1, for each of the three regions. It should be noted again that Bezirk X is a highly industrialized composite region in the GDR. The quantified human impact in the figure is divided into those impacts that occur within the region and those that occur outside the region. The impacts are divided according to the energy sector with which they are associated, namely,

- non-electrical energy consumption within the region,
- electrical energy consumption within the region,
- exported non-electrical energy, and
- exported electrical energy.

Energy export did not have a major effect on quantified impacts in these scenarios, except in the early years for Bezirk X. An example of an impact associated with electricity use within the region that occurs outside the region, in the case of Wisconsin, is the health and safety impact on coal miners. Wisconsin produces none of the coal that is consumed there. An example of an impact that is associated with non-electrical energy export and occurs within the region, in the case of Bezirk X, is the impact of air pollution near the coal briquette factories which are located within the Bezirk and export some or all of their production. One apparent conclusion from Figure 14 is that for Scenario S1, Wisconsin suffers the greatest quantified human health and safety impact on a per capita basis in the year 2025. However, as mentioned earlier, such results can be viewed from different perspectives, e.g. impacts per unit of energy consumed, that lead to different impressions.

Figure 14: Cross-Regional Comparison of Health Effects of Energy Use



The descriptions of the scenarios and cross-regional comparisons should be consulted for further discussion of the results (2).

A preference model, based on multiattribute decision analysis, has been developed to provide help in the complex task of sorting out the important and unimportant information by a particular decision maker. It is of paramount importance that effective communication and evaluation techniques be used to convey results such as shown in Figures 13 and 14. Clearly those characteristics shown there represent only one small aspect of the total impact, and should not be used in isolation. This is discussed further in the following section.

VI. Evaluation of Options and Strategies: Implementation of Results

It has been pointed out that the 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 builders and the managers and designers of the energy/environmental systems. The scenario writing process is never finished. 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 an ongoing process that rarely stops for long; new knowledge evolves continuously. Time also affects the feedback 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 a very complex task and would differ considerably across the three regions studied in the project because of their very different social and institutional structures. The general framework by which some steps have been taken in this direction is described in the following sections.

Decision Analysis - An Evaluation and Communication Tool

It has been a major task simply to describe these systems and their possible evolution. If one then adds the difficulty of embedding the descriptive and prescriptive processes into an institutional structure for implementation, the overall management problem is truly formidable.

The complexity of the management problem can be in part described by the following characteristics:

(1) <u>The Interdependencies Among Economic, Technological, and Ecological Characteristics of a Region</u>

These interdependencies are not only extremely difficult to quantify, but they imply that conflicting objectives need to be considered within the management process itself. As a well-known example, we simply mention the current controversies about whether high rates of economic growth are compatible with a high quality environment. Are environmental protection measures compatible with local economic growth and maintenance of jobs?

(2) <u>Difficulties in Identifying Costs and Benefits and in Associating Them With Specific Societal Groups</u>

Accounting in a quantitative way for attributes such as air quality, aesthetic values, and resource conservation is very difficult to do today and becomes even more complex as they evolve through time. In addition, some of the costs are equally difficult to quantify. Even with perfect information about the costs and benefits, one can see that they are associated with different groups of people and that the costs and the benefits are not always bestowed upon individuals or groups in an equitable manner.

(3) <u>Uncertainties and Changes Over Time</u>

The benefits and costs of any particular management policy may be uncertain. Even if there exists a good understanding of the system interdependencies today, they may change quite strongly over time in a manner that we do not understand or may not even expect. Some of the long-term environmental effects could have delays associated wtih them so that it is very difficult to estimate or quantify them with present information.

(4) Difficulties in Communicating Complex Material

Even if the above information is known, it is extremely difficult to communicate it to individuals and institutions which must either make a decision on the management problem or implement a strategy. The problems of communicating quantitative and technical information to people who are not specialists is indeed a formidable one. This problem increases in importance as the complexity of our technologically-oriented society increases.

(5) Multiple Decision Makers, Often Within Overlapping Institutional Frameworks, e.g. Multiple Levels of Government

Because the energy/environment system cuts across so many parts of the human enterprise, institutional structures that have evolved are seemingly as complex as the physical system. This results in a multiplicity and sometimes unidentified array of decision and policy makers who have strong involvement in the management problem.

Each of the three regions studied provide a wealth of examples of the complexity of the management problem. Decision analysis has been applied in this study as one approach to the evaluation and communication of alternative policy designs for these complex systems. The particular method used was based upon multiattribute utility theory (14). R. Keeney of IIASA was instrumental in introducing this approach to the IIASA core research group and in implementing it within the research network.

In the approach, a so-called "preference-model" is introduced into the evaluation process. The relationship between the energy/environment "impact model" and the "preference model" is illustrated in Figure 15. The outputs of the

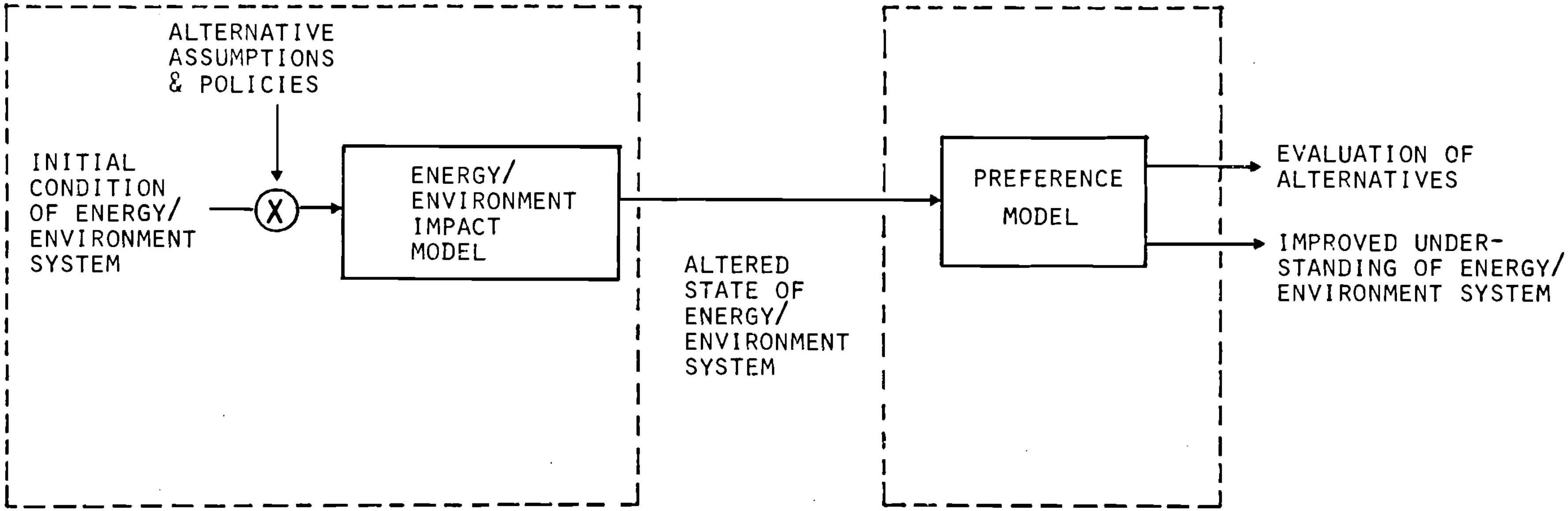


Figure 15: Relationship Between Impact Model and Preference Model.

impact model are impact levels of the "attributes", i.e. the altered state of the systems. Examples are the sets of environmental impacts associated with the various regional scenarios. The impact models are meant to be as objective as possible and contain a minimum of subjective or value-judgement content, clearly not possible in a strict sense. The construction of the preference model for a decision maker requires the assessment of a utility function for each of these attributes.

The actual assessment process requires personal interaction with the decision maker , since his utility function is a formalization of his subjective preferences for the attributes, i.e. impacts. One of the advantages of this evaluation framework is that recognized but unquantified impacts can be identified and included in the analysis by determining an appropriate proxy variable that can be measured. The overall preference model, based on the measured utility function for a particular individual, allows the calculation of the individual's expected utility associated with the combined impacts of a given policy (scenario). The expected utility calculated for an alternative is a measure of the relative desirability of that alternative for the assessed individual.

Our first application of the above method to regional energy/environment systems was based upon a set of policies related to the choice of electricity generation systems for Wisconsin. The Electricity Impact Model (13) was used to generate the following eleven attributes of a set of scenarios based upon alternative policies:

X_1 = Total Quantified Fatalities

X_2 = Permanent Land Use

X_3 = Temporary Land Use

X_4 = Water Evaporated

X_5 = SO_2 Emissions

X_6 = Particulate Emissions

X_7 = Thermal Energy Needed

X_8 = Radioactive Waste

X_9 = Nuclear Safeguards

X_{10} = Health Effects of Chronic Air Pollution Exposure

X_{11} = Electricity Generated

Utility functions were determined for two individuals from Wisconsin and used to evaluate the set of scenarios (15).

In a follow-on study (8), preliminary utility assessments were completed for five individuals from Rhone-Alpes, the GDR, and Wisconsin over a set of four attributes selected from the above set of eleven. The group of individuals included a mixture of decision makers and energy/environment specialists. The utility function u_i over attribute X_i is set equal to zero at the least desirable level of X_i in the range and set equal to one at the most desirable level of X_i in the range; the shape of the function is determined by the assessment procedure. Some representative results are shown in Figure 16 for one of the individuals assessed. The utility functions for the four individuals were used to evaluate their preferences for several hypothetical supply and environmental policies.

What have we learned from these initial applications of this approach? First of all, we must emphasize that we agree with Holling et al. (16) who, in their Forest/Pest Management studies, bemoaned the unsatisfied need for an adequate framework to interpret and use social, economic, and environmental indicators. The above approach does not eliminate the difficulties of meaningfully aggregating across kind, time, and space so that rational preferences can be expressed among alternative futures. Second, we do recognize some of the practical difficulties in implementing this procedure within many types of decision making and policy analysis structures. However, we have discovered that the process itself can have benefits, i.e. the process of building a preference model can assist in evaluating policy. Included among these benefits

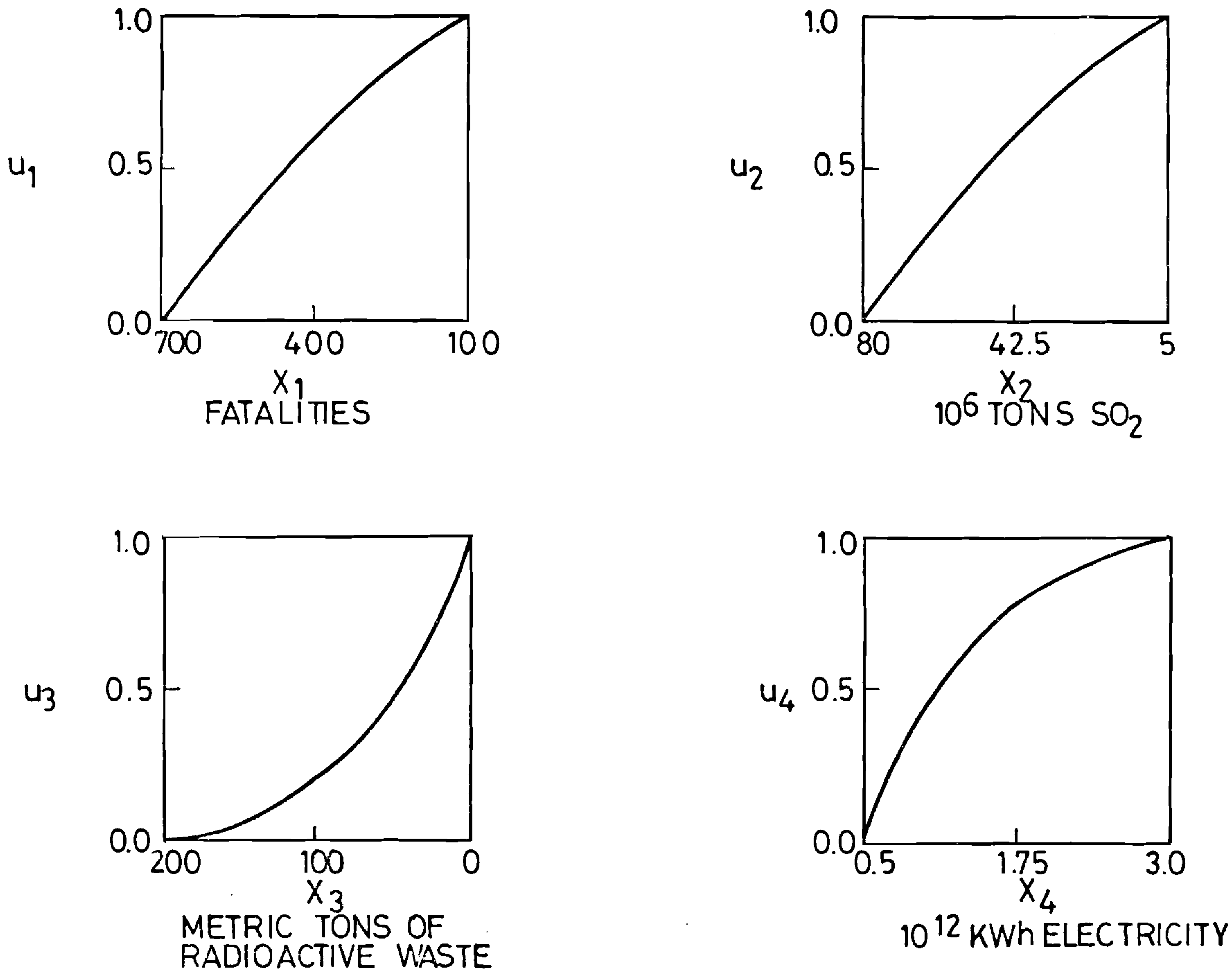


Figure 16: Utility Functions for One Individual

are:

- Aid in the understanding and communication of the value tradeoff alternatives.
- Aid in identifying important issues and sensitizing individuals to them.
- Isolating and resolving conflicts of judgement and preference among groups.
- Making modellers aware of additional areas of concern, in general leading to improvements of the impact models.

These benefits and others have made it apparent that continued and even more effort should be devoted to this component of the research program. An interinstitutional task force has been formed to continue the development of this approach and to develop procedures by which it can be integrated with some of the more traditional computational procedures.

Implementation and Transfer of the Research Results

Although each of the research components described in the preceding sections has the potential to make a contribution toward improved management of regional energy/environment systems, none of them should stand alone. It is essential that each of them be used in complement to the others and, more importantly, that they be linked together in a coherent research format which promotes frequent interaction with the institutional and decision clients for which it is intended.

The need for interaction with the client cannot be overemphasized. This was given primary emphasis during the 1975 research program. From its inception, an attempt was made to solicit information from the appropriate users - and at the conclusion of the first phase of the program, they were solicited for evaluation of the scenario building results. Frequent workshops provided a key mechanism for encouraging this interaction within the research network. This process, shown schematically in Figure 17, was perhaps the key element in integrating the several components of the research program and in providing a communication interface between the modellers in the three regions.

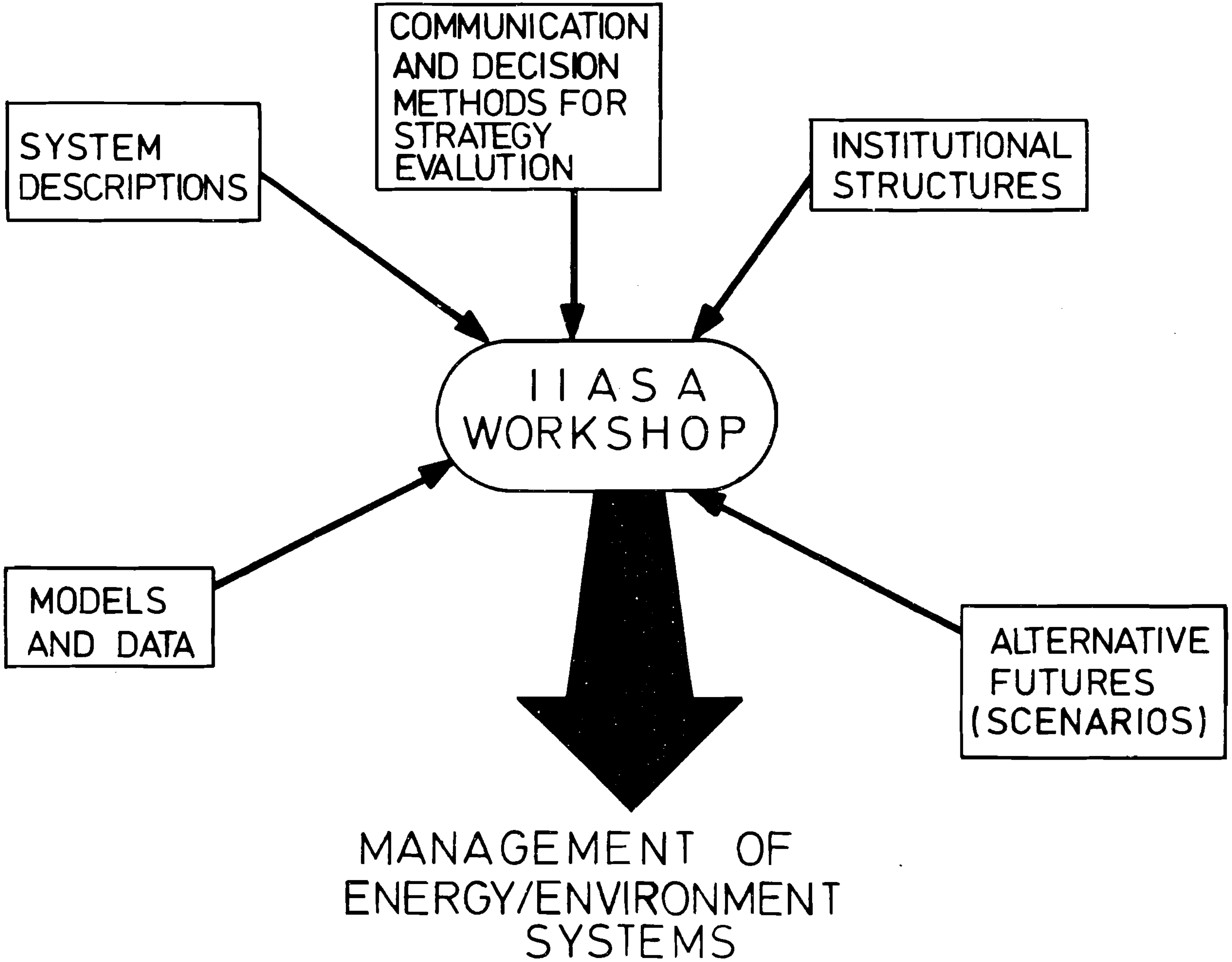

COMMUNICATION AND DECISION METHODS FOR STRATEGY EVALUTION
SYSTEM DESCRIPTIONS
INSTITUTIONAL STRUCTURES
IIASA WORKSHOP
MODELS AND DATA
ALTERNATIVE FUTURES (SCENARIOS)
MANAGEMENT OF ENERGY/ENVIRONMENT SYSTEMS

Figure 17

The research program reached a milestone in late 1975, with the holding of a workshop at IIASA, bringing together 25 scientific experts, policy makers, and members of the public from the three regions. Figure 17, in addition to describing schematically the format of the entire research program, is representative of that workshop. In addition to providing a socio-technical interaction of specialists and policy makers from the GDR, France, and the U.S., the workshop provided an opportunity to introduce the comparative scenarios and the alternative models into current planning and policy design procedures in the GDR, France, and Wisconsin.

In addition, at the November 1975 workshop, several contributed papers were presented by each of the collaborating institutions, including appraisals of each other's modelling procedures, and comparison of some of the energy and environmental planning practices in the region, e.g. pricing, environmental standards, and building practices. These contributed papers are being prepared for publication in the Workshop Proceedings.

A research transfer process which is tacked onto the tail end of a research program has almost no chance of success. It is essential that the transfer process be given high priority at the very beginning of a study whose ultimate objective is improved policy design and that this priority be preserved through the entire process. The objective of this transfer is not specific policy recommendations, but rather the transfer of concepts, models and methodologies, evaluation procedures, and a range of policy analyses. Our efforts to do this, perhaps only partially successful, have been terribly demanding of time and energy and, occasionally, even frustrating. At times, they may seem to distract us from the substantive research activities which have traditionally been the domain of specialists in each of our fields. But without exception, there is agreement among the research team that even a partial success in embedding the research outputs into the actual policy-design processes would be more than adequate justification of our efforts.

VII. Future Work

One of the most important outputs of the 1975 research has been the creation of a network of research institutions, coordinated by IIASA. This has provided IIASA with encouragement in its role as a catalyst and coordinator of policy-oriented research in the international scientific community. The three collaborating institutions will continue to pursue research during 1976, but in addition, IIASA will be extending the studies to other regions. These regions are again being chosen to cover very different socio-economic, geographic, and institutional characteristics. Specifically, one of them will be located in a less-industrialized country; its greatly different characteristics will allow the IIASA team to further generalize their models and methodologies. Although we realize there will never be a universal energy/environment model, our long-range goal is the generalization of these approaches into a coherent and sound process for resource management in all regions of the world.

REFERENCES

(1) The IIASA Ecology Project: A Status Report, RR-76-2 International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

(2) Proceedings of a Workshop on Integrated Management of Regional Energy/Environment Systems held November 10-14, 1975. International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

(3) Born, S., C. Cicchetti, R. Cudahy, and J. Pappas (Wisconsin); P. Hedrich, K. Lindner, and D. Ufer (GDR); J.-M. Martin and D. Finon (France), Energy/Environment Models and their Relationship to Planning in Wisconsin, the German Democratic Republic, and Rhone-Alpes, RM-76-21, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

(4) Born, S., C. Cicchetti, R. Cudahy, and J. Pappas, Energy/Environmental Models and their Relationship to Planning in Wisconsin, in Energy/Environment Models and their Relationship to Planning in Wisconsin, the German Democratic Republic, and Rhone-Alpes, RM-76-21, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

(5) Martin, J.-M. and D. Finon, Energy/Environmental Models and their Relationship to Planning in Rhone-Alpes, in Energy/Environment Models and their Relationship to Planning in Wisconsin, the German Democratic Republic, and Rhone-Alpes, RM-76-21, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

(6) Hedrich, P., K. Lindner, and D. Ufer, Energy/Environmental Models and their Relationship to Planning in the GDR, in Energy/Environment Models and their Relationship to Planning in Wisconsin, the German Democratic Republic, and Rhone-Alpes, RM-76-21, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

(7) Keeney, R., Energy Policy and Value Tradeoffs, RM-75-65, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

(8) Buehring, W.A., W.K. Foell, and R.L. Keeney, Energy/Environment Management: Application of Decision Analysis, RR-76-14, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

(9) Dennis, R.L., Regional Air Pollution Impact: A Dispersion Methodology Developed and Applied to Energy Systems, RM-76-22, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming,

(10) Buehring, W.A. and R.L. Dennis, Evaluation of Health Effects from Sulfur Dioxide Emission for a Reference Coal-Fired Power Plant, RM-76-23, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

(11) Foell, W.K., J.W. Mitchell, and J.L. Pappas, The WISconsin Regional Energy Model: A Systems Approach to Regional Energy Analysis, University of Wisconsin-Madison, Institute for Environmental Studies, Report 56, Sept. 1975.

(12) Foell, W.K., Scenario Writing: One Component of a Systems Approach to Energy/Environment Management, RM-76-20, International Institute for Applied Systems Analysis, Laxenburg, forthcoming.

(13) Buehring, W.A. and W.K. Foell, Environmental Impact of Electrical Generation: A System-Wide Approach, RR-76-13, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

(14) Keeney, R.L. and H. Raiffa, Decision Analysis with Multiple Conflicting Objectives: Preferences and Value Tradeoffs, Wiley, New York, (in press).

(15) Buehring, W.A., A Model of Environmental Impact from Electrical Generation, unpublished Ph.D. dissertation, Dept. of Nuclear Engineering, University of Wisconsin-Madison, 1975.

(16) Holling, C.S. et al., A Case Study of Forest Ecosystem/Pest Management, in The IIASA Ecology Project: A Status Report, RR-76-2, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

PAPERS IN THE IIASA PUBLICATION SERIES ON MANAGEMENT OF ENERGY/ ENVIRONMENT SYSTEMS

Keeney, R.L., "Energy Policy and Value Tradeoffs", RM-75-65, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

Foell, W.K., "The IIASA Research Program on Management of Regional Energy/Environment Systems", RM-76-40, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

Buehring, W.A. and W.K. Foell, "Environmental Impact of Electrical Generation: A Systemwide Approach", RR-76-13, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

Buehring, W.A., W.K. Foell and R.L. Keeney, "Energy/ Environment Management: Application of Decision Analysis", RR-76-14, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

Foell, W.K., "Scenario Writing: One Component of a Systems Approach to Energy/Environment Management", RM-76-20, International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

Born, S., C. Cicchetti, R. Cudahy , and J. Pappas (Wisconsin); P. Hedrich, K. Lindner, and D. Ufer (GDR); J.-M. Martin and D. Finon (France), "Energy/Environment Models and their Relationship to Planning in Wisconsin, the German Democratic Republic, and Rhone-Alpes", RM-76-21. International Institute for Applied Systems Analysis, Laxenburg, Austria, forthcoming.

<u>Forthcoming</u>

Dennis, R.L., "Regional Air Pollution Impact: A Dispersion Methodology Developed and Applied to Energy Systems", RM-76-22, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

Buehring, W.A. and R.L. Dennis, "Evaluation of Health Effects from Sulfur Dioxide Emissions for a Reference Coal-Fired Power Plant", RM-76-23, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

Buehring, J., "WISSIM: An Interactive Computer Simulation Control Language", RM-76-24, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.