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MANAGEMENT OF ENERGY/ ENVIRONMENT SYSTEMS

Methods and Case Studies

Edited by
WESLEY K. FOELL

International Institute for
Applied Systems Analysis

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Energy Research Center
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This is a book which concentrates on the solution of global energy problems through energy system management at regional and subnational levels. It arises from a joint study by east and west of three regional energy/environment systems with very different political, economic, and social frameworks; these are the German Democratic Republic, the Rhone-Alpes region of France, and Wisconsin in the United States of America. This is, therefore, a significant contribution to the management of the energy problems facing most industrialized societies.

Contents

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To the spirit of cooperation and to the expansion of the IIASA network of institutions and individuals from diverse countries of the world, a network devoted to the improved management of energy and environmental systems

Foreword

Achieving social, political, economic, and environmental stability on a global scale is an elusive but important objective for the benefit of future generations. The size and complexity of the world's society, the increasing demands of human population, and the finite character of the earth and its resources are forcing us to adjust to new realities. Yet, the inertia in our social system is such that it could take several generations to effect orderly changes that culminate in a sustainable balance among the earth's population, its environment, and its principal renewable or recyclable resources. Scientists and statesmen, leaders, and laymen are striving to understand the complexities of this balance.

Few of us interpret the signposts of civilization in the same way; consequently, prophesies for the future span a wide range of possibilities. No one will dispute, however, that to design and follow an orderly course to a stable, sustainable and prosperous world society will require understanding and cooperation among the diverse nations of the world. If such understanding and cooperation are to be adequately developed, international institutions will be needed in which a body of useful experience can be accumulated and ideas can evolve, mature, and become available to the world community. The International Institute for Applied Systems Analysis (IIASA) is becoming one such institution.

IIASA has defined two types of world problems – those that are universal and those that are global. Universal problems are those that many nations have in common, but that each must solve separately. These problems can be worked on by countries individually or collectively and suggested solutions made available to other interested nations. The solution of global problems, on the other hand, requires that the many nations act as one. IIASA is pursuing the understanding of and solutions to both types of problems.

The IIASA research study, Management of Regional Energy/Environment Systems, begun in 1975, has demonstrated how IIASA can assemble a multinational, multidisciplinary team to identify and analyze a given universal problem and its solutions. Such studies increase the understanding of nations on critical issues, surely a necessary step toward achieving a healthier and more stable world community.

RUSSELL W. PETERSON
Director
Office of Technology Assessment
United States Congress

Preface

This book describes an international experiment in East–West collaborative research. The study upon which it is based grew out of a conviction that one vital component of any solution to our increasingly critical global energy problems will be more effective energy system management at the *regional* and *subnational* levels. Furthermore, because of the universality of energy problems among most industrialized societies, the appraisal and further development of these management approaches could greatly benefit from an international setting that spanned economic, political, and social differences between East and West. The International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, provided exactly that setting.*

The IIASA research study, Management of Regional Energy/Environmental Systems, was formally initiated in January 1975. Taking advantage of IIASA's access to scientists and institutions in a range of countries in both the socialist and market economy groups, three distinct regions with greatly different political, economic, and social frameworks were chosen for a comparative study. The regions chosen were the German Democratic Republic (GDR), Rhone-Alpes in France, and Wisconsin in the United States. An international IIASA core team conducted in-house research in collaboration with a research institution in each of the three regions: the Institut für Energetik, Leipzig, GDR; the Institut Economique et Juridique de l'Energie, Grenoble, France; and the University of Wisconsin – Madison, Madison, Wisconsin, United States.

Since 1975, IIASA and the three research institutions have formed the nucleus of a small and informal research network coordinated by IIASA. Although IIASA provided the bulk of the financial support through its core research team, each of the three regional institutions also contributed substantially through the time and efforts of its scientific staff, both at their home base and during frequent

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* For information on IIASA, please see the inside of the front cover.

informal meetings and workshops at IIASA. Each regional representative brought with him a significant background of experience in energy systems and policy analysis in his own country. I believe that the interinstitutional arrangements within which this study was conducted served not only to improve our approaches to energy and environmental system management, but also promoted improved understanding between the countries themselves and provided a basis for further cooperation.

In the process of describing and disseminating the results of this research, we have become aware of the breadth of interests and expertise of our audience. We have structured our reporting to meet the needs of four audiences:

1. Policymakers
2. Energy/environment managers, planners, and technical advisors
3. Modelers and analysts
4. Computer systems specialists and programmers

This book is addressed primarily to groups 2 and 3. It focuses on the building and description of long-term energy scenarios for each of the regions as well as on the description of each region's current energy system and the procedures used to manage it. Although the research results provided insight into the energy systems of the regions, the research teams feel that the research *process* was of equal importance.

Because our concept of the energy/environment system of a region is broadly defined to include socioeconomic, technological, and ecological components, we believe the book offers something to the staff of energy enterprises, urban and regional planners, staff and administrators of energy regulatory agencies, environmental and energy researchers, and not least importantly, some interested members of the public. We also hope that the international perspective of this study will make it of interest to countries in both East and West.

For groups 1 and 4 above, other documentation has been or is being prepared. A short set of executive reports is under preparation; and IIASA research reports and memoranda (listed in the chapter references) provide documentation of data and models for the use of modelers and computer-oriented specialists.

The IIASA research team takes responsibility for the conclusions stated here. Although the collaborating institutions did participate extensively in all phases of the research, including the specification and definition of the alternative energy/environment scenarios, the final form of the results and the documentation has not been subject to their detailed review.

WESLEY K. FOELL

Acknowledgments

The material in this book resulted from the contributions of many individuals at IIASA and the collaborating institutions. More detailed descriptions of some of the individual contributions can be found in the references and in other publications resulting from the study. Although all the participants cannot be acknowledged here, the following individuals were associated in a major way with the research:

- International Institute for Applied Systems Analysis (IIASA)
  - Jacqueline Buehring
  - William Buehring
  - Jean-Pierre Charpentier
  - Robin Dennis
  - Loretta Hervey
  - Alois Hölzl
  - Koichi Ito
  - Ralph Keeney
  - Bruno Lapillonne
  - Harald Stehfest
  - Ralf Yorque
- Institut für Energetik, Leipzig, German Democratic Republic
  - Willy Hätscher
  - Peter Hedrich
  - Wolfgang Kluge
  - Dietmar Ufer
- Institut Economique et Juridique de l'Energie (IEJE), Centre National de la Recherche Scientifique (CNRS), Grenoble, France
  - Bertrand Chateau
  - Dominique Finon

Jean-Marie Martin

University of Wisconsin – Madison, Madison, Wisconsin, United States

Wesley K. Foell, Study Director
Mark Hanson
John Mitchell
James Pappas

Howard Raiffa, IIASA's first director, and Buzz Holling, initial leader of the IIASA Ecology/Environment Project, acted as catalysts for the study and were greatly supportive in the fragile early stages. Roger Levien, current director of IIASA, gave much encouragement in the subsequent stages of the work.

Denise Cavard and Ivano Renzetti of the IEJE, Grenoble, expertly and industriously gathered and analyzed the French data used as a basis for the Rhone-Alpes scenarios. Elizabeth Ampt, Jordanka Dimitrova, Hilary Lee, and Judy Ray of IIASA also provided substantial and dedicated assistance during the course of the research. Jerome Weingart of IIASA gave valuable advice on a reference solar energy system.

The research described in Chapters 1–7 can be attributed to the entire IIASA core group with principal contributions by the chapter authors listed below. The appendixes contain work by IIASA staff as well as specific papers by individuals from institutions in the regions. These authors are also listed below.

Chapter 1 Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison
Chapter 2 Loretta Hervey, Alois Hölzl – IIASA
Chapter 3 William Buehring – IIASA, Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison
Chapter 4 Robin Dennis – IIASA
Chapter 5 Bruno Lapillonne – IIASA
Chapter 6 William Buehring – IIASA
Chapter 7 Jacqueline Buehring, William Buehring – IIASA; Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison
Appendix A
  Section I Alois Hölzl – IIASA
  Section II Alois Hölzl – IIASA
  Section III William Buehring – IIASA
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Appendix B
  Section I Dietmar Ufer – Institut für Energetik, Leipzig
  Section II Jean-Marie Martin, Dominique Finon – Institut Economique et Juridique de l'Energie (IEJE), Grenoble
  Section III Stephen Born – Wisconsin State Planning Office, Charles Cicchetti – Wisconsin Office of Emergency Energy Assistance, Richard Cudahy – Wisconsin Public Service Commission

Appendix C
  Section I Loretta Hervey, Robin Dennis – IIASA
  Section II.A. Alfred Wischnat – Institut für Energetik, Leipzig
  Section II.B. Bertrand Chateau – Institut Economique et Juridique de l'Energie (IEJE), Grenoble
  Section II.C. J. Mitchell – University of Wisconsin – Madison
  Section III.A. L. Jordan – Institut für Energetik, Leipzig
  Section III.B. Daniel Blain – Délégation Générale à l'Energie, Ministere de l'Industrie, Paris
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  Section I.A. Peter Hedrich – Institut für Energetik, Leipzig
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  Section I.C. Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison; James Pappas – University of Wisconsin – Madison
  Section II.A. Jean-Marie Martin, Dominique Finon – Institut Economique et Juridique de l'Energie (IEJE), Grenoble
  Section II.B. Peter Hedrich, Dietmar Ufer – Institut für Energetik, Leipzig
  Section II.C. Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison; James Pappas – University of Wisconsin – Madison
  Section III.A. James Pappas – University of Wisconsin – Madison
  Section III.B. Peter Hedrich, Dietmar Ufer – Institut für Energetik, Leipzig
  Section III.C. Dominique Finon – Institut Economique et Juridique de l'Energie (IEJE), Grenoble
Appendix E William Buehring, Ralph Keeney – IIASA; Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison

Contents

APPENDIXES: BACKGROUND PAPERS

1 Introduction

I. BACKGROUND AND OBJECTIVES OF THE STUDY

Energy and environmental problems first became front-page news in the late 1960s and early 1970s. In 1972, the first report commissioned by the Club of Rome, *The Limits to Growth* by Meadows *et al.*, burst upon the world scene, generating tremendous attention and debate in many industrialized countries, not only in academic, government, and business circles, but also by the general public. The possible long-term impacts of environmental degradation and resource depletion reached the public awareness. In autumn, 1973, the cutoff of Mideast oil supplies dramatically demonstrated to the industrialized world the central role played by energy in our society and the maze of interdependencies through which it is linked to the economic and technological fabric of the human enterprise. Since that time, energy planning has become more important at all levels of government in most industrialized countries.

The above events, in concert with a number of other resource-related issues, have brought about the following:

- Increasingly often, society is *explicitly* incorporating energy into its important decision processes.
- A recognition has developed of the major role that energy plays in the quality of the environment.
- Energy and environmental management are becoming recognized as important components of national and regional planning.

This book examines the method and the practice of energy and environmental

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Chapter 1 was written by Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison.

management – from the perspective of different regions of the world. It is based upon a research program initiated in January 1975 by the International Institute for Applied Systems Analysis (IIASA). The study, designed to integrate energy and environmental management from a systems perspective, had four primary objectives:

1. To describe and analyze patterns of regional energy use and to develop insight into their relationships to socioeconomic and technical variables
2. To compare and appraise alternative methodologies for regional energy and environmental forecasting, planning, and policy design
3. To extend and develop concepts and methodologies for energy/environment management and policy design
4. To use the above methodologies to examine alternative energy policies and strategies for specific regions, to explore their implications from various perspectives using indicators related to environmental impact, energy use, and the like, and to investigate whether these strategies represent a viable choice for a given society

"Regional," as used here, is not defined as either subnational or as a specific part of the world; rather, it refers to a geographic region, appropriately bounded so that it is possible to speak of energy and environmental systems, either from a physical, socioeconomic, or administrative perspective, or from all three. A regional rather than global perspective is employed because many of the significant social and environmental consequences of energy systems are best analyzed within the context of a specific region. In the language of the systems analyst, this is referred to as "embedding" the system in a specific human environment.

What are some of the major regional issues to be addressed? To be sure, they differ according to the region, but there are, nevertheless, several concerns common to many regions. Representative of these are:

Energy Use Patterns: What are the energy implications of continuing the present evolution of energy use patterns? How are these modified by the penetration of alternative energy use technologies, e.g., mass transit systems in the transportation sector?

Energy Supply: What are the resource and environmental implications of satisfying future energy demand by the various alternative energy sources? What additions will be required in the coming decades to the electricity generating, transmission, and distribution facilities?

Human Settlements: How is energy use related to settlement density, size, types of housing, and energy supply technology? What role should these factors play in land-use planning, zoning, and building regulations? How will alternative land development patterns affect environmental quality?

Environmental Protection: What are potential environmental limits associated with alternative patterns of energy demand and supply within a region? What effects

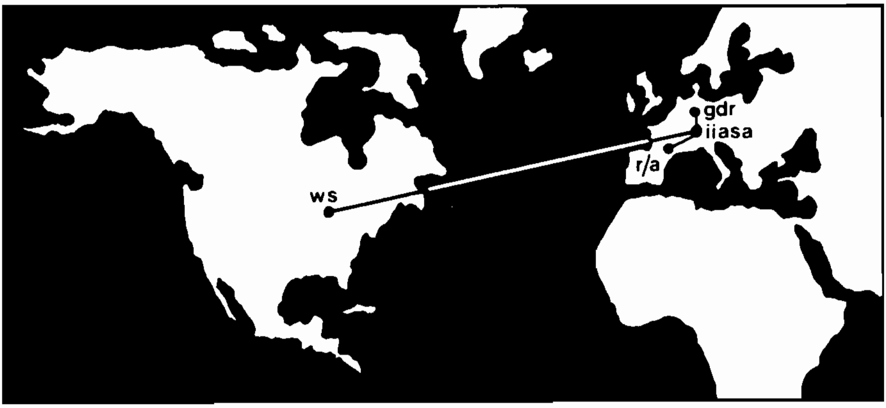

FIGURE 1.1 The 1975 international network of the IIASA Regional Energy/Environment Project. gdr = the German Democratic Republic; r/a = Rhone-Alpes; ws = Wisconsin; iiasa = International Institute for Applied Systems Analysis, Laxenburg, Austria.

would various pollution control policies have on environmental impacts associated with alternative energy strategies?

Several "world" or "global" energy studies have been conducted within the past few years, e.g., the Workshop on Alternative Energy Strategies (WAES),[1] The Second Club of Rome Report,[2] and the Organisation for Economic Co-operation and Development (OECD) energy forecast (*World Energy Outlook*).[3] These international studies play an important role in providing a broad perspective to evaluate the combined global effect of various national strategies and technological choices. In contrast, in the research described in this book, a regional rather than global approach was employed. To provide a broader view of both theory and practice, the IIASA research was organized on a comparative basis. It focuses on energy/environment management in three greatly differing regions – the German Democratic Republic (GDR), the Rhone-Alpes region in southern France, and the state of Wisconsin in the United States (Figure 1.1). These regions were chosen primarily because of their greatly differing socioeconomic and political structures, their technological base, their geographic and environmental properties, and their current institutional approaches to energy and environmental management. Comparative studies of differing systems are valuable in that they can help formulate a more generalized understanding of system behavior, as well as an appreciation of the techniques commonly used to study them. For example, it is possible to examine the applicability of a specific energy demand analysis technique to all three of the regions. Two important previous comparative studies are those of Darmstadter[4] and Schippers and Lichtenberg.[5]

The research was oriented toward methodology and policy in an effort to narrow

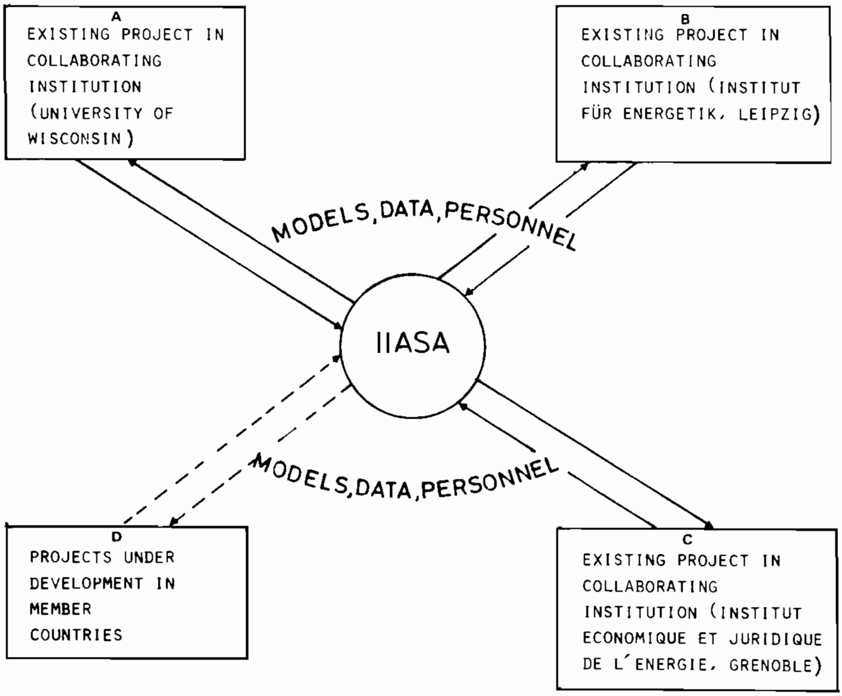

FIGURE 1.2 Interinstitutional relations within the energy/environment system study. "Member Countries" in the lower left-hand box refers to countries that support IIASA.

the gap between the practitioner and the client of applied systems analysis. The management approaches described here are aimed toward long-term management rather than day-to-day operational questions; that is, they are within a strategic rather than an operational or tactical framework.

II. ORGANIZATION OF THE STUDY

II.A. A RESEARCH NETWORK

One of IIASA's strengths is its access to research institutions and scientists throughout the world – and its ability to interact with them in applied and policy-oriented research projects. The IIASA Regional Energy/Environment Study was conducted in close cooperation with research institutions in the three regions under study. In order to be considered in the study, each region had to have an institution with a policy-oriented research program examining energy/environment systems from a broad resource management perspective.

A small core team of IIASA scientists, from several internal research projects, conducted the in-house research in collaboration with the following institutions in the regions under study:

- The Institut für Energetik, Leipzig, GDR
- The Institut Economique et Juridique de l'Energie (IEJE) in Grenoble, France, a part of the Centre National de la Recherche Scientifique (CNRS)
- The Energy Systems and Policy Research Group (ESPRG) of the Institute for Environmental Studies and the College of Engineering, University of Wisconsin – Madison, in the United States

Each of these institutions plays an active role in its country or region in conducting applied policy-oriented energy research and in advising policymakers. The interaction between IIASA and the collaborating institutions is illustrated in Figure 1.2. There was a vigorous flow of models, data, and personnel between IIASA and the institutions. These flows are outlined in more detail in the following section on research components and in Chapter 3 in conjunction with the description of the alternative scenarios developed for each region. The dotted line in Figure 1.2 represents preparations undertaken in 1976 for participation by additional countries in a follow-up study.*

II.B. COMPONENTS OF THE RESEARCH

The research activities can be broken down into six main components. These components, which more or less coincide with the divisions of this book, are as follows.

II.B.1. Description of Energy Systems in the Regions

A descriptive analysis was developed for each of the three energy systems. Included were geography, economic activity, demography, human settlement patterns, past and current energy use, and energy supply modes. The analysis was compiled in a comparative format that demonstrated some striking differences between the regions. For example, the GDR currently exhibits zero population growth – which is expected to persist at least to the end of this century. In contrast, continued population growth in the other regions will have a strong influence on their energy use (Chapters 4, 5, and 6). As a second example, Wisconsin relies heavily on the automobile in comparison with Rhone-Alpes and the GDR; however, auto ownership in the GDR is increasing at an annual rate of 12 percent in comparison with a 4-percent growth in Wisconsin. Also striking is the heavy GDR reliance on mass transit.

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* In September 1976 IIASA undertook a similar study on regional energy/environment management in Austria. It was completed in 1978.

II.B.2. Description of Regional Institutional Structure for Energy/Environment Management

Early in the research it became apparent that a strong relationship exists between the institutional and decision structures of a region and the formal models and planning tools that are used. In view of today's growing interest in new government structures and approaches to energy management, the focus on these structures as part of the research intensified as the study progressed. The stark contrasts between planning procedures and tools in the three regions ranged from the highly centralized and formalized GDR system to the extreme diffuseness of decision making and planning in Wisconsin. In contrast to these two, Rhone-Alpes exists primarily as a unit for statistical and information-gathering activities.

II.B.3. Comparison of Selected Energy and Environment Management Practices

Management practices in the environmental, technical, and economic fields were selected for comparison between the three regions. The topics chosen were

- Air quality management
- Energy-related building practices
- Energy pricing practices

Specialists in each of the regions provided descriptions of the approaches employed, and a comparison was developed by the IIASA team.

II.B.4. Description of System Models in the Regions

One of the objectives of the project was to appraise and compare the energy and environmental models of the three regions. This appraisal was valuable to each region in assessing the possibility of using models from other regions and revealed how the models are tied to characteristics of the regions. To promote an examination of the transferability of the models, the appraisal was divided into two parts. Each collaborating institution described its own system of energy/environmental models, and each appraised the models of the other two groups from the perspective of its own system and methodological requirements for planning and policy analysis. For example, the Wisconsin group identified the types of information it desires and examined whether the French models treat those areas adequately.

II.B.5. Development of Alternative Energy/Environment Futures for Each Region as a Policy Analysis Tool

Scenario building, i.e., the development of alternative futures, was employed by the IIASA core research team as a device for analyzing alternative energy and environment policies and strategies in the regions. It is a convenient tool for studying the interaction of complex and uncertain factors. Broadly described, scenario building is a detailed examination of the possible futures and the consequences of the assumptions made to produce the futures. It provides a formal quantitative framework for the examination and discussion of policy options.

The process employed was one of

1. Imposing given policies, i.e., sets of "rules," on the regions, within the framework of their initial conditions and constraints
2. Evaluating the resulting development and evolution of the region

The policy issues were jointly chosen by IIASA and the collaborating institutions in the regions and included transportation systems, energy supply systems, settlement design, and environmental protection. The assumptions underlying the scenarios were developed from lengthy interactions with specialists in the regions, and, in some cases, exogenous inputs to the scenarios were supplied directly by the collaborating institutions. Rather than national scenarios, regional scenarios were studied because of their value in addressing environmental issues, often regional in nature. A 50-year time span was chosen so as to permit the introduction of speculative technologies into the scenarios as well as modest changes in life-styles.

Three detailed energy/environment scenarios were developed for each region. Scenario 1, the "Base Case," represents a continuation of current socioeconomic trends and policies (e.g., the "Plan" in the GDR). Scenario 2 results from policies encouraging a high-energy future and is based on presumed low or moderate energy costs. It places little or no emphasis on improving efficiencies of energy use. Scenario 3 is a lower-energy future resulting from policies encouraging energy-saving technologies in transport, heating, and industry. It assumes increased environmental quality through conservation and stricter pollution controls.

The scenarios displayed a dramatically wide range of energy/environment futures for the regions. The process of evaluation of these scenarios, through workshops with specialists and policymakers (and, in some cases, members of the public) in the regions, also demonstrated a dramatic diversity of opinion about the likelihood of taking any given path into the future.

The success of the use of scenarios in design or managment depends on feedback between the scenario builders and the managers and designers of the energy system itself. Feedback in scenario writing is similar to the mechanism by which man's knowledge grows. The cycling rarely stops for long; new knowledge evolves continuously, and scenario writing is never finished! New scenarios were developed after those described here; the scenarios themselves are perhaps of less importance than the resulting examination of the assumptions and policies embodied in them.

II.B.6. A Method for Communicating and Evaluating Energy/Environment Strategies and Options

One of the major tasks of this research was to describe the systems and their possible evolution in the three regions. In this respect, the scenario-writing process was purely *descriptive*. To explicitly transform the scenario output into *prescriptive* forms, additional steps are obviously required. One of these is the embedding of the scenarios into an institutional and decision framework where *preferences* and *values* must be applied to the results. This process differs considerably across the three regions because of their very different social and institutional structures.

Decision analysis was applied in this research as one approach to the evaluation of alternative policy designs and to aid in the communication of the value trade-off alternatives. In this approach, a type of preference model is introduced into the evaluation process. This preference model provides a formalization of an individual's (e.g., an energy policymaker's) subjective preferences for various attributes of the energy system, for example, alternative environmental impacts. For that individual it allows the calculation of the relative desirability of a given scenario or policy.

III. TRANSFER OF RESEARCH RESULTS

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

Interaction with policymakers was therefore given particular emphasis in the research. From the inception of the program, information was solicited from the appropriate potential users of the research, and at the conclusion of the scenario-building process, they were asked to evaluate the results. Frequent workshops encouraged this interaction. The workshop process, shown schematically in Figure 1.3, was perhaps the key element in integrating the several components of the research program, and in facilitating communication between modelers in the three regions. There are many indications that the scenarios and the personal interactions have played a role in energy/environment planning in the regions.*

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* At the second conference, Management of Regional Energy/Environment Systems, held at IIASA, 16–19 May 1978, retrospective presentations on the scenarios were given by energy specialists or policymakers from the three regions. To provide perspective on the scenarios, summaries of the presentations are included immediately before the chapters describing the scenarios for the regions (Chapters 4, 5 and 6). They will be published in full as part of the proceedings of the conference: W. K. Foell (ed.), Proceedings of the Conference on Management of Regional Energy/Environment Systems (Laxenburg, Austria: International Institute for Applied Systems Analysis, in press).

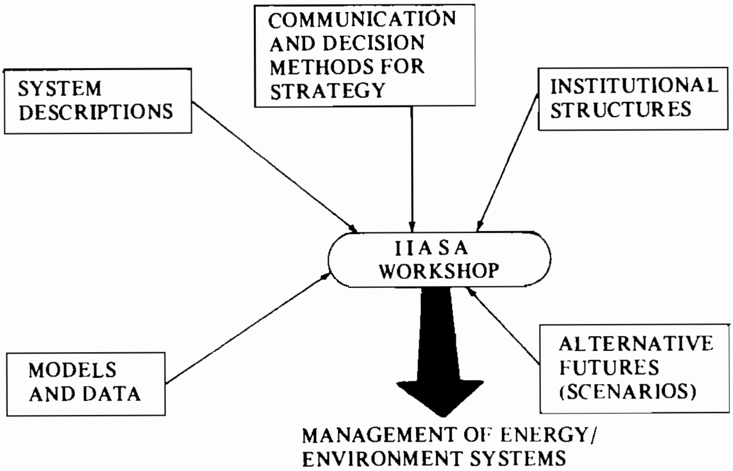

FIGURE 1.3 Diagram of the research components in the IIASA energy/environment system study.

IV. ORGANIZATION OF THE BOOK

This volume focuses upon the comparative three-region study as outlined in the previous section, within a conceptual framework for management from an energy and environmental perspective. It represents a combination of original material written by the IIASA core research team, and papers contributed to IIASA workshops by specialists from the regions.

The main part of the book focuses on the building and description of energy scenarios for each of the regions. Included is a brief comparison of the three regions (Chapter 2); a summary of the basis and methods underlying the scenario building (Chapter 3); a description of the long-term scenarios developed for each region (Chapters 4, 5, and 6); and lastly, a cross-regional comparison of the resulting scenarios (Chapter 7).

The appendixes begin with a more detailed picture of the regions, including socioeconomic, geographic, and energy-use characteristics (Appendix A). They present an overview of the administrative and institutional structure of energy management in the regions as well as a description of selected energy and environmental management practices in each of the three regions (Appendixes B and C). Appendix D discusses system models employed in each of the regions and has an appraisal of these models by specialists from each of the other two regions. Appendix E describes an approach used in the study for evaluation and choice of alternative energy/environment strategies.

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2 Summary Comparison of the German Democratic Republic, Rhone-Alpes, and Wisconsin

This chapter contains a comparative summary of selected socioeconomic characteristics and energy systems in the German Democratic Republic (GDR), Rhone-Alpes, and Wisconsin as a prelude to the alternative energy futures developed in the next chapters. The characteristics presented here are among those which have a strong influence upon the evolution of the energy systems in the regions. They are an important part of the initial conditions for the scenarios described in subsequent chapters.* Appendix A presents a more detailed picture of each of the regions.

I. GENERAL CHARACTERISTICS

The location and boundaries of the three regions are shown in the maps in Figures 2.1 and 2.2. Table 2.1 gives a comparison of their sizes, populations and population densities. Wisconsin is by far the largest of the regions. The contrast between the overall densities of sparsely settled Wisconsin and the heavily populated GDR is striking; the GDR population density is more than 5 times greater. Figure 2.3, a comparison of recent population figures in the regions, shows the current zero-population-growth behavior of the GDR, in contrast to the continuing, although modest, growth rates in Rhone-Alpes and Wisconsin (currently approximately 1 percent and 0.8 percent). The contrasting population dynamics had a strong influence on the scenarios presented in later chapters, despite the fact that Wisconsin's population is expected to stop growing shortly after the first quarter of the twenty-first century.

Chapter 2 was written by Loretta Hervey and Alois Hölzl – IIASA.

* 1972 was chosen as the reference year because for later years consistent data could not be obtained for all three regions.

TABLE 2.1 Population and Area of the Three Regions (1972)

	GDR	Rhone-Alpes	Wisconsin
Population ($\times 10^6$)	17.0	4.7	4.5
Area (km^2)	108,178	43,634	145,370
Population density ($people/km^2$)	157	108	31

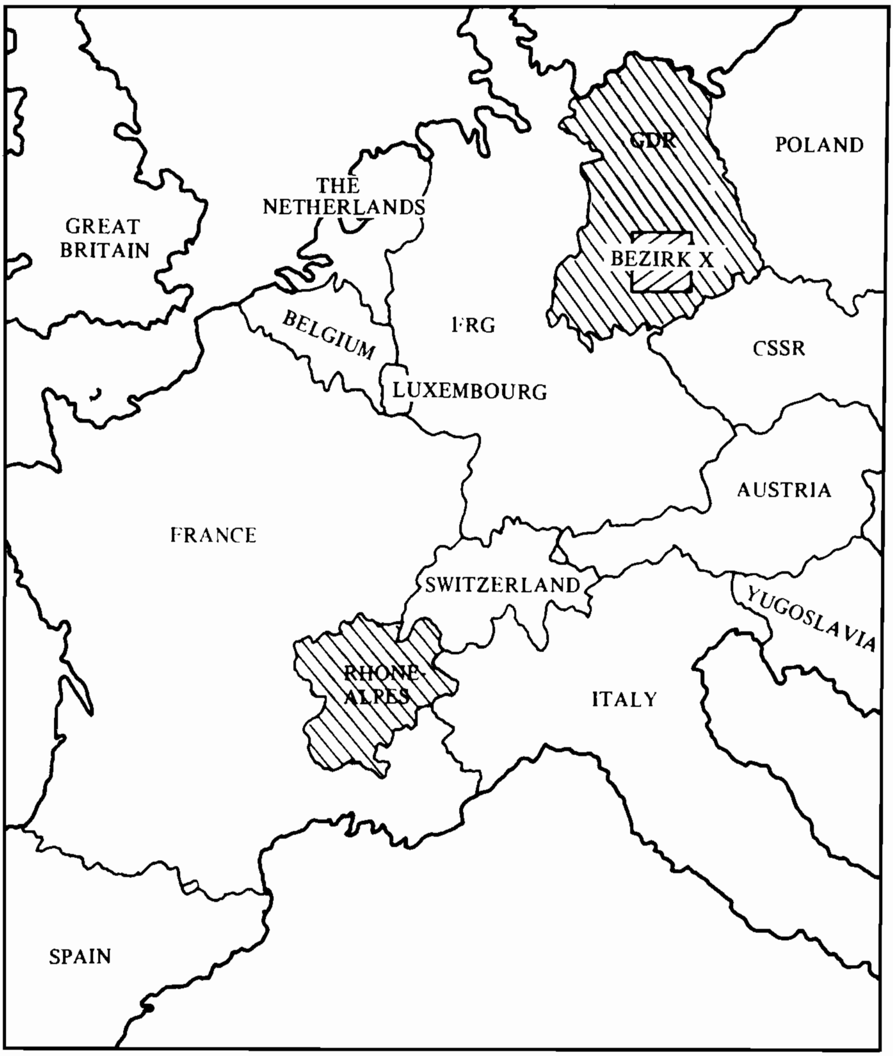

FIGURE 2.1 Location of the GDR and the Rhone-Alpes region.

FIGURE 2.2. Wisconsin and bordering states in the United States.

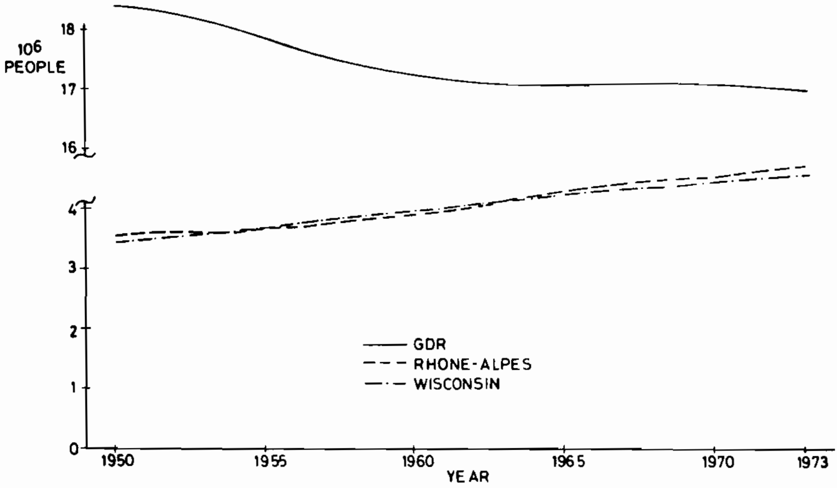

FIGURE 2.3 Cross-regional comparison of population (1950–1973).

Table 2.3 shows cities and towns in the three regions by population categories. These data make it possible to see the structure as well as the degree of urbanization in the study regions. A high percentage (40) of the Rhone-Alpes population live in large cities of 100,000 or more inhabitants. The percentage of the population in Wisconsin and the GDR living in cities of this size is only half as large.

TABLE 2.2 Selected Population Statistics

		GDR[a]	Rhone-Alpes[b]	Wisconsin[c]
Total population (× 10^3)	1960	17,241	3,722	3,952
	1972	17,011	4,685	4,526
Median age	1960	32.4[d]		29.4
	1972	36.8[d]	33[e]	27.2[f]
Birth rate per 1,000 residents (births/yr)	1960	17.0		25.1
	1972	11.8	17.1	14.3
Death rate per 1,000 residents (deaths/yr)	1960	13.6		9.6
	1972	13.8	10.0	9.3
Percent urban population (communities with 1,000 residents or more)	1960	50	53[d]	53[d]
	1972	54	68[d]	51[d]
Average household size	1960	2.8[d]		
	1972	2.7[d]	3.1	3.1

[a] SOURCE: *Statistisches Jahrbuch 1974 der DDR.* Staatsverlag der Deutschen Demokratischen Republik, Berlin, 1974.
[b] SOURCE: *Annuaire Rhône-Alpes*, 1974, Principaux Résultats Statistiques en 1973, Supplément de no. 9 de la revue, "Points d'Appui pour l'Economie Rhône-Alpes."
[c] SOURCE: *The State of Wisconsin 1973 Blue Book.* Wisconsin Legislative Reference Bureau, Madison, Wisconsin, 1973.
[d] Estimated.
[e] Average for France.
[f] 1970 value.

II. TRANSPORTATION

Table 2.4 gives a comparison of motor vehicles in the regions in 1972. Here the heavy reliance on the automobile in Wisconsin is vividly demonstrated. Furthermore, the number of registered motor vehicles in Wisconsin has increased approximately 3 times faster than population since 1960. However, recent time series studies show that the auto ownership in the GDR is increasing at an annual rate of 12 percent, in comparison with a 4 percent growth in Wisconsin. Still, in the GDR there is a strikingly heavy reliance on mass transit.

III. ECONOMIC CHARACTERISTICS

Both the GDR and the Rhone-Alpes are more industrialized than Wisconsin. The industrial infrastructures of the three regions also differ significantly. Table 2.5 shows the estimated percentages of total working population in each region by economic sector in 1972. Although there may be some inconsistencies in sector definition, Wisconsin has a significantly smaller percentage of workers in the industrial sector.*

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* Wisconsin nevertheless ranks twelfth in total industrial output among the 50 states in the United States.

TABLE 2.3 Cities and Towns by Population Categories

Size	GDR[a]		Rhone-Alpes[b]		Wisconsin[c]	
	Number of Municipalities	% of Total Population	Number of Municipalities	% of Total Population	Number of Municipalities	% of Total Population
1,000,000 or more	1	6.4	1	24.3		
500,000 to 999,999	2	6.4 } 23.3		} 39.3	1	16.2 } 19.1
100,000 to 499,999	10	10.5	2	15.0	1	3.9
50,000 to 99,999	18	7.1	5	9.1	8	12.5
20,000 to 49,999	82	15.1	15	10.8	17	12.6
10,000 to 19,999	107	8.9		} 40.8	28	8.7 } 54.7
Less than 10,000		45.6			565	46.0
Total		100.0		100.0		100.0

[a] Data from 1973; SOURCE: *Statistisches Jahrbuch 1974 der DDR*. Staatsverlag der Deutschen Demokratischen Republik, Berlin, 1974.

[b] Data from 1968; SOURCE: *Annuaire Rhône-Alpes*, 1974, Principaux Résultats Statistiques en 1973, Supplément de no. 9 de la revue, "Points d'Appui pour l'Economie Rhône-Alpes."

[c] Data from 1970; SOURCE: *The State of Wisconsin 1973 Blue Book*. Wisconsin Legislative Reference Bureau, Madison, Wisconsin, 1973.

TABLE 2.4 Cross-Regional Comparison of Motor Vehicles (1972)

	GDR		Rhone-Alpes		Wisconsin	
	Total (X 10^6)	Per 1,000 people	Total (X 10^6)	Per 1,000 people	Total (X 10^6)	Per 1,000 people
Autos	1.400	82	1.259	270	1.969	436
Motorcycles	1.373	81	0.502	106	0.070	15
Buses	0.018	1.1	0.007	1.5	0.010	2.2
Trams and trolleys	0.0048	0.28	0.0003	0.07		
Trucks	0.256	15	0.328	69	0.376	83
Tractors	0.203	12	0.011	2	0.230	51

TABLE 2.5 Total Working Population by Economic Sector (1972)

	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
Total	100.0	100.0	100.0
Percentage of total population	48.6	43.4	40.8

TABLE 2.6 Industrial Sector by Activity (1972)

	GDR (% of Net Industrial Product)	Rhone-Alpes (% of Industrial Value-Added)	Wisconsin (% of Industrial Value-Added)
Food	11.6	8.7	15.8
Building materials	2.1	3.5	1.3
Primary metals	4.7	5.8	5.6
Machinery[a]	42.0	44.5	49.0
Chemicals and rubber	17.0	14.7	6.0
Light industry	22.6	22.8	22.3
Total	100.0	100.0	100.0

[a] Mechanical, electrical, and transportation equipment.

Table 2.6 presents a cross-regional comparison of fractional industrial activity by sector. The greatest relative differences occur in the food and chemical sectors. Wisconsin ranks high in the United States in food production, particularly in dairy products. On the other hand, it has relatively little activity in the chemical and rubber sectors, both of which are important in the GDR and Rhone-Alpes.

TABLE 2.7 Primary Energy Use (1972)

	Annual Energy Use (10^{15} cal/yr)	Annual Energy Use Per Capita (10^9 cal/person/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

TABLE 2.8 Annual Sectoral End-Use Energy Consumption (1972)

	GDR		Rhone-Alpes		Wisconsin	
	10^{15} cal	% electrical	10^{15} cal	% electrical	10^{15} cal	% electrical
Industrial	312	13	48	28	77	10
Residential and Service	139	12	52	8	106	16
Transportation	55	2	20	3	79	0
Other	15	31			8	11
Total	521	12	120	15	270	9

IV. ENERGY CONSUMPTION

A comparison of energy use in the three regions has revealed some interesting differences, most of which are discussed in detail in connection with the alternative energy futures in the following chapters. Table 2.7 summarizes primary energy use in the regions in 1972. Wisconsin has by far the greatest per capita energy use, whereas, on a density basis, the GDR has almost twice that of Rhone-Alpes and three times that of Wisconsin. Although the energy density varies considerably within a region, the overall density for the region is nevertheless indicative of the concentration of energy-related activities. Table 2.8 shows a comparison of end-use energy consumption by economic sectors in the three regions.

The percentage of end-use energy consumed by the industrial sector is far greater in the GDR (60 percent) than in either Rhone-Alpes (40 percent) or Wisconsin (29 percent). This in part reflects the more industrialized structure of the GDR economy, but also is related to the less energy-intensive character of the residential and transportation sectors. For example, in Wisconsin, the heavy reliance on autos and trucks as modes of transport results in the transportation sector's being responsible for 29 percent of total end-use energy. This contrasts with 17 and 11 percent in the Rhone-Alpes and the GDR. The relatively high percentage of end-use energy in Rhone-Alpes industry supplied by electricity is also striking, although not surprising if one is aware of the heavy concentration of industry that is located near the mountains to take advantage of inexpensive hydropower there.

TABLE 2.9 Electricity Use (1972)

	GDR	Rhone-Alpes	Wisconsin
Electricity consumption (10^9 kWh)	74.0	20.0	28.0
Per capita electricity consumption (kWh/person)	4.3	4.3	6.2
Average annual growth (%/yr) in			
Total consumption	4.8[a]	5.3[b]	7.2[c]
Consumption per capita	4.9[a]	3.7[b]	6.1[c]

[a] Average for 1960 to 1972.
[b] Average for 1969 to 1972.
[c] Average for 1961 to 1972.

One of the important issues investigated in this research program was the potential need for additional electricity generation capacity in the regions. Table 2.9 gives a cross-regional comparison of total and per capita electricity use and growth rates. Although data limitations prevented comparisons for the same time period, the total growth rates are similar. The slightly lower rate of the GDR may in part reflect its relatively stable population during the period.

A comparison of fuel mixes for electricity generation in 1972, shown in Figure 2.4, illustrates the dominance of lignite in the GDR, hydropower in Rhone-Alpes, and coal in Wisconsin. During the past few years, the reliance upon coal has greatly decreased in Wisconsin; in 1976, nuclear plants contributed more than 30 percent of the electricity generated.

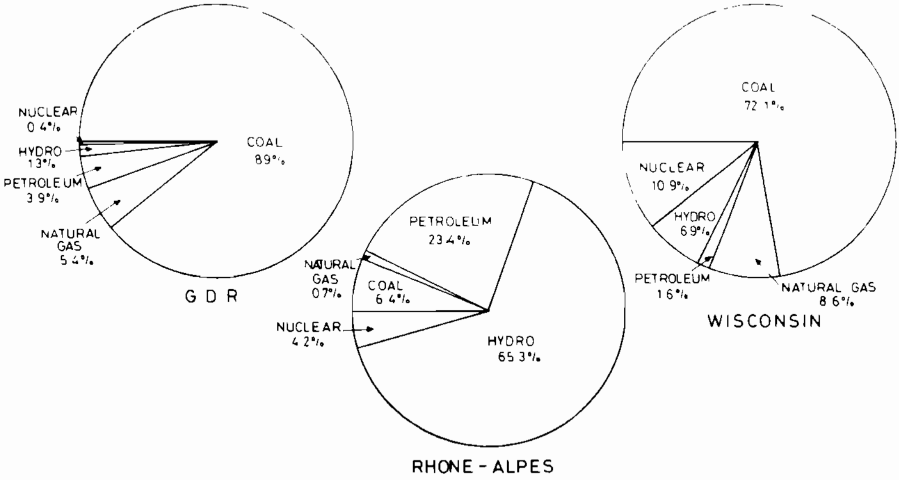

FIGURE 2.4 Cross-regional comparison of fuel use for electricity generation (1972).

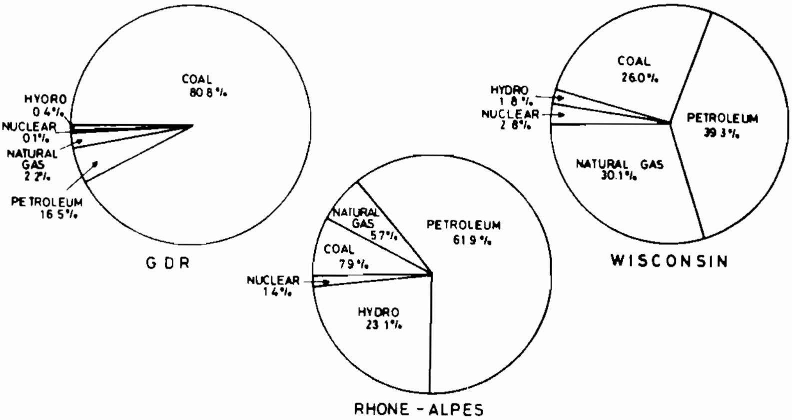

FIGURE 2.5 Cross-regional comparison of primary energy by source (1972).

V. ENERGY SUPPLY

The primary energy sources for the three regions differ significantly, as illustrated in Figure 2.5. The GDR relies heavily on coal (mainly domestic, strip-mined lignite), whereas Rhone-Alpes is heavily dependent on petroleum and hydropower. Wisconsin, although having no naturally occurring fuel resources within its boundaries, has a diverse supply mix mainly of petroleum, natural gas, and coal; uranium is providing a growing percentage of its energy (2.8 percent in 1972 and 8 percent in 1976).

VI. IMPORTING AND EXPORTING IN THE THREE REGIONS

GDR Hard coal, petroleum, and natural gas is practically all imported; these energy forms represented in 1972 approximately one third of the primary energy supply. There is some export of refined petroleum products (gasoline and diesel fuel), and of lignite products. Electricity imports and exports are almost balanced.

Rhone-Alpes Rhone-Alpes has to import all energy sources except coal and hydropower for electricity generation. Because of the declining use of coal, petroleum imports are an increasing percentage of the primary energy supply. About 50 percent of the petroleum products are refined within the region. Rhone-Alpes has historically been exporting electricity to other regions. (It had a 20 percent surplus in 1972), but the export surplus is declining.

Wisconsin Wisconsin has to import practically all of its primary energy supply. There are some small refineries within the region. Electricity imports and exports are almost balanced.

3 A Methodology for Constructing and Modeling Energy/Environment Futures

Views about the future – scenarios, forecasts, or predictions – constitute the language of policy debate, the frames of reference of decision makers, and the bases of assumptions about what is or what is not inevitable. The "tools" used to develop these views are vital to managers and political leaders. They may range from the application of pure intuition, on the one hand, to complex and data intensive computer models, as described in Appendix D. The future with regard to energy is particularly difficult to forecast because of the intricate manner in which energy is interwoven among virtually all of man's activities. What will energy demand be in the coming years? How much of the demand can be satisfied by electricity and at what prices? What rates of growth will be experienced in those industrial sectors that are very energy-intensive? What effect will the dispersion of energy-related pollutants have on human health?

This chapter focuses upon writing alternative energy and environmental futures, i.e., scenario writing, as a tool for policy analysis. It describes a concept, process, and models for writing alternative energy/environment futures for the three regions studied in the IIASA research program, and serves as a prelude to Chapters 4, 5, and 6, which present the scenarios themselves. Although the three regions for which the futures have been written are very different in their socioeconomic, geographic, and technological structures, an attempt has been made to apply a consistent approach.

Section I of the chapter defines the general approach and outlines the objectives of writing alternative scenarios. Section II describes the issues chosen for study and their role in each of the regions. Section III presents the energy system structures used as a basis for writing these futures, and is followed in Section IV by a summary

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description of the models, data bases, and general methodology used. These models are described in more detail in a large number of reports published by IIASA and other institutions collaborating in the study.

I. OBJECTIVES

The writing of alternative futures, often referred to as scenario building, is a convenient tool for studying the interaction of complex and uncertain factors. Broadly described, scenario building is a detailed examination of the possible futures and the consequences of the assumptions made about them. This set of futures may provide a better view of what is to be avoided or facilitated, the types of decisions that are important, and the points in time after which various decision branches will have been passed.

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 crucial times for decisions. In general they answer two types of questions:

1. Precisely *how* might some hypothetical situations come about?
2. What *alternatives* exist for each actor at each step for preventing, diverting, or facilitating the process? Scenarios are in some ways like the plot of a stage play.

Alternative futures place 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, in this study we have used the terms "scenarios" and "alternative futures" interchangeably.

In more explicit terms, the primary objectives of the scenario writing in this study are:

- To illuminate significant structural differences or similarities between the energy/environmental characteristics of the three regions
- To describe the sensitivity of energy use and environmental impact to the natural, socioeconomic, and technical infrastructure of a region
- To investigate possible energy-related limits of development in the regions
- To describe and analyze the consequences of specific energy/environmental policy options

The greatest value of writing these alternative futures may be their contribution to inducing fresh thinking. *It must be stressed that these futures should in no way be considered as forecasts.*

II. POLICY ISSUES

Scenario building was employed as a device for analyzing alternative energy and environment policies and strategies in the regions. The process was one of (a) imposing given policies on the regions, within the framework of their initial conditions and constraints, and then (b) evaluating the resulting development and evolution of the regions.

The policy issues were chosen on the basis of two criteria. They had to be of special interest to at least one region and of general interest to the other two; and they had to have sufficient focus and data that they could be approached in at least a semiquantitative manner with the methods available to the IIASA scientists. They also had to be relevant to medium- and long-term policy analysis (5–50 years).

The procedure for choosing policy issues satisfying the above criteria was an iterative one, beginning with discussions with the collaborating institutes in the regions. After several issues were identified, they were explored by the IIASA team to see whether they could be approached within the time frame of the project and with the expertise available at IIASA. After general decisions were made on these policy issues and on the types of scenarios that would help illuminate important policy questions, some months were spent gathering data and developing quantitative relationships with which to describe the alternative futures. The issues chosen for study as a result of the above procedure are described in the following section.

II.A. HUMAN SETTLEMENTS

The structure of human settlements and, in particular, urban settlements, plays a major role in determining man's use of energy and the nature of the influence of energy use upon both the man-made and the natural environment. Urbanization, as a by-product of industrialization, is to a large extent responsible for excessive concentrations of wastes with which man must cope. Many of these wastes are directly or indirectly related to energy. The environmental impacts that accompany man's use of energy are a function of the design of human settlements, 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 were identified.

How is energy use and environmental impact related to urban density and size, types of housing, and energy supply technology and type? In all three regions the answers to these questions are useful for policy discussions related to land-use planning, zoning, building codes, and so on. In the GDR, significant portions of the populace live in large housing districts with central district heating systems.[1] There is interest in assessing the tradeoffs between district heating, direct burning of lignite or lignite briquettes, and electric space heating. Such district heating systems are also being constructed in Rhone-Alpes; clearly, however, their feasibility depends upon urban patterns; in the Lyon and Grenoble areas new compact cities are being planned – the so-called *cités dortoirs*. In Wisconsin, land-use planning is becoming a major issue, and the State Planning Office has been studying several strategies for development patterns.[2]

II.B. TRANSPORTATION SYSTEMS

In each of the three regions, transportation is responsible for a major portion of energy consumption, particularly in Wisconsin and Rhone-Alpes, where transportation accounts for 17 and 29 percent of end-use energy consumption, respectively. 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 transportation was of interest to all three regions. The following issues are of particular interest:

- What are the energy and environmental implications of present trends of intercity and intracity passenger transportation? How are these modified by the introduction of alternative modes, including mass transit systems? These are of special interest in the Rhone-Alpes region where there is some experimentation with increased mass transit in the larger cities, as well as development of a large system of high-speed trains between Paris and Grenoble and Lyon. In Wisconsin the state government has proposed a complete reorganization of the administration of the state transportation system to give much higher priority to mass transit systems and to assign a larger fraction of the automobile's social costs to the users. The GDR already provides a large fraction of its passenger transportation without using automobiles,[3] but is moving toward a greater reliance on the automobile.
- What will be the energy and environmental implications of higher efficiency automobiles? This question is closely linked to the reliance of each region on imported petroleum. In Wisconsin this is a major policy issue, addressed in part through proposed legislation to increase license fees for low-efficiency autos.

II.C. ENERGY SUPPLY

Concern about reliability of a region's energy supply has increased in recent years. For example, Wisconsin is at the "end of the pipeline" in the United States, and, having no indigenous energy sources except for bright sunshine (usually), is very concerned about future availability and prices of its current energy sources. Although Rhone-Alpes and the GDR obtain significant fractions of their energy from sources within their borders, these sources will not supply future demand, according to most long-term demand forecasts. New technologies could play major roles over a 50-year period, but great uncertainties exist about their costs and reliability.

Several policy issues related to energy supply were suggested for inclusion in the study:

- What are the implications of satisfying future energy demand from alternative energy sources? In Rhone-Alpes coal now plays a minor role; the major potential sources are hydroelectric energy, nuclear energy, petroleum and gas, and possibly solar and geothermal energy. In the GDR, lignite currently plays a major role, nuclear energy may have potential for the middle- and long-term; solar and fusion energy are feasible to a lesser degree and only in the long-term. In Wisconsin the energy mix is currently very diverse, and all the energy sources appear to be major contenders for heavy use in the future; emphasis on gas could continue if coal gasification were technically and economically feasible. Solar energy is under considerable discussion in Wisconsin, and various proposals are being studied for legislation which would help this source of energy achieve economic viability. One of the most discussed supply issues is substitution of electricity for other energy sources to provide end-use energy.
- What is the feasibility of the introduction or expanded use of alternative technologies, including district heating, combined thermal–electric plants (cogeneration), and systems that use waste heat? These energy conversion strategies are of interest in all three regions. Some of them have already been implemented in the GDR, and therefore form an interesting comparative subject for study in the other two regions.

II.D. ENVIRONMENTAL PROTECTION AND RESOURCE CONSERVATION

Energy-related environmental issues are of major importance in the three regions. In each of the regions, energy problems and environmental problems are viewed as inseparably linked. Environmental considerations are important in urban settlement, economic growth, transportation, and energy supply systems. Several specific environmental issues were identified:

- Are there environmental limits associated with various patterns of energy demand and supply? What would the impact of the energy futures be on the man-made and the natural environment?
- What are the effects of various pollution control policies associated with alternative energy system strategies? Are these control measures sufficient to permit the implementation of otherwise infeasible energy systems? In Wisconsin this issue is related to the problem of meeting air pollution standards as specified by federal regulations. An analogous situation exists in the other two regions. In the GDR, a serious concern is the use of scarce cooling water in the most efficient manner possible. Within the Rhone-Alpes region, the Rhone river is under major environmental scrutiny because of the plans of Electricité de France to locate most of their nuclear plants on it.
- What are the major environmental trade-offs associated with alternative fuels for the production of electricity? In both the Rhone-Alpes and Wisconsin, the effect of nuclear power plants is an important issue.
- How will a policy encouraging expansion of district heating influence air quality?

III. STRUCTURE OF THE SCENARIOS

The policy issues described in section II were addressed by two specific paths. First, three alternative "policy sets" were developed for application in each region. In selecting a limited number of scenarios for study, rationales were chosen that were applicable to all of the regions, combined the majority of the above policy issues, and could conveniently be compared with one another. The second approach was the development of *sensitivity studies* to evaluate the effects of variations in one policy variable while holding the others constant.

In order to specify a policy set within which a scenario could be built, it was necessary to develop a means for expressing a policy in terms of a limited number of characteristics. The framework for a given scenario was described using the following terms:

- Population
- Economic growth and structure
- Human (urban) settlement location and form
- Technologies of energy use
- Transport systems for people and goods
- Primary energy conversion and supply technology (including electricity generation)
- Environmental control and protection

The general framework then was used to provide the exogenous functions, boundary conditions, and constraints for the models used to build the scenarios.

The above process can be summarized by three main steps:

1. Identification and choice of the *issues*
2. Definition of the scenario *framework* and the *assumptions*
3. Use of the models to build and evaluate the alternative futures

Figure 3.1 shows this process schematically. The models produce "system-indicators," e.g., energy requirements and environmental impacts, which are useful in evaluating alternative strategies.

As emphasized earlier, scenario building was employed as a device for analyzing alternative energy and environment policies and strategies in the regions. The resulting scenarios were not developed as predictions. They are intended to help test and compare the consequences of different policy choices. It is obvious that each of the regions has many energy futures open to it; the scenarios chosen for the research highlight only three of them in order to improve our understanding of energy and environmental management.

It should be emphasized here that the assumptions underlying the scenarios were not chosen arbitrarily by the IIASA research team. They were developed after

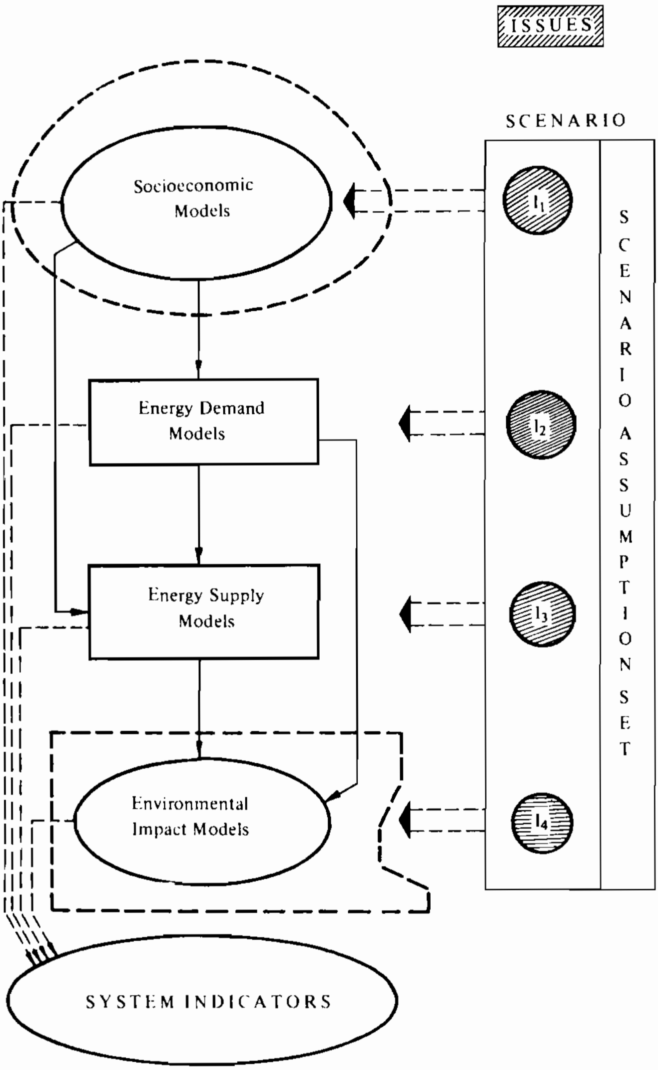

FIGURE 3.1 Relationship between issues, scenarios, and models.

lengthy and repeated interactions with collaborating specialists in the respective regions; in some cases exogenous inputs to the scenarios were supplied directly by the collaborating institutions. Whenever possible, these were tested by reference to other economic or technical studies, e.g., the Energy Policy Project of the Ford Foundation,[4] the GDR long-term energy outlook,[5] and national energy assessments in France.[6] Where feasible, the *WIS*consin Regional *E*nergy (WISE) Model (discussed in more detail later in this chapter) was used to construct sectoral energy demand descriptions, based upon data and parameters from the respective regions. However, the 50-year time span of the scenarios clearly introduces major uncertainty into many of the underlying assumptions and parameters. In all cases, care was taken that the regional socioeconomic development scenarios were consistent with the national or global patterns or both; possible national or global resource constraints were also taken into account.

Because the studies were conducted simultaneously, some scenario characteristics could be specified common to all three of the regions, e.g., stronger conservation measures, or greater emphasis on renewable energy sources. For all regions the energy scenarios could be categorized as high, medium, or low cases. The scenario characteristics are summarized by the following:

- *Scenario S1*, the "Base Case," assumes in general a continuation of past or current trends (at the time the scenarios were constructed) and assumes no dramatic changes in energy prices. For example, in the GDR, it follows the objectives of the 20-year plan* and its expectation of future socioeconomic developments.
- *Scenario S2*, "High-Energy Case," results from combinations of policies favoring higher growth in energy use than S1. It is based on an assumption of decreasing energy costs and few incentives for improved efficiency of energy use.
- *Scenario S3* is based on an assumption of higher energy costs and on the desirability of energy-saving measures; emphasis is placed on conservation of energy resources. However, it does not depict the lowest energy consumption future that could be reasonably constructed.

The policy areas explicitly addressed in the scenarios are:

- Urban form
- Energy-use technology
- Transportation system design
- Energy supply technologies
- Environmental control

Alternatives were formulated in each of these areas and were arranged in groups of consistent policies corresponding to the scenarios.

Tables 3.1, 3.2, and 3.3 give an overview of the scenarios for the three regions. The overall framework comprises socioeconomic structure, lifestyle, technology, and environment. Within each of these general areas, more specific aspects of the scenarios were addressed, namely:

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* An official "20-year plan" is not developed in the GDR. (See section I. in Appendix B). We use this term to describe what the Leipzig Institut für Energetik refers to as "long-term development over 20 years."

TABLE 3.1 Scenario Overview for Bezirk X (GDR)

Summary Characteristics		Scenario S1 (Base Case)	Scenario S2 (High case)	Scenario S3 (Low Case)
Socioeconomic structure	Population	Slight decrease to zero population growth by 1990	Same as S1	Same as S1
	Human settlements	Urban containment with no growth	Same as S1	Same as S1
	Economy	Linear growth of service sector (factor of 1.67 by 2025); exponential growth in industry (8.3% per year)	Same as S1	Same as S1
Lifestyle	Personal consumption	Current patterns	Same as S1	Same as S1
	Transportation	Car ownership: Increase in cars/household from 0.173 in 1970 to 0.65 in 2025; only slight decrease in km/yr driven	Car ownership increase to 1.0/household by 2025	Same as S1
	Housing	Emphasis on basic electrical appliances Low penetration of dish washers, freezers, clothes dryers; 66% of dwelling units apartments	Same as S1	Same as S1
Technology	Industry	Large decrease in industrial energy-intensiveness	Smaller decrease in industrial energy intensiveness relative to S1	Industrial energy intensiveness for electricity decreases faster than S1 (20% lower than S1)
	Transportation	Increase in efficiency of freight transport and mass transit due to electrification; only small improvements in auto energy efficiency	Emphasis on truck freight transport (68% by 2025)	Penetration of electric auto to 10% by 2025; lower auto use per capita

	Housing	No change in insulation patterns; Apartments 25% more energy efficient than 1-family houses; High use of DH[b]	Same as S1	15% of 1- and 2-family houses meet strict insulation standards by 2000; 60% by 2025
	Energy supply	Electricity 100% coal-based until 1995; thereafter nuclear penetration (1,228 MW by 2020) Export of electricity and coal briquettes Emphasis on coal-based district heating Electricity grows faster than total energy consumption (6.6% per year)	No nuclear power; Large electricity imports Less rapid penetration of district heating in residential sector	Penetration of solar-electric plants (20% of capacity is solar by 2025) Nuclear penetration 818 MW by 2025 Large penetration of solar in residential sector: by 2025, 50% of new 1- and 2-family houses constructed with solar units
Environment	Environmental regulations	Present trends in control of PM[a] and SO_2 By 2025: SO_2 : 60% control, electricity; 35% control, DH; 20% control, industry coal PM : 99% control, electricity ; 95% control, DH; 95% control, industry coal	No control of PM and SO_2 beyond present-day practices	High control of PM and SO_2 By 2025: SO_2 : 90% control, electricity; 60% control, DH; 30% control, industry coal PM : 99% control, electricity; 99% control, DH; 99% control, industry coal

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[a] PM ≡ Particulate matter.
[b] DH ≡ district heat.

Table 3.2 Scenario Overview for Rhone-Alpes

Summary Characteristics		Scenario S1 (Base Case)	Scenario S2 (High Case)	Scenario S3 (Low Case)
Socioeconomic structure	Population	Decline in growth rates: 1.3%/yr in 1970s to 0.4%/yr after 2000	Same as S1	Same as S1
	Human settlements	Continuation of current patterns of urbanization	Dispersed urban settlement patterns	Growth in small-scale compact cities
	Economy	Growth rate of GRP/yr:[a] 1971–1985 5% 1985–2000 4.2% 2000–2025 3.5%	Same as S1	Same as S1
Lifestyle	Personal consumption	Continuation of current trends	Same as S1	Same as S1
	Transportation	Predominance of autos	Same as S1	Same as S1
	Housing	60% of new houses are apartments	Same as S1	Same as S1

Technology	Industry	Large decreases in energy intensiveness Large penetration of electricity	Reduction of energy intensiveness for nonelectric use slightly lower than for S1	Heating energy intensiveness decreases 35% by 1985; 15% between 1985 and 2000 Furnace energy intensiveness decreases 15% by 1985 and 10% between 1985 and 2000 Steam energy intensiveness decreases 25% by 1985 and 20% between 1985 and 2000
	Transportation	Continuation of current auto and truck fuel efficiencies	Same as S1	Efficiency gains for autos and trucks Shift from truck to train for freight
	Housing	Stringent insulation standards	Same as S1	Same as S1
	Energy supply	Electricity generation from nuclear; large penetration of electric space heating	Mix of nuclear, oil, coal for electricity generation	Maximum feasible hydroelectricity Solar electric No new nuclear plants
Environment	Environmental regulations	Increasing controls: continuation of present trends	Low control (maintenance of current levels)	Strict control

[a] GRP ≡ Gross regional product.

TABLE 3.3 Scenario Overview for Wisconsin

Summary Characteristics		Scenario S1 (Base Case)	Scenario S2 (High Case)	Scenario S3 (Low Case)
Socioeconomic structure	Population	Declining growth rate from 1%/yr to 0.4%/yr; average approximately 0.75%/yr from 1970–2025; slow decline in average family size to a level in 2025 that is 30% below 1970 level of 3.3	Same as S1	Same as S1
	Human settlements	Suburban extension, continuation of present trends	Exurban dispersal, growth in low density areas distant from cities	Small compact cities of 20,000–100,000
	Economy	Continued expansion of service in relation to industry. Service growth averages 4.0%/yr; industrial 2.25%/yr	Same as S1	Same as S1
Lifestyle	Personal consumption	Current trends in personal consumption, e.g., appliance ownership	Current trends with preference for electrical energy supply	Current trends with emphasis on conservation measures
	Transportation	Trend to compact and small cars Ownership at current levels of about 430 autos/1,000 people	1975 auto size distribution continues into the future Ownership as in S1	Mass transit doubles from S1 Increased load factors Accelerated trend to small cars, including small urban car
	Housing	25% of new dwellings are apartments	10% of new dwellings are apartments	50% of new dwellings are apartments
Technology	Industry	Almost constant energy use per unit value-added in service and industry	Increasing energy use per unit value-added Emphasis on electricity	Decline in both electrical and nonelectrical use per unit value-added Conservation measures
	Transportation	Auto efficiency gain; by 1980, 12 liters /100 km 75% of freight by truck	No auto efficiency gain Introduction of urban electric auto 75% of freight by truck	Large auto efficiency gain; by 1985, 8.5 liters/100 km 50% of freight by truck

	Housing	Gas heat in most new residences Appliance saturation	Almost all new residences use electric heat	Improved insulation reduces heating needs per house by 30 to 40% Solar space and water heating
	Energy supply	Synthetic fuels from coal Mix of coal and nuclear for electricity Increased coal use in industry	Synthetic fuels from coal Mostly nuclear for electricity Emphasis on electricity	Solar for heating and electricity; solar supplies 30% of electricity by 2025 No new nuclear Synthetic fuel from coal
Environment	Environmental regulations	Present trends of increasing controls for SO_2 and particulates. Emission standards for electrical generating plants. 30% of SO_2 removed from industrial coal emissions	Low controls for SO_2 and particulates except for electrical generation. No SO_2 removal from industrial coal emissions	Stringent controls for SO_2 and particulates for electrical and nonelectrical generating plants. 70% removal of SO_2 for industrial coal use
		Dust standards enforced in underground coal mines	Same as S1	Same as S1
		Mostly closed-cycle evaporative cooling at power plant	Same as S1	Same as S1

- Socioeconomic structure: demography, human settlements, and the economy
- Lifestyle: personal consumption, transportation use, housing types, and appliances
- Technology: industrial technology, transportation systems, housing climate control and fuels, and energy supply and conversion technologies
- Environment: environmental controls and environmental regulations

For several of the regions, some of the factors were not varied between the scenarios. For example, the level of economic activity in Wisconsin was not varied between scenarios. In addition, the mix of manufacturing and service activity was not varied from scenario to scenario, although it changed over time. Population growth for a given region was also in general the same for all scenarios. Examples of contrasts in the scenarios are the assumed evolutions of human settlement patterns in Wisconsin (Table 3.3). Population growth and spatial distribution affects virtually all components of the energy system. For example, travel patterns and distances are strongly related to city size; the location of pollution sources relative to population strongly influences associated health impacts. Several alternative settlement patterns have been postulated and quantitatively incorporated into these scenarios.

In addition to the scenarios, many sensitivity studies were conducted in which only a single parameter is varied in a given scenario. Typical of the parameters varied are housing type, penetration of solar home and water heating, insulation standards, electricity supply alternatives, and SO_2 control regulations.

The scenarios for the GDR were constructed for "Bezirk X," a composite region typical of the heavily industrialized southeastern GDR.* A detailed comparison of the socioeconomic and energy characteristics of Bezirk X and the GDR as a whole is given in Chapter 4. The IIASA research team felt the Bezirk was very representative and that an analysis of its energy system did indeed provide considerable insight into that of the entire country.

As pointed out earlier, regional rather than national scenarios were studied because many significant social and environmental consequences of energy systems are best analyzed within the context of a specific region. However, because none of the regions are politically or economically autonomous, it is not possible to discuss regional scenarios while ignoring the evolution of the national systems. The scenarios were based upon policies that could be implemented, albeit in varying degrees, both nationally and regionally; the resulting energy patterns and environmental consequences were then evaluated for the regions.

IV. MODELS AND METHODOLOGY

The objectives of this section are to provide the reader with a picture of some of the broad aspects of scenario building, and of the specific approach used in the

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* **_Bezirk_ can mean _district_ or _region_ in English.**

IIASA research. Further descriptions of models and data bases are provided in the references.*

One of the main tools used for scenario writing was a family of simulation models, originally developed at the University of Wisconsin[7] and extended at IIASA to treat regional energy/environment systems with characteristics differing from Wisconsin. The Wisconsin Regional Energy Model (WISE) simulates a region's energy system within a framework that includes energy demand, regional supply systems, and environmental impacts. Most of the models are based on engineering process descriptions. Socioeconomic aspects of the regions, e.g., population, settlement patterns, and economic activity, were modeled differently in each of the regions.†

A simulation structure was chosen for several reasons. First, simulation is a convenient method of integrating the variety of analytical techniques likely to be employed in a multidisciplinary effort of this type. Second, a simulation structure provides a great deal of flexibility in both the modeling process and the application of the model to systems analysis. For example, it enables one to modify selected components of the system without the necessity of reworking the entire model, and to focus attention on specific areas of the energy system as well as on the system as a whole. Finally, the simulation structure lends itself to the scenario-generating approach that is extremely useful in the analysis of major policy issues and alternatives. That is, simulation facilitates the application of the model to questions of the "what if" type.

In addition to the significant extension of the Wisconsin model, some new models and quantitative approaches were developed at IIASA during the course of this research. Among these are energy/environment preference models,[8,9,10] and methods for analyzing regional air pollution impacts on human health.[11,12]

The general structure used to describe the energy/environment system is shown in Figure 3.2. The major components are:

- Socioeconomic activities
- Energy demand
- Energy conversion and supply
- Primary energy sources
- Environment

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* A general description of the family of models used in the IIASA Regional Energy/Environment Studies is given in W.K. Foell, J.S. Buehring, W.A. Buehring, R.L. Dennis, M.E. Hanson, L.A. Hervey, A. Hölzl, K. Ito, R.L. Keeney, J.P. Peerenboom, E. Pönitz, J. Richter, and A. Toifelhardt, A Family of Models for Regional Energy/Environment Analysis (Laxenburg, Austria: International Institute for Applied Systems Analysis, in press).

† In the recent application of this model to Austria, a demand-oriented input–output model (AUSTRIA II) provided economic scenarios for the study; see W.K. Foell, R.L. Dennis, M.E. Hanson, L.A. Hervey, A. Hölzl, J.P. Peerenboom, and E. Pönitz, Assessment of Alternative Energy/Environment Futures for Austria: 1977–2015 (Laxenburg, Austria: International Institute for Applied Systems Analysis, in press).

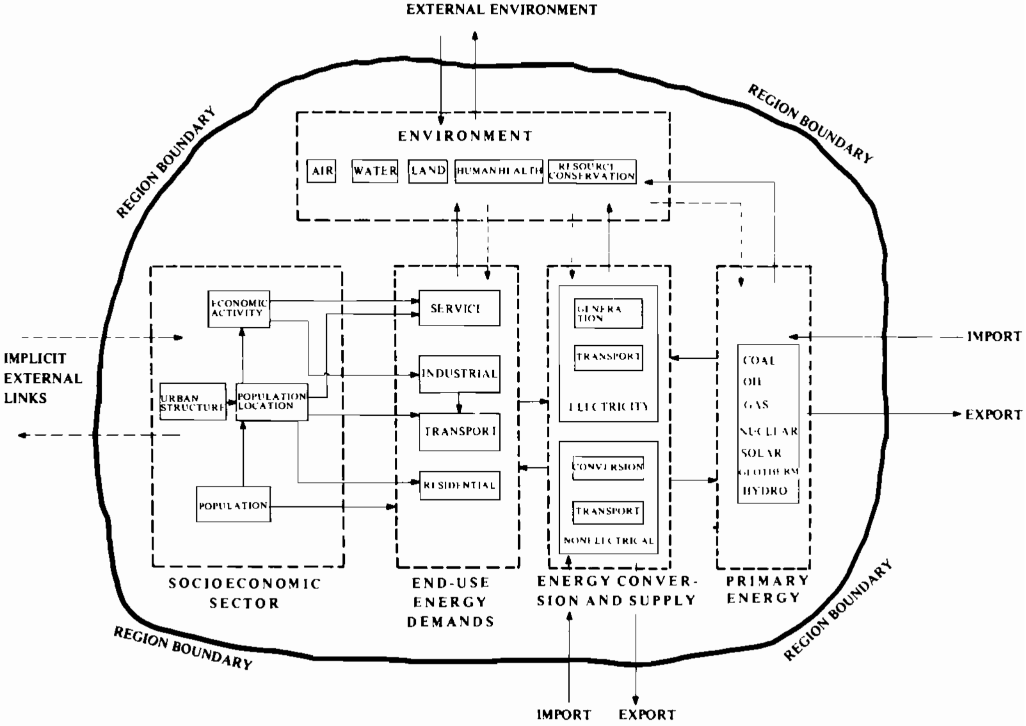

FIGURE 3.2 Structure of the energy/environment system for scenario development.

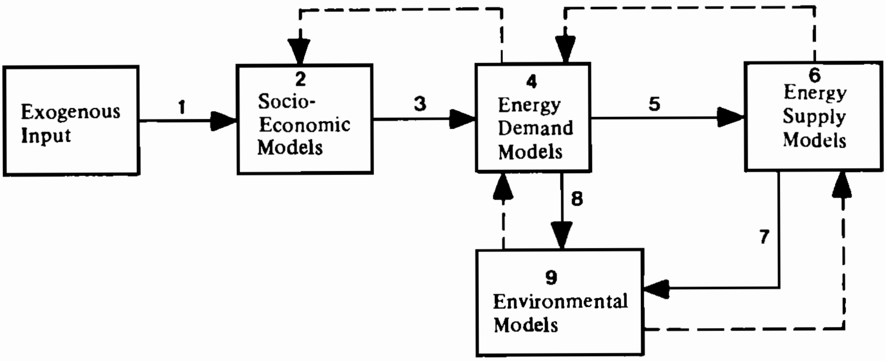

FIGURE 3.3 Simplified diagram of the overall information flow between model components.

This structure was based primarily upon the Wisconsin energy model. For the most part, the following description of the modeling that was used in the scenario-building process is based upon the Wisconsin model with significant modifications for the GDR and Rhone-Alpes where required.

The overall flow of information between these components is shown in a highly simplified manner in Figure 3.3; it can be summarized as follows:*

1. Regional socioeconomic information (e.g., population, settlement patterns, economic activity) is provided exogenously [1] or by models, or both exogenously and by models [2].
2. The socioeconomic information serves as input [3] to energy demand models [4], which are structured according to economic sector (e.g., industry, service, or agriculture) or by technological process (e.g., heating, cooling, or lighting). In general the outputs of the energy demand models are in the form of annual demand, usually specified by fuel.
3. The outputs of the energy demand models form the inputs [5] to energy supply models, which in turn are used to calculate primary energy requirements, needed conversion and transport facilities, supply system costs, and so on. In most of the analysis conducted with these models, supply was directly matched to demand or related to demand within a framework of constraints.
4. The energy flows in the supply system [6] and the end-use energy serve as inputs [7, 8] to the environmental impact models [9]. These models calculate impacts on a broad spectrum of areas, including human health and safety, on a systemwide and localized basis.

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* The numbers in the brackets correspond to indicated flows or components in Figure 3.3.

The additional flows of information between the major components are indicated by the dashed lines in Figure 3.3. In general, although not in all cases, the dashed flows are implemented by human intervention and not by formal mathematical links.

The methods originally used for modeling the Wisconsin system had to be modified for some aspects of the modeling for the GDR and Rhone-Alpes mainly because of the following considerations:

- Since a "plan" exists in the GDR (through the year 1990) that the government intends to implement by exerting a great deal of control, the range of options was more narrowly perceived by GDR planners than by planners in Wisconsin. In addition, the role of the WISE end-use demand models was greatly diminished because energy use is one of the variables in the economy that is explicitly specified in the plan.
- The Rhone-Alpes region of France is not a distinct political or administrative unit. Therefore, only limited data are available and in many cases the models had to be simplified to take advantage of the data that could be obtained.

The following sections describe the modeling procedures according to the system components of Figure 3.2.

IV.A. SOCIOECONOMIC MODELS

The socioeconomic models provide demographic and economic data that are used as input to the end-use demand models and the human health and safety aspects of the environmental impact models.

IV.A.1. Population Size and Distribution

Population is a main driving force in the end-use demand models and has an important effect on the environmental impact models as well, particularly in the area of air pollution and its effect on health. In order to provide sufficient spatial resolution, the region being studied is divided into *districts*.* Population size and distribution within each district are described in terms of community size and geographic relationship to urban centers. This degree of disaggregation is required for several reasons:

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* These areas are called districts or regions in the GDR, departments in Rhone-Alpes, and counties in Wisconsin.

- Urban structure affects the number of passenger trips in the transportation sector.
- Population density affects the feasibility of urban mass transportation systems.
- Urban structure affects the percentages of single-family and multiple-family houses that will be constructed.
- Population density affects the potential market for district heat and solar heat.
- Geographic distribution affects the population's exposure to emissions of air pollutants.

The first level of disaggregation is the *districts*, mentioned above. Population is further divided into four *subdistricts*. An area is classified according to whether

- It lies within 30 miles of a large urban center (greater than 500,000 people).
- It lies within 30 miles of a medium-sized urban center (100,000 to 500,000 people).
- It lies within 30 miles of a small urban center (20,000 to 100,000 people).
- It is nonurban.

Areas within 30 miles of an urban center with more than 20,000 people are then subdivided into 6 *sectors*:

1. Central city and mature suburbs
2. Suburbs and fringes
3. Exurban areas
4. Rural and small communities (less than 2,500 people)
5. Adjacent communities (2,500 to 5,000 people)
6. Satellites (5,000 to 20,000 people)

Areas lying 30 miles or more outside an urban center are called nonurban areas and are categorized as either sector 4, 5, or 6. Each sector is then described in terms of total population, land area, and population growth rate.

Within the above descriptive framework, 4 distinctly different spatial development patterns were specified for use in the scenarios:

1. Suburban extension: The growth rate is equal in all sectors.
2. Small compact cities: Growth occurs in the central city and mature suburbs of cities with less than 90,000 people, and in satellites, and brings the population in these cities to between 40,000 and 90,000.
3. Urban containment: Growth occurs in the central city and in the mature suburbs of large cities of over 100,000 people.
4. Exurban dispersal: Growth occurs in exurban areas, rural and small communities, and in adjacent communities.

It must be realized that urban structure represents a long-term commitment, and that even a severe change in growth patterns will only very slowly modify the existing structure.

IV.A.2. Economic Activity

Because of the links between economic activity and energy use, a description of economic growth is an important component of energy studies for each of the regions. In the studies described here, collaborating institutions in each of the regions provided descriptions (alternative forecasts) of economic activity that could be linked with models for end-use energy demand. This approach was far more practical than any efforts by the IIASA research group to develop independent economic models for the regions.

In this study, economic activity was represented by exogenous variables, e.g., value added or value of output, that represent the level of economic activity in the three regions. The exact description of the indicators, the delineation of the industrial and service sectors in each of the regions, and the techniques to project the indicators into the future will be discussed for each region in the scenario descriptions. In all cases the level of economic activity is expressed in constant monetary terms to remove the effects of inflation and is disaggregated by industry and by district.

Regional economic activity was generally expressed in relative rather than absolute terms. That is, economic activity is described relative to a base year in the regions. Comparisons of alternative energy futures were then analyzed in terms of economic development after the base year. This approach avoided the difficulties associated with the development of a consensus on appropriate currency exchange rates. Although it does not permit direct comparisons of the ratio of energy consumption to gross domestic product (E/GDP), as examined in detail by Darmstadter *et al.*[28] and others, it does allow examination of some of the energy-related consequences of changes in the relative economic indicators.

Employment is also recognized as an important factor in the service and industrial sectors. Depending upon the availability and reliability of the data, either employment or other economic indicators (expressed in monetary terms) are the driving forces behind the development of the service sector.

IV.B. END-USE ENERGY DEMAND

The purpose of the end-use demand models is to provide annual end-use energy demand by fuel type for the transportation, residential, service, and industrial sectors of the economy. In general, the socioeconomic models described above are the driving forces behind the sectoral end-use demand models. An economic approach is used in the industrial model; the other models are based on a combination of economic and technical or engineering approaches.

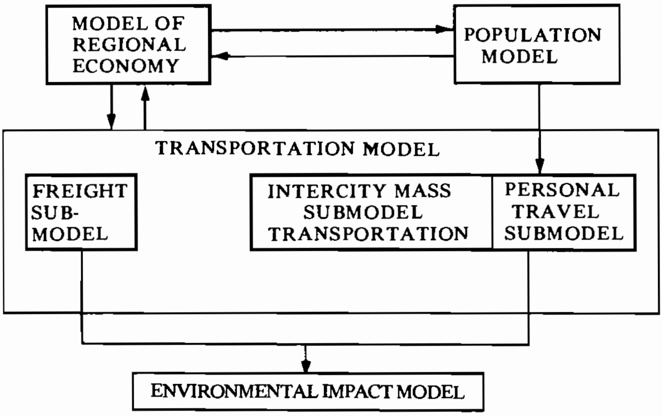

FIGURE 3.4 Overall structure of the transportation model (Source: Hanson and Mitchell[13]).

IV.B.1. Transportation Sector

The transportation model is divided into two submodels; the passenger transport submodel and the freight transport submodel.[13] Energy use and emissions are calculated by district and subdistrict within the region. A schematic representation of the transportation model is shown in Figure 3.4. The number of trips required is a major component of the passenger transport submodel. The population model provides population data by district and subdistrict. Person-trips per day have been found to be a function of population density and automobile ownership. Trips are split between local and intercity trips as a function of city size, and into urban passenger auto travel and urban mass transit. Average trip length has been found to be a function of city population. A load factor (persons per vehicle) may be determined from available data; passenger trips can then be converted to vehicle-kilometers.

The second major factor in the passenger transportation calculation is the vehicle population characteristics. Automobiles are disaggregated by year of manufacture and class (conventional, compact, and subcompact or electric). Average intercity and intracity energy intensiveness (energy required per unit distance traveled) is specified for each class and year of manufacture; kilometers per vehicle are calculated as a function of class and age. Then total energy use for passenger auto transport can be calculated. Vehicle characteristics for intracity and intercity mass transit are also specified externally, allowing energy use for mass transit to be calculated.

Demand for freight transportation and its distribution by mode of transport are inputs to the freight transportation model. The demand over time is usually linked with the level and type of industrial production in the region. Energy intensiveness for truck, rail, and air transport are estimated from available data.

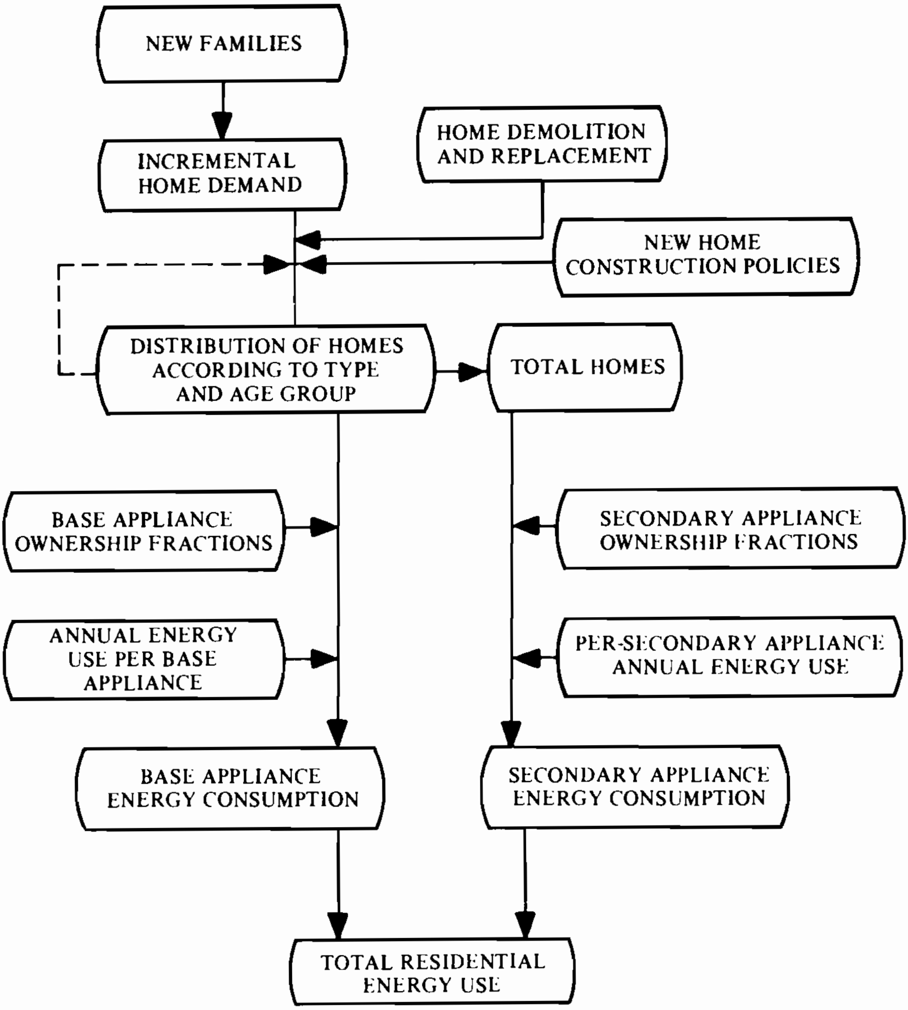

FIGURE 3.5 Block diagram of the residential submodel (Source: Frey[14]).

The methodology used for the transportation sector in Bezirk X and Rhone-Alpes was essentially the same as the approach used for Wisconsin. Data from Bezirk X were provided by the Institut für Energetik in Leipzig and reflected goals in terms of automobiles per household, intercity and intracity travel, and energy intensiveness. For mass transit, projected passenger-kilometers and energy use per passenger-kilometer were estimated from variables such as load factor. This resulted in some simplification of the transportation model for Bezirk X.

IV.B.2. Residential Sector

A schematic diagram of the residential model[14] is shown in Figure 3.5. The general approach is to calculate total energy demand based upon the number of households in the region and the characteristics of those households, such as the percentage that are in multifamily dwelling units or the number of appliances owned. New dwelling units will be constructed to meet the demand created by new families and the demolition of old homes. The demolition function represents the probability that a dwelling unit of a certain age will be destroyed in any year. The percentages of new dwelling units that are single family and multifamily units are inputs to the model and are determined in part by the "urban scenario" selected. Since apartments are usually smaller and have some common walls, the energy required to heat the average apartment is less than that required to heat the average single-family home.*

Space heating, water heating, and central air conditioning are called "base" appliances. The percentage of new dwellings that contain a base appliance of each fuel type and the average yearly energy consumption of such applicances are forecast for each category of appliance.

The fraction of homes with a particular secondary appliance (i.e. dishwasher, television, washing machine) is independent of the construction of new homes and follows a saturation curve defined by input parameters.

The demolition and construction parts of the residential model were not appropriate for either Rhone-Alpes or Bezirk X. The plan for Bezirk X provided the number of units demolished and built as well as the fraction of total units that were multifamily housing units. Energy use for space heating per housing unit by fuel type and housing type and the fraction of each type of housing unit heated by each type of fuel were also provided. Since the data required for the demolition function were not available for Rhone-Alpes, the number of pre-1970 homes demolished and the number of new homes build in each 10-year period to the year 2025 were estimated.

IV.B.3. Service Sector†

The service sector model[15] is based upon engineering design of service sector buildings and a forecast of floor area. Energy use is broken down into four physical end-use processes: illumination, space heating, air conditioning, and process energy. The basic relationship for all final consumption calculations is

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* J.W. Mitchell and G. Venkataro, Energy Use in a Sample of Homes in Madison, Wisconsin, Institute for Environmental Studies Report No. 72 (Madison, Wisconsin: University of Wisconsin, Feb. 1977) provides a detailed empirical description of these heating requirements for typical Wisconsin households.

† In this study, *service sector* refers also to the commercial sector, unless the commercial sector is mentioned explicitly.

$$E_{i,j} = \frac{EI_i A P_{i,j}}{N_{i,j} C_j}$$

where

$E_{i,j}$ = the annual energy consumption for end-use i and fuel type j
EI_i = the annual energy intensity for end use i
A = the total service floor area
$P_{i,j}$ = the fraction of A assignable to end use i using fuel type j
$N_{i,j}$ = the mechanical equipment efficiency corresponding to end use i and fuel type j
C_j = the conversion factor for consistency in energy units

The fraction of the floor area assignable to each fuel type by end-use ($P_{i,j}$) and the mechanical equipment efficiencies ($N_{i,j}$) are input parameters. For illumination, the intensity ($E_{i,j}$) is based upon the illumination intensity (watts per square meter) and the equivalent operating hours per year. Space heating and space cooling energy intensity depends upon the engineering design of the buildings: the weighted heat transmission coefficients, the wall-to-floor and roof-to-floor area ratios, and an overall temperature difference. The analysis also accounts for the internal heat contributions provided by people, lights, and commercial equipment as well as heat loss from the introduction of outside ventilation air and natural infiltration. Process energy is energy for restaurant kitchen equipment, office machines, elevators, and other commercial equipment.

The GDR has no statistics on floor space but has very good data on employment. Their plan gives the fraction over time of the population working in the service sector by subregion and the average end-use energy (both total and for space heating) by fuel type per worker in the service sector.

Floor area data as well as the technical engineering information necessary for the energy intensity calculation were also lacking for the Rhone-Alpes. Employment projections in the service sector were available, however. Therefore employment was used as the basic driving force of the model and a conversion factor was used to obtain floor area. Energy intensity for space heating and cooling was estimated since the technical data were not available.

IV.B.4. Solar Heat and District Heat

The penetration of solar heating and district space and water heating into the residential and service sectors creates a special modeling problem. In the case of solar heating, the ultimate *market capture potential* is a fixed percentage of the total market. For residential heating in particular, the market capture potential declines in high-density areas. Since there will also be periods with no sunlight that will last longer than the economically feasible supply of stored energy, a backup oil, gas, or electric system must be provided that will typically be required to supply 30 to

50 percent of the total energy depending upon local climate.[16] In the case of district heat, the feasibility increases with density and is usually only available for multifamily dwelling units and service sector establishments.

The penetration of a new product into a market usually follows a logistic curve[17]

$$\ln \frac{f}{1-f} = c(t - t_0)$$

where

f = the fractional penetration into the total potential market, $0 < f < 1$
c = a constant
t = time
t_0 = the time at which $f = 0.5$

If the fractional penetration is known at two times, the constants are determined and f at any time t can be calculated. This approach was implemented for solar penetration into the residential sector.

IV.B.5. Industrial Sector

The industrial model[18] is based upon economic activity indicators rather than engineering design. Its primary input is the forecast of economic activity by industry. Energy intensiveness (energy per unit of output) projections, by type of industry, are based upon a study of past trends and judgment about future trends. The basic demand equation is

$$E_{i,j} = VA_i EI_{i,j}$$

where

$E_{i,j}$ = the annual energy consumption in industry i of fuel type j
VA_i = the annual value added (in constant monetary terms) in industry i
$EI_{i,j}$ = the energy intensiveness (energy per unit of value added) in industry i of fuel type j

A schematic diagram of the industrial calculations is shown in Figure 3.6. The calculations for all three regions were similar.

IV.C. ENERGY SUPPLY

The energy supply system in the scenarios was based upon the end-use energy demands and was specified by the introduction of alternative assumptions about the supply system. Although no formal supply model was used in the development of these scenarios, a broad spectrum of policy issues was investigated.* It was not

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* In addition to the approach described here, a formal resource allocation model was used in an energy/environment study of Austria: Foell *et al.*, Energy/Environment Futures for Austria.

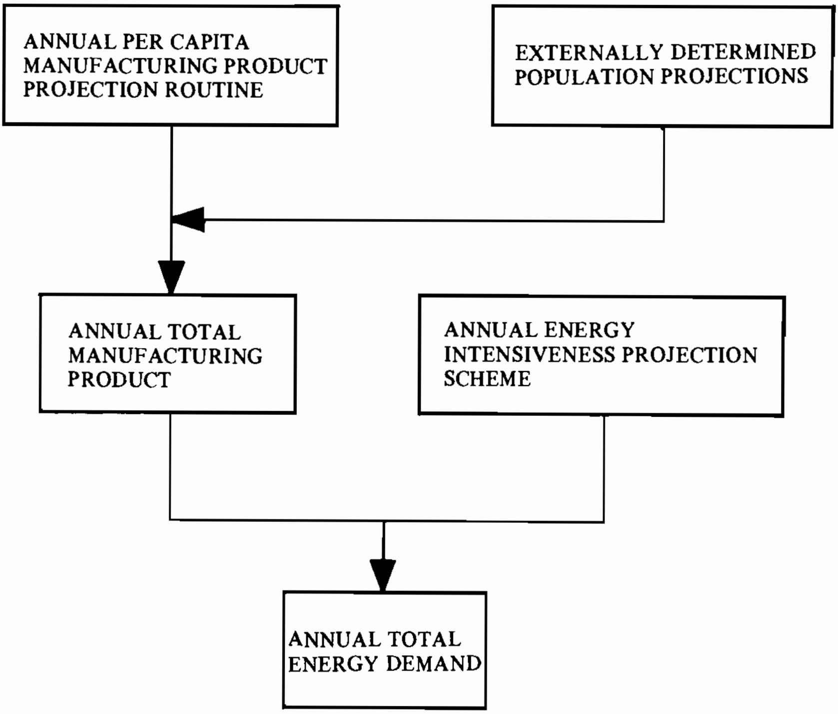

FIGURE 3.6 Schematic representation of the industrial submodel (Source: Shaver *et al.*[18]).

assumed that any one of the alternative supply scenarios had a higher probability of realization than any other. However, the scenarios do present a helpful picture of some of the consequences of alternative energy supply strategies that result from the considerations treated here.

IV.C.1 Definitions and General Concepts for Energy Supply

The energy system as defined in this study includes the complete fuel system, from resource extraction, transportation, and energy conversion, through waste disposal. The specification of the energy supply not only includes the quantity of energy obtained from each of the supply options, but also the location of the original resource extraction. Such information is used as input to the environmental impact models in order that systemwide environmental impacts can be identified and, to some degree, their locations specified.

Energy supply can be divided into several categories. The main division is between *nonelectrical* and *electrical* energy. The demand models provide the end-use needs for each of the supply options in the nonelectrical sector and the kilowatt-hours of electricity consumed. Another important distinction is between *end-use* energy and *primary* energy. The primary energy is determined from the end-use demands by accounting for losses, such as in electricity transmission, and the efficiency of conversion from primary fuels to another energy form, such as from coal to electricity or district heat. The primary sources considered were coal, petroleum, natural gas, nuclear fuel, hydropower, solar energy, and geothermal energy.

The calculations became somewhat more complicated when *import* and *export* of energy were considered. In all scenarios for all regions, some importing of primary fuels from other regions is required. In some scenarios, secondary energy forms, such as electricity or gas made from coal, are imported or exported. In no scenario in these studies is primary fuel export considered. Therefore, the total primary energy requirement for the region depends not only on the end-use demands, losses, and conversion efficiencies, but also on the amount of electricity exported and the corresponding conversion efficiency. The primary energy requirement is given by

$$P = E + L + C + P'$$

where

P = primary energy requirement
E = end-use demands
L = losses, such as in electricity transmission
C = energy used in conversion of energy forms, such as from coal to electricity
P' = primary energy used to produce electricity for export

The energy derived from the sun was defined as primary energy after absorption by a collection device. Thus, the reflected portion of the solar energy falling on a collector is not included in the primary energy. The energy rejected as waste heat at a solar power plant that uses a conventional steam cycle is included in the primary energy.

Geothermal energy used for space heating in the Rhone-Alpes region was defined as primary energy when removed from the ground. The losses in transmission then had to be subtracted to obtain end-use geothermal energy.

Hydroelectricity was assumed to be produced at an efficiency of 85 percent. The corresponding primary energy is representative of the energy actually used, not the fossil fuel energy that would have been used as a substitute.

IV.C.2. Nonelectrical Energy Supply Systems

In most scenarios the end-use demand calculations specify the nonelectric energy supply from the alternative sources to some degree. For example, transportation energy demand is strongly linked to petroleum. In some cases, however, substitution among some fuels to carry out the same function, or the use of synthetic fuels, is possible.

The nonelectrical supply options are represented by a reference system for each alternative. Typical reference system characteristics were used that are representative of the particular situation in each region. The importance of the individual nonelectrical energy sources varied considerably among the regions; this will become evident in the scenario comparisons (Chapter 7).

The nonelectrical energy sources are assumed to be able to supply the needs of each region; no detailed model of world energy markets or reserves has been used.* In some cases special constraints were used that required some substitution among supply options. However, in general, either the supplies or synthetic substitutes are assumed to be available. Energy imports are important in all three regions considered in these studies, and therefore the energy supply within each region is strongly dependent on conditions outside the region.

The nonelectrical supply options and some basic considerations are listed below. Other potential supply options were not included because the probability of major penetration by 2025 was felt to be low or because reasonably well-defined system descriptions were unavailable.

Coal Bezirk X is the only region that has significant coal reserves within its borders.

Petroleum Petroleum must be imported in all three regions.

Natural Gas Natural gas must be imported in all three regions.

District Heat from a Central Plant District heat obtained from coal- or oil-fueled plants was assumed at various levels in the Rhone-Alpes and Bezirk X scenarios. The district heat is used for both space heating and process energy.

Solar Space Heating and Water Heating Solar energy was assumed to provide space heating and water heating in some scenarios for all three regions. A solar system on a building is assumed to provide a significant percentage of the energy needs for space heating and water heating; the remaining energy requirement is assumed to be provided by an auxiliary system.

Synthetic Fuels Synthetic fuels were assumed to be available in some scenarios for Bezirk X and Wisconsin. The synthetic fuel for Bezirk X is *Stadtgas*,† used primarily for residential and commercial purposes in cities. The synthetic fuels for Wisconsin are assumed to be made from coal and to be substitutable for natural gas and petroleum.

Geothermal Energy Some geothermal energy is assumed to be available for heating purposes in Rhone Alpes.

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* The recent IIASA study of Austria (Foell *et al.*, Energy/Environment Futures for Austria) used a world petroleum forecast developed by the Workshop on Alternative Energy Strategies (WAES).[29]

† Literally, *Stadtgas* means "*city gas*;" it is usually coal gas.

IV.C.3. Electrical Energy Supply Systems

In contrast to nonelectrical energy, the end-use demand calculations for electricity do little to specify the mix in electrical energy supply from the alternative sources. The end-use demands, exports,* and transmission losses determine the *total* generation requirement. Because of time-varying electricity loads, an appropriate mix of types of generating capacity is needed, e.g., base-load, intermediate-load, and peaking plants. In these studies the focus of the analysis was on generation (kilowatt-hour) requirements; typical load characteristics were assumed to apply in order to determine capacity needs (kilowatts).

The relative potential for each of the alternative generation sources to be installed when new capacity is needed is specified exogenously. The generation and capacity by fuel type as a function of time is input to the electricity impact model.

The alternative electrical generating systems are represented by individual reference systems that can change over time because of technology advances or changes in regulation. The reference systems include those options that had well-defined system descriptions available in the literature and that were felt to have a reasonable probability of major market penetration by 2025.† The electrical supply options and some basic considerations are listed below.

Hydropower Although hydropower is currently the major source of electricity in Rhone-Alpes, this option does not have a potential for major expansion in that region. Hydropower is a minor source of electricity generation in the GDR and in Wisconsin, and the potential for further development is small.

Coal Coal is expected to continue as a major fuel source for electrical generation in Bezirk X, with its extensive reserves, and in Wisconsin, where the coal must be imported from other states.

Petroleum It is unlikely that significant quantities of new electrical generating capacity will be oil-fired in any of the three regions. Relatively small amounts of high-priced petroleum may be used for peaking plants.

Natural Gas Natural gas supplies and prices will probably prevent this fuel from being a significant factor in future electrical generation in any of the three regions.

Nuclear Fission The pressurized water reactor (PWR), because of its current operating capacity and according to announced plans, is the preferred type of nuclear plant in all regions.[19] Although the boiling water reactor (BWR) makes up about one-third of all operating and ordered nuclear capacity in the United States, only one small 50-MWe BWR is among the nuclear plants (with a capacity of 4,500 MW) that are operating or have been announced for Wisconsin. No BWRs are in the announced plans for the Rhone-Alpes or the GDR. However, the BWR is a viable nuclear alternative and has been included as a supply option. The high-temperature

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* Electricity export is an important policy issue. For these studies it was assumed to be specified exogenously and to be supplied within resource constraints.

† Some system descriptions are provided in the Appendix of this chapter.

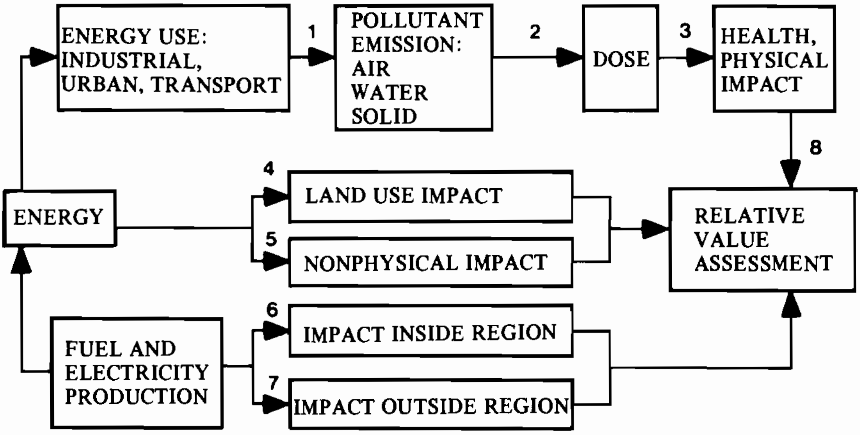

FIGURE 3.7 Pathways for environmental impact analysis. This structure is essentially identical to that used in the Wisconsin Regional Energy Model.[7] 1 – Emission; 2 – Dispersion; 3 – Dose–response, 4 – Direct land use, 5 – Direct economic effects, 6 – Fuel chain impacts within region, 7 – Fuel chain impacts outside region, 8 – Value assessment of alternatives. These pathways encompass three geographic scales: local impacts, regional impacts, and impacts outside the region due to use of energy in the region.

gas-cooled reactor (HTGR) may become an attractive advanced reactor; it has not yet received the general acceptance that the PWR and BWR have. The liquid-metal fast-breeder reactor (LMFBR) has been included although, unlike the other nuclear systems included in the model, it clearly is not a current alternative. Since detailed information on its expected performance and fuel cycle are available,[20] the LMFBR has been included as a *future* alternative.

Solar Energy Solar thermal electric plants were assumed to be available and to be a favored type of electric generation in one scenario for each region.

IV.D. ENVIRONMENTAL IMPACT

The energy supply systems discussed in the previous section form the basis for the environmental impact calculations. In this section the methods employed for impact estimation are summarized along with some of the problems and limitations of this type of analysis.

IV.D.1. Systemwide Impacts

The impacts associated with any particular energy scenario have been estimated from a *systemwide* perspective. Therefore, some impacts are included that occur outside the region because of energy use inside the region. Some general considerations involved in the environmental impact analysis are displayed in the pathway diagram (Figure 3.7). Energy use may cause pollutant emission, pollutant transport, and exposure of living organisms, and corresponding health impacts. Obtaining the

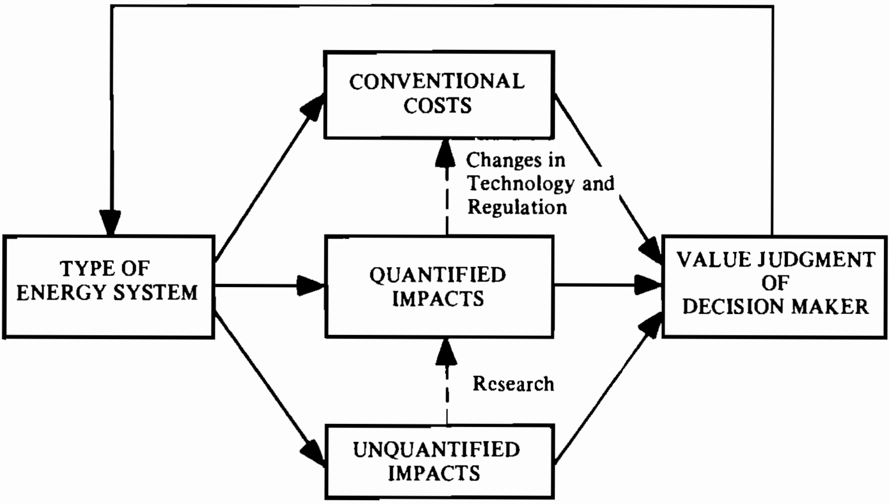

FIGURE 3.8 Factors in energy decision making.

primary fuels may result in impacts outside the region, such as land disturbed for coal mining, as well as impacts within the region where the energy is finally used.

For these studies the system boundary was defined to include all end-use energy activities and associated fuel supply industries. Therefore, impacts resulting from the mining of coal to produce electricity are included, but the impacts associated with the production of coal-mining machines are not included.

IV.D.2. Quantified and Unquantified Impacts

All impacts cannot be quantified in a satisfactory manner. Therefore, the quantified impacts as estimated by the models that are described in the following sections are by no means the "total" environmental impact. Other environmental impacts not included in the models are defined as "unquantified" impacts. Some environmental concerns are recognized as falling in the unquantified category. Further research may allow some of the unquantified impacts to enter the quantified category as suggested in Figure 3.8. However, some impacts will most likely always remain unquantified. This may be because the impact has just been recognized as potentially important and no research has been devoted to it, or because the impact quantification is based almost entirely on value judgment.

Quantified impacts are the focus of the impact models to be described. They include systemwide effects such as water consumption and pollutants emitted. When new control technologies become available or new standards are set, some quantified impacts are generally reduced or eliminated while conventional costs usually increase. Thus, transfers between the categories in Figure 3.8 may take place as a function of time.

IV.D.3. Value Judgments and Preferences

When decisions must be made on alternative energy sources, at least three important sets of information need to be considered: (1) conventional costs, (2) quantified impacts, and (3) unquantified impacts. These impacts and costs are, in general, combined through the value judgment of decision makers, who may be utility executives, government regulators, or average citizens (Figure 3.8). This is a complex and difficult task, but these value judgments are being carried out, though perhaps not explicitly, since decisions on energy matters are being made.

These complex problems related to value judgments are discussed in some detail in Appendix E; multiattribute decision analysis is presented to provide some help in thinking about complex trade-offs involving costs and both quantified and unquantified impacts.

IV.D.4. Characterizing Impacts

Categorization of impacts is itself a form of value judgment and would differ among individuals. However, for the purposes of organization, the quantified impacts have been classified into five broad categories:

1. Human health and safety
2. Air quality
3. Water quality
4. Land
5. Fuel resource, efficiency

Human health and safety includes both public and occupational effects. Typically, the impacts are measured as premature fatalities, nonfatal injuries, or illness. In an attempt to measure the severity of these accidents and health effects in a single unit, results are sometimes displayed in terms of person-days lost (PDL). In the United States the number of disability days associated with various accidental injuries is determined by tables developed by the American National Standards Institute.[21] These tables have been used here and extended to all human health and safety impacts, including deaths or total disability (6,000 PDL), and nonfatal injuries and illnesses at correspondingly lower PDL per occurrence.

Impacts that fall in the other categories are not readily combinable in most cases. Therefore, only representative impacts from the other categories have been selected for display.

Another problem of characterization is the location of impacts and their associated causes. The four classifications selected were:

1. Impacts that occur within the region because of energy use within the region
2. Impacts that occur outside the region because of energy use within the region

3. Impacts that occur within the region because of energy export to other regions
4. Impacts that occur outside the region because of energy export to other regions

These classifications show the degree to which impacts are exported to other regions because of energy use within the region. In the case of energy export (exclusively electricity export in these studies), the region suffers some impacts in order to supply the export energy. Impacts within the region because of energy production outside the region are included in the models as a background contribution.

IV.D.5. Description of the Models

The four main models used in these studies were related to thermal pollution, emission and dispersion of air pollutants, air pollution health effects, and general systemwide impacts. A brief description of each of these models follows.

Waste Heat Disposal The regional environmental impacts of waste heat disposal from electric power plants have been examined. Two direct consequences of disposal of heat into a water body are (1) a temperature increase of the water body, and (2) evaporation of water. Since these consequences have several different impacts themselves, most of which are difficult to quantify, artificial water temperature increase and evaporation have been used as indicators of the environmental impact of waste heat disposal from electric power plants.

The cooling options considered in this analysis were once-through cooling on rivers (water passes from the river, through the condenser, and back to the river), wet (evaporative) cooling towers, and dry (nonevaporative) cooling towers. Waste heat is fed into water bodies with once-through cooling water and blow-down water* from cooling towers. Water is evaporated artificially from both wet cooling towers and the heated surfaces of bodies of water.

The increase in river temperature is calculated as a function of distance along the river, waste heat rejected, width of the river, and wind speed. Radiative, evaporative, and convective heat losses are included in the calculation.†

The amount of waste heat included in the blow-down from the cooling towers is a function of the water flow rate, water evaporation from the cooling tower, and the salinity of makeup water. For rivers with high salinity the temperature increase of the river rather than the amount of water available may be the limiting factor for wet cooling towers.

The impact on the weather is measured by the artificial increase in relative

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* Blow-down is the intermittent release of water from a cooling tower system in order to prevent the buildup of salts.

† Some details for the calculation of water temperature, waste heat from blow-down, and weather effects of evaporation are given in the Appendix of this chapter.

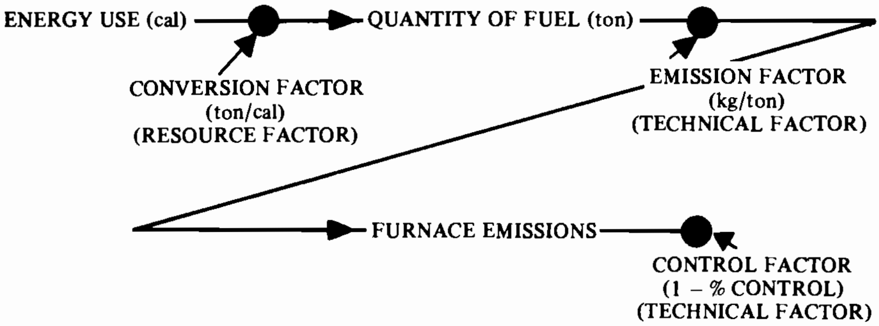

FIGURE 3.9 Emission submodel.

humidity. Disregarding local phenomena from single towers or single warm water plumes, the increase in humidity over a region can be calculated approximately. A Gaussian plume model is used for the dispersion calculation that provides an estimate of the increase in relative humidity at ground level.

Air Pollution and Health Effects This section describes the methodology used in the top pathway of Figure 3.7, energy use → emissions → dose → health impact. The models for calculating emissions, dispersion, and dose-response are briefly outlined below. More detailed accounts are available in other publications.[11,12]

Pollutant emission The purpose of the emission submodel is to calculate emissions of air pollutants that result from energy use; the calculations are performed on an annual basis over a given study period at the subregional level. The total emission submodel consists of five sectors (i.e., residential, service, industrial, transportation, and power plant sectors), and emissions of five critical air pollutants are calculated, namely, particulates, sulfur oxides (SO_x), nitrogen oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO). The structure of the submodel is shown in Figure 3.9; a brief overview of each important sector follows.

RESIDENTIAL, SERVICE, AND INDUSTRIAL SECTORS As input data to the emission submodel, annual sectoral energy demand is given for each fuel type. These data come from the demand models for various scenarios over the study time period. Fuel is divided into four categories: coal (anthracite, bituminous, coke), oil, gas (coal and natural), and district heating. Taking into account the calorific content of each fuel used in the region, the energy value is converted into the quantity of fuel consumed. By multiplying the fuel consumption by emission factors and control factors as shown in Figure 3.9, subregional emissions of air pollutants (particulates, SO_x, NO_x, CO, HC) are estimated. Emission factors depend significantly on the fuel characteristics (e.g., percent ash and sulfur content) and furnace characteristics (e.g., type, size, and fuel preparation). Therefore, emission factors will be different in the different sectors for the same fuel type. Emission factors must generally be considered in a time series to reflect changes of fuel combustion technology. Control factors are estimated in a time series taking into account the possible advances of future emission control technology. For SO_x and particulates, three emission control policies for the future (low, middle, and high controls) are assumed by sector and by fuel type for each region. No pollution control is assumed for air pollutants of NO_x, CO, and HC. It is desirable to use the regional average emission and control factors, but national average values have been used in most cases.

TRANSPORTATION SECTOR The emission computations are directly tied to the vehicle mileage by class and year. The emission factors are based on U.S. Environmental Protection Agency surveillance data of current vehicles. Future emission factors are estimated from potential emission control and vehicle age. The model assumes emissions to increase linearly with vehicle age for hydrocarbons and CO, and exponentially with vehicle age for NO_x. Emissions are determined separately for urban and rural areas.[13]

POWER PLANT SECTOR Power plant emissions are determined as part of the general environmental impact model, which is described later in this section. Emissions of carbon dioxide (CO_2), aldehydes, and various trace elements of coal, such as mercury and arsenic, are included, as well as SO_x, NO_x, particulates, hydrocarbons, and CO. Important control policy options can be examined by the model with respect to SO_x and particulates. Radioactive emissions from nuclear plants are also computed by the model.

Pollutant dispersion The geographic detail of the dispersion model is at the level of urban areas of the region. The model is divided into two parts, urban and rural – urban areas are treated specifically and rural areas are treated generally. Emissions must be split into urban and rural components as part of the input to the dispersion model. The dispersion model is based on a mix of empirical monitoring data, physical dispersion models, and meteorological data.

URBAN COMPONENT The urban component of the model requires that emissions be given in three classes: (1) tall stacks (power plants), (2) medium stacks (industry and district heat), and (3) low-level sources (residential sector, service sector, transportation sector). For each source class a dispersion scaling parameter is calculated using the detailed dispersion models at Wisconsin and IIASA[27] to convert tons of pollutant emitted to an annual ambient concentration, or dose, in micrograms per cubic meter ($\mu g/m^3$). The three classes of doses add together to give the total dose from the energy use considered.

$$UD = \alpha(E_T D_T + E_M D_M + E_L D_L)$$

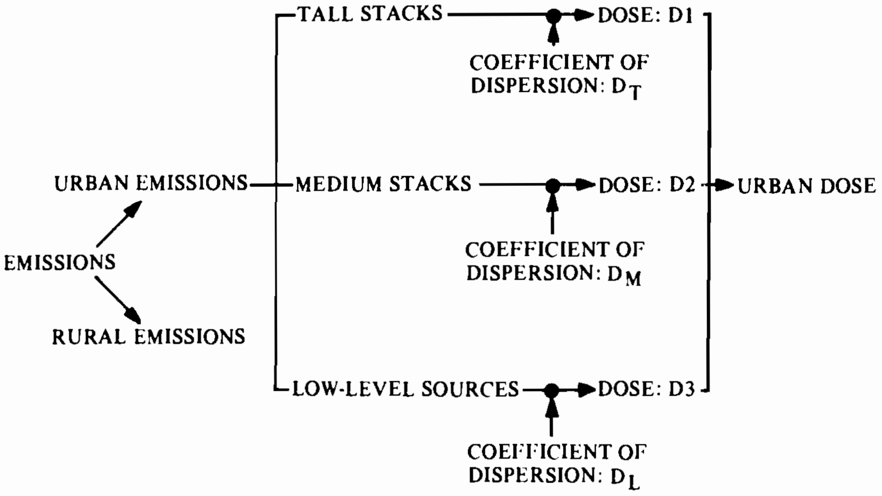

FIGURE 3.10 Dispersion submodel.

where

UD = urban dose.
α = calibration constant determined from empirical data.
E_T = emission from tall stacks.
E_M = emission from medium stacks.
E_L = emission from low-level sources.
D_T = dispersion coefficient for tall stacks.
D_M = dispersion coefficient for medium stacks.
D_L = dispersion coefficient for low-level sources.

This is schematically shown in Figure 3.10. The dispersion coefficients are based on the assumption that the population is mobile and that, on the average, individuals encounter the arithmetic mean of the dose calculated for the entire urban area; that is, gradients across the urban areas are averaged by population mobility. As a result of this averaging, the dispersion coefficient for industry is independent of the location of the industrial sources and of the industrial density over several orders of magnitude for a constant number of sources. For low-level sources, the scaling factor is dependent on city size.[27] For Wisconsin the coefficients are in the ratio 1 : 11 : 57 (D_T:D_M:D_L). These ratios show the importance of dispersion and indicate that impact is not directly proportional to emissions.

Most of the calibrations for the dispersion coefficients were based on detailed modeling and empirical data for Wisconsin. The dispersion coefficients were then adjusted for the other regions, primarily using meteorological data on wind roses* and atmospheric stability characteristics. Only those adjustments were made that could be inferred from the data available.

The health impact model discussed on the following pages requires a geometric standard deviation (GSD) in addition to the annual average pollution concentration. The GSD is obtained from empirical data relating GSD and city size; in general the GSD decreases with increasing city size.

This methodology could be used for other pollutants, but has only been applied in this set of models to SO_2 because SO_2 has the most extensive data set and damage functions are available. The problems associated with partial quantification of impacts and value judgments have been mentioned earlier (Sections IV.D.2 and 3).

The health impacts associated with emissions from electric power plants are treated separately and are based on detailed calculations for reference plants. The reference plant concept assumes a distribution of air pollution and GSD divided into quadrants that extend 80 km from the plant. The distribution is then combined with different population distributions to arrive at an average dose-impact to the population.

RURAL COMPONENT The rural impact is treated in a more general manner using empirical data from each of the regions to set the 1970 value. The rural values are proportional to total regional emissions, because all of the emissions influence the rural values; relative contributions are determined by dispersion models. The rural dose is then given by:

$$RD = \beta(E_R + E_L + E_M + 0.1E_T)$$

where

RD = the rural dose.
β = 1970 proportionality constant between rural dose and total emissions.
E_R = emissions from the rural area.
E_L = emissions from low-level sources.
E_M = emissions from medium stacks.
E_T = emissions from tall stacks.
0.1 = factor accounting for elevated releases and dispersion from very tall stacks.

For the pollutant calculation, it is assumed (1) that the climate of the region does not change over time, and (2) that the emissions from surrounding areas change proportionately to the emissions within the region.

To calculate the impact on health of pollutant emission and dispersion, a health impact model, based on an EPA model of health effects[22] was used. At the time this study was carried out, the EPA model provided the best estimation of health

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* A wind rose is a diagram that gives the percentage of occurrence for all combinations of wind direction and wind velocity.

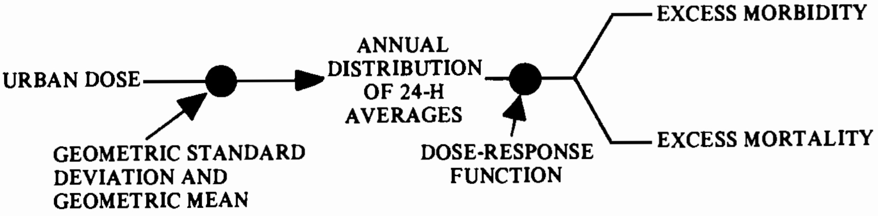

FIGURE 3.11 Health model relating pollution dose to damage.

impacts associated with acid sulfates produced from the conversion of SO_2.* However, the model does not include all health effects thought to be related to air pollution.

Central to the model are two assumptions: acid sulfates, not SO_2, are the cause of SO_2-related health effects, and the important averaging time is one day (24 h). The 24-h distribution is obtained by using the GSD and by taking into account the fact that the frequency of occurrence of different levels of pollution in the course of a year is distributed log-normally.

Dose-response functions related to acid sulfates are given for:

- Excess daily mortality (with a threshold effect)
- Excess aggravation of heart and lung disease (no threshold)
- Excess aggravation of asthma (no threshold)
- Excess acute lower respiratory disease in children (with a threshold effect)
- Excess risk of chronic bronchitis for smokers (with a threshold effect) and for nonsmokers (with a threshold effect)

The dose–response functions give an excess mortality and excess morbidity in the population resulting from air pollution (Figure 3.11) This is not the total impact, but only an indication. These are then converted to person-days lost, as defined earlier (section IV.D.4.) and combined with the other energy-related impacts as a human health effect.

Features of the Environmental Impact Submodel (EIS) The Environmental Impact Submodel (EIS)† was used in addition to the detailed waste heat and air pollution calculations described in the previous sections. The EIS provides a broad view of selected quantified impacts that occur throughout the energy supply system as a result of energy use. Both nonelectric and electric supply systems are included in the model. An overview of the model follows.

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* Although acid sulfates may not be the causal agent of the health impacts, they are considered to be a good indicator of the impacts.

† This model is an extension of the Electricity Impact Model (EIM).[23]

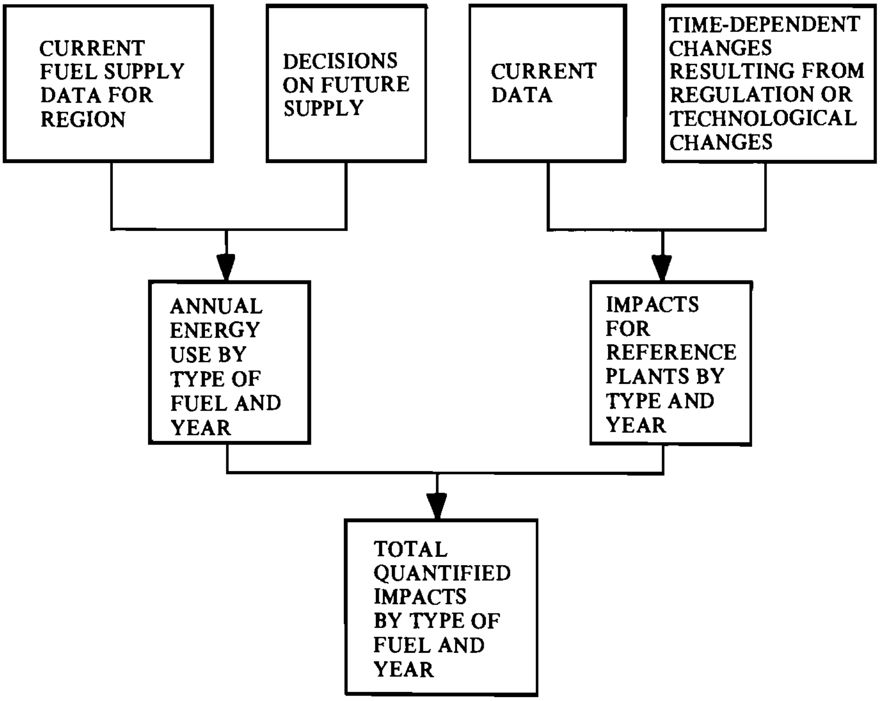


FIGURE 3.12 Basic structure of the Environmental Impact Submodel.

The input required by EIS is the year and the quantity of energy use by fuel source. Additional input is required to change any of the numerous parameters that describe the reference systems. The output from EIS is quantified environmental effects that result from the energy use and the supporting fuel system activities.

The basic structure of EIS is shown in Figure 3.12. The fuel supply data for each year of computer simulation are combined with impacts associated with reference plants to obtain total quantified impacts by fuel type and year. A reference system for a particular year may have different impacts from the reference system for the same fuel type in another year because of time-dependent factors, such as a reduction in SO_2 emissions per unit electrical generation because of sulfur removal systems or increased use of low-sulfur coal.

"Impact factors" are associated with each type of fuel supply. The factors have been determined from collection and analysis of relevant data; they are calculated in the model as a function of energy (kcal or kWh) or, in some cases, electrical capacity (kW).

The impacts are calculated by multiplying the matrix of impact factors for a particular year and a particular energy source by the energy use from that source. The quantified impacts are given by:

$$Q_{ijk} = E_{jk} I_{ijk}$$

where

Q_{ijk} = quantified environmental impacts of type i in year j resulting from energy source k.
E_{jk} = quantity of energy source k used in year j.
I_{ijk} = impact factor of type i in year j for energy source k.

The quantified impacts can be summed over index j to obtain cumulative impacts for a particular energy source. Impacts with similar units can be summed over index i to obtain totals for a particular year and energy source, and over index k to obtain totals for all energy sources in a particular year.

The impact factors were determined from reviews of impact quantification in the literature as well as independent analysis of the specific regional situation. Many of the factors determined in this manner were directly applicable only to current energy systems. However, modification of impact factors in the future can simulate effects of changes in technology, regulation, population, or other considerations. The impacts associated with annual electrical generation of a 1,000-MWe unit in 1970 are not necessarily the same as for annual generation from that same unit in 1980.

As an example, underground coal miners face the well-known health hazard of black lung disease, also known as coal workers' pneumoconiosis (CWP). In the advanced stages, CWP spreads even without exposure to coal dust, which is the original cause of the problem, and may lead to death or total disability. A fraction of the underground coal miner labor force became disabled in 1970 from this disease. If their disability rate could be shown to be related to coal production over a period of time, a certain quantity of coal miners' disability could be associated with each unit of coal obtained by underground mining. However, the CWP disability rate should diminish as new standards are instituted and new miners join the miner work force. By studying the data and the statements of appropriate experts, an estimate can be made for a CWP impact factor that decreases as a function of time. Thus, as a result of a new regulation, the impact factor, total disability from CWP per unit of underground coal, is a function of time.

A general characteristic of EIS is that impacts are associated with the energy use that caused them. Therefore, uranium mining accidents that may have occurred two or three years before the electrical generation, and exposure to krypton-85 and tritium that may occur many years after the generation, are tabulated in the year of the energy use. A mathematical expression that describes the impacts at time t' because of electrical generation at time t is

$$Q(t) = E(t) \int_{t'} I(t, t')dt'$$

where

$Q(t)$ = quantified environmental impacts associated with energy use at time t.

$E(t)$ = energy use at time t.
$I(t, t')$ = impacts that occur at time t' per unit energy use at time t.

It should be noted that the time that the impacts occur is not specified in EIS. $I(t, t')$ is not provided. The impacts are associated with the energy use that caused them.

APPENDIX

ELECTRICAL ENERGY SYSTEM CHARACTERISTICS

There is not sufficient space to list all the important assumptions associated with each reference system. However, a few of the characteristics for the reference coal, PWR, and solar electric systems for Wisconsin are listed in Tables 3A.1–3A.3.

Characteristics of the coal plant that uses bituminous coal are listed in Table 3A.1 separately from the characteristics for a plant using sub-bituminous coal because the plants and associated impacts are significantly different. Thus, one of the important parameters is the fraction of coal delivered to Wisconsin power plants that is sub-bituminous from western states. This fraction is assumed to increase from its 1970 value of only 0.01 to 0.25 by the year 2000. The 1970 reference coal system and the annual flow rates of coal to support the annual operation of a 1,000 MWe plant at 70 percent capacity factor are displayed in Figure 3A.1.

The characteristics for the Wisconsin coal systems are in general not applicable to reference systems for Rhone-Alpes or Bezirk X. For example, the heating value in 1975 for typical coal (lignite) for Bezirk X was only 2,300 kcal/kg; the sulfur content was 1.4 percent by weight; and the typical shipping distance was only 10 km. Therefore, different reference systems were used in the other regions only when the appropriate data were available.

The reference PWR system for Wisconsin (Table 3A.2 and Figure 3A.2) and the other reference nuclear systems for Wisconsin were assumed to hold equally well for the other two regions. Some data obtained for the PWRs used in the GDR indicated that a lower equilibrium burnup and lower fresh fuel enrichments would be appropriate.

The reference solar electric system for Wisconsin (Table 3A.3) was only adjusted in the following characteristics for the other regions

- Assumed average solar input
- Power per unit area
- Land area per 100 MWe

The assumed solar input was 3 kWh/m^2/day for Bezirk X, based on observations

TABLE 3A.1 Reference Coal-Fired Electrical Generation Systems for Wisconsin

	Bituminous Coal from Midwestern States	Sub-bituminous Coal from Western States
Fraction of coal used in Wisconsin	0.99[a]	0.01[a]
Coal heat content per unit mass (kcal/kg)	6,670	4,720
Sulfur content (weight %)	2.5	0.6
Ash content (weight %)	10.0	10.0
Source of coal	outside region	outside region
Percent surface mined	50[a]	100[a]
Surface area disturbed by surface mining (m^2/metric ton)	1.4	0.089
Coal mining fatalities per million metric tons mined:		
Underground mining	0.72[a]	
Surface mining	0.13	0.13
Coal shipping distance (km)	640	2,240
Metric tons coal per train	9,100	9,100
Public fatalities per million train-kilometers	2.3	2.3
Power plant heat rate with once-through cooling (kcal/kWh)	2,220	2,370
Capacity at a single site (MWe)	2,000	2,000
Millions of people within 80 km:		
Urban site	6.30	6.30
Average site	2.25	2.25
Rural site	0.30	0.30
Fraction of ash collected	0.99[a]	0.99[a]
Fraction of SO_2 collected	0.0[a]	0.0[a]
Trace-element emissions	proportional to ash	proportional to ash
Percent of coal cleaned:		
underground mining	70	
surface mining	30	0.0
Disabling cases of black lung disease per million metric tons coal mined underground	0.47[a]	

SOURCE: Buehring[23]

[a] Assumed to vary as a function of time. Only initial conditions (1970) are listed.

for Leipzig and Dresden. A reasonable average solar input for Rhone-Alpes was approximately the same as for Wisconsin, so the same reference plant was used for these two regions.[24]

ENVIRONMENTAL IMPACT OF WASTE HEAT DISPOSAL

The alternatives for disposal of waste heat produced by electric power plants considered were

TABLE 3A.2 Some Characteristics of the Reference Pressurized Water Reactor System for Wisconsin

Percentage of uranium from surface mines	54[a]
Grade of the ore (percent U_3O_8 in ore)	0.2
Uranium mining fatalities per thousand metric tons U_3O_8:	
Underground mining	0.79
Surface mining	0.20
Land disturbed for surface mining of uranium (m^2/metric ton of ore)	0.75
Source of Uranium	outside region
Percentage of ^{235}U in enrichment tailings	0.25
Uranium recycled	yes
Plutonium recycled	no
Fresh fuel enrichment (percent ^{235}U)	3.3
Spent fuel enrichment (percent ^{235}U)	0.89
Equilibrium burnup (MW-days/metric ton)	33,000
^{85}Kr in spent fuel (Ci/MW-day)	0.34
Tritium in spent fuel (Ci/MW-day)	0.021
Average capacity factor for reactor[b]	0.70
Power plant heat rate with once-through cooling (kcal/kWh)	2,670
Noble gas release at reactor (μCi/kWh)[c]	0.45
Tritium release at reactor (μCi/kWh)	0.045
Occupational exposure at reactor (person-rem/1,000 MWe-yr)[d]	450

SOURCE: Buehring[23]

[a] Assumed to vary as a function of time. Only initial conditions (1970) are listed.

[b] Capacity factor is the actual generation (kWh) divided by the maximum possible generation of the unit continuously operated at full power.

[c] μCi = 10^{-6} Ci

[d] The value listed is associated with annual operation of each 1,000 MWe of capacity regardless of capacity factor. A person-rem (or man-rem) is a measure of population exposure to radiation.

TABLE 3A.3 Reference Solar Electrical Generation System for Wisconsin

Maximum rated capacity of a module (MWe)[a]	333
Average output capacity from solar (MWe)	100
Annual solar capacity factor[b]	0.30
Power plant heat rate with once-through cooling (kcal/kWh)	2,150
Assumed average solar input for Madison, Wisconsin (kWh/m^2-day)	4
Collection efficiency (electricity/solar input)[c]	12.5%
Power per unit area (W/m^2)	20
Land area per 100 MWe (km^2)	5.0

SOURCE: Weingart[24]

[a] This may be a hybrid fossil–solar plant so that excess steam cycle capacity will not be idle most of the time. Another parameter is the number of hours of storage capacity for the solar plant.

[b] Capacity factor is the actual generation (kWh) divided by the maximum possible generation of the unit continuously operated at full power.

[c] The efficiency represents the percentage of the solar input falling on the entire land area that is converted to electricity. It is estimated that less than half of the land area will be covered by collectors.

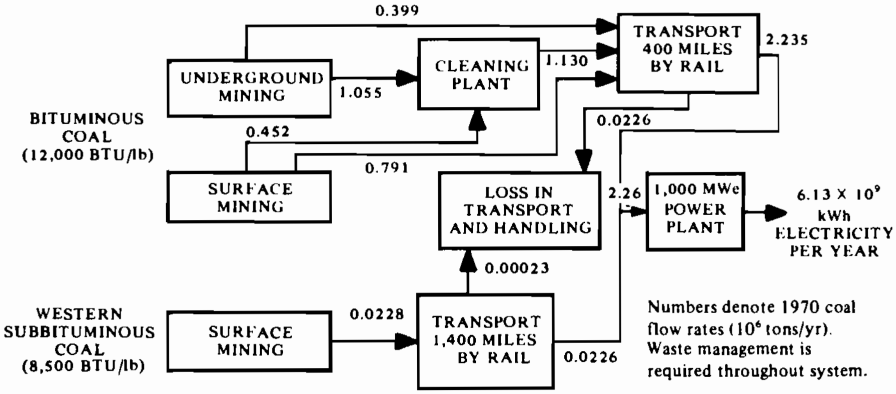


FIGURE 3A.1 The coal electrical energy system in Wisconsin (Source: Buehring[23]).

- Once-through cooling on rivers
- Wet cooling towers
- Dry cooling towers

The monetary cost increases from the first to the third.

The regional environmental impacts of the first and second alternatives result mainly from two direct consequences of the waste heat disposal:

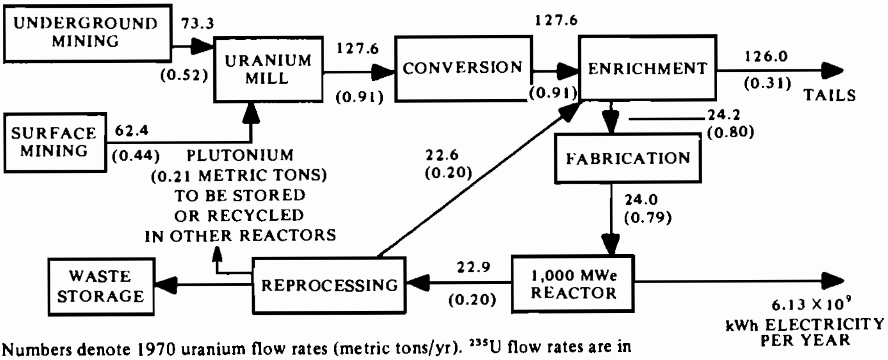
- Increase of the temperature of the water body to which the heat is discharged
- Evaporation of water

Both consequences occur with both alternatives: waste heat is fed into water bodies with both cooling water and blow-down water; water is evaporated artificially from both cooling towers and heated surfaces of water bodies. Since the two consequences have several different impacts, most of which cannot be quantified satisfactorily at present, artificial water temperature increases and evaporation are taken as indicators for environmental impact and analyzed quantitatively.

An artificial increase of water temperature influences mainly aquatic flora and fauna and drinking water production. In polluted water the main influence is through acceleration of self-purification, which may in rare cases be beneficial.

Artificial evaporation means less water is available for other purposes (drinking water, navigation), and there is an increase of fog frequency, clouding, icing, rainfall, and plant diseases.

Relatively little is known about the environmental impacts of dry cooling towers. They can increase cloudiness and they may facilitate the formation of thunderstorms. However, it is felt that their environmental impacts are small compared to those of the other cooling alternatives, and therefore these impacts are not considered here.



Numbers denote 1970 uranium flow rates (metric tons/yr). ^{235}U flow rates are in parentheses. Waste management is required throughout the system.

FIGURE 3A.2 Pressurized water reactor reference system in Wisconsin (Source: Buehring[23]).

The increase ΔT of the natural river water temperature due to sources of waste heat depends on the river flow rate Q and some meteorological parameters, which affect the heat transport through the water–air interface. It can be calculated approximately from an easily solvable differential equation of the form[25]

$$\frac{d\Delta T}{ds} = \frac{\chi(s)}{cQ} - \frac{Y_0(s)}{cQ}\phi(w, T)\Delta T$$

where

s = distance along the river
χ = waste heat ejected per unit distance and time
c = specific heat of water
Y_0 = width of the river
w = wind speed
T = water temperature

The function ϕ is made up of three terms which account for radiative, evaporative, and convective heat losses. ϕ does not depend on air temperature and humidity, although the natural water temperature is influenced by those parameters.

The total amount of water evaporated in the region is of interest. For evaporation from water surfaces it can easily be calculated using the appropriate term in $\phi(w, T)$. For evaporation from cooling towers it is sufficient to assume that the waste heat is removed exclusively by evaporation and blow-down water discharge.

With regard to meteorological effects of artificial evaporation, the artificial increase of relative humidity is a more useful measure of impact than the total amount of water evaporated. Disregarding local phenomena from single towers or single warm water plumes, the increase in humidity in the region can be calculated approximately. Each river is looked upon as two line sources of humidity emission:

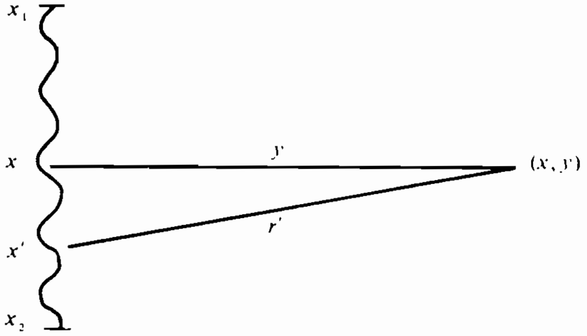


FIGURE 3A.3 Increase in humidity at (x, y) from a line source of evaporation.

one at ground level (evaporation from river surface) and one at a height h equal to cooling tower height plus plume rise (evaporation from cooling towers on the river). For the dispersion of humidity from these line sources, the Gaussian plume model can be used. If uniform, isotropic winds of velocity w, constant thickness H of the dispersion layer, and a stability class are assumed, the increase $\Delta\epsilon$ of humidity at ground level at point (x, y) (in Figure 3A.3) can be calculated according to

$$\Delta\epsilon(x,y) = \frac{1}{2\pi wH}\left(\int_{x_1}^{x_2} \frac{e_1(x')f(0,H,r')}{r'}\,dx' + \int_{x_1}^{x_2} \frac{e_2(x')f(h,H,r')}{r'}\,dx'\right) \qquad (1)$$

where

e_1 = water evaporated from river per unit distance and time
e_2 = water evaporated from cooling towers per unit distance and time
$r' = \sqrt{(x-x')^2 + y^2}$

The function f is the ratio between actual ground level concentration and concentration in the case of complete vertical mixing within the dispersion layer. (This means $f \to 1$ for $r' \to \infty$.) The function f is analytically known.[25] If there are many rivers in the region one can assume a homogeneous area source instead of many line sources and derive a formula analogous to Eq. (1).

The amount of waste heat carried to rivers with blow-down water is determined by the maximum permissible salinity C_m of the water which enters the condenser. The amount W_d of blow-down water can easily be derived from the balance equations of the cooling system.

$$W_d = \frac{W_0 - W_e}{1 + \dfrac{W_0}{W_e}\left(\dfrac{C_m}{C_i} - 1\right)} \qquad (2)$$

where

W_0 = water flow through the condenser
W_e = water evaporated in the cooling water
C_i = salinity of makeup water

For calculating the heat discharge into the river, one can assume that for fixed weather conditions the temperature of the blow-down water does not depend on the temperature of the makeup water.[26] One can see from Eq. (2) that for rivers with high salinity the temperature increase of the river rather than the amount of water available, may be limiting for wet cooling towers.

The cooling options discussed above are of different importance for the different regions. Rhone-Alpes and Wisconsin have good water resources per capita, and therefore once-through cooling and wet cooling towers will be the only cooling options of interest for the next decades. For the GDR the water resources per capita are so small that once-through cooling is out of the question now and even cooling with wet cooling towers will be limited in the near future.

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Prologue to Chapter 4
The GDR Scenarios in Retrospect

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May 1978

During the past few years, intensive work has been carried out in the GDR on long-term energy planning. The precision of the planning has been increased and the planning horizon has been extended.

One important innovation in planning has been a move from national-level to district-(Bezirk) level planning. Appropriate models have been developed and applied for this purpose. Regional authorities are now responsible for the statistical registration of energy demand and for providing the necessary energy supply. These authorities can also exercise some influence upon energy supply strategies in their regions.

The institution of regional planning has shown the necessity of coordinating regional plans with central plans. Regional plans are only acceptable if they conform to the provisions of the national plan. For instance, within the long-term planning context, the per capita residential electricity demand was calculated for all 15 districts of the GDR. The results showed that the demand in 1990 in 1 district was 4 times higher than in another district, although both had comparable economic and population structures. No explanation could be found for this large difference. The problem of regional inequalities is being resolved through planning restrictions that the regional authorities receive from the central planning agencies.

At the second conference, Management of Regional Energy/Environment Systems, held at IIASA, 16–19 May 1978, retrospective presentations on the scenarios were given by energy specialists or policymakers from the three regions. To provide perspective on the scenarios, summaries of the presentations are included immediately before the chapters describing the scenarios for the regions (Chapters 4, 5, and 6). They will be published in full as part of the proceedings of the conference: W.K. Foell (ed.), Proceedings of the Conference on Management of Regional Energy/Environment Systems (Laxenburg, Austria: International Institute for Applied Systems Analysis, in press).

It is hoped that in the future a more satisfactory correspondence between regional and central planning will be achieved.

Our collaboration with IIASA, especially in preparing for and attending the 1975 Three-Region Workshop, has brought us new knowledge that is of great value for our work in energy planning. For instance, we fully agree with the conclusions presented at the 1975 Workshop on the benefits of district heating, and we are going to continue to develop this energy technology in the GDR. Four rationales underlie our expansion plans. We want to (1) utilize our lignite in the most efficient way, (2) protect the environment, (3) offer the population a maximum of convenience, and (4) help the economy. Currently, district heating is being developed to as great an extent as the nation can afford economically. At the present time about 75 percent of all new flats are connected to district heating. During modernization, existing residential districts are also being partially adapted to district heating. To achieve economy, standardized heating power stations with steam generators of 320 tons/h and 60 MW turbines (and larger) have been developed and will become operational within the next few years.

Our interaction with IIASA also encouraged us to examine the potential for developing solar power in the GDR. We have concluded that, due to the geographic conditions of our country, the solar electric option cannot be seriously considered for the near future. Only the production of low-temperature heat for hot water and space heating seems promising. For this purpose, the GDR has begun large-scale production of solar collectors. Despite our plans for the development of solar power, it appears that the contribution made to total primary energy requirements by this energy source by the year 2000 will be very small. Economic reasons underlie this rather pessimistic estimation. At present, the costs of supplying heat from solar energy are twice as high as the costs of supplying heat from oil and six times higher than the costs of supplying heat from lignite briquettes. The cost of solar collectors must be lowered, and their efficiency must be increased. In addition, efficient heat storage systems must be developed for times when solar energy is not available.

The application of the IIASA models to Wisconsin, Rhone-Alpes, and Bezirk X is very promising for long time horizons. However, for shorter horizons, like the year 2000, it is necessary to investigate the effect of the energy scenarios on the economy, as well as on the environment. Such an analysis would make decisions possible that serve society as a whole. Even the scenario that is best in terms of environmental control is worthless if the society is not able to pay for it.

A last note on the question of industrial energy intensiveness in the GDR: At the 1975 Workshop there were vehement discussions about the great decreases in industrial energy intensiveness which were assumed to take place in the scenarios until 2025. In the GDR, an annual rate of decrease of five percent in energy intensiveness is used as a basis for planning for the next one to two decades. This corresponds to past trends. However, an extrapolation beyond the year 1990 is not possible. Over longer time periods, significant changes in economic structure may occur which could affect energy demand. In order to make realistic estimates of industrial energy intensiveness for years after 1990, complex economic analyses are needed.

Now let us turn to the environmental sphere. At the time that our collaborative venture with IIASA began, we were aware that environmental problems would have to be integrated into the energy models, but it had not yet been done. Therefore, this aspect of the IIASA research was of special interest to us. At the present time, two important environmental factors, land use for open pit lignite mining and its reclamation, and SO_2 emissions and ground level concentrations (as criteria for air quality), have been built into our model, and soon we expect to include water, as a limited resource, as a third environmental factor. Through a vigorous land reclamation program, the adverse effects of land use for mining have been almost completely eliminated in the GDR.

The work carried out by the IIASA team on pollution levels in the GDR has led us to compare ground level SO_2 exposures as calculated by our own models with the exposures calculated by the IIASA models. The comparison revealed a good correspondence for low- and medium-level sources, but for point sources with tall stacks (120 m or taller), the figures calculated by our models were larger than those calculated by the IIASA models. The explanation may lie in differences in the stack heights, differences in the meteorological conditions, or differences in the allocation of emissions from large point sources (that actually lie 10–20 km away from the city center) to the urban area.

As a next step, we studied large emitting sources in more detail, and disaggregated SO_2 emissions in a district capital into those caused by industry, district heating, and low-level heating sources – classes similar to those used in the IIASA work. The emissions and resulting ambient concentrations associated with these sources were projected until 2025; then, in an extension of the IIASA sensitivity analysis of the environmental implications of district heating, the effect of a flue-gas desulfurization policy on pollution levels from industry and district heating emission sources was studied. The results indicated that under our conditions of primary energy supply, district heating and flue-gas desulfurization must be used together in order to improve air quality in the future. In presenting such findings to decision makers, it is very helpful to have evidence from other research teams, like IIASA's and our own.

Finally, we have made an analysis of the economic implications of several SO_2 emission control strategies. A comparison was made of the costs of improvements in ambient air quality in urban areas because of urban sources and surrounding large point sources of emissions. It was found that increasing the stack heights of district heating plants outside the urban area from 180 to 300 m would be effective, but not possible because some stacks would interfere with air traffic. Although flue-gas desulfurization is more costly than increasing stack heights, it must be used for these stacks. For existing plants within an urban area, costs being equal, one would prefer flue-gas desulfurization to increases in stack heights for environmental reasons. For industrial emitters situated in the urban area, a change-over to district heating produced from a combined cycle plant situated 20 km from the city center is clearly a cost-effective way to reduce exposure in the urban area. For more distant new power plants (i.e. over 30 km from a city center), it is more economical to assure that stacks are sufficiently tall (300 m) than to use flue-gas desulfurization.

As these remarks suggest, our collaboration with the IIASA regional energy/environment management study has proved to be of notable relevance to our own planning. The IIASA work has underscored our interest in the expansion of district heating networks and the integration of environmental factors into energy planning, and spurred the development of the solar option. Our planning is now reaching new levels of precision, through a regional focus on energy demand and supply, through specification of sources of pollution, and through the testing of pollution control strategies.

4 Alternative Energy/Environment Futures for the German Democratic Republic

I. INTRODUCTION

This chapter describes the background, assumptions, character, and results of the three alternative futures developed for a region within the German Democratic Republic (GDR). The concept and objectives of writing alternative futures are discussed in detail in Chapter 3. Major emphasis is given in this chapter to what is termed the "Base Case" to provide a framework for comparison with the other two alternative futures (scenarios).

The rest of this introduction describes the character of the region studied, the character of the data, the policy questions of concern within the region and an overview of the three scenarios. Section II presents the base case in detail. Section III describes the two other scenarios, compares them with the base case scenario, and then presents some sensitivity studies that relate to certain policy issues. Finally, some overall conclusions are presented in Section IV.

An overview of the GDR is contained in Appendix A, and we need only describe here three major aspects:[1]

- Human geography – the majority of the population (~ 63 percent) resides in the lower one-third of the country.
- Economic geography – most of the industrial production (68 percent) occurs in the lower third of the country.
- Resource geography – almost all of the lignite is produced in five of eight Bezirks in this lower third of the country.

Chapter 4 was written by Robin Dennis – IIASA.

TABLE 4.1 Comparison of Bezirk X and the GDR

	Bezirk X (1970)	GDR (1972)
Population ($\times 10^6$)	1.425	16.95
Rural population (%)	46.2	45.6
Land area (km^2)	4,820	108,000
Population per km^2	290	157
Industrial net goods per capita (mark)	9,831[a]	4,495
Freight (rail and truck) per capita (ton-km)	3,789	3,443
Passenger cars per capita	0.063	0.083
Per capita end-use energy consumption (10^9 cal)	20.31	24.8
Electricity (kWh)		
Per capita generation	9,430	4,103
Per capita net export and losses	5,937	319
Per capita consumption	3,493	3,794
Primary energy per capita (including exported energy) (10^9 cal)	110.7	42.4
Primary energy use per capita (excluding exported energy) (10^9 cal)	37.8	~ 42.4

SOURCES: *Statistisches Jahrbuch 1974 der DDR*;[1] Institut für Energetik;[3] United Nations Economic Commission for Europe;[4] Doblin;[5] United Nations Economic Commision for Europe.[6]
[a] 1975 value.

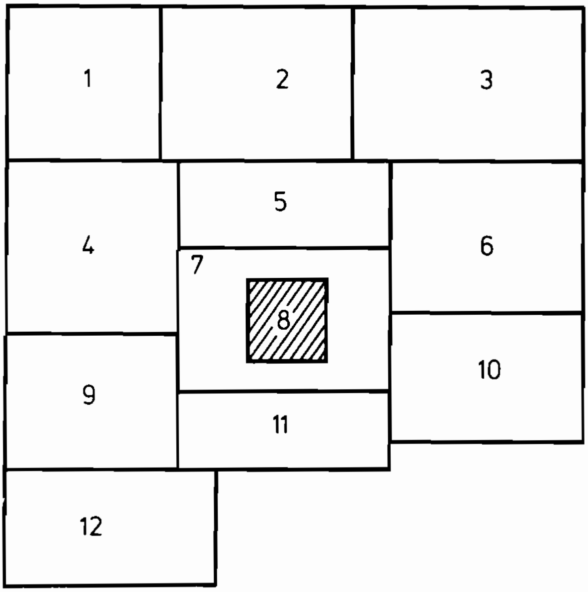

FIGURE 4.1 Map of Bezirk X.

I.A. BEZIRK X

Difficulty in obtaining official data of the breadth and depth needed and in the short time required by the research program necessitated the construction of a fictitious Bezirk, or administrative region, named Bezirk X. The alternative was to model the entire GDR or a part of it. Bezirk X, shown in Figure 4.1, is a regional composite of a typical industrial Bezirk of the lower third of the country, such as Leipzig, Halle, Karl-Marx-Stadt, or Dresden.[2] The main features of Bezirk X are:[3]

- Human geography – Subregion eight is a major city of 535,000 people surrounded by a rural area (subregion seven). Each other subregion has a single town; the average population per town is 23,000. This characteristic of having a single major city in the region is similar to Wisconsin and Rhone-Alpes, although the population of the Bezirk's main city is half that of Milwaukee, Wisconsin, or Lyon, France.
- Industry – Bezirk X represents a highly industrialized region of the GDR; the Bezirk produces industrial goods for the rest of the country, as is evident in Table 4.1. This industrial character is comparable with the relation of Rhone-Alpes to France, but not so much with the relation of Wisconsin to the United States.
- Resources – Large amounts of strip mining occur in Bezirk X and account for 20 to 25 percent of the GDR total.[1] This makes Bezirk X unique among the three regions; Rhone-Alpes and Wisconsin have insignificant mineral fuel resources.
- Energy – Coal is the main energy source; there is significant use of district heating for space heat and industrial processes.[7] This contrasts greatly with Wisconsin and significantly with Rhone-Alpes. The Bezirk is also an energy exporter.
- Environment – Bezirk X was defined to represent Bezirks with SO_2 pollution problems.[2]

For any results to be meaningful in this research context, Bezirk X must be realistic and representative. Several indices are compared with the GDR published statistics in Table 4.1 to demonstrate that this is indeed the case, and to show the industrial character of Bezirk X. The Bezirk, in strong contrast to Wisconsin, and to a lesser degree to Rhone-Alpes, is a major energy source for the GDR; in 1970 it exported 66 percent of its primary energy flow to the rest of the country.

I.B. THE DATA

I.B.1. General Characteristics

The framework for the data to be compiled for Bezirk X was defined by collaborative efforts of the IIASA and Leipzig researchers based on the methodology presented in Chapter 3. Values for many variables that span the 55-year study period were compiled in Leipzig and sent to IIASA where the models were run.[3] Through the year 1995 these data represent the outlook of the "20-year plan"* of the GDR for industrial Bezirks; from 1995 to 2025 they are an extrapolation of the trends exhibited by the 20-year plan.[2] For all of the demand sectors and the supply sector, the data were supplied for the twelve Bezirk X subregions (*Kreise*). In some cases, statistics available in the GDR did not fit the detailed Wisconsin Regional Energy (WISE) model requirements, and alternative means were defined to obtain the needed results.

I.B.2. Special Constraints

Several factors, in addition to the ones mentioned above, make this composite GDR Bezirk stand apart from the other two regions. First, the GDR *planning process* takes a relatively long (20-year) detailed planning horizon with a high emphasis on plan implementation. Thus, the near future is fairly tightly constrained in the scenario development. Second, the *population* of the GDR is expected to decrease slightly and then remain constant. This removes a major force for the increase in energy demand, so that the GDR represents an industrial zero population growth (ZPG) society. Third, the unique features of *lignite* as the energy base, with its low energy content, high water content, and high transportation costs, played an important role in the composite Bezirk.

I.C. SCENARIO DEVELOPMENT

I.C.1. Rationale

As discussed in Chapter 3, scenarios have several objectives. The most important is their use in addressing policy questions of interest to the region. Policy questions of special concern to the GDR include:

- Urban Setting – How is the energy use and environmental impact connected to the urban setting, especially with high use of district heat?[7,8,9]
- Transportation – What are the consequences of present trends for intercity and intracity transport and of a greater dependence on automobiles than desired?[2,10]
- Energy Supply – What are the demands on the present resource base of lignite in view of energy self-sufficiency and what new fuels might help to meet the demand for energy?[2,10]
- Economic Growth – What is the relationship between energy use and supply and desired economic growth?[2,7,10]
- Environment – There is a very strong interest in connecting energy use and environmental impacts and a strong interest in environmental control, especially cooling-water requirements and air pollution.[2,7,8,9,11]

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* An official "20-year plan" is not developed in the GDR. (See Section I. of Appendix B). We use this term to describe what the Leipzig Institut für Energetik refers to as "long-term development over 20 years."

The scenario methodology calls for the systematic comparison of various alternative futures. Several discussions were held between the IIASA and Leipzig researchers to discuss criteria for combinations of interests, assumptions, and boundary conditions for different scenarios. With the backdrop of the above interests, the requirements of the WISE models, and the GDR planning process, it was decided that Bezirk X should be defined by the Leipzig researchers and that the objectives of the GDR 20-year plan should form the foundation for the Base Case scenario. The input data to the year 2025 for the Base Case, described in detail below, were to be provided by the Leipzig researchers, along with any special constraints or boundary conditions for other scenarios.[3] The IIASA team and the Leipzig group felt that following the 20-year plan for the Base Case would best reflect the GDR's interests and concerns.

Two other scenarios were also chosen to illuminate regional structure, policy questions, and various sensitivities to energy and environment. The writing of these scenarios was begun in the meetings between the Leipzig and IIASA staffs; after the Base Case was received from Leipzig, the other two scenarios were further defined at IIASA and completed there. A concerted attempt was made at IIASA to remain in the spirit of the boundary conditions developed with Leipzig. Thus, certain basic socioeconomic variables, such as population, industrial growth, service sector growth, and housing were not varied from scenario to scenario. In a few instances the IIASA team felt that parameters should be varied over a greater range than that recommended by the Leipzig team. Such judgment was used sparingly in the two scenarios which were developed in addition to the Base Case.

I.C.2. Sketch of the Scenarios

The three scenarios can be briefly characterized as follows:

•S1: Base Case – This scenario follows the objectives of the long-term GDR plan until 1995 and represents an extrapolation of the trends from 1995 to 2025. A considerable industrial growth shapes the character of this scenario.

•S2: High-Energy Case – The assumptions for this scenario tend to result in higher energy use in the transportation and industrial sectors. Supply options are highlighted in sensitivity studies. An objective is to elucidate impacts of industrial efficiencies and demands on the Bezirk's resource base as well as on the environment. Lax environmental controls are assumed.

•S3: Conservation Case – This scenario includes some technical conservation policies, with emphasis on solar energy and energy efficiencies in automobiles and homes. Strict pollution control is assumed.

Factors that remain constant across scenarios are

- Population growth

TABLE 4.2 Policies and Assumptions for the Three Bezirk-X Scenarios

	Scenario		
Growth Assumptions	S1	S2	S3
Population	• Slight decrease to ZPG[1] by 1990	• Same as S1	• Same as S1
Economy	• Linear growth in service: factor of 1.67 by 2025	• Same as S1	• Same as S1
	• Exponential growth in industry: factor of 60 by 2025 over 1975	• Same as S1	• Same as S1
Policy Areas			
Technology	• Large decrease in industrial energy intensiveness • High penetration of district heating	• Smaller decrease in industrial energy intensiveness relative to S1 • Medium penetration of district heat	• Industrial energy intensiveness for electricity decreases faster than S1 • Very high penetration of district heat plus penetration of solar-thermal and solar-electric energy
Transportation	• Low automobile use • Efficient freight mode	• Greater auto use relative to S1 • Much less efficient freight relative to S1	• Lower auto use than S1 with more mass transit • Freight same as S1
Energy Supply	• Electricity almost all coal, some nuclear after 2000	• Must imported electricity due to increased direct demand for coal	• Less nuclear energy than S1 • Solar-electric energy penetrates
Environment	• Present trends in control of particulates and SO_2	• Low control of particulates and no SO_2 control	• High control of particulates and SO_2

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[1] Zero Population Growth.

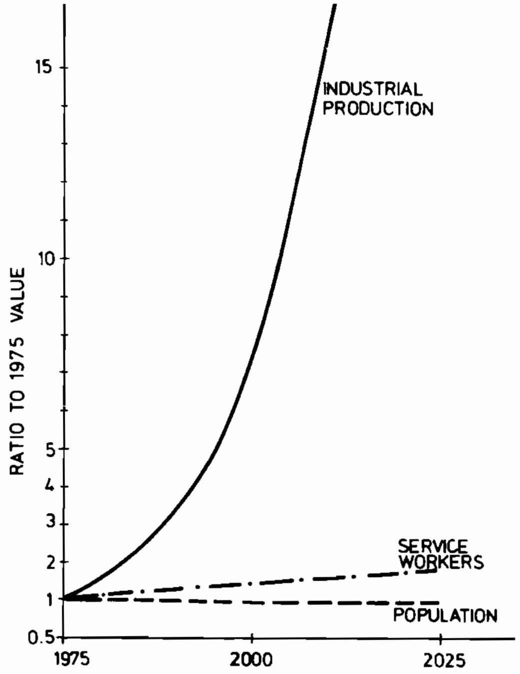

FIGURE 4.2 Basic economic indicators of Bezirk X (Source: Institut für Energetik[3]).

- Housing growth and ratio of single-family homes to apartments
- Industrial growth

In Chapter 3, the breakdown of the scenarios into building blocks was discussed. Table 4.2 presents a key-word overview of the three scenarios in this form.

II. BASE CASE SCENARIO

II.A. BASIC ASSUMPTIONS

The most important socioeconomic data provided by Leipzig[3] are shown in Figure 4.2 (normalized to 1975) and Figure 4.3.* The dominant feature is that the industrial growth is extreme, an exponential growth of 8.3 percent per year. This is much faster than Wisconsin's or Rhone-Alpes' growth; and furthermore the Bezirk's industrial growth does not taper off and shift into the service sector as it does in the

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* These socioeconomic indicators are the same in the three scenarios.

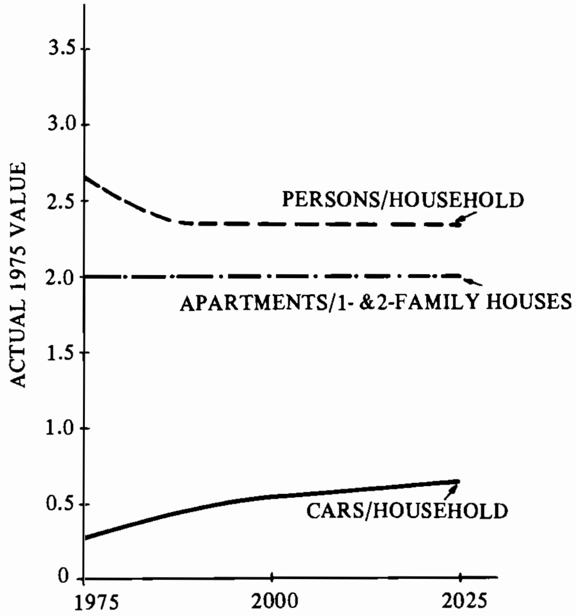


FIGURE 4.3 Additional indicators for Bezirk X.

other two regions. Bezirk X differs appreciably from Wisconsin and Rhone-Alpes in that it has no population growth; car ownership in 1975 was one-seventh that in Wisconsin. However, the occupancy per housing unit is nearly the same as the other two regions. By 2025 car ownership per capita will have increased in Bezirk X by a factor of 2.66; although this increase in car ownership is much greater than in Wisconsin or Rhone-Alpes, there will be fewer cars per capita in the GDR in 2025 than in Wisconsin and Rhone-Alpes.

Assumptions that are important to the Base Case are shown in Figures 4.4 to 4.7. The figures are self-explanatory, but it is worth pointing out in Figures 4.4 and 4.5 the dominance of coal in service and residential space heating in 1970, the emerging dominance of district heating by 2025, and the relatively low penetration of electricity and gas by 2025. Coal is still important in 2025 because of Bezirk X's resource base; the low penetration of electricity by 2025 reflects an attitude of careful use of primary energy to remain as nearly energy-sufficient as possible.

The Leipzig research group provided dwelling unit demolition and construction projections for each subregion; these vary across the Bezirk. Space heating requirements for a given fuel type for old and new homes were also provided, but since the difference was only 6 percent, the same value was used for old and new homes. In the residential sector, one- and two-family houses are 20 percent more energy intensive than apartment units. The space heat requirements for the service sector were provided on a per worker basis. By 2025 there was a 1 percent decrease in the

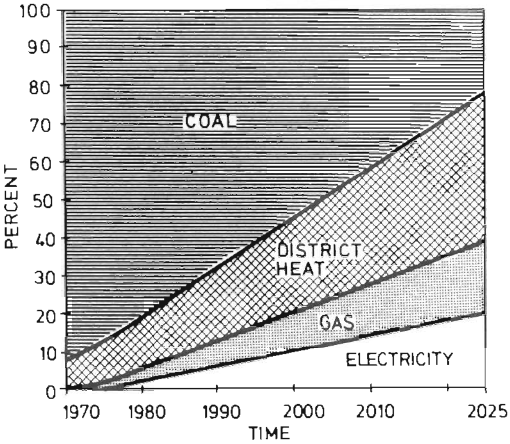


FIGURE 4.4 Contributions to residential heating by fuel type for subdistrict 9 (Bezirk X).

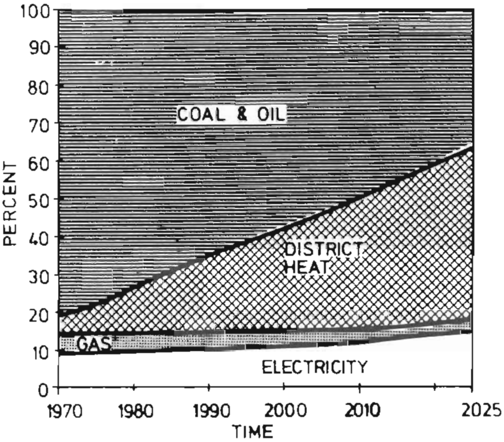


FIGURE 4.5 Representative contributions to service sector heating by fuel type for the small cities in Bezirk X.

average space heat required per worker. For these two sectors the fraction of the space heat demand met by a given fuel type was provided until the year 2025 as shown in Figures 4.4 and 4.5.

Saturation curves until 2025 were provided for all of the major secondary appliances. A sample is shown in Figure 4.7 where it can be seen that selected major electric appliances, such as clothes driers and single-room air conditioners, have a low priority in Bezirk X's plans for the future.[2]

The industrial sector was divided into six categories: metals, metal processing

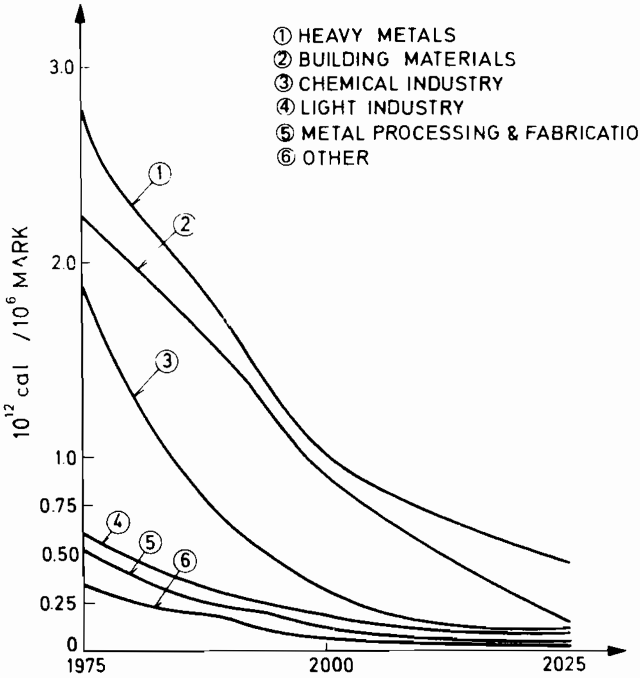


FIGURE 4.6 Energy intensiveness for each industrial subsector in Bezirk X.

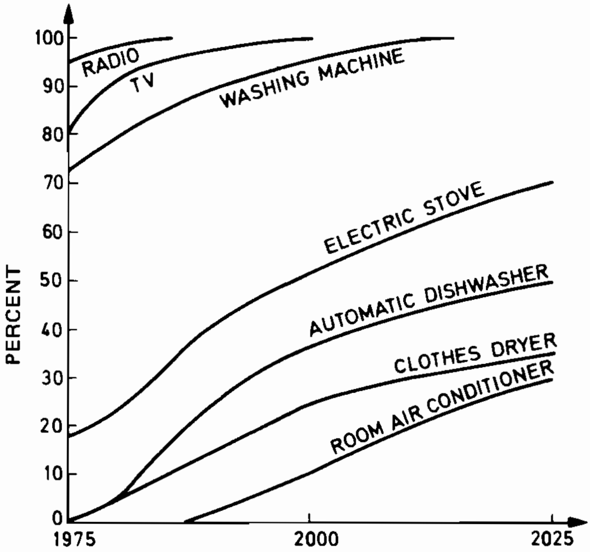


FIGURE 4.7 Saturation curves for selected appliances in households in Bezirk X.

TABLE 4.3 Base Case Transportation Indices for Bezirk X

	1970	2000	2025
Cars per household	0.173	0.54	0.65
Auto use (km/yr)	9,000	9,500	8,700
Mass transit (10^6 passenger-km/yr)			
Intercity	4,420	6,100	6,100
Intracity	1,240	1,225	1,190
Freight (10^9 ton-km)	5.4	36.0	215

TABLE 4.4 Characteristics of Bezirk-X Fuels

	% Sulfur	% Ash	Heat Value
Lignite	1.35	10	2,300 kcal/kg
Briquettes[a]	2.7	5	4,700 kcal/kg
Coal gas			3,380 kcal/m^3

[a] A 1-kg briquette requires 1.9 kg of lignite.

and fabrication, chemicals, building materials, light industry, and other. The industries in Bezirk X of major importance for energy are chemicals and metal processing and fabrication. Industrial and service activity are different in each of the Bezirk's subregions; three subregions dominate the industrial activity (much like Rhone-Alpes). The industrial energy intensiveness shown in Figure 4.6 drops quite steeply in accordance with GDR historical trends of the past several years.[2] (France also has a declining industrial energy intensiveness, but the decline is not as rapid.)

A view of the Base Case transportation picture is given in Table 4.3. Mass transit is high, but does not grow significantly; automobiles triple in number, but ownership remains at half the current U.S. value; freight transport, following industry, increases dramatically.

In the energy supply sector, coal-fired power plants produce 100 percent of the electricity through 1995, after which nuclear power is allowed to penetrate. By 2025 three pressurized water reactors (PWR) with a total capacity of 1,228 MW are assumed to exist in the Bezirk.[10,12] No other fuels are assumed for electricity production. It is important to note that the Bezirk is an electricity exporter and remains so through 2025. A lignite strip-mining capacity of 60 million tons per year was specified for Bezirk X by the Leipzig researchers; this was interpreted as a resource limit and desired mining capacity limit. This limit, maintained through the year 2025, represents about 20 percent of the present GDR coal tonnage and about 20 percent of the expected sustained peak of GDR coal tonnage for future years.[1,2]

A significant amount of lignite production goes into briquette export from the Bezirk: 27.9 million tons in 1970 (49 percent of total coal production in the Bezirk); 19 million tons in 2000 (32.4 percent of the total); and 1.9 million tons in

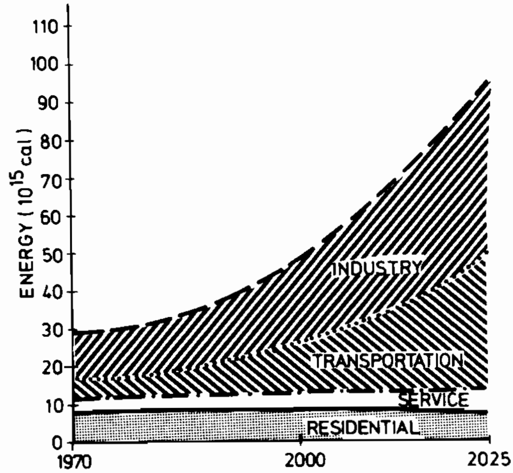


FIGURE 4.8 Annual end-use energy demand by sector (Base Case scenario for Bezirk X).

2025 (3.2 percent of the total). The export of briquettes makes up 86.5 percent, 84.7 percent and 42.4 percent of the briquette production in 1970, 2000, and 2025, respectively. Table 4.4 presents some important characteristics of Bezirk X fuels. Bezirk X imports oil, small amounts of anthracite coal, and natural gas.

II.B. ENERGY DEMAND RESULTS

II.B.I. End-Use Energy

Figure 4.8 shows the total annual energy demand calculated by the models for the Base Case scenario developed by Leipzig and IIASA. Figure 4.9 presents the annual per capita end-use energy by sector for the years 1970, 2000, and 2025.

Residential demand hardly changes, because coal is being replaced by more efficient district heat and demand-efficient electricity. The service sector grows steadily, but the energy demand per worker remains almost constant. Industry and transportation energy demands increase rapidly even with the large improvements in energy intensiveness in industry. Figure 4.10 shows the industrial end-use demand by sector, and Figure 4.11 shows this same industrial demand by fuel type. District heat is dominant in industry in 1970 and remains so; the demand for electricity makes up most of the remainder of the total demand by 2025. To keep the industrial energy demand at its present growth rate of 2.38 percent per year, the energy intensiveness of district heat use in the industry decreased by more than a factor of 10, while electricity energy intensiveness decreased overall by less than a factor of 3 in 55 years. This great increase in the efficiency of low-temperature district heat is difficult to explain.

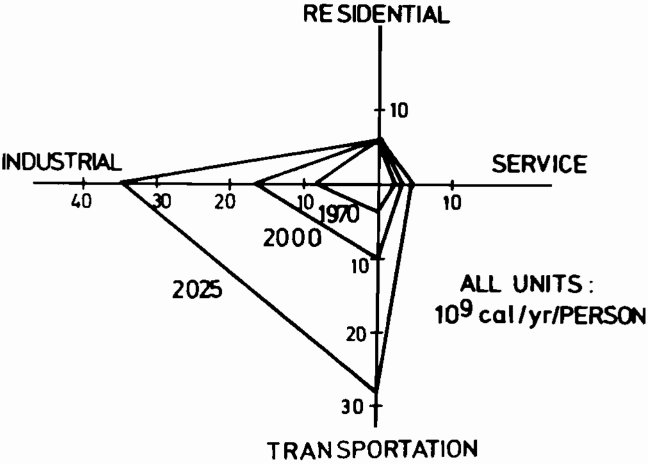


FIGURE 4.9 Annual per capita end-use energy demand by sector (Base Case for Bezirk X).

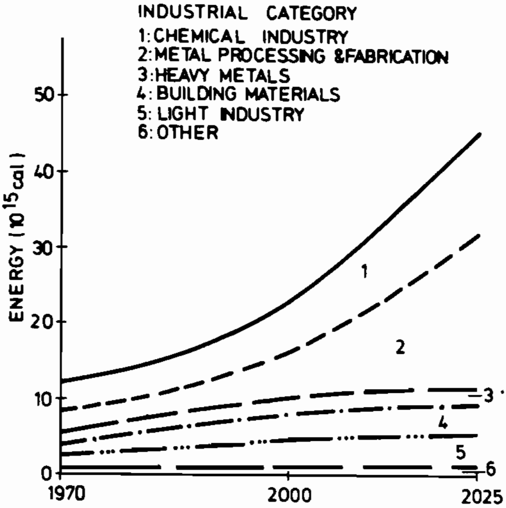


FIGURE 4.10 Industrial end-use energy demand by fuel type (Base Case scenario for Bezirk X).

Figure 4.12 shows the transportation demand disaggregated into its components. The effect of the increase in car ownership is apparent; the freight component is tied to the industrial growth. Associated with freight and intercity mass transit end-use energy demands are increases in efficiency due to significant shifts from coal and diesel trains in 1970 to electric-powered trains by 2025 (diesel efficiency is

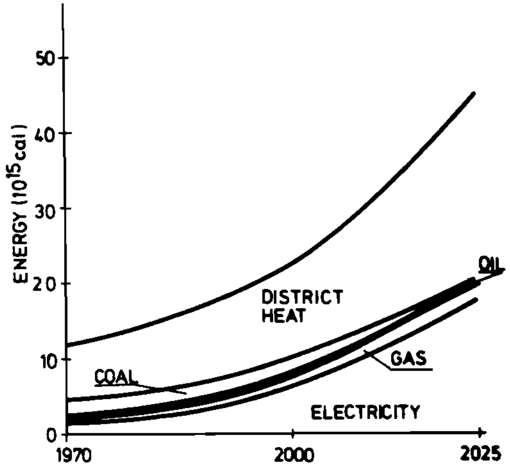


FIGURE 4.11 Industrial end-use energy demand by fuel type (Base Case scenario for Bezirk X).

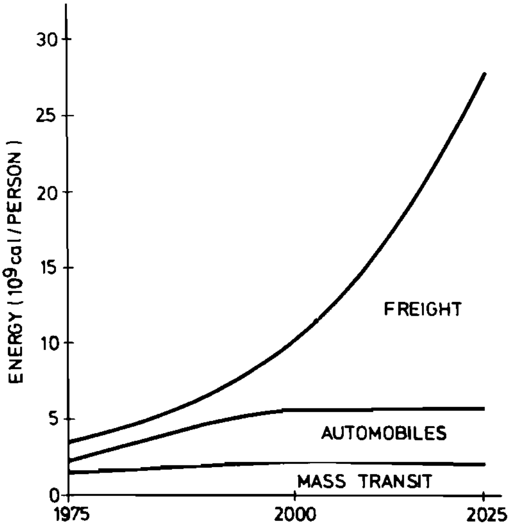


FIGURE 4.12 Per capita transportation end-use demand by mode (Base Case scenario for Bezirk X).

284 kcal/ton-km and electricity is 44 kcal/ton-km*. Mass transit in the Bezirk is more important than in the other regions, because of intercity use of trains. Energy

[*] This is end-use energy and does not account for waste heat in electrical generation or transmission losses. However, the electrical transport remains more efficient even after accounting for these factors.

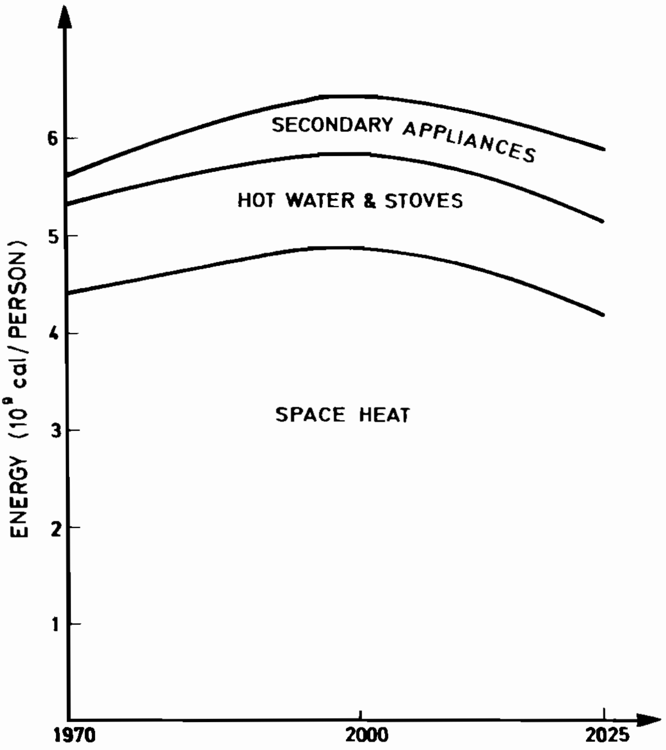


FIGURE 4.13a Residential end-use demand per capita by type (Base Case scenario for Bezirk X).

use per capita in transportation increases more rapidly than the other two regions because of the dominance of freight. Residential end-use demand per capita for base appliances and secondary appliances is shown in Figure 4.13a (secondary appliances are 100 percent electric). By 2025 district heat accounts for 35 percent of the residential space heating demand. Since the number of dwelling units stabilizes by 2000, the replacement of the more energy-intensive coal by district heat and electricity (Figure 4.13b) causes the end-use energy demand for space heating to drop between 2000 and 2025. These are the main demand sector results for the Base Case.

II.B.2. Supply Sector Results

Table 4.5 shows the total primary energy supply by fuel type calculated to meet the end-use energy demands of Scenario S1, the Base Case. The total lignite production by category of use in Bezirk X is given in Table 4.6. In 1970, 48 percent of the lignite produced was exported as briquettes. The total coal produced per year in

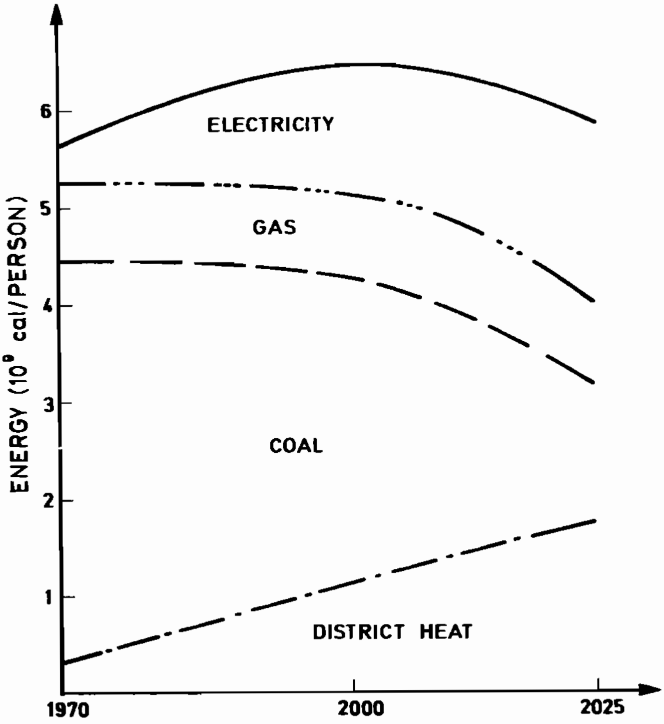


FIGURE 4.13b Residential end-use demand per capita by fuel (Base Case scenario for Bezirk X).

the Bezirk remains rather constant, according to long-term planning for the Bezirk as specified by the Leipzig researchers. Resource base longevity was a major reason for this constraint on coal production in the scenario.

The two largest components of the supply sector in 1970 are the export of briquettes (43.8 percent of the total primary energy) and the export of electricity (14 percent of the total primary energy). Table 4.6 shows that electricity production and briquette export required most of the coal in 1970 (84 percent of the total). In 2025 these two still require 82 percent of the total; however, almost all of the coal is now going to electricity production and very little to briquette export; a trade-off has occurred as a result of the industrial demand for electricity in Bezirk X. District heat requires the second largest amount of coal by 2025, but it still requires a minor amount compared with electricity.

While energy exports are 58 percent of the Bezirk's primary energy flow in 1970, they are only 14.8 percent of the total primary energy flow in 2025. The Bezirk is a strong energy supplier for the rest of the country in 1970, but it is unable to maintain this after 2000 because of its own industrial energy demand and the limit

TABLE 4.5 Primary Annual Energy Flow in the Supply Sector for Bezirk X (10^{15} cal/yr)

	Coal						
		Briquettes		Electricity[a]		District heat[a]	
	Nonbriquette	Bezirk	Export	Bezirk	Export	Briquettes	other
1970	3.41	10.9	69.1	17.0	22.0	13.5	10.5
2025	1.20	6.4	4.7	66.2	22.6	0.7	36.6

	Gas	Oil	Nuclear	Other
1970	0.90	4.4	0.0	6.3
2025	3.2	30.2	19.5	0.0

[a] Includes efficiency losses.

TABLE 4.6 Annual Lignite Coal Demand in Bezirk X (10^6 tons/yr)

	Direct Use		Indirect Use Via Briquettes			
	Electricity	District Heat	Direct Demand	District Heat	Export	Total
1970	21.1	4.7	3.4	1.1	27.9	58.2
2025	42.6	7.2	1.1	1.7	1.9	54.5

placed on annual lignite production. This could have important consequences for the energy supply for the rest of the country. The GDR will most likely have to begin importing significant quantities of energy if it maintains the high industrial growth represented in the Base Case.

II.C. ENVIRONMENTAL IMPACTS

A limited number of quantified impacts have been chosen to highlight different aspects of the chain of energy-related environmental impacts that have been calculated by the environmental impact models. The overall methods for calculation are described in Chapter 3. The environmental effects selected for presentation here are representative of impacts that are judged important to the Bezirk or to the GDR.[2,7,8,10,11] They highlight important aspects but by no means form a complete set of information. As mentioned in the discussion of the evaluation of options (Appendix E at the back of the book), not all impacts have been quantified; therefore, some individuals may feel that other quantified impacts or selected unquantified impacts are more important. The emphasis in this section is on quantified human health and safety impacts and particularly on air pollution effects.[13,14,15]

The emission control factors for fossil fuels assumed for the Base Case are shown in Table 4.7.[10] Emissions of SO_2 are shown in Figures 4.14–4.16. Figure 4.14 presents different measures of emissions for the entire Bezirk; Figure 4.15 gives the total SO_2 emissions by sector for 1970, 2000, and 2025. The large decline in the

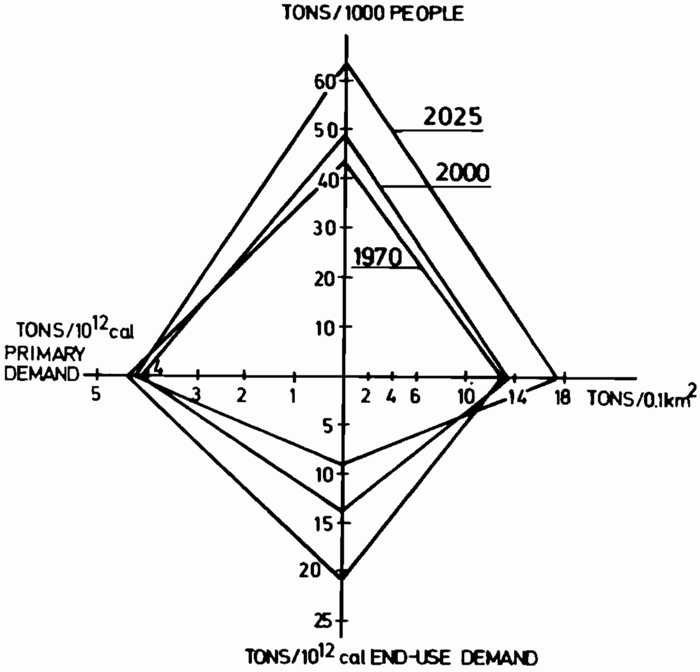


FIGURE 4.14 Selected indicators of total SO_2 emissions (Base Case scenario for Bezirk X).

TABLE 4.7 Assumed Control Factors for Particulates and SO_2 for the Base Case in Bezirk X (percentage removed prior to emission)[a]

	1970		2000		2025	
	P.M.[b]	SO_2	P.M.	SO_2	P.M.	SO_2
District heat						
Coal	70	0	95	35	95	35
Industry						
Coal	60	0	95	6	95	20
Oil	0	0	0	50	0	50
Gas	0	0	0	20	0	40
Electricity generation						
Coal	80	0	99	30	99	60

[a] The service and residential sectors had no controls, except for a refinery-produced 50% reduction in the sulfur content of oil by 2000. The district heat SO_2 control in 2000 was assumed to be a combination of SO_2 control at the plant and a reduction of sulfur content of the coal and oil used.

[b] Particulate matter.

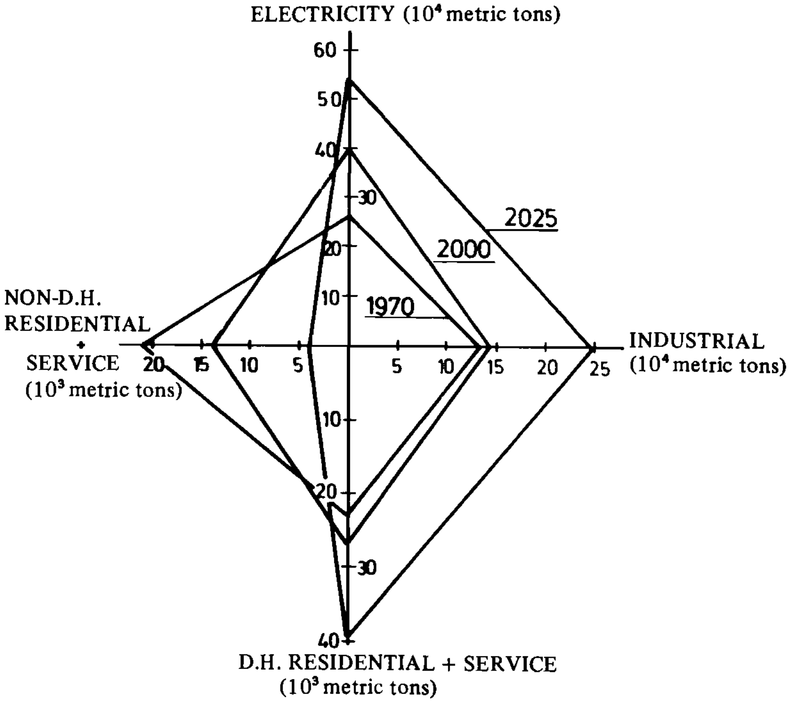


FIGURE 4.15 Demand sector and electricity SO_2 emissions (Base Case scenario for Bezirk X). *D.H.* stands for district heat.

non-district heat emissions in the residential and service sectors is striking. Figure 4.16 shows the emission by subregion and by residential, service, and industrial sectors for 1970 and 2025. The large variation in emission among subregions is an important factor in the calculation of selected health impacts associated with SO_2. Subregion 9 has a very large emission relative to the other subregions, primarily because all briquette production is in Subregion 9 and because a large quantity of low-temperature heat is used in that district. Of the 206,000 tons of SO_2 emitted in Subregion 9 in 1970, 81 percent is associated with the briquette factory.

The electrical generation and industrial sectors account for most of the SO_2 emissions. However, health effects are not directly proportional to emissions; the character of the emission sources must be taken into account. For example, the percentage of the emissions in each emission class (sources with high, medium, and ground-level release heights) and their respective percentage of the calculated average ground-level concentration (average dose) are shown in Figure 4.17 for two Bezirk cities. Clearly, the near-ground-level emissions from the residential and service sectors are much more important for human health impact than the relative magnitude

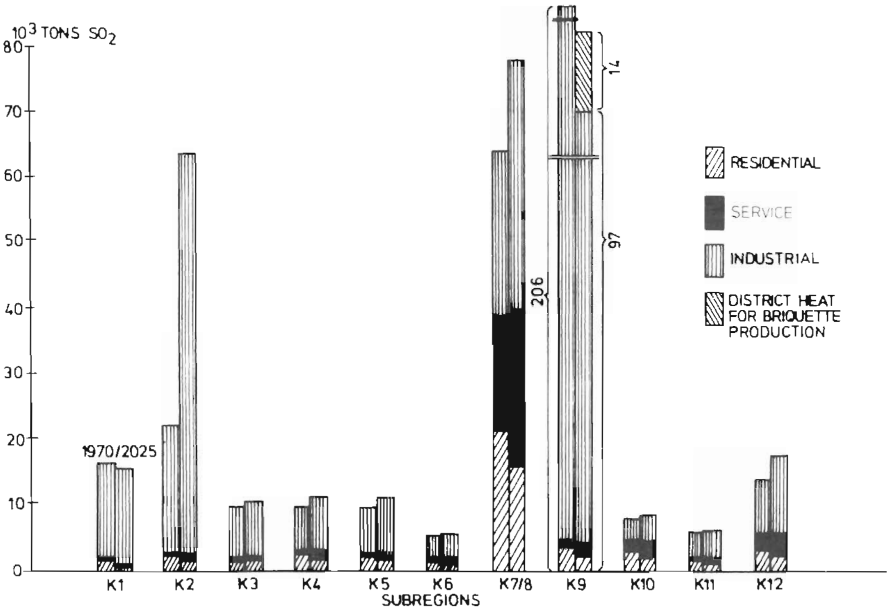
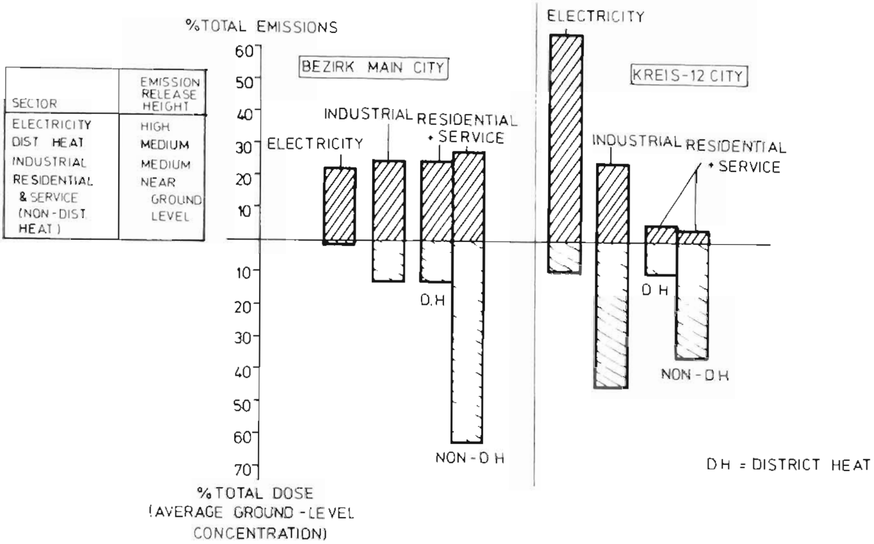


FIGURE 4.16 SO_2 emissions by subregion (Base Case for Bezirk X).



SECTOR	EMISSION RELEASE HEIGHT
ELECTRICITY	HIGH
DIST HEAT	MEDIUM
INDUSTRIAL	MEDIUM
RESIDENTIAL & SERVICE (NON-DIST. HEAT)	NEAR GROUND LEVEL

FIGURE 4.17 1970 Bezirk X SO_2 emissions and SO_2 doses.

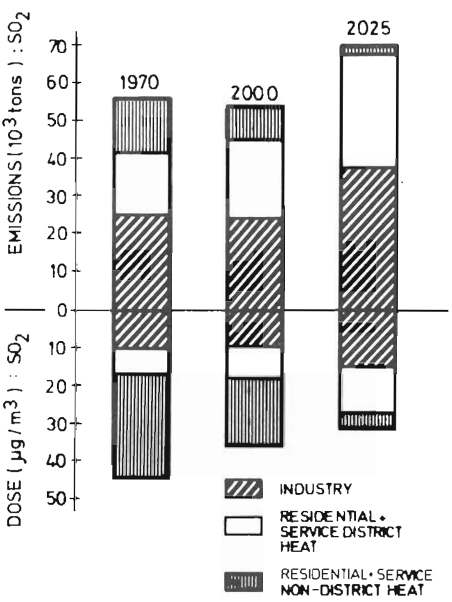


FIGURE 4.18 SO_2 emission and dose by source in the main city of Bezirk X (Base Case).

of their emission would indicate. This is primarily attributable to differences in dispersion for the three types of emission sources.[15]

Even though the calculated results indicate that SO_2 emissions will increase with time in the Bezirk main city, the average ground-level concentration (dose) declines (Figure 4.18). The increasing use of district heat in the residential and service sectors causes the decreasing ambient air concentrations. The district heat plants have tall stacks, while the individual heating units that district heat replaces have near-ground-level release heights.

The calculated dose can be used with the SO_2 health impact model[14] to provide an indication of premature mortality and excess morbidity related to air pollution. The premature mortality and excess morbidity are expressed in terms of person-days lost (PDL). Health impacts and accidents of different severity have various quantities of PDL associated with them. For example, excess asthma attacks and aggravation of heart and lung disease in the elderly have one PDL per event, and each premature fatality has 6000 PDL associated with it. PDL from accidents, morbidity, and mortality related to energy use can be aggregated to obtain a measure of the total quantified human health and safety impact.*

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* Because some impacts are not quantified, the total quantified health and safety impact clearly cannot be equated to the total health and safety impact.

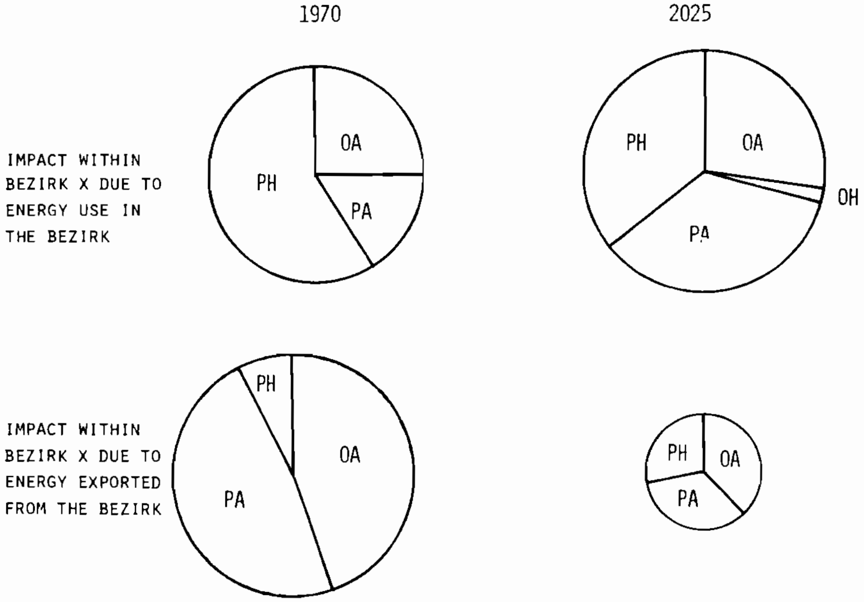

FIGURE 4.19 Human health impact in terms of person-days lost (Base Case for Bezirk X). OA – occupational accidents; OH – occupational health; PA – public accidents; PH – public health.

The total PDL within Bezirk X for energy production and use in 1970 and 2025 is shown in Figure 4.19; the total PDL is divided into components of accident and health for both occupational and general public impacts. In 1970 the Bezirk suffers a major human health and safety impact associated with energy export. The largest share of the PDL resulting from energy export is public accidents, i.e., accidents resulting from the transport of the energy sources, such as lignite and briquettes. In contrast, the largest quantified impact within the Bezirk due to the Bezirk's own energy use is public health PDL from air pollution. In 2025 the public health impact from energy use within the Bezirk is approximately equivalent to the sum of PDL from energy-related occupational accidents and public accidents. Although SO_2 emissions increased from 1970 to 2025 (Figure 4.14), the public health impact within the Bezirk in 2025 is slightly less than in 1970 mainly because of SO_2 controls and shifts to district heat. The small occupational health impact in 2025 is the radiation health impact on nuclear power plant personnel. Human health and safety impacts in the Bezirk associated with energy export in 2025 are significantly reduced from the 1970 level because energy export is reduced (Table 4.5).

Table 4.8 shows the quantified PDL, classified by the cause of the person-days-lost (occupational accidents, public accidents, occupational health, or public health), the location of the impact (inside or outside the Bezirk), the source of the impact (electrical or nonelectrical system), and whether the energy associated with the

TABLE 4.8 Quantified Person-Days Lost Resulting from Energy Flow in Bezirk X for the Base Case[a]

	1970					2025				
	Electrical		Nonelectrical			Electrical		Nonelectrical		
	Bezirk	Export	Bezirk	Export	Total	Bezirk	Export	Bezirk	Export	Total
Impacts within Bezirk X										
Occupational accidents	9,600	12,000	9,600	34,000	66,000	21,000	7,100	6,100	1,500	36,000
Occupational health	0	0	0	0	0	600	0	0	0	600
Public accidents	3,300	4,300	6,700	26,000	40,000	13,000	4,400	6,700	1,800	26,000
Public health	12,000	16,000	37,000	2,200	66,000	21,000	6,800	25,000	58	52,000
Impacts outside Bezirk X										
Occupational accidents	0	0	700	3,800	4,500	1,300	0	4,800	270	6,400
Occupational health	0	0	0	0	0	170	0	0	0	170
Public accidents	0	0	3,000	32,000	35,000	120	0	21,000	2,200	23,000
Public health	0	0	0	0	0	510	0	0	0	510
Totals										
Occupational accidents	9,600	12,000	10,000	38,000	70,000	23,000	7,100	11,000	1,700	42,000
Occupational health	0	0	0	0	0	770	0	0	0	770
Public accidents	3,300	4,300	9,700	57,000	75,000	13,000	4,400	27,000	4,000	49,000
Public health	12,000	16,000	37,000	2,200	66,000	21,000	6,800	25,000	58	52,000
Grand total	25,000	32,000	57,000	97,000	211,000	58,000	18,000	63,000	5,800	140,000

[a] One death or case of total disability is equated with 6,000 person-days lost (PDL). Columns and rows may not add to totals because of rounding.

impact is used inside the Bezirk or exported. The quantified impacts outside the Bezirk that result from energy use within the Bezirk are not as large as impacts within the Bezirk; yet, these effects outside the Bezirk are not insignificant. The total PDL inside the Bezirk, categorized according to energy use within the Bezirk and energy export, form the basis for Figure 4.19. Public health and public accidents that result from involuntary exposure are responsible for a sizeable majority of the total PDL both within and outside the Bezirk. The total PDL resulting from energy use in 2025 are equivalent to 24 premature deaths.

Human health and safety has been emphasized here because it is generally considered one of the most important categories of quantified impacts. Other environmental impacts associated with the GDR scenarios are presented in later sections and in Chapter 7.

II.D. IMPORTANT ASPECTS OF THE BASE CASE SCENARIO

Several important features of Bezirk X emerge from the Base Case. The first of these is the extreme dominance of the energy use by industry and the freight component of transportation, two sectors that are closely connected. The high energy use of freight transport is also associated with the large energy export foreseen by the scenario. Essentially, three factors underlie the energy growth in these sectors:

- Zero population growth removes a cause of increased energy use from the other sectors.
- The Bezirk is a major industrial area that must produce goods for the rest of the country as well as for itself.
- The planning of the GDR has a strong emphasis on high industrial growth compared with present trends in free-market countries.

The possibility of continuing industrial growth and decreasing industrial energy intensiveness even after the year 1995 in the Bezirk was the subject of much discussion during the workshop; some participants from the other two regions expressed great doubts that the industrial projections could be realized. The GDR participants pointed out that Bezirk X is embedded in the country and is not independent of the whole in its production. In addition, the assumed decreases in energy intensiveness for industry, as anticipated by the Leipzig researchers, are in fact historical trends of the past 10 years.

The nonfreight components of transportation deserve attention. The increase in energy use for automobiles is solely due to an increase in car ownership per household (only a small improvement in fuel economy per car can be expected). The total mass transit energy use is dominated by long-distance train and bus travel, 78 percent and 84 percent of the passenger-km in 1970 and 2025, respectively. This implies an extensive use of trains and buses for intercity travel. As in 1970, trains account for three-fourths of the intercity mass transit passenger-km in 2025 and become increasingly energy-efficient as steam engines are replaced by diesel engines and then diesel engines by electric engines. Freight transport is very energy-efficient in this scenario because all intercity freight hauling is by rail (there is no trucking).

In the residential sector after the year 1990, there is a decrease in end-use energy per capita, clearly noticeable in Figure 4.13a.* This decrease is the result of a shift from coal to district heat, electricity, and gas, each of which requires less end-use energy than coal. No changes in housing structure or insulation patterns occur. Among appliances, penetration of dishwashers, deep freezers and clothes dryers is low; room air conditioners penetrate even less, and central air conditioning is not introduced. These projections reflect an official GDR attitude toward the best use of resources.

From an environmental perspective, district heat is quite significant; it results in lower ground-level air pollution concentrations in the urban area than does normal space heating with equivalent emissions. This health impact advantage disappears when the air pollutants disperse from the urban area to the rural areas because the effect of space-heating emissions is roughly the same, whether they come from a district heating plant or household units.

Bezirk X, unlike Wisconsin and Rhone-Alpes, not only absorbs environmental impacts due to its own consumption of energy and goods, but it also absorbs large impacts, especially before the year 2000, associated with demands outside the region. Bezirk X exports a lot of its electricity and coal briquettes, and its industry produces for the rest of the country. The impacts associated with energy production for industrial exports and energy export occur mostly within the Bezirk because lignite is the basic fuel and no lignite is imported into the Bezirk, even by 2025.

II.E. OBSERVATIONS ON THE BASE CASE SCENARIO

The Base Case for Bezirk X represents an extrapolation of the GDR's 20-year outlook for industrial regions of the country. This 20-year outlook provided a consistent set of socioeconomic and technical assumptions for the scenario development. Extrapolating the trends in the GDR outlook had inherent uncertainty associated with it; no claim is made about the likelihood that the Base Case will be realized. The Base Case did point up several problem areas, which is one of the reasons that the scenario approach is useful.

One major area of concern was the likelihood of a high rate of industrial growth continuing over such a long time-span. By 2025 the industrial output per worker must increase by a factor of 80 over the output in 1970, a heroic achievement to say the least.

A closely related area of concern was the continuing decrease in industrial energy intensiveness over the entire 55 years. The projected tenfold increase in the efficiency of the use of low-temperature heat (district heat) in industry is difficult

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* The average number of people per household is constant after 1990 (Figure 4.3).

to justify. The decreasing intensiveness coefficients do represent recent historical trends; however, analysis of their correctness is complex because both space heat and process heat demands are combined in the coefficients.

The Base Case indicated that the twin objectives of energy export and material export (industrial goods) could not be maintained, even with the large increases in industrial energy efficiency posited. An increase in mining capacity would be required to do both, reducing the lifetime of the GDR's resource base and forcing an earlier relinquishing of energy self-sufficiency in coal.

Growth rates of end-use demand and total electricity produced, 4.3 percent and 6 percent, respectively, were quite representative of current European experience[4] and for electricity, representative of earlier Wisconsin experience. Electricity, as in other countries, grows somewhat faster than total energy consumption.

The Base Case indicates that the population living in Bezirk X accepts a large environmental burden for the welfare of the rest of the country. In the beginning years the burden is the result of energy export, and in the final years of the scenario, it is the result of material export.

Other observations on the Base Case are made in the following comparison with the other two scenarios and in sensitivity studies. Comments concerning modeling difficulties are presented in the conclusion of this chapter.

III. OTHER SCENARIOS

Two additional scenarios will be presented here and compared with the Base Case. There will also be a selection of sensitivity studies that highlight features of Bezirk X. The two additional scenarios have been simply labeled as the High-Energy Case, S2, and the Energy-Conservation Case, S3. The rationales for their development is as follows:

- High-Energy Case (S2): Some energy aspects of the Base Case appeared questionable over the long term. These were (1) the industrial energy intensiveness, (2) long-distance freight hauling only by rail, and (3) the low number of cars per household through 2025. Changes in these characteristics were the primary basis for definition of the high case. No economic parameters were changed.

- Energy-Conservation Case (S3): Here energy-saving technological modifications were introduced into a Base Case that was already quite energy conserving. Major changes were (1) improved fuel economies, (2) stricter insulation standards, and (3) the penetration of solar thermal and solar-electric alternatives. Again, no economic changes were introduced.

TABLE 4.9 Policies and Assumptions for Scenarios S2 and S3 for Bezirk X

Bezirk X: Scenario S2

Industrial energy-intensiveness decreases only 1/3 as much by 2025 as in Scenario S1 (similar to the Rhone-Alpes Base Case).

By 2025, 80 percent of the long-distance freight (ton-km) is transported by truck.

The number of cars per household increases to 1.0 in 2025.

District heat penetrates less rapidly in the residential sector.

Supply: No nuclear power; large import of electricity.

No sulfur controls for fuels before 2025.

Bezirk X: Scenario S3

Insulation standards reduce 1- and 2-family house space heat requirements by 20%:

- By 2000, 15% of the 1- and 2-family houses meet the new standards.
- By 2025, 60% of the 1- and 2-family houses meet the new standards.

Low-temperature solar space heat units that can replace 50% of the space heat demand in 1- and 2-family houses are made available beginning in 1980:

By 2025, 50% of 1- and 2-family houses constructed in that year have the new solar units.

The penetration of the solar units for space heat for the service sector matches the penetration in the residential sector.

Industrial electricity energy-intensiveness is 20% lower than in S1.

Transportation
- Penetration of electric auto is 10% by 2025.
- There is lower auto use per capita.
- Trains are 100% electric by 2025.

Supply
- 20% of electricity capacity is solar by 2025.
- There are two nuclear pressurized water reactors (PWRs) (818 MW) by 2025.

There are strict sulfur and particulate matter controls.

III.A. SCENARIO COMPARISONS

Table 4.9 gives the most important parameter changes for S2 and S3. Tables giving energy supply, demand, and sources for the three scenarios can be found in the Appendix to this chapter.

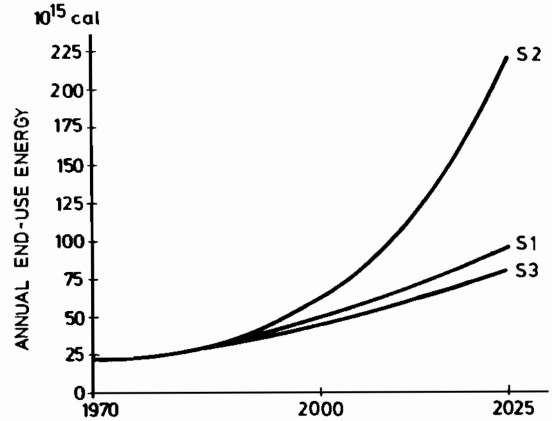

FIGURE 4.20 Total end-use energy demand by scenario for Bezirk X.

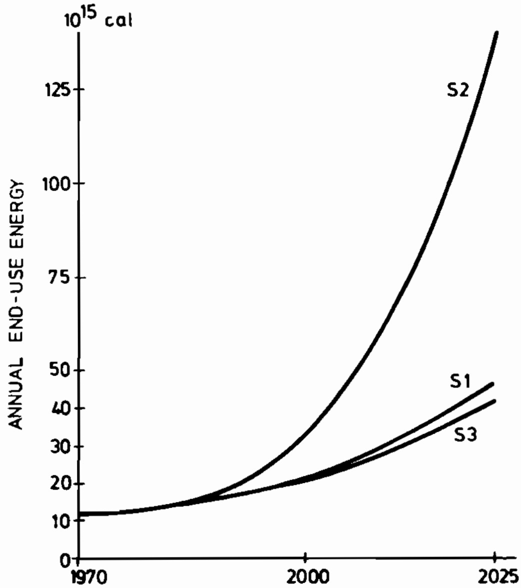

FIGURE 4.21 Industrial end-use energy demand by scenario for Bezirk X.

Figure 4.20 shows a comparison of the total end-use energy demand for the three scenarios. As expected, Scenario S3 is quite similar to S1; the small differences are mostly attributable to industry and transportation. The industrial end-use demand and the transportation end-use demand are shown in Figures 4.21 and 4.22. The change in industrial demand is due only to a change in energy intensiveness; for transportation the change is due to a change in transport mode and fuel economy. Interestingly enough, the shift in favor of trucks for long-distance freight had about

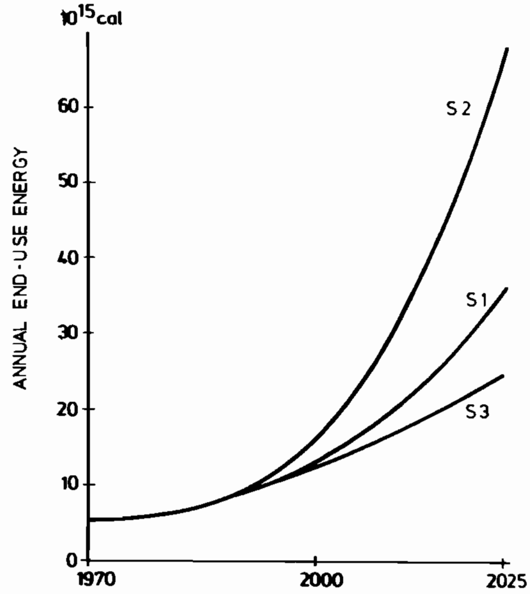

FIGURE 4.22 Transportation end-use energy demand by scenario for Bezirk X.

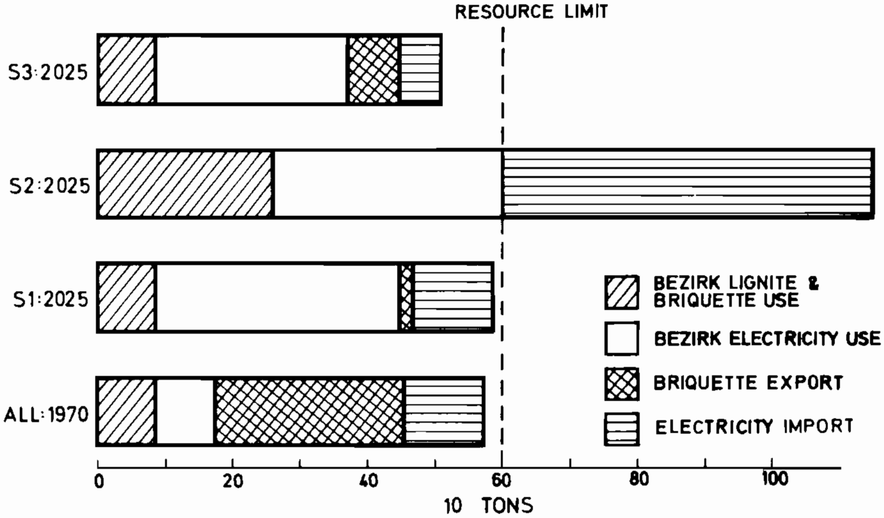

FIGURE 4.23 Total lignite coal demand in Bezirk X by use and scenario.

the same effect on the energy demand as changing the energy intensiveness for industry. This has important implications for the Bezirk and the GDR, because Scenario S2 provides for industrial energy conservation efforts similar to those cur-

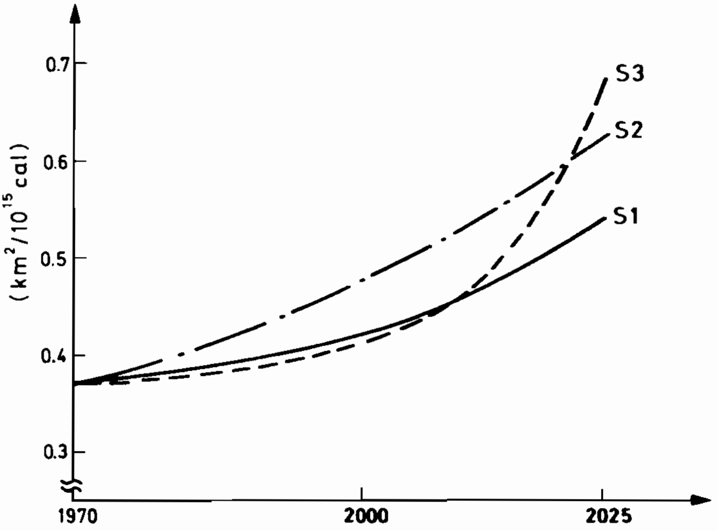

FIGURE 4.24 Land intensiveness of end-use and export energy production for Bezirk X.

rently underway in the United States and Western Europe. However, the decrease in industrial energy intensiveness for S2 is larger than even the Wisconsin conservation case. This indicates that, with its postulated high industrial growth and with current world industrial energy intensiveness trends (rather than the postulated efficiency improvements), the GDR would have no hope of being energy self-sufficient past the year 2000. In the residential and service sectors, there was no significant change in the energy end-use demand for the three scenarios. Of interest is the use of district heat and the penetration of solar-thermal; these will be discussed for the residential sector in the sensitivity studies described in section III.B.

There are several significant differences in the environmental impacts for the three scenarios. Some of these differences result from the fact that in Scenario S1, the Bezirk is an exporter of an appreciable fraction of its electricity production, whereas in S2, it imports a significant fraction of its electricity demand. This is illustrated in Figure 4.23. Interestingly enough, for S1, almost all of the coal production initially used for briquette export is required to satisfy the Bezirk's own demand for electricity by 2025. To be achieved, S2 would require a major mining activity outside the Bezirk for the importation of electricity. Electricity rather than coal would be imported because of the high lignite transportation costs in the GDR. The large increase in mining activity (in the country as a whole) required by S2 would imply an earlier dependence on imports of primary energy for the GDR.

Total land disturbed (by coal mining, power plants, or nuclear reprocessing plants) is shown in Figure 4.24 for the three scenarios; it is expressed in units of land area per unit of end-use energy (including energy exported). In all scenarios,

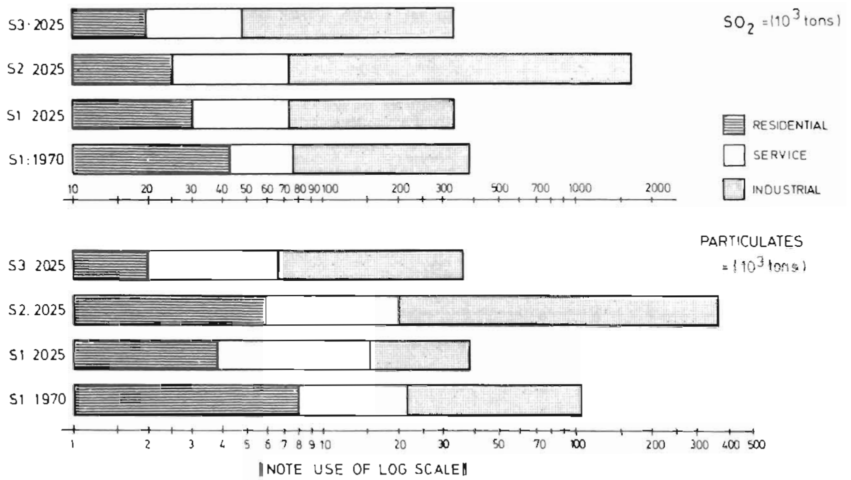

FIGURE 4.25 Demand sector emissions of particulates and SO_2 due to energy use.

increasingly more land per unit of energy is required because of the continuing shift to electricity and district heat (an increase of almost 50 percent by 2025 for Scenario S1). In S1, mining accounts for 60 percent (~ 21.8 km^2/yr) of the land disturbed in 1970 and 38 percent (~ 22.4 km^2/yr) in 2025; the rest of the energy-related land use is for energy facilities. The shift to electricity does not require more land for mining (because briquette export decreases at the same rate as the associated mining) but does require more land for the additional power plants. The same applies to district heat. In S3, the land intensiveness increases significantly in later years because of more use of solar energy. By 2025, even though solar energy provides only 20 percent of total electrical capacity, it requires about 50 percent of the land needed for all energy facilities (power plants, for example); in fact, solar energy facilities account for 35 percent of the total quantified land used for energy, including mining.

Sulfur dioxide and particulate matter emissions are shown for 1970 and 2025 by sector and by scenario in Figure 4.25 (it should be noted that the emissions are displayed on a logarithmic scale). The differences among scenarios are due not only to changes in energy use, but to differences in assumed pollution control. In general, however, the fact that in Scenario S1 the emissions in 2025 are less than in 1970, even though total primary energy use is greater, can be attributed to emission controls.

When these emissions are translated into ambient air concentrations, health impacts can be calculated. As presented in Table 4.10, one indicator of differences in the health impacts for the three scenarios is a comparison of the calculated number of days the standards are exceeded in selected cities. These numbers represent ambient concentrations calculated by a dispersion model.[15] Although the calculated results are somewhat low compared to small samples of actual data, the relative magnitudes are adequate for comparative purposes. Calibration with empirical data is not possible because Bezirk X is a composite region.

TABLE 4.10 Estimate of the Number of Days That SO_2 Standards in the GDR Are Exceeded in Selected Bezirk Cities (GDR Standard = $150 \mu g/m^3$)

	Number of Days			
	1970	2025		
Subregion Number for the City[a]	S1	S1	S2	S3
2	3	10	108	10
8	24	13	90	9
9	59	20	140	25
12	2	2	27	1

[a] See Figure 4.1 for a map of the Bezirk and its numbered subregions.

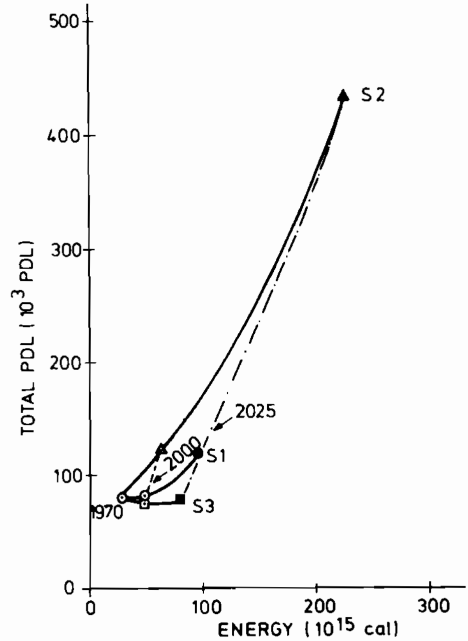

FIGURE 4.26 Total PDL due to end-use energy demand in Bezirk X over time for S1, S2, and S3.

As mentioned earlier, one indicator of human health impact is person-days lost (PDL). It is of interest to examine the total PDL in the Bezirk as a function of its own energy demand. As shown in Figure 4.26, this indicator is a nonlinear function of energy, mainly because there are mortality threshold effects in the air pollution health impact model.

In 1970, only 30 percent of the Bezirk's PDL is attributable to electricity

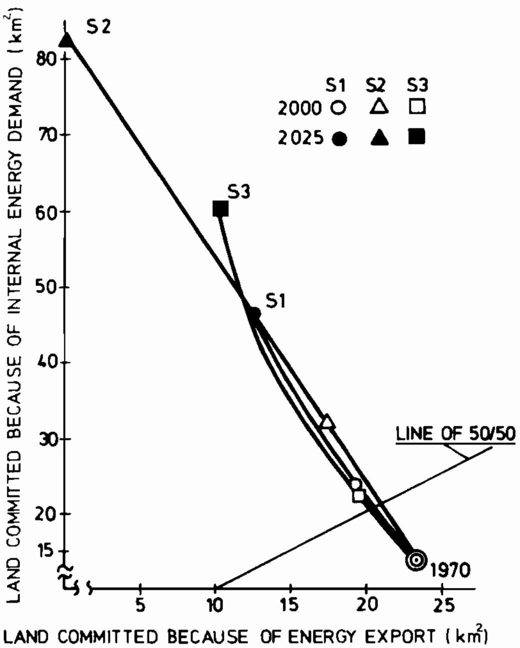

FIGURE 4.27 Land use for Bezirk demand versus land use for export demand.

production. In all but S3, the share of the Bezirk's PDL due to electricity production increases significantly during the time frame of the scenarios. This increase in electricity's contribution to total PDL has three main causes: (1) the fraction of space heat demand met by district heat continually increases; (2) briquette production for export dramatically decreases; and (3) electricity production increases. However, if SO_2 controls are instituted as in S3, then there is no significant increase in electricity's share of total PDL. Thus controls on SO_2 emissions from electricity generation could have importance in terms of health impacts.

Since the Bezirk exports so much energy, it is of interest to see what kinds of export-related impacts occur. Figure 4.27 compares the land in the Bezirk committed to meet its own energy demand with land related to energy export. For S1 and S3, not until about 1990 does the land used for the Bezirk's own energy needs equal the land used for exported energy. For export, the land use is almost entirely strip mining, which necessitates land reclamation efforts in the Bezirk. By 2025 in S1 and S3, much of the strip mining activity must support the Bezirk's own energy demands.

In Figure 4.28 the human health impacts of energy export and internal energy use are displayed. In 1970, over half the human health impact is due to the export of energy. Health impact due to energy export in S3 remains low because of stringent pollution control on electric power plants (95-percent SO_2 control is assumed).

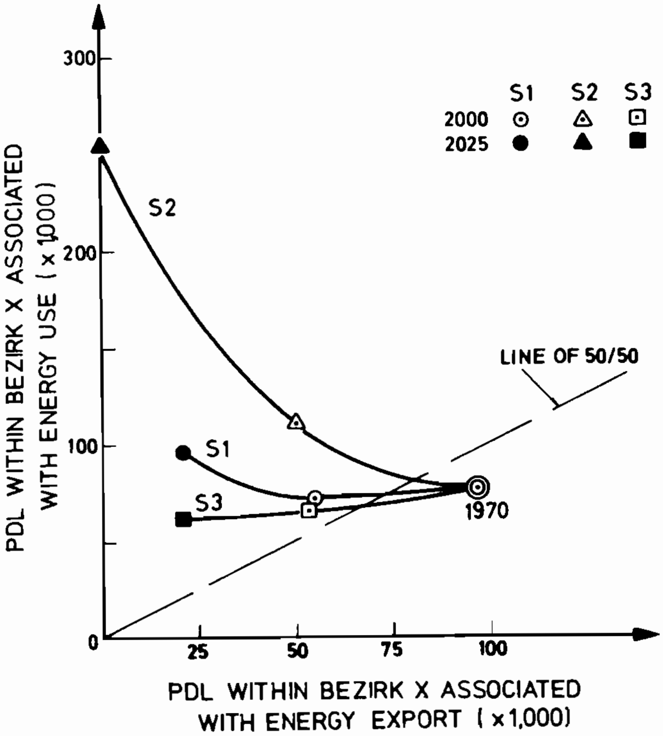

FIGURE 4.28 PDL in Bezirk X due to internal energy use and export.

Health impact due to energy export in S1 initially decreases due to the introduction of improved SO_2 controls through 2000; from then until 2025, no significant improvement in controls occurs, and any increase in energy use produces an increased impact on health. S2 indicates the consequences of uncontrolled SO_2 emissions and high energy use. In the year 2000 differences between S1 and S2 are largely due to the difference in pollution control measures (compare with Figure 4.20), mostly instituted in the electricity sector.

Various emission controls were included in the three scenarios. Scenario S1 had moderate controls; S2 had low or no controls; and S3 had stringent controls. The sensitivity of the SO_2 and particulate emissions from coal to these control assumptions is shown in Figure 4.29. The controls are specified according to five different groupings; the difference between the groups is the ease (both technological and economic) of implementation. They are normalized to the low control case (S2), and expressed in terms of the percent of control greater than in S2. For example, in the case of particulate emissions from electricity generation plants, there was 95 percent particulate control in S2 and 99 percent in both S1 and S3. Thus the control in S1 and S3 allowed release of only 20 percent as many particulates as in S2, as

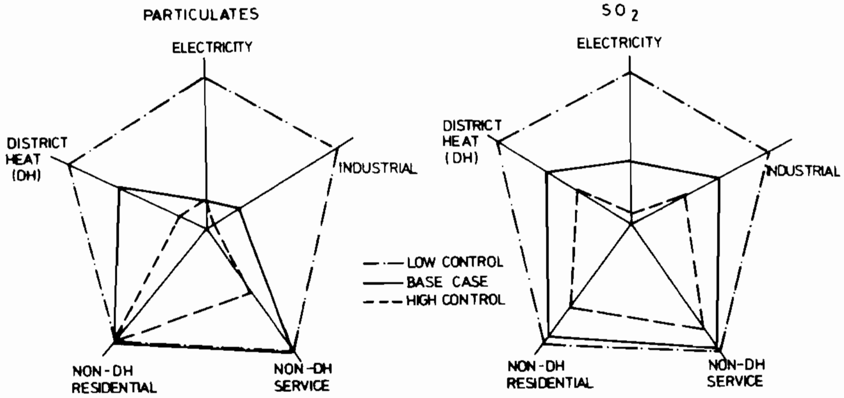

FIGURE 4.29 Sensitivity of the particulates and SO_2 emissions in Bezirk X in 2025 to different control levels.

can be seen in Figure 4.29. One may also conclude from this figure that controls are most easily applied to electricity generation facilities because they are highly centralized; controls on industry are the next easiest because industry is also relatively centralized and has money to spend on controls; buildings in the residential and service sectors are the most difficult to control.

III.B. SENSITIVITY STUDIES

Several studies were conducted to examine how sensitive various scenario results were to alternative assumptions. The results of four representative studies are presented in this section.

III.B.1. Electricity Supply and Emission Control

As expected, changes in types of electrical generation and emission controls affect quantified environmental impacts both inside and outside the Bezirk. Study of the effect of such changes on health was the objective of a sensitivity analysis (based on S2) for 2025, which considered the following supply and control options:

- All electricity generated to meet Bezirk demand (62 percent must be imported) is from coal-fired power plants; no control of SO_2 emissions is assumed. These are the assumptions of Scenario S2.
- All electricity generated to meet Bezirk demand (62 percent must be imported) is from coal-fired power plants; 90 percent control of SO_2 emissions is assumed.
- All electricity generated to meet Bezirk demand is produced within the Bezirk.

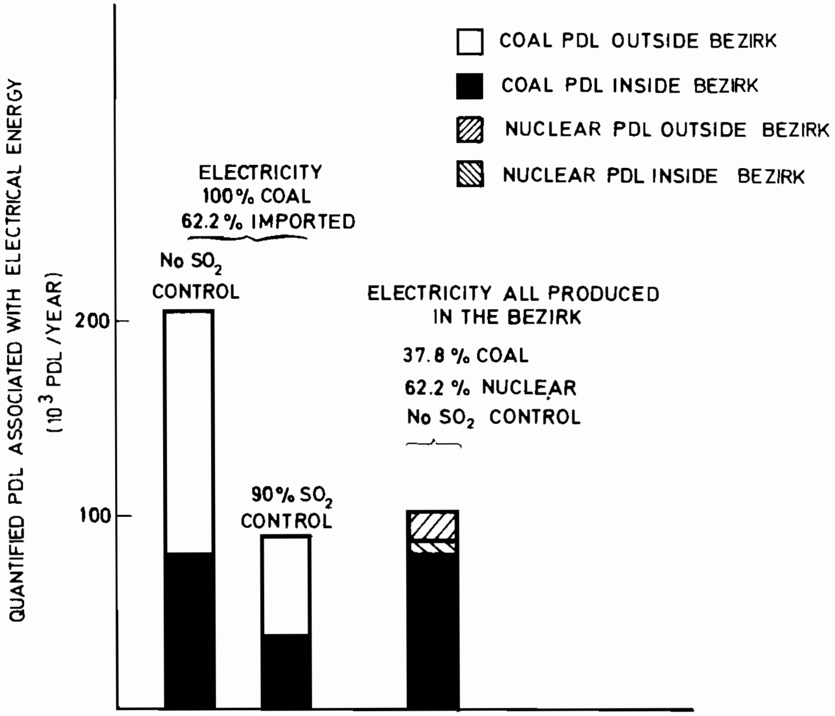

FIGURE 4.30 Quantified PDL for S2 with different electrical supply options in Bezirk X.

Nuclear power (six pressurized water reactors) is used to generate the electricity that otherwise would have to be imported. No control of SO_2 emissions from coal-fired power plants is assumed.

The results in terms of quantified PDL related to electrical generation are displayed in Figure 4.30. The case with 90 percent SO_2 control and the case with nuclear generation each result in slightly more than a 50-percent reduction in PDL compared with the S2 results. The case with nuclear generation has almost all the PDL within the Bezirk, while the non-nuclear cases have a significant share of the PDL in regions outside the Bezirk (because most of the coal mining and electricity generation to supply the Bezirk occurs in other regions).

If both SO_2 controls and nuclear generation were available, then a further reduction in human health impact due to electricity generation could be achieved, a reduction of approximately 75 percent compared with S2. In this case the majority of the PDL would also occur in the region of energy use, Bezirk X.

TABLE 4.11 Annual Space Heating Consumption in the Residential Sector in Bezirk X (10^{12} cal).

	S1		S3		
	Total	Electric	Total	Electric	Solar
1970	6,260	4.5	6,260	4.5	0
2000	6,370	452	6,260	426	26.5
2025	5,480	785	5,070	453	332

III.B.2. Solar Penetration in the Residential Sector

It was of interest to know how much potential saving there might be in space heating using solar thermal energy. Current estimates indicate that solar heating could provide 50 percent of the space heat requirements of a single-family house in the southern part of the GDR[16] and electricity would provide the rest. In the sensitivity study, solar heating was substituted for electricity in an increasing percentage of new one- and two-family rural houses; the percentage increased from 0 to 50 between 1980 and 2025 (see Table 4.11).

The potential saving in 2025 from solar energy is 42 percent of the residential space heat electricity demand. Of the total residential electricity demand (with appliances) and the total residential space heat demand in 2025, solar energy represents a saving of 22 percent and 6 percent, respectively. Solar energy can replace a significant portion of the space heat electricity demand in Bezirk X, but the amount of energy it represents is relatively low, even by 2025.

Seventy-five percent of the difference in the total energy for space heating between S1 (Base Case) and S3 (Conservation Case) is due to the insulation standards and 25 percent to the increased use of district heating. The same amount of energy was saved in 2025 with better insulation in 60 percent of the one- and two-family houses (20 percent reduction in space heat requirement per home) as with solar space heat. Of course the number of houses with solar space heat was much smaller, but the cost for a solar house would be much larger than for a well-insulated house. Thus, for the 55-year period of the scenario, the use of solar energy for residential space heating does not appear to be as economical as providing better insulation in houses. Solar heating, however, would compare more favorably with a longer time horizon.

III.B.3. District Heat versus SO_2 Dose

There is a great interest in the GDR industrial districts in reducing the SO_2 air pollution that now exists. The ground-level air pollution concentration (dose) due to the emission of a given amount of pollutant depends on the type of source that emits the pollutant.[15] There is a large difference between the dose due to pollutants emitted from a house chimney (a low-level source) and the dose due to pollutants emitted from a district heating plant (a medium-level source with a stack). One

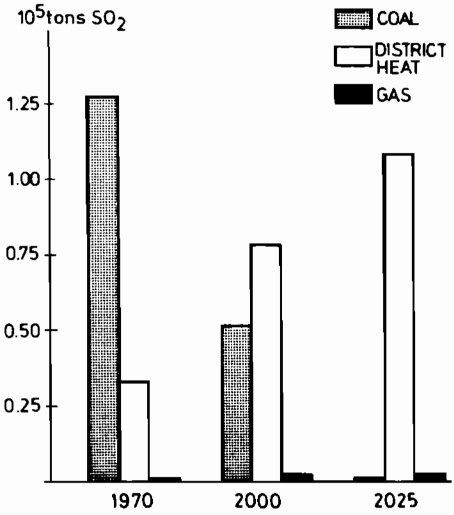

FIGURE 4.31 Residential SO_2 emissions by source in the main city of Bezirk X.

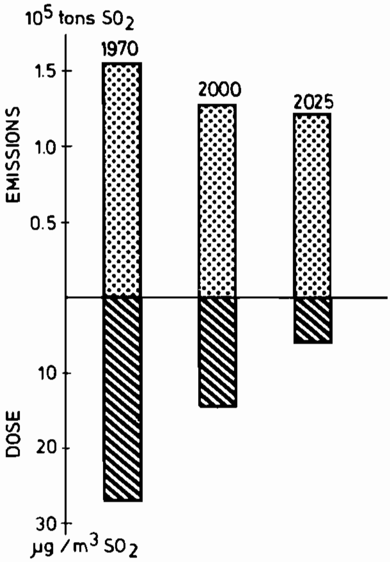

FIGURE 4.32 SO_2 emissions and dose from district heat used for space heat for the residential sector in the main city of Bezirk X.

method to reduce the SO_2 dose is to use district heat rather than house or apartment furnaces to supply space heat needs. It was of interest to investigate what effect district heat could have on SO_2 dose.

The Bezirk-X main city was chosen for this sensitivity study because it has almost complete penetration of district heat for residential space heating by 2025. Figure 4.31 shows residential emissions as a function of space heat source in the Bezirk X main city. By 2025 the main source of emissions has shifted from direct coal burning to district heat. Direct coal and gas burning are low-level sources.

The sensitivity of the dose due to residential space heating to the increase in district heat use for space heat is shown in Figure 4.32 for the data of Figure 4.31. The total SO_2 emissions decrease slightly because better SO_2 control at district heat plants is assumed (30 percent SO_2 removal before emission). Importantly, the dose per unit of SO_2 emitted in 1970 is much less than in 2025, 17.1 $\mu g/m^3$ per 10^5 tons SO_2 and 4.9 $\mu g/m^3$ per 10^5 tons SO_2, respectively. By switching from the direct burning of coal to district heat, the dose per ton of SO_2 emitted decreased by a factor of 3.5. The dose itself decreased by a factor of 4.5 because of the pollution controls at the district heating plants. With better SO_2 controls than assumed, the reduction in dose attributable to residential space heating could be reduced even further. It is clear that the use of district heat can provide a good means to reduce the SO_2 air pollution that now exists in the urban areas of regions like Bezirk X.

IV. CONCLUSION

Some general conclusions can be drawn from the scenarios. These are grouped around issues that were thought important in the region. It should be re-emphasized that Bezirk X represents a major industrial center in the GDR; its zero population growth provided an interesting ingredient in the study by removing a powerful driving force from the scenarios.

Socioeconomic Aspects

- The planned growth in the industrial sectors after the year 2000 is extremely optimistic. Because the population is not increasing, the projected growth assumes a seemingly unrealistic increase in labor productivity.
- Industrial growth, together with its associated freight transportation, was the dominant driving factor for energy demand in Bezirk X. This growth will be of major concern if energy prices continue to increase.

Energy Intensiveness

- The postulated strong reduction in energy use per unit of output resulted in a manageable growth in industrial energy demand despite the high industrial growth.

The reduction in industrial energy intensiveness was extrapolated from a strong historical emphasis on energy saving. If this decline does not continue, a much larger increase in energy demand will occur. This should be an area for more investigation.

Transportation

- Freight was the dominant driving force behind transportation energy demand. Changes in the freight sector will strongly influence energy demand.
- Freight transport was relatively efficient, with the emphasis on trains for long hauls. If more freight were shifted to trucks for long hauls, the energy demand for freight would greatly increase.
- Passenger transport was also relatively efficient because of emphasis on mass transit. Obviously an increase in auto use would significantly increase gasoline demand. There is, however, room for improved auto fuel efficiency.

Energy Supply

- Bezirk X is self-sufficient in coal, the fuel that powers most of its activity.
- Failures in achieving the assumed increases in energy efficiencies will result in great pressure on the energy supply system in the future. This will have an effect on the entire GDR because Bezirk X is a significant exporter to the rest of the country at present. Such failures, if industrial growth does not slow down, could mean that the rest of the country would have to shift to energy sources other than coal. Any major shift to trucks for freight would increase the demand for imported oil.
- The use of district heat both for process heat in industry and for space heat in all sectors allows the region to exploit its coal resources better and to depend less on imports.
- The primary electricity supply option today is coal, and in the future, nuclear and possibly solar energy.
- Solar space heat does not have a large impact in terms of relative number of units installed. However, its impact could be greater if it could be installed in areas whose population density is too low to justify district heating economically.

Environment

- Coal is better utilized, from an environmental perspective, in district heating plants and electricity generating plants. In the first place, this reduces pollution concentrations in the urban areas. Second, total emissions, which affect the rural areas, can be more easily controlled at central facilities such as district heating plants.
- A significant environmental impact is being absorbed by the Bezirk because of its export of energy. Impacts in the Bezirk due to export of energy decrease over time because the Bezirk requires more and more of its own energy resources, leaving less for export.

- A significant decrease in human health impacts would be effected through the application of SO_2 emission controls. Impacts due to SO_2 air pollution are the fastest growing human health impact considered in this study.

APPENDIX: ENERGY TABLES FOR BEZIRK-X SCENARIOS

SCENARIO S1

TABLE 4A.1 Primary Energy Supply (10^{15} cal)

	1970	2000	2025
Petroleum	5.5	14.0	32.1
Natural gas	2.0	2.7	3.3
Coal	143.0	139.1	135.5
Nuclear energy	0.0	0.0	19.5
Hydropower	0.0	0.0	0.0
Other	0.0	0.0	0.0
Total	150.5	155.8	190.4

TABLE 4A.2 End-Use Energy Consumption (10^{15} cal)

1970	Coal	Gas	Oil	Electricity	District Heat	Solar	Total
Industrial	2.1	0.6	0.6	1.7	7.2	0	12.2
Residential	5.9	1.1	0	0.6	0.4	0	8.0
Service	2.0	0.3	0	0.3	1.0	0	3.6
Transportation	1.3	0	3.8	0.1	0	0	5.2
Total	11.3	2.0	4.4	2.7	8.6	0	29.0
2000							
Industrial	1.7	1.3	0.5	6.0	12.5	0	2.0
Residential	4.1	1.1	0	1.7	1.5	0	8.4
Service	2.0	0.3	0	0.6	1.6	0	4.5
Transportation	0	0	12.0	1.1	0	0	13.1
Total	7.8	2.7	12.5	9.4	15.6	0	48.0
2025							
Industrial	0	2.0	0.5	17.7	25.3	0	45.5
Residential	1.9	1.1	0	2.4	2.3	0	7.8
Service	2.2	0.2	0	1.0	2.4	0	5.8
Transportation	0	0	29.7	6.7	0	0	36.4
Total	4.1	3.3	30.2	27.8	30.0	0	95.5

TABLE 4A.3 Sources of Electricity

	Generation (10^9 kWh)			Primary Energy (10^{15} cal)		
	1970	2000	2025	1970	2000	2025
Coal	16.3	24.9	42.2	48.8	64.8	105.4
Nuclear energy	0	0	7.5	0	0	19.5
Solar energy	0	0	0	0	0	0
Total	16.3	24.9	49.7	48.8	64.8	124.9

SCENARIO S2

TABLE 4A.4 Primary Energy Supply (10^{15} cal)

	1970	2000	2025
Petroleum	5.5	17.4	70.1
Natural gas	2.0	3.4	7.4
Coal	143.0	146.2	143.7
Nuclear energy	0	0	0
Hydropower	0	0	0
Other	0	0	0
Total	150.5	167.0	221.2

TABLE 4A.5 End-Use Energy Consumption (10^{15} cal)

1970	Coal	Gas	Oil	Electricity	District Heat	Solar	Total
Industrial	2.1	0.6	0.6	1.7	7.1	0	12.2
Residential	5.9	1.1	0	0.6	0.4	0	8.0
Service	2.0	0.3	0	0.3	1.0	0	3.6
Transportation	1.3	0	3.8	0.1	0	0	5.2
Total	11.3	2.0	4.4	2.7	8.5	0	29.0
2000							
Industrial	2.1	2.0	0.6	8.7	19.7	0	33.1
Residential	3.2	1.1	0	2.8	1.2	0	8.4
Service	1.7	0.3	0	0.9	1.6	0	4.4
Transportation	0	0	15.4	0.8	0	0	16.1
Total	7.0	3.4	16.0	13.2	22.5	0	62.0
2025							
Industrial	0	6.1	1.6	35.5	97.7	0	140.8
Residential	0	1.1	0	5.4	1.9	0	8.4
Service	1.2	0.2	0	2.1	2.4	0	5.9
Transportation	0	0	66.5	1.4	0	0	67.9
Total	1.2	7.4	68.1	44.4	102.0	0	223.0

TABLE 4A.6 Sources of Electricity

	Generation (10^9 kWh)			Primary Energy (10^{15} cal)		
	1970	2000	2025	1970	2000	2025
Coal	16.3	30.5	26.1	48.8	79.3	67.9
Nuclear energy	0	0	0	0	0	0
Solar energy	0	0	0	0	0	0
Total	16.3	30.5	26.1	48.8	79.3	67.9

SCENARIO S3

TABLE 4A.7 Primary Energy Supply (10^{15} cal)

	1970	2000	2025
Petroleum	5.5	13.5	19.4
Natural gas	2.0	2.6	3.3
Coal	143.0	136.9	124.7
Nuclear energy	0	0	15.8
Hydropower	0	0	0
Solar energy	0	0	7.1
Other	9.6	0	0
Total	160.1	153.0	170.3

TABLE 4A.8 End-Use Energy Consumption (10^{15} cal)

1970	Coal	Gas	Oil	Electricity	District Heat	Solar	Total
Industrial	2.1	0.6	0.6	1.7	7.2	0	12.2
Residential	5.9	1.1	0	0.6	0.4	0	8.0
Service	2.0	0.3	0	0.3	1.0	0	3.6
Transportation	1.3	0	3.8	0.1	0	0	5.2
Total	11.3	2.0	4.4	2.7	8.6	0	29.0
2000							
Industrial	1.7	1.3	0.5	5.4	12.5	0	21.4
Residential	3.9	1.1	0	1.7	1.6	0.03	8.3
Service	1.9	0.3	0	0.6	1.6	0.03	4.4
Transportation	0	0	11.6	1.1	0	0	12.7
Total	7.5	2.7	12.1	8.8	15.7	0.06	46.8
2025							
Industrial	0	2.0	0.5	13.3	25.3	0	41.1
Residential	1.3	1.1	0	2.1	2.6	0.3	7.4
Service	1.9	0.2	0	1.1	2.4	0.3	5.9
Transportation	0	0	17.0	8.2	0	0	25.2
Total	3.2	3.3	17.5	24.7	30.3	0.6	79.6

TABLE 4A.9 Sources of Electricity

	Generation (10^9 kWh)			Primary Energy (10^{15} cal)		
	1970	2000	2025	1970	2000	2025
Coal	16.3	24.2	33.0	48.8	62.9	85.8
Nuclear energy	0	0	5.0	0	0	13.0
Solar energy	0	0	3.0	0	0	7.8
Total	16.3	24.2	41.0	48.8	62.9	106.6

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Prologue to Chapter 5
The Rhone-Alpes Scenarios in Retrospect

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Since the scenarios were written in 1975, several significant changes have occurred in the economic and energy sectors of France. First, Rhone-Alpes, and France as a whole, has been experiencing rising unemployment and low economic growth. GNP growth has averaged 3 percent annually, instead of the 5.5 percent annual growth rate assumed in the scenarios. The industries most affected include the steel industry and the textile industry. In the energy sector, the ambitious national nuclear development program, which called for 6 new 1,000 MW plants per year, has been delayed by 18 months, mostly for technical reasons. This should not have major consequences since a slowing in the growth of electricity demand accompanied the slowing of economic growth. At the same time, however, research priorities have shifted from the development of nuclear technologies to energy conservation measures. Important studies have been conducted on the recovery of waste heat from conventional and nuclear power plants for use in district heating in the residential sector and for provision of process heat in the industrial sector. New standards for equipment efficiency and building insulation in the residential, service, and industrial sectors are also being developed.

Several institutional changes have also occurred in the energy sector since 1975. The *Agence pour l'Economie de l'Energie*, which is concerned with energy conservation, and the *Commissariat de l'Energie solaire*, which deals with solar energy,

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At the second conference, Management of Regional Energy/Environment Systems, held at IIASA, 16–19 May 1978, retrospective presentations on the scenarios were given by energy specialists or policymakers from the three regions. To provide perspective on the scenarios, summaries of the presentations are included immediately before the chapters describing the scenarios for the regions (Chapters 4, 5, and 6). They will be published in full as part of the proceedings of the conference: W.K. Foell (ed.), Proceedings of the Conference on Management of Regional Energy/Environment Systems, (Laxenburg, Austria: International Institute for Applied Systems Analysis, in press).

have been set up. Concurrent with the creation of these agencies, there has been a surge of interest in the local determination of energy policies. Energy matters in France are under the jurisdiction of the central government, and regional authorities do not possess real decision-making power in this sphere. However, in the past three to four years local authorities have acquired more "bargaining power." The "Agency for Energy Conservation," for instance, has a budget which is allocated at the regional level for promotion of waste heat recovery, for the study of power plants for the combined production of electricity and heat, and for similar activities. The regional representative of the energy conservation agency has authority to make the allocations, and his dynamism determines to a great degree the freedom of a region in pursuing its own energy strategies. Perhaps such developments indicate the beginning of a new type of decision-making at the regional level in France.

Turning to the usefulness of the scenarios, one must carefully distinguish the areas in which they are applicable to the real decision-making process. The scenario approach may be used to reveal the future point in time when disruptions may occur, and to explore policies which could be implemented to avoid such disruptions. The long time horizon of the scenarios – the year 2025 – is also appropriate for the definition of research and development strategies. The time scale makes it possible to build a consistent energy/economic future and to identify the actions that would have to be taken to reach such a future.

On the other hand, the scenario approach cannot be used to make predictions. It also has limited usefulness for short- or medium-term decision making. Finally, it is very important to avoid the pitfalls of extrapolating the trends of the past 10–15 years to the 2000–2025 time period. For example, it is clear that new solar technologies and other innovations may be developed during the next several years that could greatly affect the energy situation in 2025. If it is possible to produce inexpensive solar cells in the next 20 years, the energy picture for the next 50 years could be completely changed.

If a scenario stressing strong development of nuclear power were to be written today, it would be important to include construction of combined power plants. It appears that in France such plants will be more and more frequently built, and, in addition, existing plants could be converted for the coproduction of electricity and steam or heat. The results of studies carried out in Rhone-Alpes indicate that the steam or heat that could be produced by nuclear plants is almost competitive with steam or heat produced from conventional fuels (oil or coal). Last year, a consulting commission in Paris, convened by the "Ministry of Industry", held numerous hearings on the topic of heat recovery and combined heat and power production. Though a real policy decision has not yet been made, the conclusions of the commission were favorable to the development of such plants.

5 Alternative Energy/Environment Futures for Rhone-Alpes

I. INTRODUCTION

As background to the three scenarios for Rhone-Alpes, there will be a brief description of the current economic condition of the region and of the trends or phenomena that could have an influence on the evolution of the region.

Although this study focused on one region in France, most of the data and scenario assumptions are relevant to France as a whole. The use of Rhone-Alpes as a focus of study allowed analysis at a local level and clearly showed the environmental implications of the scenarios in a small geographic area.

II. INITIAL CONDITIONS AND CURRENT PLANS*

II.A. SOCIOECONOMIC ASPECTS

Rhone-Alpes is one of the most dynamic regions in France. The growth rate of the population is one of the highest of the 21 regions; the region's economic activity contributes about 10 percent of the French gross national product (GNP); the region employs about 10 percent of the French labor force and uses about 10 percent of the energy consumed in France. Rhone-Alpes is not uniformly developed, however, since three departments dominate the economy.† Rhone, Isere, and Loire provide 70 percent of the employment in the industrial sector and even more in the service sector. The largest city in Rhone is Lyon (1,130,000 people). In

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Chapter 5 was written by Bruno Lapillonne – IIASA.

* More detailed information on the initial conditions is given in Chapter 2.

† There are 8 departments in Rhone-Alpes: Ain, Ardeche, Drome, Isere, Loire, Rhone, Savoie, and Haute-Savoie (see Chapter 2).

Isere the largest city is Grenoble (330,000 people), and in Loire the largest city is St. Etienne (330,000 people).

Rhone-Alpes is primarily an industrial region; industry provides 45 percent of the employment and contributes 60 percent of the gross regional product (GRP, defined here as the sum of value-added of all sectors). Heavy industries (steel, aluminum, and pulp and paper) are concentrated in the Alps because of the low price of hydroelectricity, but chemical industries are concentrated around the three main cities of Lyon, Grenoble, and St. Etienne. The other industries (see Table 5.8) are more evenly distributed, but they are predominantly in the three most productive districts.

Transportation in France is mainly by automobile and truck. Automobiles are used for 75 percent of the passenger transport and trucks are used for 40 percent of the freight transport. The connections between Rhone-Alpes, the Paris area, and neighboring European countries (particularly Italy, the FRG and Switzerland) are being improved by

- The completion of the highway network connecting the largest cities of Rhone-Alpes (St. Etienne, Lyon, Valence, Annecy, Grenoble, and Chambery) with Paris, Geneva, and Marseille
- High-speed trains between Paris and the largest cities in Rhone-Alpes. The trains should be running by 1980
- The Rhone-Rhine canal
- The development of Lyon International Airport

Because of communication and transportation difficulties elsewhere, French companies are now concentrated in Paris. Improvements in the transportation network in Rhone-Alpes will encourage them to move some of their offices to places like Lyon and Grenoble.

II.B. ENERGY SUPPLY

Although Rhone-Alpes is a net exporter of electricity, energy production in the region is very low. All the oil used in the region is imported. It is refined in the large refinery of Lyon-Feyzin which has a capacity of 6 million tons per year. In 1972, sixty percent of the electricity generated in Rhone-Alpes was from hydropower, 24 percent from oil, 4 percent from nuclear power, and 6 percent each from coal and gas. There are 2 coal mines in Rhone-Alpes. They do not contribute significantly to the energy supply and were scheduled to be closed in 1980. But the rise in oil prices may keep the mines open.

There is geothermal energy in Rhone-Alpes, but little is known about it. What is known was learned as a by-product of oil prospecting. The French government is now using financial incentives to stimulate research on the use of geothermal energy, though on a small scale. In Rhone-Alpes, the use of geothermal district heating in

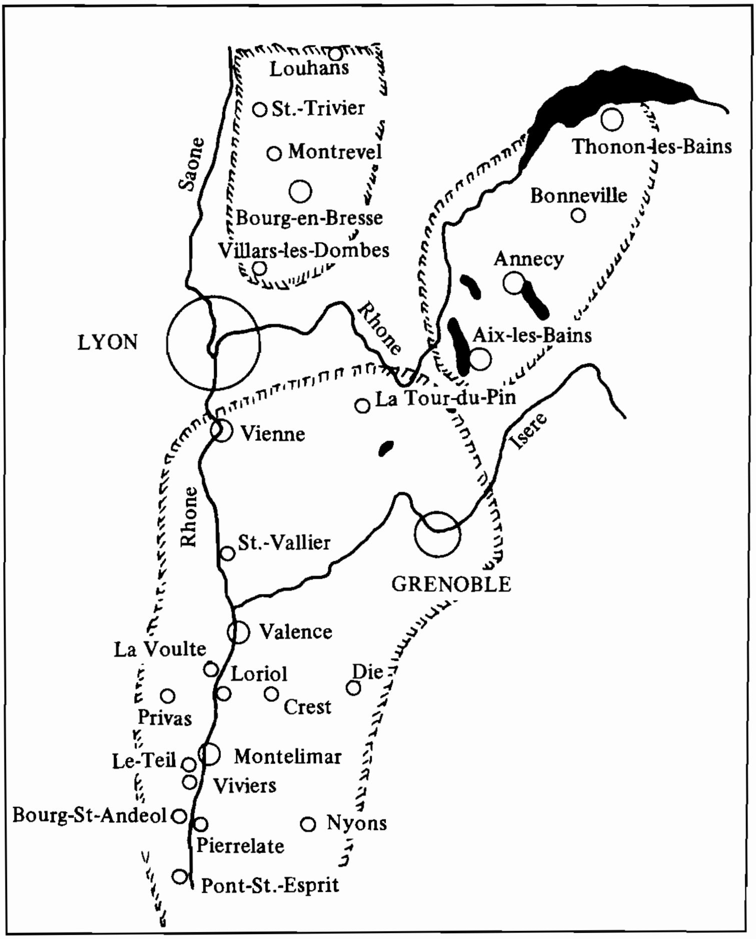

FIGURE 5.1 Regional geothermal reserves (Rhone-Alpes). In the area of Bourg-en-Bresse, the average geothermal gradient is estimated at 3.3°C/100 m. For the other areas (Grenoble, Valence) the figure could be of the same order of magnitude. Under Bourg-en-Bresse the water temperature reaches 90°C at 2,000 m.

Bourg-en-Bresse is being contemplated. Figure 5.1 shows the location and extent of geothermal fields in the region.

The Rhone-Alpes is a good area for nuclear plants since they could be cooled with the water of the Rhone River. Figure 5.2 shows the locations of the existing and planned reactors. Immediately following the oil crisis in 1972, the French government decided to develop nuclear energy as the basis for the energy supply of France. An initial long-term program provided for the construction of six nuclear plants each year until 1977 and the construction of an enrichment plant and a reactor to supply it in the south of the region at Tricastin. But the implementation

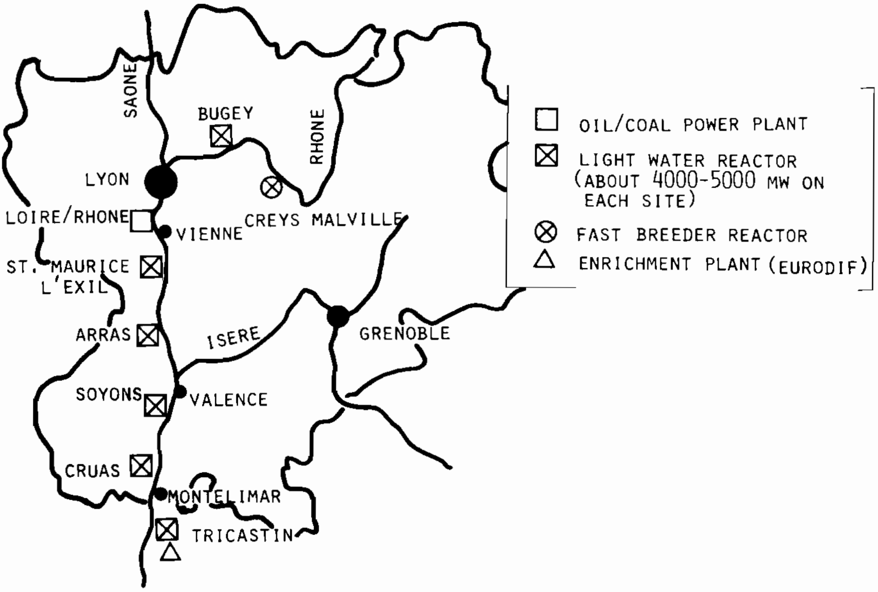

FIGURE 5.2 Nuclear sites in Rhone-Alpes. One plant in Bugey went into operation in 1973. The planned dates of other plants to go into operation are: Cruas – 1984 (2 plants), 1985 (1 plant); Bugey – 1978 (1 plant), 1979 (3 plants); St. Maurice l'Exil – 1985 (1 plant); Tricastin – 1979 (2 plants), 1980 (1 plant), 1981 (1 plant). The other sites are tentative.

of the plans of *Electricité de France* (EDF), the government-run company responsible for electricity production, that are shown in Figure 5.2 has been delayed.*

The possibility of building an experimental solar plant is now being studied. Solar houses are being built in the south of France, and official reports estimate that the number of solar houses built every year will grow to 50,000 by 1985, or 10 percent of total housing construction.

III. GENERAL CONSIDERATIONS FOR THE SCENARIOS

III.A. PRESENTATION OF THE SCENARIOS

Rhone-Alpes is a more financially and politically dependent region than the GDR or Wisconsin. A discussion of Rhone-Alpes cannot take place without a discussion of France as a whole, so the scenarios that will be described include policies for both Rhone-Alpes and France.

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* See EDF Enerpresse No. 1994, Jan 19, 1978.

III.A.1. Urban Policy

Besides the current trends of urban development, two other alternatives were considered.

- Very concentrated urbanization in the form of new compact cities like the ones built around Paris (*"villes nouvelles"*) and the rapid growth of small existing towns with between 20,000 and 50,000 inhabitants. These kinds of urbanization are now being tested on a small scale in France. L'Isle d'Abeau near Grenoble is an example of a new compact city in Rhone-Alpes. The new compact cities are thoroughly planned and include low-cost mass transportation and space heating for the entire community. All of the new towns near Grenoble, for example, will be served by a district heating system already connected to about 10,000 housing units. It is planned to heat L'Isle d'Abeau from the nuclear plants now under construction in Bugey.
- Growth of the population in small cities or in rural areas. Such growth could result from a modification of urban trends within the current economic framework, in which people continue to work in cities but live outside of them (urbanization similar to that in the United States). Or, such growth could result from a decentralization of the economy.

III.A.2. Transportation Policy

In addition to the current situation described in section II.A., one other alternative has been considered for transportation: A shift from cars and trucks to railways and other forms of mass transit brought about through intervention by municipalities, the regional administration, and especially the central government. Such an interventionist policy, radically different from the current one, could be implemented to save energy or to stimulate the development of public transportation.

III.A.3. Energy Policy

With respect to energy supply, the current plans emphasize nuclear energy. As Rhone-Alpes is very much involved in the current nuclear energy program, it seemed very interesting to explore in the Base Case the environmental impacts of implementation of a long-term policy based on nuclear energy. In contrast to such a policy, two alternatives were considered.

- The first was based on a large-scale development of new sources of energy (solar and geothermal) in order to examine the fraction of the energy markets that could be penetrated over a long period of time and to compare the resultant environmental impacts with those associated with nuclear energy.
- The second policy corresponds to an intermediate nuclear energy policy in

TABLE 5.1 Policies and Assumptions for the Three Rhone-Alpes Scenarios

Growth Assumptions

Growth rate of GRP/year	1971–1985	5%
	1985–2000	4.2%
	2000–2025	3.5%

Population growth: Gradual decrease from 1.3% per year in the 1970s to 0.4% after 2000.

	Scenario		
Policy Areas	S1	S2	S3
Urban form	• Continuation of current patterns	• Dispersal; emphasis on single family houses (80% of post-1975 houses)	• Growth in small-scale compact cities • Multifamily buildings
Technology	• High level of conventional fuel prices – high penetration of electricity for space heating and industrial uses – large decrease in energy intensiveness	• Low level of fuel prices – smaller decrease in energy intensiveness than for S1 – low penetration of electricity for thermal uses	• Low penetration of electricity in industry • Large reduction of energy intensiveness • High penetration of solar and geothermal heating
Transportation	• Predominance of auto • Slight increase of intercity mass transportation	• Same as S1	• Mass transit increase • Efficiency gains for autos and trucks • Shift from truck to train for freight
Energy supply	• Electricity generation from nuclear energy	• Mix of nuclear, oil, and coal for electricity generation	• Maximum feasible hydroelectricity • Solar electric • No new nuclear plants
Environment	• Present trends of increasing controls	• Low control (current levels)	• Strict controls

which nuclear energy would be used only for electricity generation and not to replace conventional fuel for space heating and industrial thermal uses.

With respect to energy demand, several trends were considered based on the rate of growth of energy prices and on energy conservation. All the options were combined into consistent policies from the point of view of a decision maker, and from these policies three scenarios were selected. Those scenarios were selected that had meaning for the other regions and could be easily compared. At the same time, each scenario assumes a different level of energy consumption (high, medium, and low).

- S1, the Base Case, assumes the continuation of current socioeconomic trends and the extension of the current nuclear program because of high conventional fuel prices.
- S2 assumes the implementation of an exurban dispersal policy. Such a policy can only be considered in a context of low fuel prices, which would lead to a smaller reduction of energy intensities than in the other scenarios, and a transportation system still based on cars and trucks.
- S3 assumes the implementation of an urban policy based upon the development of compact cities. A shift of economic activity from industry to the service sector is also assumed. This scenario can only be realized with an interventionist policy by the government to develop mass transit and district heating, require lower pollution levels, and implement energy-saving measures.

S3 assumes low energy use, S2 assumes high energy use, and S1 assumes medium energy use. The three scenarios are summarized in Table 5.1.

III.B. CHARACTER OF THE DATA

Data collection at the regional level is very difficult since the French regions were only recently created and have no real political independence. Data gathering in Rhone-Alpes is done by the *Institut National de la Statistique et des Etudes Economiques* (INSEE), which has an office in Lyon. The INSEE data is far from complete, and is mainly on the residential sector.* With respect to economic activity, only employment data are available.† We therefore tried to estimate the value-added of Rhone-Alpes economic sectors from the Rhone-Alpes employment data and from national data on labor productivity. For some aggregated sectors, the estimates have been corrected to account for the difference in structure between France and Rhone-Alpes. In the transportation sector, there are data on internal traffic, but information on the flows of passengers and freight through the region was incomplete. All the data on energy intensiveness were taken from national data. For space heating and hot water heating in the residential and service sectors, data were drawn from Chateau.[3] For the transportation and industrial sectors the data came from the *Centre d'Etudes Regionales sur l'Economie de l'Energie* (CEREN).[4]

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* When the results of the last census have been analyzed, data on Rhone-Alpes will be much better than they are now.

† An unsuccessful survey was organized by INSEE – Rhone-Alpes to evaluate the value-added of the major economic sectors. It was thwarted because of the centralization of the French economy and because most of the companies in Rhone-Alpes are run from outside of the region – mostly from the Paris area.

TABLE 5.2 Estimated Population, Households, and Working Population for Rhone-Alpes

Year	Population ($\times 10^3$)[a]	Average Growth Rate per Year in Each Period[a]	Number of Households ($\times 10^3$)[a]	Average Number of Persons per Household[a]	Working Population ($\times 10^3$)[a]	Percentage of Working Population in Total Population
1972	4,660	1.2%	1,500	3.1	2,030	44%
1980	5,130	1.1%	1,730	3.0	2,160	42%
1985	5,410	0.8%	1,870	2.9	2,270	
1990	5,630		2,000	2.8	2,300	41%
1995	5,800	0.6%	2,150	2.7	2,380	
2000	5,980	0.4%	2,350	2.7	2,400	40%
2025	6,600		2,640	2.5	2,640	

[a] Data based upon INSEE estimates for France up to the year 2000 and corrected so as to take into consideration the particularities of the region; after 2000, as no demographic estimates have been made, a growth rate of 0.4% per year is assumed.

TABLE 5.3 Dynamics of Housing in Rhone-Alpes

Period	Annual Increase of Housing Units[a]	Number of Housing Units Demolished Each Year[b]	Number of Housing Units Built Each Year
1962–1968	23,500	12,700	36,200[c]
1968–1970	25,000	19,200	44,200[c]
1970–1980	28,000	20,000	48,000
1980–1990	27,000	30,000	57,000
1990–2000	25,000	29,000	54,000
2000–2025	13,600	12,400	26,000

[a] See Table 5.1 for the assumptions about housing used in the scenarios.

[b] Until 1970, the number of demolitions is calculated from the number of housing units built and from the number of new households; from 1970 until 1985, we assume the demolition of all substandard, pre-1949 houses; demolition of all 1949–1961 houses is assumed to take place between 1985 and 2000 (houses built after the Second World War and corresponding to very low standards). The necessity of maintaining the activity of the building industry at a high level was taken into consideration (because of the high fraction of total employment in this sector and its importance in the economic growth).

[c] Actual figures according to INSEE.[1]

Up to the year 2000, the scenarios were constructed with the help of studies made of France at the University of Grenoble.[5] For 2000 to 2025, rough extrapolations were made that assumed a slowing of the previous trends.

Two assumptions are shared by all the scenarios.

- Projections of population growth, number of households, and working population (see Table 5.2).
- Projections of number of housing units built and demolished during each period. This implies that the housing policy of the government is identical for all the

TABLE 5.4 Single-Family Housing in Rhone-Alpes by Date of Construction ($\times 10^3$)[a, b]

	Single-Family Housing Occupied In				
	1970	1980	1990	2000	2025
Pre-1949	915 (51%)[b,c]	715 (51%)	495 (51%)	350 (51%)	250 (51%)
1949–1961	225 (46%)	225 (46%)	145 (46%)		
1962–1970	310 (36%)	310 (36%)	310 (36%)	310 (36%)	150 (36%)
Total pre-1975	1,450 (47%)	1,490 (46%)	1,190 (45%)	900 (44%)	640 (45%)
1975–1980		240	240	240	240
1980–1990			570	570	570
1990–2000				540	540
2000–2025					650
Total post-1975		240	810	1,350	2,000

[a] For the dynamics of housing see Table 5.3.

[b] Percentage of housing that is single houses and percentage that is apartments is drawn from national data[1] (excluding Paris and its metropolitan area) and corrected with the help of estimates for the distribution of current housing in Rhone-Alpes.

[c] Percentage of total number of single-family houses.

scenarios (see Table 5.3). The percentages of pre-1975 and post-1975 housing have been calculated using the assumptions detailed in Table 5.4. These percentages are important because after 1975, all new housing units have to be well insulated to standards close to those of electrically heated housing units.

IV. BASE CASE SCENARIO

IV.A. SOCIOECONOMIC ASSUMPTIONS: CONTINUATION OF CURRENT TRENDS

IV.A.1. Economic Growth

Scenario S1 can be characterized (a) by a slight shift from the heavy industries to the service sector, (b) by a continuing decrease in agricultural activities, and (c) by an increase in light industry activity (at approximately the same rate as the service sector). The contribution of the major economic sectors over time to the GRP is shown in Table 5.5a. Table 5.5b shows annual growth rates of the GRP. Table 5.6 shows the changing distribution of the working population by sector.

IV.A.2. Urban Growth

Each population density class will grow roughly the same as it grows now; the 6 density classes are 0–2000 inhabitants/km^2, 2000–3,000, 3000–5,000, 5,000–8,000, 8,000–15,000, and more than 15,000. Forty percent of new housing units have been assumed to be single-family houses.

TABLE 5.5a Breakdown of Rhone-Alpes Gross Regional Product by Economic Sector

			1985		2000		2025	
	1968[a]	1971[a]	S1, S2	S3	S1, S2	S3	S1, S2	S3
Agriculture	7%	5%	4%	4%	3.5%	3.5%	3%	2.5%
Industry								
Heavy	51%	10%	9.5%	9%	8%	7.5%	6%	5%
Light		41.5%	42%	39.5%	43.5%	37%	45%	35.5%
Building, public works	10%	10%	10%	10%	10%	10%	10%	10%
Service sector	32%	33.5%	34.5%	38%	35%	42%	36%	47%
GRP (10^6 francs)[b]		56.4	115	100	215	160	495	290
GRP/capita (10^3 francs)		12.3	21.3	18.5	36	27	75	44
GRP/capita (10^3 dollars)		2.5	4.4	3.8	7.4	5.5	15.3	9.0

[a] These are estimates (see section III.B. of this chapter).
[b] 1963 francs. $1 = 4.9 francs.

TABLE 5.5b Annual Growth Rates of GRP and GRP/Capita by Period

	1971–85	1985–2000	2025
GRP	5%	4.2%	3.5%
GRP/capita	4%	3.5%	3%

IV.A.3. Transportation

Table 5.7 summarizes the main assumptions used for the Rhone-Alpes freight transportation sector for energy intensiveness, distribution of transportation modes, and total freight demand. For passenger transportation, it is assumed that, as a result of the urban pattern, the number of trips per capita will remain approximately constant. Moreover, it has been assumed that the distribution of cars, mass transit systems, and railways remains constant over time.

IV.B. TECHNOLOGICAL ASSUMPTIONS

IV.B.1. Industrial Sector

The rise in oil prices will have two effects on the energy intensiveness of French industry.

- Electricity will be used instead of other fuels for thermal uses and space heating. Table 5.8 shows the distribution of industrial energy consumption in 1971.

TABLE 5.6 Distribution of Working Population by Economic Sector

				1985		1990		2000		2025	
	1962	1968	1972	S1, S2	S3	S1, S2	S3	S1, S2	S3	S1, S2	S3
Agriculture	18%	12%	9%	6.5%	6.5%[d]	6%	6%[d]	5.5%	5.5%	4.5%	4%
Heavy industries[a]	36%	6%	5.5%	5%	5%	5%	4%	5%	4%	4%	3%
Light industries[b]		30%	30.5%	31.5%	30.5%	32%	28%	32.5%	26%	34.5%	24%
Building, public works	9.5%	10%	9.5%	9%	9%	9%	9%	9%	9%	9%	9%
Service sector[c]	36.5%	42%	45.5%	48%	49%	48%	53%	48%	55.5%	48%	60%
Total employment (thousands)	1,710	1,819	2,032	2,270		2,300		2,400		2,640	

NOTE: We assumed a slight decrease of the current level of employment in the primary metal industry as well as in the chemical industry, and for the building materials industry a growth rate of employment close to the present trend.

[a] Primary metals, chemicals and building materials industries (energy industries included).

[b] Other than heavy industry, building, and public works.

[c] Commercial, tertiary, and transportation sectors.

[d] The estimate of the working population in agriculture in 1985 is 145,000 persons, after 1985 a slight reduction of working population in this sector has been assumed (120,000 persons by 2025).

TABLE 5.7 Freight Transportation in Rhone-Alpes for Scenario S1

	1970	2000	2025
Fraction of total ton-km by mode of transport			
Rail	.38	.35	.30
Truck	.54	.58	.64
Barge	.08	.07	.06
Energy intensiveness (kcal/ton-km)[a]			
Rail	110	110	110
Truck	710[b]	710	710
Barge	160	160	160
Total energy for freight transport (10^{15} cal)	6	20	37

[a] From Lapillonne.[2]
[b] 400 kcal/ton-km for transportation over distances of more than 150 km.

TABLE 5.8 Distribution of the Industrial Energy Consumption in France by Main Processes

	Electrical Uses		Fuel Uses		
Industrial Sector	Lighting and Process Energy (%)	Thermal Processes and Electrolysis (%)	Steam (%)	Direct Uses of Fuel (Furnaces) (%)	Heating (%)
Food industry	97	3	74	13	13
Building material	90	10	5	95	
Primary metals			low[a]	> 90[a]	low
Manufactured goods	60	40	20	43	37
Chemical industry	65	35	50	45	5
Paper	98	2	90	4	6
Miscellaneous	90	10	60	20	20
Percentage of total used by each process	65	35	40	50	10

NOTE: Data are estimated from the CEREN survey of 1971.[4]
[a] The main consumption is the use of coke in the steel industry; in this sector no substitution for one fuel by another can be envisaged.

- Energy intensiveness will decrease. The amount of the decrease will vary from sector to sector depending on the importance of energy costs in the production cost and on the distribution of energy consumption among space heat, furnaces, steam, and so on. The distribution among the different processes determines the economic and technological limits on the decrease of energy intensiveness.

In order to calculate the degree to which electricity will be used instead of other fuels, we:

TABLE 5.9 Change Over Time in the Rhone-Alpes Industrial Energy Intensiveness for Scenario S1[a]

	Reduction of Energy Intensiveness (%)		
	1970–1985	1985–2000	2000–2025
Heating (nonelectric)	25	15	0
Furnaces (nonelectric)	10	10	0
Steam	15	15	0

[a] Values for all electric processes for each sector are extrapolated from past trends and vary from one sector to another.

1. Calculated the energy intensiveness by fuel for nonelectric use. Fuels for space heating, all steam generation, and most of the furnaces (the three make up more than 90 percent of the thermal uses) were considered.
2. Evaluated the overall energy intensiveness; all fuels were aggregated in terms of useful energy by considering the efficiency of the fuel in comparison with electricity.
3. Calculated the distribution of this useful energy intensiveness by process. Three processes were considered – space heating, steam, and furnaces. Table 5.8 indicates the values used for each sector.
4. Identified for each sector the market competition between electricity and conventional fuels. It was assumed that this market includes space heating and furnaces.
5. Specified the rate of penetration of electricity into this market: 20 percent in 1985, 50 percent in 2000, and 80 percent in 2025.
6. Calculated the electric and nonelectric intensiveness.

For each process the assumed reductions in energy intensiveness are indicated in Table 5.9.

IV.B.2. Service Sector

Initial data on energy use in the service sector are shown in Figure 5.3.* The following assumptions have been made:

- Oil and gas heating efficiencies are improved from 60 to 75 percent and from 70 to 80 percent, respectively, by the year 2000.
- The energy use per worker for heating and hot water is assumed to decrease in the following way: 15 percent between 1972 and 1985, 25 percent between 1985 and 2000, and 30 percent thereafter. This reduction can be justified by the consideration of two phenomena: (a) Buildings constructed now are much more

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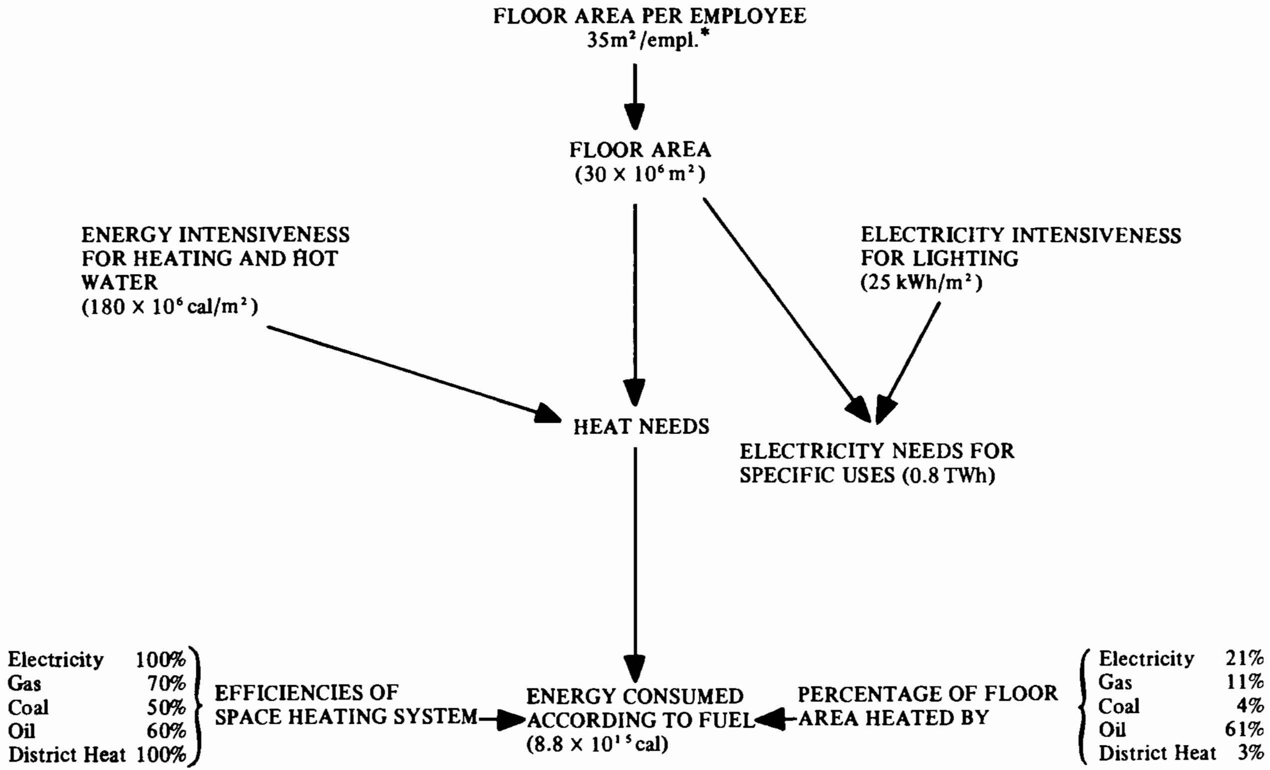
* Data on energy use are from the IEJE study.[5]



* For this factor an average growth rate of 0.5%/yr was assumed.

FIGURE 5.3 Energy use in the French service sector (1972) (Source: Chateau and Lapillonne[5]).

TABLE 5.10 Fuel Mix in the Service Sector

	Percentage of Floor Area Heated by				Percentage of Floor Area Cooled by Electricity
	Electricity	Gas	Oil	Oil District Heating	
1985	35%	20%	40%	5%	5%
2000	50%	15%	30%	5%	20%
2025	80%	10%	5%	5%	50%

TABLE 5.11 Average Energy Used in Space Heating in France (10^9 cal)

	Pre-1975 Housing Units						Post-1975 Housing Units[d]	
	1970[a]		1985[b]		2000 and 2025[c]		1975–2025	
	Single House	Apartment	Single House	Apartment	Single House	Apartment	Single House	Apartment
Electricity	16.4	9.4	16.4	9.4	16.4	9.4	16.4	9.4
Gas	26.0	15.0	34.0	20.0	32.0	18.8	20.5	11.8
Oil	30.3	17.5	36.4	23.1	34.0	20.0	21.9	12.5
Coal	36.4	21.0						
District Heat[e]		10.5		15.0		15.0		9.4
Solar							16.4	

[a] Data are based upon the following assumptions: average heat requirements of about 14.2×10^9 cal/house (18.2 for single houses and 10.5 for apartments – actual data for France in 1970); average efficiencies for space heating: coal 55%, oil 60%, gas 70%; number of housing units with space heating appliances: 1.1 million (out of 1.4 million).

[b] All houses are supposed to be equipped with space heating appliances; average heat requirements: 25.5×10^9 cal/yr for a single house and 15.0×10^9 cal/yr for an apartment; average efficiencies: oil 65%; gas 75%.

[c] Average efficiencies are oil 75% and gas 85%; these are the efficiencies of the most efficient current heating system.

[d] Housing units to which new insulation standards must be applied. For the specification of these standards, France has been divided into three areas (*A*, *B*, *C*): *A*, the coldest one, includes mainly two districts, Savoie and Haute-Savoie, plus some mountainous areas in other departements (about 20% of Rhone-Alpes population); all the other places in Rhone-Alpes are in the second area. *B*. The standards are as follows in terms of the insulation parameter $G \equiv \text{kcal/m}^3/\text{h/°C}$: area *A* – single houses ($G = 1.25$), aparments ($G = 0.85$); area *B* – $G = 1.38$, and 0.90, respectively.

[e] End-use energy of district heat in the housing units.

energy efficient than old buildings because there is now recovery of some thermal loss from electric lighting and elevators: and (b) the percentage of buildings in the service sector constructed after 1975 increases rapidly from 40 percent in 1985 to 85 percent in 2000.

- Demand for electricity is assumed to increase at a rate of 1.5 percent per year.

The assumptions for the changes over time in the fuel mix for heating and cooling are listed in Table 5.10.

TABLE 5.12 Average Energy Use for Hot Water in France (10^9 cal/yr/household)

Electricity, district heat, and solar energy	2.3
Gas	2.9
Oil	3.7
Coal	4.6

SOURCE: Chateau.[3]

TABLE 5.13 Annual Electricity Consumption for Basic Secondary Appliances in Rhone-Alpes (1972)

	Annual Electricity Consumption per Housing Unit[a]	Percentage of Housing Units Owning these Appliances[b]
Refrigerator	350 kWh	85%
Television	300 kWh	74%
Washing machine	100 kWh	69%
Dishwasher	360 kWh	3%

[a] Data based on U.S. consumption estimates for television, washing machine, and dishwasher and checked with the consumption in Rhone-Alpes.
[b] Data from INSEE study.[1]

IV.B.3. Residential Sector

Table 5.11 shows the change over time in the average energy use for space heating in France by fuel and type of housing unit.* About 77 percent of French households own hot water heaters. The distribution by source of energy was approximately the following in 1972: electricity 23 percent, gas 20 percent, oil 21 percent, coal 10 percent, district heat 3 percent. We assumed that the average energy use for hot water would be 1.5 times higher in 2000 than in 1970 and twice as high in 2025. The current average energy use for hot water in households is indicated in Table 5.12.

Only four secondary "appliances" were considered. Their average consumptions are listed in Table 5.13.

Other electrical energy consumption for lighting, dryers, and so on has been summed and in 1972 was an average of 270 kWh per family. The change over time of total electrical consumption by this category of appliances has been calculated from past trends. Past trends have also been used as a basis for predicting penetration rates of new appliances. Figure 5.4 gives the expected rate for equiping households with these appliances. The form of the curves was taken from observations in more developed countries such as the United States.

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* Because no data on "base appliances" (space heaters and hot water heaters) were available for Rhone-Alpes, national data were used from the IEJE study.[5]

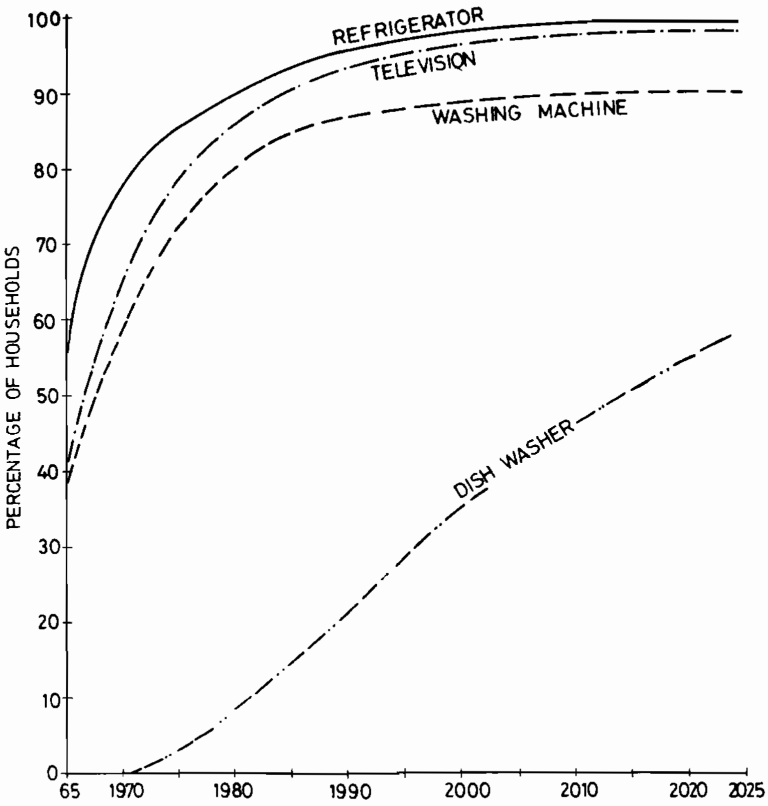

FIGURE 5.4 Evolution of the percentage of households owning major secondary appliances in Rhone-Alpes (Source: INSEE[1] before 1972; later estimates based upon the experience of other countries).

The following assumptions underlie the choice of a fuel mix for space heating and hot water heating in Scenario S1:

- Maximum penetration of electric heating.
- The share of gas increases to about 40 percent of the market in 2025. Now it has 5 percent of the market.
- No pre-1975 housing units could be converted to electric heating because of the very strict insulation standards required for this type of heating, and the difficulties of implementation at a reasonable cost in existing housing units (in 2025, 5 percent of the housing units would be heated using electricity).
- In 1985 all housing units would be equipped with space heating and hot water appliances.

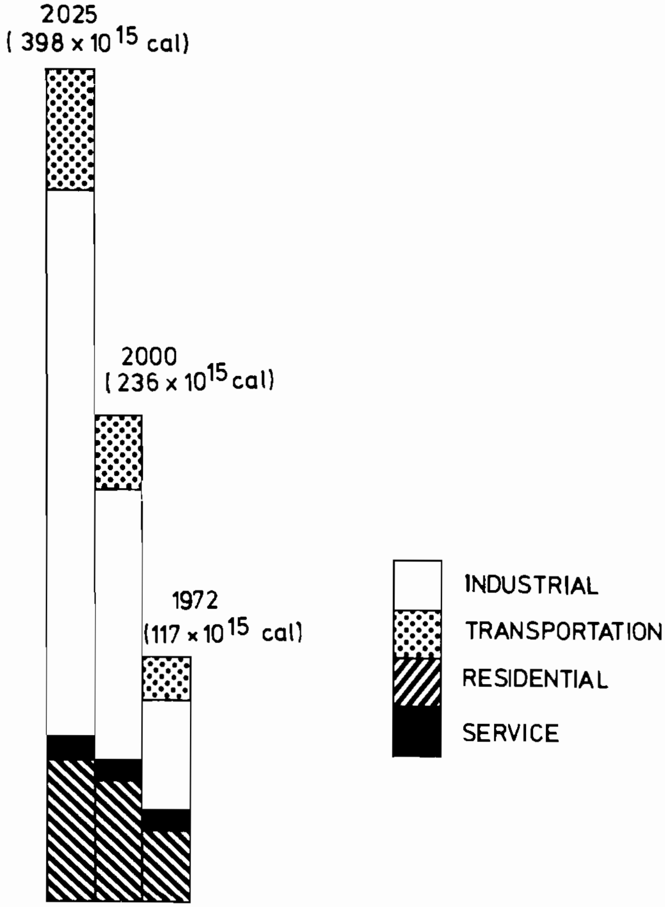

FIGURE 5.5 Distribution of the total end-use energy by sector in Rhone-Alpes (Scenario S1).

type of housing, would be the last ones to be demolished. Consequently, 10 percent of the housing units will be heated by district heat in 2025.

IV.C. RESULTS FOR SCENARIO S1

IV.C.1. End-Use Energy

Figures 5.5 and 5.6 show the distribution of the total end-use energy over time by economic sectors and fuel type, respectively, as calculated for S1 by the demand models. These results correspond roughly to an average demand growth rate of 2.3 percent per year (1.7 percent per year per capita). The share of the industrial sector

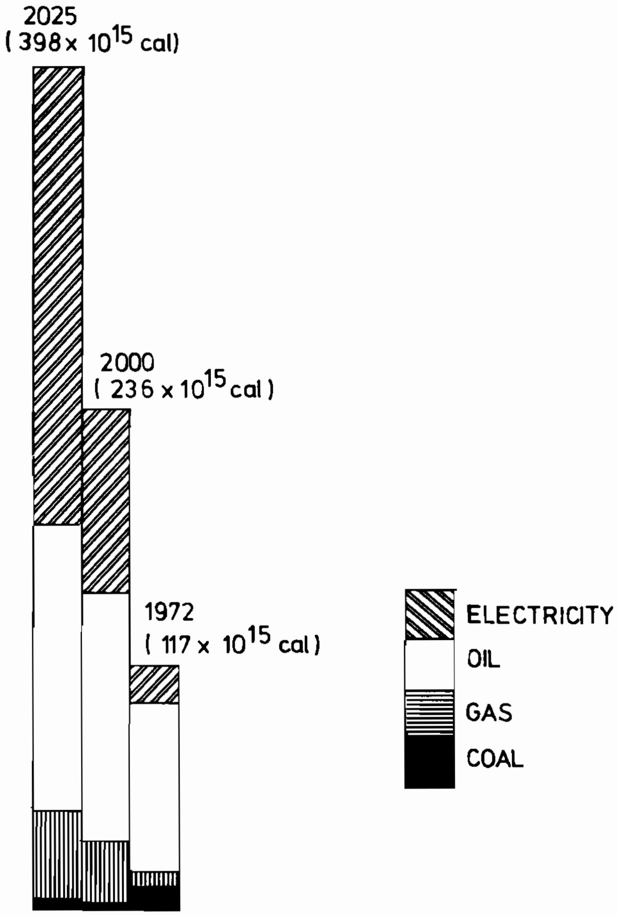

FIGURE 5.6 Distribution of the total end-use energy by fuel types in Rhone-Alpes (Scenario S1).

in the total demand increases very rapidly, since, according to these projections, this sector would account for about 65 percent of the total energy consumption in 2025 (compared with 45 percent currently). The demand of the residential sector decreases from 30 percent to about 15 percent of total demand. This can be easily explained by the combination of two phenomena: (1) the population, which is the driving force behind the residential energy demand, grows slower than the industrial value-added, and (2) a saturation effect of the energy needs seems to appear in the residential sector after 2000.

The latter phenomenon is due to the increase in the number of well-insulated housing units and the saturation of appliances such as televisions, refrigerators, and washing machines between 1985 and 2000 (see Figure 5.4). This is reflected in the

TABLE 5.14 Fuels for Space Heating and Hot Water Heating for Post-1975 Housing Units in Rhone-Alpes (S1 Assumptions)

	1975–1985		1985–2000		2000–2025	
	Single Houses	Apartments	Single Houses	Apartments	Single Houses	Apartments
Electricity	30%	30%	75%	40%	95%	60%
Gas		30%		30%		20%
Oil	70%	40%	20%	25%		5%
Oil district heat				5%		10%
Geothermal district heat						5%
Solar energy			5%		5%	

consumption per capita which only increases from 9.8×10^9 cal in 2000 to 10.4×10^9 cal in 2025. In 1970 it was about 7.0×10^9 cal.

The importance of electricity increases significantly, although in 2025 only 54 percent of the total end-use energy demand is for electricity. It was assumed that decision makers would rapidly reduce dependence on conventional fuels, particularly oil, by replacing them with electricity produced from nuclear energy. But the percentage of electricity in end-use energy only increases in S1 from 16 to 54 percent in approximately 50 years, an illustration of the difficulty of achieving this aim. The reduction of the dependence on oil and gas can only be envisioned over a very long time period. In the change over time of the fuel mix in each sector, two major constraints partly explain this dependence phenomenon. (1) In the residential and service sectors, it was assumed that most of the new housing units would be heated by electricity (Tables 5.10 and 5.14). Nevertheless, only 48 percent of the residential heating demand in 2025 is actually supplied by means of electricity (80 percent for the service sector) because pre-1975 housing units, which were assumed not to be convertible to electric heating, remain in the housing stock even over a long period of time (Table 5.4). (2) In the industrial sector, the rate of penetration of electricity is constrained by the size of the market because electricity cannot replace conventional fuels used in industrial furnaces and space heating, for example.

IV.C.2. Environmental Impacts

The following discussion will deal only with impacts from nuclear energy since Scenario S1 is based primarily on the use of nuclear energy. The evaluation of nuclear impacts raises some difficulties, because some important ones are unquantified (e.g. aesthetic impacts of high cooling towers or wide transmission line corridors, the risk of theft of radioactive products), or because others are not well known and hence very often debated. Special care has therefore been taken to avoid the aggregation of impacts about which knowledge is uncertain. The importance of each impact that is described is left to the judgment of the reader.

Number of sites The nuclear capacity can be calculated from the level of electricity generation (95×10^9 kWh and 255×10^9 kWh in 2000 and 2025 and from the average load factor of all the nuclear plants. The latter factor is difficult to evaluate because it depends on technical considerations (improvements in reactor availability) and on the structure of the load curve of electricity demand. As a basis, we have assumed an average capacity factor of 60 percent to account for the fact that all these plants could not be used for the base load. Hence the nuclear capacity would be about 18,000 MWe in 2000 and 48,500 MWe in 2025 (15,500 MWe and 42,000 MWe if a 70 percent capacity factor was assumed).

Although currently four to six 900 MWe reactors are constructed on each site, 1,200 MWe light water reactors are expected to be used before 1980. The fast breeder reactor now under construction will have a capacity of 1,200 MWe. If 1,200 MWe reactors are used, Rhone-Alpes would have 4 or 5 sites in 2000.* The number of sites in 2025 will depend on the strategy followed by EDF. If the capacity on each site is 5,000 MWe, then 4 new sites would have to be constructed between 2000 and 2025. If 10,000 MWe sites are developed, then the initial 5 sites would be enough.

The latter strategy would avoid the public opposition to the opening of new sites, reduce the number of radioactive shipments and hence the risk of theft, and take advantage of economies of scale. But some environmental impacts would be greater. For example, thermal pollution would be very concentrated. The characteristics of the nuclear potential in 2025 are summarized below.

- Capacity in 2025: 42,000 MWe (70 percent load factor) to 48,500 MWe (60 percent load factor)
- Number of sites: 9 sites of about 5,000 MWe or 4–5 sites of about 10,000 MWe
- Percentage of light water reactors (LWR) in 2025: 60 percent (fast breeder reactor: 40 percent)

Thermal Discharges Only once-through cooling and wet cooling towers were considered as cooling techniques for nuclear power plants in Rhone-Alpes. Once-through cooling was assumed to be limited by a maximum permissible increase of Rhone River temperature (ΔT) under unfavorable conditions: minimum flow in a dry year and minimum natural cooling. Table 5.15 shows the possibilities for the disposal of waste heat for two control policies. The resultant water evaporation has also been included.

Figure 5.7 shows the probability density functions of a ΔT increase in the river water temperature at the southern border of the region by seasons if the less restrictive standard applies. (See Chapter 3, section IV.D.5 for the method of calculation.) This figure shows that, in the south of the region, the normal temperature of the Rhone river increases 5°C during 50 to 60 days per year and 4°C during about 140

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* Bugey, Tricastin, St-Maurice-l'Exil, Arras, Soyons, Cruas. See Figure 5.2 for location of these sites.

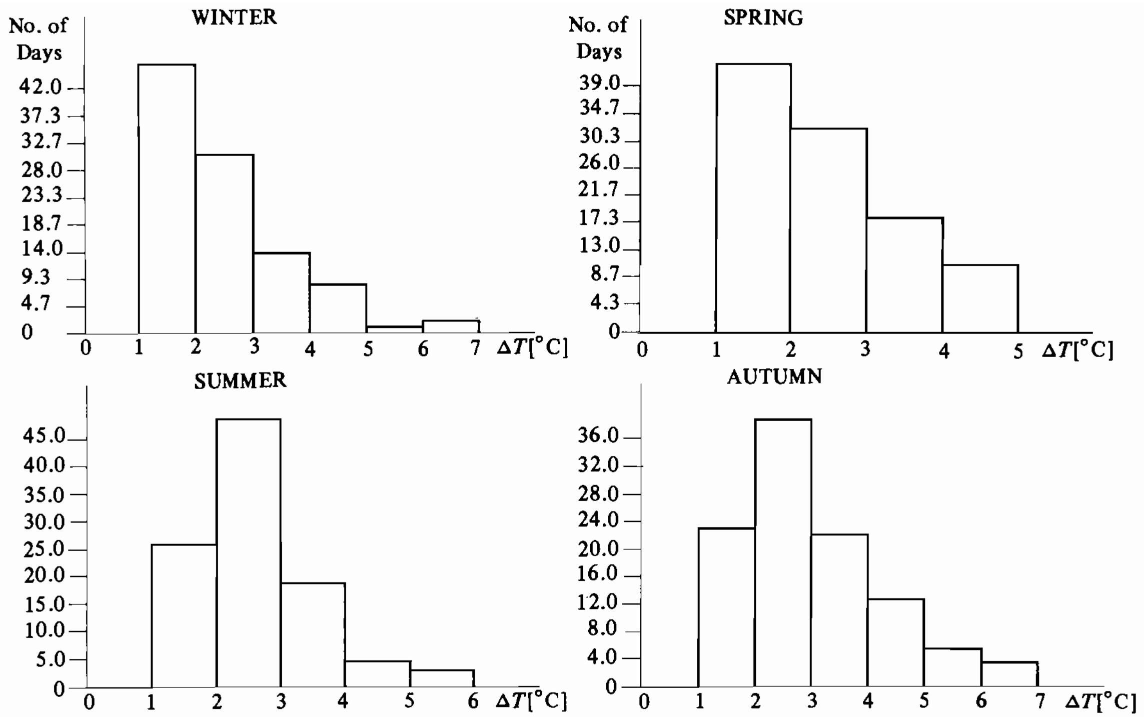

FIGURE 5.7 Probability density function of a ΔT increase of the river temperature at the southern border of the Rhone-Alpes region.

TABLE 5.15 Cooling System Requirements in Rhone-Alpes for Scenario S1 in 2025

	Maximum Waste Heat Dischargeable into Rhone River (Gigawatts)	Percentage of Nuclear Capacity Using Once-Through Cooling[b]	Water Evaporated Artificially (m^3/sec)[c]
Low control ($\Delta T \leqslant 5°C$)[a]	21	41	15
High control ($\Delta T \leqslant 3°C$)[a]	14	27	18

[a] ΔT is used here instead of a maximum permissible temperature T_{max} of the Rhone River because the limitation by a maximum permissible temperature is not very reasonable. With hybrid cooling the water temperature could be close to T_{max} throughout the year, which would affect the aquatic flora and fauna that are adapted to an annual temperature cycle.
[b] The remaining capacity uses cooling towers.
[c] From cooling towers and heated surfaces of water bodies. The average flow of the Rhone is about 1,100 m^3/sec in the south of Lyon (recorded minimum: 200 m^3/sec; average yearly minimum: 700 m^3/sec) and 500 m^3/sec in the north.

days per year. Nevertheless, it is clear that the average temperature increase below each nuclear site is higher, since the above figures account for some dilution of the waste heat in the river.

The limitation on the temperature increase of the Rhone River requires the utilization of closed-cycle cooling systems. In this study only wet cooling towers were considered. The cooling of a light water reactor of 1,000 MWe requires a tower approximately 150 m high with a diameter between 120 and 140 m in the case of natural draft systems.[10] According to the level of control of thermal discharges (high or low; see Table 5.15), the number of such towers would be between 28 and 34 in 2025, corresponding to an average of 3 towers on each site (considering a 5,000 MWe site). In the case of 10,000 MWe about 6 or 7 such towers would be needed on each site. In the case of mechanical draft systems, the towers are smaller, but each 1,200 MWe reactor requires 2 towers 30 to 50 meters high.[11]

Each light water reactor cooled with a wet cooling tower causes an evaporation of approximately 0.8 m^3/sec.* Some water containing salt and chemicals is discharged into the river (blow-down water discharge of about 0.8 m^3/sec). Because of the heat discharged into the atmosphere (1.7×10^{12} cal/h/tower), these cooling towers may induce climatic perturbations (artificial rain, modification of the local insolation, or increase of foggy days). These impacts were not quantified because of the very site-specific nature of the impacts and the detailed analysis required for their quantification.

Table 5.16 shows the amount of water evaporated by cooling towers at typical sites. Once-through cooling causes about 25 percent less evaporation than natural draft wet cooling towers.

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* Average of U.S.[8,9] and French[7] data for a 1,000 MWe reactor. For comparison, the average annual volume of water flowing in the Rhone at Bugey is 10^9 m^3/yr.

TABLE 5.16 Water Evaporated by Cooling Towers at Typical Nuclear Sites

Site Type	Capacity Cooled with Wet Cooling Tower	Water Evaporated by Cooling Towers m^3/sec^a	Water Evaporated by Cooling Towers 10^6 m^3/yr
5,000 MWe	Low control 3,000 MWe	2.4	45
	High control 4,000 MWe	3.2	60
10,000 MWe	Low control 6,000 MWe	4.8	91
	High control 7,000 MWe	5.6	106

[a] The assumption was made that the reactors operate at full power and that 0.8 m^3/sec evaporates per 1,000 MWe reactor.

Right-of-Way for Transmission Lines For each 5,000 MWe site, a corridor 200 m wide would be necessary to "evacuate" the electricity generated.[10] If the average capacity at a site were 10,000 MWe, the width of the transmission corridors would be 500 m representing a very intensive network of wires and pylons. (The total corridor is actually divided into 4 or 5 smaller corridors.)

Land Use The land used for reactor sites in the Base Case is 55 km^2 in 2000 and 150 km^2 in 2025. It was assumed that each 1,000 MWe reactor uses about 3 km^2, regardless of the number of reactors on a site.[9,10] A large part of Rhone-Alpes is covered by the Alps, a part of the Jura, and the Massif Central, so the land used for reactors is not insignificant. Nuclear sites in 2025 will occupy approximately one quarter of the area in Rhone-Alpes on which buildings are standing in 1970. Part of this land for reactor sites is a long-term commitment, since it will be set aside when the reactors are no longer in service. From 5.3 to 7.3 km^2 in Rhone-Alpes, 50 to 70 km^2 at the national level, will be set aside for retired reactors and will be occupied for a very long time.

Table 5.17 indicates the annual and cumulative land use in 2025 for uranium mining and radioactive waste storage. The land disturbed for the nuclear fuel supply of all power plants from 1970 to 2025 is about 40 percent of the land occupied by the power plants themselves. There is no uranium in Rhone-Alpes, so the mining is outside the region and probably outside of France. At the national level, about 25 km^2 will be used for radioactive waste and, like the land used for retired reactors, it will not be available for other uses for a long time.

Annual Radioactive Shipments from Power Plants to Reprocessing Plants The only reprocessing plant in France is located on Cape La Hague, about 1,000 km from the Rhone-Alpes plants. It seems difficult, from both technical and environmental considerations, to locate another reprocessing plant near Rhone-Alpes, or even in another part of France. It has therefore been assumed that all additional reprocessing plants would be located near the existing one. Calculations based on the Impact Model,[9,10] show that 50 percent of the radioactive shipments would be by train at a

TABLE 5.17 Land Associated with Nuclear Energy Use in Rhone-Alpes for Scenario S1

	2025	Cumulative Requirements 1970–2025
Surface mining (km^2)[a]	1.5	35
Radioactive waste storage (km^2)[b]	0.1	2.5
Retired reactors (km^2)[c]		
18 Reactors (25-yr lifetime)	7.3	
13 Reactors (30-yr lifetime)	5.3	

NOTE: Figures are based on the Environmental Impact Model.[9,10]

[a] Assumes 100% of uranium from surface mining, with an ore grade of 0.2%. Mining of very low-grade ores would increase the total land disturbed. No reclamation has been assumed.

[b] All types of wastes: low level (such as packaging) through high level.

[c] Assumes 0.4 km^2/reactor.

TABLE 5.18 Impacts Associated with Electricity Generated by Nuclear Plants in 2025 for Scenario S1

	65% Surface Mining	100% Surface Mining
Accidents (PDL)[a]	13,000	5,500
Health (PDL)	2,500	

[a] 1 PDL ≡ one person-day lost (6,000 PDL are equivalent to 1 death).

rate of 3.0 tons of fuel per shipment, and fifty percent would be by truck at 0.5 tons of fuel per shipment. The number of shipments in 2000 and 2025 would be 471 and 1,250.

Health Impacts from Uranium Mining These impacts depend heavily on how much of the mining is underground and how much is on the surface. The impacts from uranium mining associated with electricity are listed in Table 5.18. The cumulative quantified impacts of the nuclear energy program from 1970 to 2025 show that 1,600,000 person days would be lost if 65 percent of the uranium mining were done on the surface. If all the uranium mining were done on the surface, 15 percent fewer person days, 1,350,000, would be lost. Approximately 75 percent of these PDL are occupational impacts and the remaining 25 percent are public impacts.

Selected quantified impacts, including those caused by sources other than nuclear energy, are listed in the scenario comparison section that follows. But since the consumption of conventional fuel is small, a significant share of these impacts has to be associated with nuclear energy.

V. OTHER SCENARIOS

The major socioeconomic assumptions for the three scenarios have already been mentioned (see Tables 5.1 to 5.6). Therefore only the technological assumptions will be described here, usually in relation to the Base Case.

TABLE 5.19 Reduction in Intensiveness for Nonelectric Industrial Energy Use in Scenario S3 (%)

	1970–1985	1985–2000	2000–2025
Heating	35	15	0
Furnaces	15	10	0
Steam	25	20	0

TABLE 5.20 Fuels used for Space Heating and Cooling in the Rhone-Alpes Service Sector

	Percentage of Total Floor Area Heated								
	1985			2000			2025		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Electricity	35	15	15	50	10	12	80	5	10
Gas	20	30	35	15	40	45	10	45	60
Oil	40	50	40	30	45	25	5	30	10
District heating	5	5	10	5	5	18	5	20	20
Percentage of floor area cooled	5	5	5	20	20	10	50	50	25

NOTE: In S3, solar substitutes in part for each heating fuel.

V.A. TECHNOLOGICAL ASSUMPTIONS

V.A.1. Industrial Sector

The penetration of electricity into the industrial sector is the same for S2 and S3: 5 percent in 1985, 15 percent in 2000, 30 percent in 2025. The reduction of energy intensiveness for nonelectric use in S2 is slightly lower than in S1. For S3 see Table 5.19.

V.A.2. Service Sector

Energy use per employee in the service sector is slightly higher for S2 than for S1. For S3 it is assumed that the energy efficiency for space heating or hot water heating could be improved by the addition of solar collectors with a resultant dramatic decrease in end-use energy of 30 percent between 1972 and 1985, 45 percent between 1985 and 2000, and 30 percent thereafter. For the fuels used in space heating and cooling, see Table 5.20.

V.A.3. Residential Sector

Space heating uses the same amount of energy for all the scenarios. The current insulation standards are already very stringent and cannot be increased significantly because the marginal cost of investment to improve insulation is very high compared

TABLE 5.21 Energy Sources Assumed for Space Heating in Housing Constructed After 1975 in Rhone-Alpes

	1975–1985				1985–2000			
	Single Houses		Apartments		Single Houses		Apartments	
	S2	S3	S2	S3	S2	S3	S2	S3
Electricity	5%	5%	5%		15%	5%	15%	
Gas			40%	35%			35%	15%
Oil	95%	90%	50%	35%	80%	65%	30%	15%
Oil district heat			5%	22%			15%	25%
Geothermal heat[a]				8%			5%	15%
Solar energy		5%			5%	30%		30%

	2000–2010				2010–2025			
	Single Houses		Apartments		Single Houses		Apartments	
	S2	S3	S2	S3	S2	S3	S2	S3
Electricity	30%		20%		30%		20%	
Gas			20%				20%	
Oil	55%	25%	10%		45%	25%	10%	
Oil district heat			35%	10%			30%	
Geothermal heat[a]			15%	30%			20%	30%
Solar energy	15%	75%		60%	25%	75%		70%

NOTE: Percentage of single houses: S2 – 80%, S3 – 20%.

[a] In S3 it has been estimated that about 30% of the new flats built between 1975 and 1985 would be located above geothermal fields, 30% in the period between 1985 and 2000, and 60% thereafter.

with the marginal fuel savings. For the energy sources for space heating, see Table 5.21.

The assumptions about hot water heating for S2 are the same as for S1. For S3, there is a small increase in consumption over that of 1970.

V.A.4. Transportation Sector

Freight Transportation Freight transportation in S2 is the same as in S1. In S3 there is a shift from trucks (53 percent of the traffic in 1970) to railways (37 percent) and barges (10 percent). It has been assumed that the truck traffic will stay constant after 1985, resulting in an increase of the percentage of freight carried by train to 60 percent in 2000 and 65 percent in 2025, and a corresponding decrease in the percentage for trucks to 30 percent and 25 percent. Moreover, a 20 percent increase in the energy efficiency of trucks has been assumed. Consumption of motor fuel drops from 710 kcal/ton, which is the S1 average, to 600 kcal/ton.

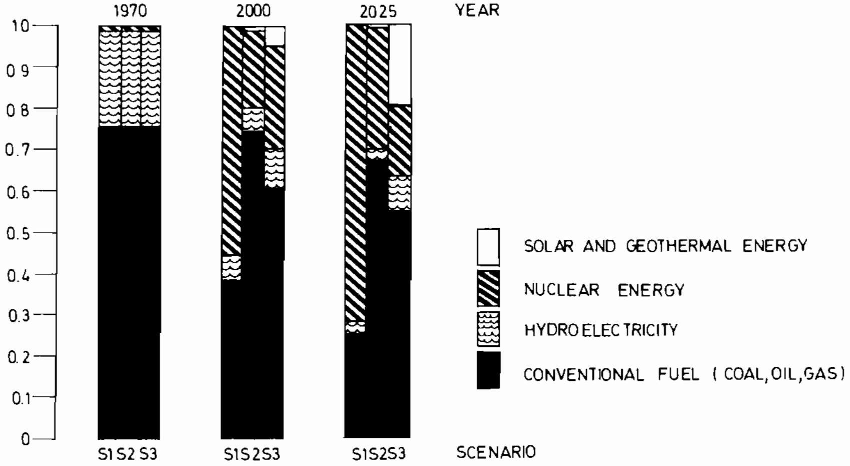

FIGURE 5.8 Primary energy use: the fraction of different energy sources used for the three Rhone-Alpes scenarios.

Passenger Transportation For S2 and S3 the effects of the changing urban pattern on the transport demand per capita were based on American studies (see the assumptions made for Wisconsin in Chapter 6, section III.C.6.). In addition, an increase in the efficiency of cars and a shift to mass transit systems have been assumed for S3.

V.A.5. Energy Supply Sector

For electricity generation, in S2 there will be a mix of oil, coal, and nuclear energy. For S3 there will be an increase of the hydroelectric capacity. There will be no construction of new nuclear plants, but the plants already built or under construction will be used. Solar electricity plants will be developed after 1990 and will provide 1 gigawatt electric (GWe) peak power in 2000. In 2025 they will provide 13 GWe peak power or 4 GWe average power (the power produced if the plant were running all year) and generate 35×10^9 kWh per year. A mix of oil and coal will supply the rest of the demand.

V.B. ENERGY SUPPLY AND END-USE ENERGY CONSUMPTION

V.B.1. Primary Energy

The change over time of the distribution of primary energy consumption by energy source in the three scenarios is displayed in Figure 5.8. In Scenario S1, the penetration of nuclear energy is clearly the highest and seems the maximum feasible because of requirements for conventional fuels for cars and trucks and in some industrial processes. Even with very favorable assumptions about the rate of development

TABLE 5.22 Primary Energy Consumption in Rhone-Alpes for the Three Scenarios (10^{15} cal/yr)[a]

	Coal	Gas	Oil	Hydroelectricity	Nuclear Energy	Geothermal Energy	Solar Energy	Total
2000								
S1	14 (11)	29	130 (11)	25 (25 TWh)[b]	252 (95 TWh)			450
S2	47 (44)	38	215 (44)	25 (25 TWh)	80 (30 TWh)			405
S3	29 (26)	38	135 (26)	35 (35 TWh)	80 (30 TWh)	4	14 (3 TWh + 7 × 10^{15} cal)	339
2025								
S1	25 (22)	44	159 (22)	25 (25 TWh)	645 (255 TWh)	1.5	0.5	900
S2	113 (110)	73.5	375 (110)	25 (25 TWh)	265 (100 TWh)	1.5	2	855
S3	68 (65)	100 (55)	149 (65)	35 (35 TWh)	80 (30 TWh)	7.0	83 (35 TWh + 11 × 10^{15} cal)	522

[a] For coal and oil, the numbers in parentheses represent the quantity of fuel used for electricity generation.
[b] TWh ≡ terawatt hour.

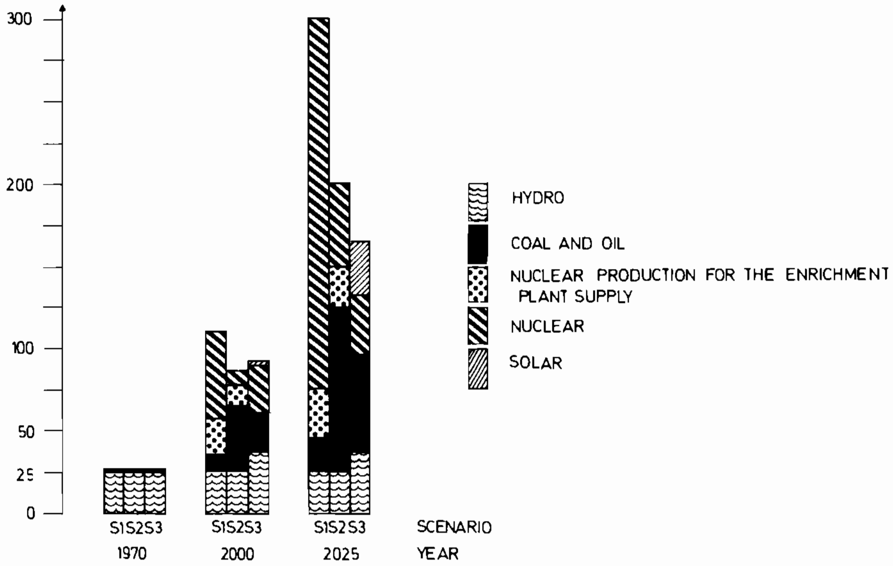

FIGURE 5.9 Fuel mix for electricity generation for the three Rhone-Alpes scenarios.

of new energy sources (solar and geothermal energy), their contribution to the total primary energy is rather limited – no more than 20 percent after a 50-year period. For Scenario S2, the important conventional fuel requirements will have to be supplied with imports. Table 5.22 indicates primary energy consumption by energy source and scenario. In 2025, the total primary energy consumption is almost twice as high in the highest cases (S1 and S2) as in the lowest case (S3). Energy consumption is very sensitive to policy option. The fuel mix for electricity generation in the three scenarios is displayed in Figure 5.9.

V.B.2. End-Use Energy

The change over time of the total end-use energy per capita is displayed in Figure 5.10. Scenario S2 has the highest final consumption, which is consistent with the assumptions made for this scenario (more single housing units, urban patterns requiring more transportation, high energy intensiveness). In S3, despite the drastic energy conservation policy there is still growth of end-use energy per capita mainly because of the energy requirements of the industrial and service sectors.

The energy use per capita in the residential sector is graphed in Figure 5.11. The decrease of the final energy consumption in S3 is a result of the increase in the housing stock of the percentage of apartments, whose energy requirements are lower than single houses. In addition, electric and district heating are used, which are very

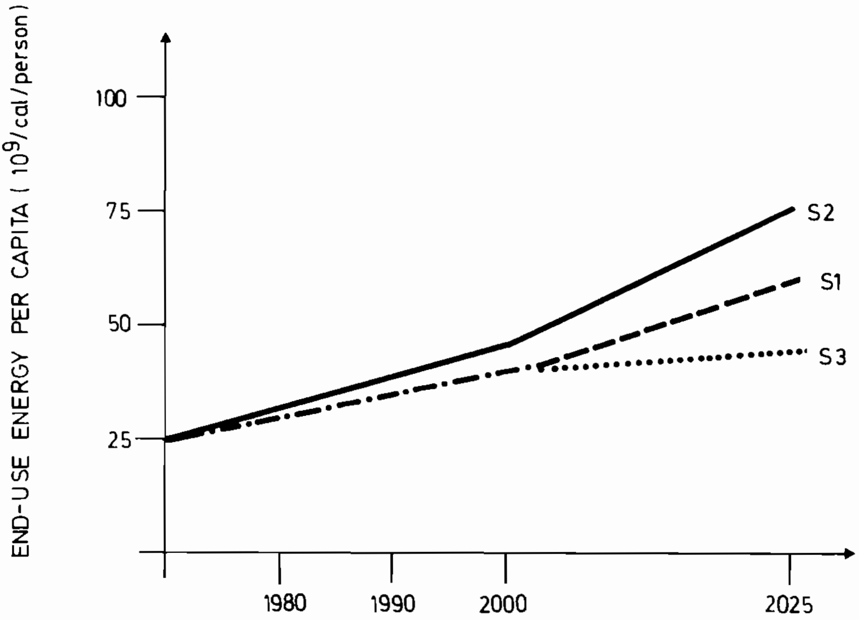

FIGURE 5.10 Total end-use energy per capita for the three Rhone-Alpes scenarios.

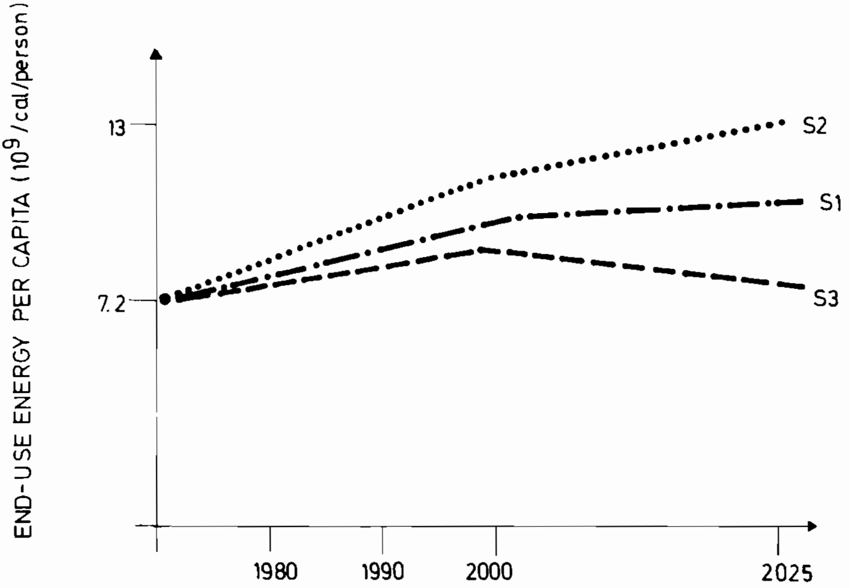

FIGURE 5.11 End-use energy use per capita in the residential sector for the three Rhone-Alpes scenarios.

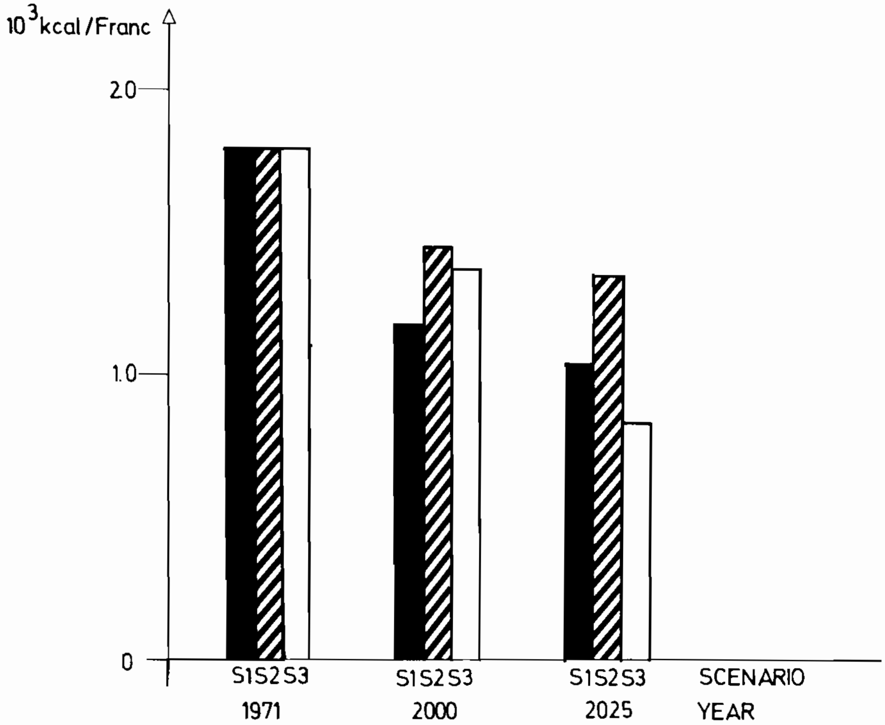

FIGURE 5.12 Energy intensiveness in the industrial sector for the three Rhone-Alpes scenarios.

efficient. The values plotted in Figure 5.11 correspond to the end-use process, for which electric and district heating are 100 percent efficient. A corresponding curve for primary energy per capita would be different because of energy losses before end use.

Energy intensiveness in the industrial sector is displayed in Figure 5.12, personal transportation energy use per capita in Figure 5.13, and energy use in freight transportation in Figure 5.14. No comments are necessary since these figures illustrate clearly the assumptions underlying the scenarios.

V.B.3. Environmental Impacts

Three impacts have been selected to characterize the environmental consequences associated with each scenario. The quantification of these impacts was achieved by means of the impact model described in Chapter 3, section IV.D.5. Other impacts could be presented, but, in order to simplify the presentation of the results, we restricted the scenario comparison to

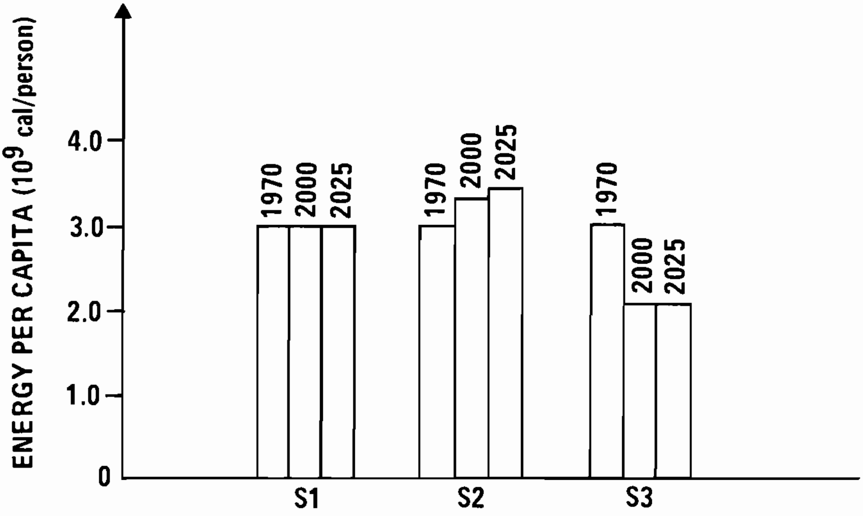

FIGURE 5.13 Personal transportation energy use per capita for the three Rhone-Alpes scenarios.

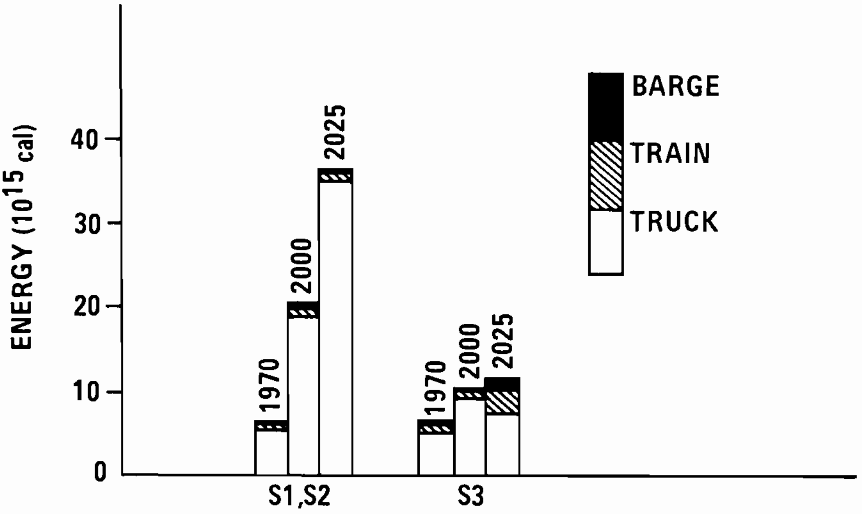

FIGURE 5.14 Energy use by freight transportation for the three Rhone-Alpes scenarios.

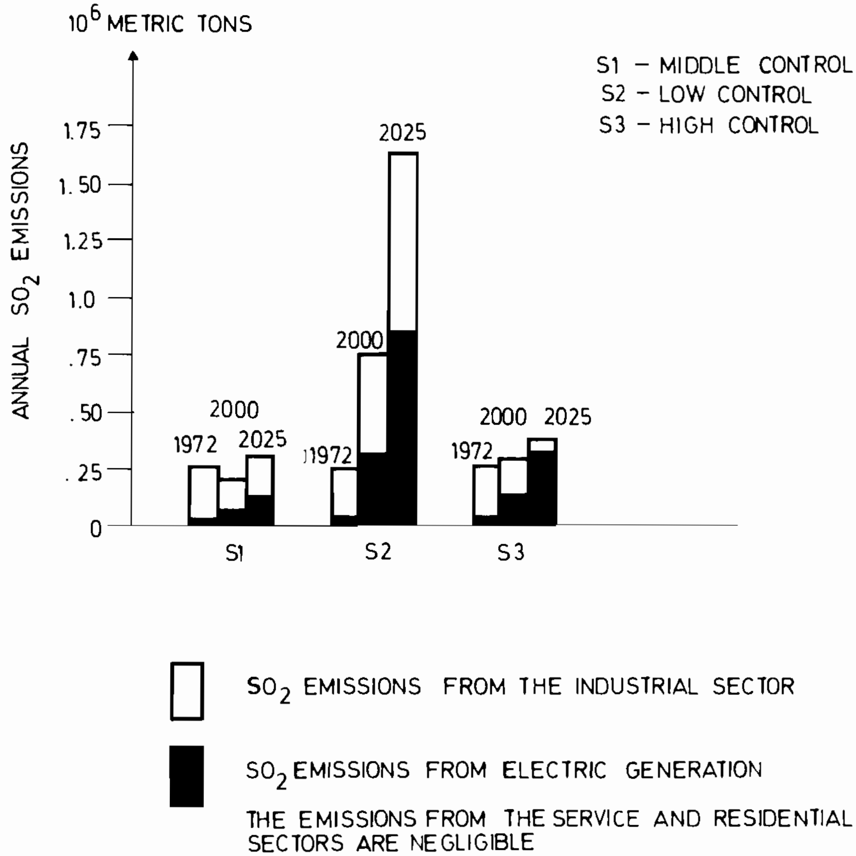

FIGURE 5.15 Comparison of the total SO_2 emissions for the three Rhone-Alpes scenarios.

- SO_2 emissions (Figure 5.15)
- Total person-days lost (Figure 5.16) as an aggregated measure of the total unquantified impact on human health
- Land use for energy generation (Table 5.23)

Table 5.24 summarizes all the quantified impacts.

If we only consider the first two impacts, the second scenario, which assumes a low level of nuclear energy development and a continuation of the use of conventional fuel, has the highest environmental impact. In the case of Scenario S1, in which there is a rapid development of nuclear energy, the total PDL in 2025 is about 215,000. This is roughly equivalent to 36 fatalities, if all PDL were from fatalities, and might appear to be too small an estimate to individuals opposed to

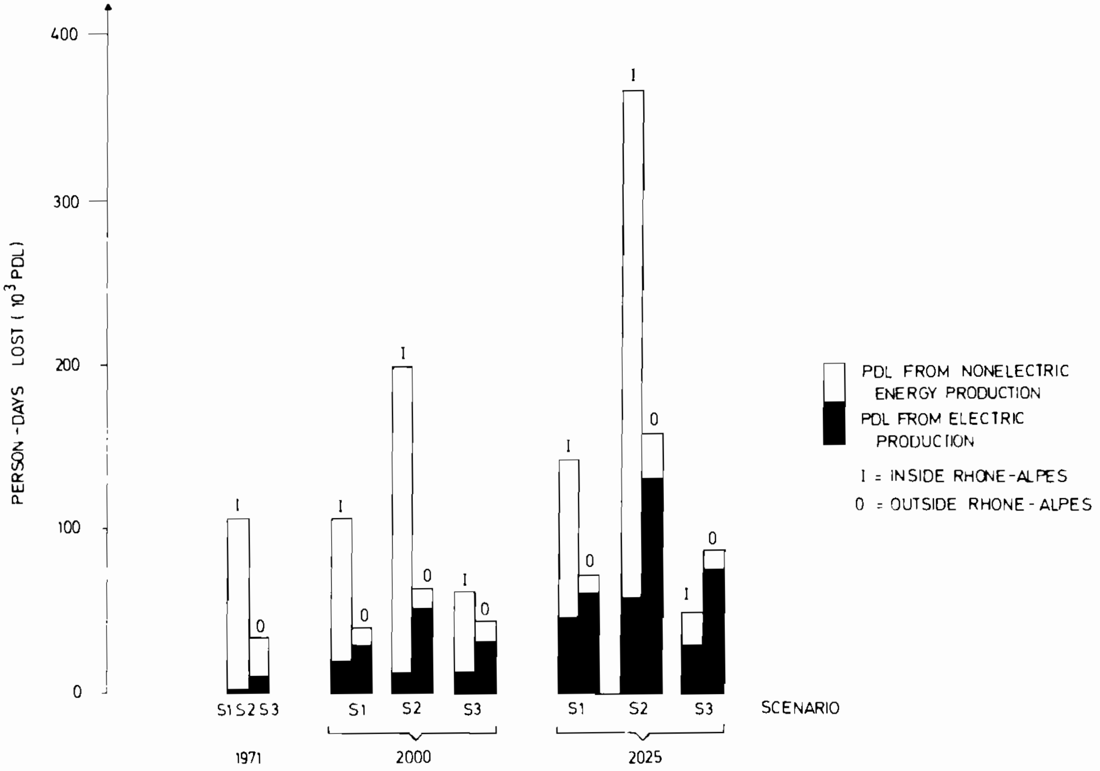

FIGURE 5.16 Total quantified person-days lost (PDL) for the three Rhone-Alpes scenarios. (Note: Air pollution health impact from nonelectric energy use is calculated using a different SO_2 removal policy in each of the scenarios.)

TABLE 5.23 Annual and Cumulative Land Use Associated with Energy Production in Rhone-Alpes

	Facilities (km^2)	Resource Extraction (km^2)[a]		Total (km^2)	
S1	2025	2025	1970–2025	2025	1970–2025
Electricity (nuclear energy)	154.0	1.5	49.0	155.6	203.0
Electricity (coal)	3.2	3.0	79.0	6.2	82.0
Electricity (oil)	2.9	0.5	0.5	3.4	3.4
Nonelectrical energy	2.8	4.0	4.0	6.8	6.8
Total	162.9	9.0	132.5	172.0	295.0
S2					
Electricity (nuclear energy)	60.0	0.8	21.0	60.8	81.0
Electricity (coal)	16.0	15.4	352.0	31.4	368.0
Electricity (oil)	14.0	2.7	2.7	16.7	16.7
Nonelectrical energy	5.0	7.1	7.1	12.1	12.1
Total	95.0	26.0	382.8	121.0	477.8
S3					
Electricity (nuclear energy)	18.0	0.3	12.0	18.3	30.0
Electricity (coal)	10.0	10.0	205.0	20.0	215.0
Electricity (solar)	200.0			200.0	200.0
Electricity (oil)	9.0	2.0	2.0	11.0	11.0
Nonelectrical energy	2.0	2.0	2.0	4.0	4.0
Total	239.0	14.3	221.0	253.3	460.0

SOURCE: Buehring,[9] and Buehring and Foell.[10]

[a] Surface uranium mining and surface coal mining exclusively; extraction occurs both inside and outside the region; no reclamation.

nuclear energy who emphasize its unlikely but dangerous risks. Not all impacts have been quantified in terms of human health because of lack of information about some of them, and above all because there is divergent opinion among experts about others. The nuclear health impact calculations utilize the Rasmussen report[11] for reactor accidents and the linear dose–response relationships used by the U.S. National Academy of Sciences for routine exposures.[12]

S2 has a very high health impact because of SO_2 emissions. It was not based on stringent environmental conservation policies. SO_2 emissions for S2 in 2025 are about 1.7×10^6 tons, which is more than 60 percent of emissions for France in 1970. SO_2 emission at the national level in 1970 was 2.9×10^6 tons, of which the Rhone-Alpes region contributed 8 percent.[15] In 1970 in France, electricity generation was only responsible for 20 percent of the total emission. In Scenario S2 in 2025, the percentage of emission from electricity generation is almost half the total emission from Rhone-Alpes. In all of France, this scenario would produce a total SO_2 emission of about 20×10^6 tons in 2025 – a factor of 8 larger than the current emission levels.

Because of the large land requirements for solar electricity generation, S3 uses the most land of all the scenarios. Land use for S3 is 50 percent higher than for S1 in

TABLE 5.24 Scenario Comparison of Selected Quantified Environmental Impacts

		2025		
	1970	S1	S2	S3
Inside Rhone-Alpes				
Health impacts				
Total fatalities		6	6	2
Occupational accidents (PDL)[a]	1,100	13,000	9,500	7,200
Accidents affecting the public (PDL)		1,300	4,600	2,800
Occupational health (PDL)		24,000	9,300	2,800
Public health	100,000	100,000	340,000	43,000
Land use (km^2)				
Facilities land use	1	150	87	240
Long-term commitment	0	0.7	0.3	0.1
Air pollution				
SO_2 Emissions (10^6 metric tons)	0.25	0.30	1.7	0.35
CO_2 Emissions (10^6 metric tons)	26.0	57.0	130.0	88.0
Outside Rhone-Alpes				
Health Impacts				
Total fatalities	4.6	9	17	9
Accidents and health impacts (PDL)	33,000	74,000	150,000	88,000
Land use				
Resources extractions and related facilities (km^2)	5	19	34	16
Total				
Fatalities	5	15	23	11
Health (PDL)	140,000	210,000	510,000	140,000
Land (km^2)	6	170	120	250

NOTE: Impacts due to electricity generation and end-use energy consumption are calculated from the Impact Model.[9,10] All figures are rounded.

[a] PDL ≡ person-days lost.

2025. For comparison with the land use figures in Table 5.24, see the comments on land use in the Base Case in section IV.C.2.

With regard to cumulative land use from 1970 to 2025, S1 requires much less land than S3. But if we change Scenario S3 so that the coal used to produce electricity is replaced by gas or oil, for example, than S3 requires only 250 km^2. S1 requires 295 km^2. In the nuclear energy scenario, however, about 70 percent of the land is disturbed outside the region, whereas the solar energy scenario uses a huge area within the region. Moreover, some of the land disturbed for uranium mining can be reclaimed.

All these comments show that the land use for each scenario depends on a great number of factors and that in each case the assumptions underlying the figures for land use should be carefully considered.

VI. SENSITIVITY STUDIES

Two variants of the Base Case have been selected to show the influence of changes in the energy supply on the environmental impacts.

$S1_L$: Little development of fast breeder reactors. In the Base Case, 40 percent of the electrical capacity in 2025 is from fast breeder reactors. In this sensitivity study, only 10 percent is from fast breeder reactors in order to show the difference between light water reactors and fast breeder reactors from an environmental standpoint.

$S1_H$: Development of hybrid reactors producing electricity, and hot water or steam. Since hybrid reactors have little waste heat and high efficiency, fewer hybrid reactors than fast breeder reactors would be required to supply energy demands. Hybrid reactors can supply heat either by way of the electricity they produce or by way of district heat. This analysis shows the sensitivity of selected environmental impacts to district heating from nuclear energy as compared with heating with electricity from nuclear energy. The analysis does not take into account the economic feasibility of the hybrid reactors.

The assumptions made about the technical characteristics of the hybrid reactor, as well as about the integration of these reactors into the total energy supply system (number of housing units that can be supplied, storage requirements, and so forth) are based on the preliminary research of B. Bourgeois and B. Chateau.[13] The potential market for district heating from nuclear energy was roughly calculated from the investigations carried out for Scenarios S2 and S3. It was assumed that 30 percent of the industrial and residential heat demand could be supplied by nuclear district heat and that 40 percent of the floor area in the service sector could be heated by nuclear district heat. The total consumption of nuclear district heat would then be 90×10^{15} cal.

In summary, the energy supply of Rhone-Alpes in this sensitivity study has:

- An electricity production of 190×10^9 kWh instead of 225×10^9 kWh as in S1
- Fifteen hybrid reactors producing 90×10^{15} cal and 70×10^9 kWh. The study by Bourgeois and Chateau[13] refers to a standard 900 MWe reactor where 20 percent of the heat produced is withdrawn to supply district heat. The real electric capacity is then 720 MWe. Each hybrid power plant could supply the needs of about 340,000 housing units.
- A 20 percent reduction of oil consumption by industry. Some of the oil used for steam generation is replaced by nuclear heat.
- A total nuclear capacity of 39,500 MWe, of which 10 percent is supplied by breeder reactors

Table 5.25 shows selected impacts for S1 and its two variants. With regard to $S1_L$, the reduction in the penetration of the liquid metal fast breeder reactor (LMFBR) and the corresponding increase in the pressurized water reactor (PWR) capacity, with everything else held constant, does not really affect the quantified

TABLE 5.25 Comparison of Environmental Impacts for Three Nuclear Development Variants in 2025.

	S1 – 2025[a]	$S1_H$ – 2025[b]	$S1_L$ – 2025[c]
Impacts from nuclear power			
Annual global health impact[d]			
Person-rem to public	12,000	11,900	14,600
Expected excess cancer deaths	2.2	2.1	2.6
Expected excess genetic effects	1.8	1.8	2.2
Total annual public fatalities (health and accident)	3.2	2.9	3.6
Uranium miners (annual impact)			
Accidental fatalities	1.7	2.1	0.6
Excess cancers	0.4	0.5	0.6
Total annual occupational fatalities (Health and Accident)	7.9	7.4	9.1
Total quantified person-days lost (annual)	75,100	70,000	86,100
Thermal discharge			
Annual heat discharge to condenser water (10^{12} kWht)	0.49	0.40	0.53
Annual water evaporated (10^6 m^3)	564	457	614
Annual land use for mining and milling of uranium (km^2)	1.0	1.2	1.5
Annual radioactive shipments	6,700	4,820	5,920
Shipments of plutonium and high level waste	152	52	64
Radioactive cesium released as liquid waste at reactors[e] (Ci/yr)	11.4	14.1	17.3
Electricity needed for gaseous diffusion to supply fuel for PWR[f] (10^9 kWh/yr)	6.9	8.5	10.4
Nonelectric impacts			
Health impacts (PDL)	87,500	67,500	87,500

NOTE: Figures are based on the Impact Model.[9,10]

[a] S1: Development of fast breeders (40% of the total electric capacity).

[b] $S1_H$: Development of nuclear district heating.

[c] $S1_L$: Low penetration of fast breeders (10% of the total electric capacity).

[d] Only global doses from complete release of ^{85}Kr and ^{3}H at reprocessing are included.

[e] Radioactive strontium releases are much lower than cesium.

[f] Pu produced at pressurized water reactors (PWRs) is not taken into account.

health and safety impacts. There is a slight increase of the total person-days lost from 75,000 to 86,000 mainly because of public exposure to radioactivity and because of uranium mining. The total quantity of water evaporated increases by less than 10 percent. However the annual land use for uranium mining is 50 percent higher than in S1 and the annual quantity of radioactive cesium released by the reactors is more than 50 percent higher. The limitation on the development of breeder reactors yields a 60 percent decrease in the annual shipments of plutonium and highly radioactive waste.

All the conclusions about the differences between the environmental consequences of S1 and $S1_L$ are uncertain and above all subjective. Some impacts of $S1_L$ may be less severe than those of S1, but others may be more severe and more important, and outweigh those that were less severe.

In relation to S1, $S1_H$ leads to a

- 20 percent decrease in the total health impacts (from nuclear and nonelectric use)
- 25 percent decrease in the annual quantity of water evaporated, and of the total waste heat rejected, which means fewer climatic impacts and less water drawn from the regional resources
- 20 percent decrease in the land disturbed by uranium mining
- 20 percent decrease in the annual radioactive shipments
- 20 percent reduction of the radioactive cesium released as a liquid waste

These sensitivity studies show that the environmental impacts of the hybrid reactors are less severe than those of the fast breeder reactor. Even if it is more economical to heat with electricity produced from nuclear reactors than to heat with nuclear district heat, the low social cost of nuclear district heating must also be taken into account.

VII. CONCLUSIONS

The following comments and observations do not apply just to Rhone-Alpes. Rather, they are more characteristic of the energy strategies than of the region.

VII.A. ENERGY DEMAND

Each of the alternative futures has a different level of energy use. For a given growth rate of the GNP, the level of energy demand will depend on the nature of the economic growth.* Therefore, since the energy consumption of a region does not have a linear relationship with GNP or any other macroeconomic indicator, forecasts of energy consumption should be based on detailed investigations of the technological and societal changes and the main political options (human settlement policy, transportation policy, industrial policy, and so on.

VII.B DEPENDENCE ON OIL

Most countries are trying to develop nuclear energy as fast as possible to reduce their dependence on oil, and France is one of the countries trying the hardest. But

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* Energy Policy Project of the Ford Foundation, *A Time to Choose: America's Energy Future* (Cambridge, Massachusetts: Ballinger, 1974).

Scenario S1, the nuclear energy scenario, shows that dependence on oil cannot be reduced significantly or as fast as might be expected. The rate of penetration of electricity from nuclear plants is constrained by the time needed for installation of electrical end-use equipment and by the rate of increase in demand for electrical end-use energy. At the upper limit, only about 50 to 60 percent of end-use energy demand is for electricity. Electricity cannot yet be economically used in place of motor fuels, in steam production, or in some large capacity kilns, for example. Obviously, technological innovations may raise the limit on electrical end-use energy. A drastic reduction of oil consumption through the development of nuclear energy can only be achieved by using nuclear energy to produce other sources of energy such as hydrogen, hot water, or steam.

VII.C. RATE OF DEVELOPMENT OF NEW ENERGY SOURCES

For similar reasons, though on a different scale, the rate of penetration of solar and geothermal energy is very slow. In Scenario S3, which has very favorable assumptions about the development of these two energy sources, their contribution to the total end-use energy is not more than 20 percent after a 50-year period.

VII.D. ENVIRONMENTAL IMPACTS

Based on the judgment of the IIASA team, the most significant environmental impacts have been selected. But it is certain that some impacts have been neglected or that too much emphasis has been placed on others. Unlike the description and interpretation of energy patterns, the evaluation of environmental impacts is very controversial. We will try to summarize the important results for four major impacts considered in this study: waste heat, land use, SO_2 emissions, and human health impacts.

VII.D.1. Waste Heat

Whatever the cooling system, waste heat is discharged into the environment: into a water source if once-through cooling is used, or into the air with cooling towers. In the nuclear energy scenario, S1, light water reactors discharge 66 percent of their primary energy as waste heat, and liquid metal fast breeder reactors discharge 60 percent of their primary energy as waste heat. In Scenario S1, the high amount of electricity produced leads to a lot of waste heat. In the other scenarios the thermal wastes are low compared with their level in S1.

The utilization of once-through cooling is limited by the acceptable temperature increase of the water source. In the case of the Rhone River, two levels of control were considered, one allowing a maximum temperature increase of 5°C (a maximum of 40 percent of the nuclear capacity could use once-through cooling) and the other allowing a temperature increase of only 3°C (less than 30 percent of the nuclear capacity could use once-through cooling). In the case of the less restrictive control policy, the temperature of the Rhone River in the southern part of the region would be artificially increased by 4°C for approximately 140 days per year, and by 5°C for 50 to 60 days. If the remainder of the capacity uses wet cooling towers, there will be two major environmental impacts: 28 to 34 towers each 150 m high with a diameter between 120 and 140 m, and an estimated artificial evaporation between 0.5 and $0.6 \times 10^9\ m^3/yr$. The evaporation might create local climatic perturbations and cause a loss of water from the Rhone, an important water source.

VII.D.2. Land Use

It is beyond all question that solar electricity generation requires a lot of land. If we compare, for instance, the "nuclear scenario" (S1) and the "solar scenario" (S3), the land occupied by energy facilities is 1.5 times higher for S3 than for S1 (239 km^2 for S3 compared with 163 km^2 for S1).

The land use for resource extraction, e.g. coal mining, occurs outside the region and cannot be compared with land use for facilities. The consumption of coal requires a lot of land especially if the coal comes from surface mines.

In the case of S1, the high increase of electricity consumption requires the development of transmission networks and wide corridors for the transmission lines throughout the region. The aesthetic impact of the transmission networks may be greater than the land-use impact.

VII.D.3. SO_2 Emissions

The "conventional fuel scenario," S2, has high SO_2 emissions. With the current emission standards, this scenario would be unacceptable for most people because of the very high level of SO_2 emissions: eight times higher in 2025 than in 1970. The high level causes human health impacts which were quantified as far as possible, but also damage to flora and fauna which was not evaluated. In S1 and S3, SO_2 air pollution is almost negligible since the total emissions in 2025 are only slightly higher than in 1970 (see Table 5.24).

VII.D.4. Health Impacts

The health impacts have been quantified for the three scenarios and expressed in person-days lost for accidents and diseases and in number of deaths for fatalities. It should be noted that health impacts that are not recognized or recognized but unquantified were not included in the health impact estimates. Because of the large SO_2 emissions, S2 has the highest health impacts. The development of solar energy in Scenario S3 results in very few health impacts. However, it was assumed that more than 20 percent of the electricity in Scenario S3 is generated from coal, and the human health impacts from coal mining are high. If oil or gas were used instead of coal, the impacts would be lower.

The sensitivity studies on the Base Case show the difficulty of differentiating from an environmental standpoint between nuclear energy development with the liquid metal fast breeder reactor and nuclear energy development without it. They show that using waste heat from nuclear plants has less of an impact on the environment than simply discharging it into a body of water. The use of waste heat also reduces the amount of uranium needed.

A very interesting technique based on multiattribute decision analysis has been developed to deal with the complexity of judging environmental impacts and has already been applied in the case of Wisconsin.[14,16] The technique is summarized in Appendix E at the end of the book.

APPENDIX: ENERGY CONSUMPTION AND END-USE ENERGY TABLES FOR RHONE-ALPES

TABLE 5A.1 Energy Consumption in 1970 (10^{15} cal)

	Coal	Gas	Oil	Electricity	District Heating[a]	Total	Total Electricity (TWh)[b]
Industrial	5.6	5.0	29.0	13.5		53.1	15.7
Residential	4.1	2.3	23.8	2.2	1.0	33.4	2.6
Service	0.5	0.9	5.9	2.1	0.3	9.7	2.2
Transportation			20.0	0.4		20.4	0.5
Total	10.2	8.2	78.7	18.2	1.3	116.6	21.0

SOURCE: CEREN.[4]

[a] Estimate from national data.

[b] TWh ≡ terawatt hours.

TABLE 5A.2 End-Use Energy in Scenario S1 (10^{15} cal)

	Coal	Gas	Oil	Electricity	Oil District Heating	Geothermal	Solar	Total	Total Electricity (TWh)
2000									
Industrial	2.6	16.2	45.7	65.4				129.9	76.0
Residential		11.4	32.1	14.0	1.0			58.5	16.5
Service		1.0	2.1	5.6	0.5			9.2	6.5
Transportation			37.3	0.9				38.2	1.0
Total	2.6	28.6	117.2	85.9	1.5			235.8	100.0
2025									
Industrial	3.1	29.5	56.7	171.1				260.4	199
Residential		13.4	19.5	32.7	2.0	0.5	0.5	68.6	38
Service		0.6	0.3	9.5	1.0	0.5		11.9	11
Transportation			55.6	1.7				57.3	2.0
Total	3.1	43.5	132.1	215	3.0	1.0	0.5	398.2	250

TABLE 5A.3 End-Use Energy in Scenario S2 (10^{15} cal)

	Coal	Gas	Oil	Electricity	Oil District Heating	Geothermal	Solar	Total	Total Electricity (TWh)
2000									
Industrial	2.6	25.4	77.0	55.0				160.0	64.0
Residential		9.4	47.8	7.2	1.4	11.0	0.4	66.2	8.4
Service		3.0	3.5	3.5	0.5			10.5	4.1
Transportation			39.3	0.9				40.2	1.1
Total	2.6	37.8	167.6	66.6	1.9	11.0	0.4	276.9	77.6
2025									
Industrial	3.1	60.9	146.0	130.7				340.7	152.0
Residential		9.4	51.3	19.6	2.5	0.7	2.0	85.5	22.8
Service		3.1	2.9	6.3	1.2	0.4		13.9	7.3
Transportation			58.7	1.2				59.9	1.4
Total	3.1	73.4	258.9	157.8	3.7	1.1	2.0	500	183.5

TABLE 5A.4 End-Use Energy in Scenario S3 (10^{15} cal)

	Coal	Gas	Oil	Electricity	Oil District Heating	Geothermal	Solar	Total	Total Electricity (TWh)
2000									
Industrial	2.6	20.4	61.1	65.3				149.4	75.9
Residential		15.2	23.2	5.2	5.0	2.9	2.2	53.7	0.6
Service		2.5	1.5	2.1	0.5		4.6	11.2	2.4
Transportation			22.0	1.2				23.2	1.4
Total	2.6	38.1	107.8	73.8	5.5	2.9	6.8	237.5	85.7
2025									
Industrial	3.0	34.0	30.0	138.0				205.0	160.4
Residential		9.0	17.6	7.9	8.0	4.9	5.0	52.5	9.2
Service		2.0	1.0	3.5	1.0	0.6	5.6	13.7	4.1
Transportation			23.6	2.2				25.8	2.6
Total	3.0	45.0	72.2	151.6	9.0	5.5	10.6	297.0	176.3

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Prologue to Chapter 6
The Wisconsin Scenarios in Retrospect

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May 1978

Comparisons between the GDR, Rhone-Alpes, and Wisconsin suggest that Wisconsin has perhaps the farthest to go in improving its efficiency of energy use, strengthening its conservation policies, and reducing its rates of energy growth. Since the Wisconsin scenarios were written in 1975, some progress has been made in these areas; many ideas for energy-related reforms in Wisconsin have grown out of interactions with our colleagues in the GDR and Rhone-Alpes during the three-region study.

Energy use in Wisconsin has been marked by high growth during the 1960s and a leveling off in the 1970s. The growth experienced during the 1960s can be traced to several factors. First, the cost of end-use energy fell by 50 percent between 1960 and 1970. Second, the implementation of environmental protection measures began during the 1960s; improved pollution control required increases in energy use. Finally, in the early 1960s Wisconsin industries were characterized by a high level of energy intensiveness. All of these factors contributed to the dramatic growth in energy-use figures of the 1962–1970 period.

This exponential growth did not continue into the 1970s, however. The tradeoff between increased energy use and environmental protection did not result in continued high rates of growth in energy use. The mix of industries also shifted toward those that are less energy intensive. In fact, since the oil embargo of 1973–

At the second conference, Management of Regional Energy/Environment Systems, held at IIASA, 16–19 May 1978, retrospective presentations on the scenarios were given by energy specialists or policymakers from the three regions. To provide perspective on the scenarios, summaries of the presentations are included immediately before the chapters describing the scenarios for the regions (Chapters 4, 5, and 6). They will be published in full as part of the proceedings of the conference: W.K. Foell (ed.), Proceedings of the Conference on Management of Regional Energy/Environment Systems (Laxenburg, Austria: International Institute for Applied Systems Analysis, in press).

1974, there has been virtually no increase in energy consumption in Wisconsin. During some years there has been a modest 2–3 percent increase in electricity consumption, but this has been offset by decreases in natural gas use. This is a great change from the 7–10 percent annual increases in electricity consumption in the early 1970s. In light of these developments, the projections of continued exponential growth made in the Wisconsin Base Case scenario seem to be outdated. Actually, the State of Wisconsin has set itself the goal of reducing its energy use by 10 percent by 1985.

One way in which it is hoped that this goal will be achieved is through government regulations designed for energy conservation. In suggesting areas in which reforms were needed, Wisconsin's collaboration with the GDR and Rhone-Alpes brought us several tangible benefits. For instance, we learned from the French that our technique of pricing electricity was counterproductive. Not only did the French bring to our attention the diseconomy of charging customers less when they buy electricity in bulk, but they also suggested a better pricing mechanism. Following their example, Wisconsin is now adopting a system of marginal cost-pricing for electricity – i.e. the state is instituting a time-of-day variation in tariffs. At the present time, 40 percent of Wisconsin's electricity is sold during high demand hours on a time-of-day pricing system. Also, in a pioneering U.S. effort, it is planned to install residential "time-of-day" meters or load management systems in the city of Milwaukee within one or two years. The natural gas pricing system is beginning to be changed according to the same principle of marginal cost pricing that we learned from our French colleagues.

Our interactions with representatives from the GDR made us aware of the potential of district heating, and we have decided that district heating, as a concept, should be encouraged. We are requiring electric utilities to continue to sell steam to industrial users; new plants built to replace decommissioned plants are required as well by state regulations to sell steam to industries. Whenever any new coal-burning plant is built, all potential industrial users in the surrounding service area must be asked if they would like to purchase the plant's waste heat. Because of the controversy currently surrounding the nuclear question, no decision has been made yet about the use of waste heat from nuclear power plants.

The use of waste heat to increase the temperature of drinking water by about five degrees centigrade is also under consideration in Wisconsin. The water is very cold, so there may be no health problem from bacteria connected with this scheme. Early studies have indicated that use of waste heat in the drinking water system would reduce energy costs and bring tangible savings to residential customers in their bills for water-heating. Until now, heat pumps were not very practical in Wisconsin because of the coldness of the state's water. But if the temperature of the drinking water were to be increased, some engineers believe that efficient heat-pump systems would be feasible. The example the GDR gave us for the utilization of waste heat was a real impetus for better utilization of this energy source on our part.

It has been asked which features of the research results were surprising. No one in Wisconsin was surprised that so much of the state's energy consumption was related to transportation, in comparison with energy use patterns in the GDR and Rhone-Alpes. But it was surprising to see how much more energy Wisconsin was using for residential space heating, even after correcting for differences in degree-days, and excluding energy for air-conditioning purposes. A part of the higher use is due to the larger size of Wisconsin housing units – i.e. floor space per person. But as we learned from the other regions, a much more important factor is heat losses because of poor insulation. This realization convinced us that we ought to be changing the state's building codes. Wisconsin is now one of the few states in the United States that has a complete building code with measures for real enforcement. The Wisconsin Public Service Commission has also developed a set of pricing rules that will penalize people who do not improve insulation in existing housing. Again, the impetus for these changes came from our new awareness of practices in the other regions.

The interregional comparisons also provided us with new insights about energy savings in the transportation sector. We were convinced of the savings that could result if large cars were replaced with small cars, even if distances traveled remained constant. On the basis of our recommendations, the governor of Wisconsin proposed a set of taxes and subsidies that would have made the purchase of new cars vary by as much as $1,000, depending on size. (At the time, a typical car in Wisconsin cost about $4,000.) Because the State of Wisconsin is a major automobile manufacturer, these proposals were politically very risky – especially since most of the discounts would apply to European and Japanese cars and the taxes would be levied on American cars. As might be expected, the governor was not able to win legislative approval. Still, this serious attempt at policy change in the transportation sector resulted from ideas we gained through interaction with representatives from the other regions. As a footnote, it is interesting that even without the benefit of federal regulations and state taxes, people in Wisconsin are buying smaller cars and reducing the amount they drive.

There have been several other events of significance in the energy field in Wisconsin since 1975. State legislation has been passed to give tax credits to people who install solar energy systems. The Public Service Commission has also passed a special set of tariffs for the electric back-up systems needed for solar units. In industry, there has been a significant amount of energy conservation and conversion from natural gas spurred by the oil embargo of 1973 and the gas shortage of 1976. In the residential sector, voluntary conservation measures, such as lowering thermostats, are also being taken. The result of these activities has been the creation of a conservation bubble – i.e. Wisconsin now has excess energy supplies. However, this should not be understood to mean that we can return to "business as usual." Wisconsin is firmly committed to the goal of reducing energy consumption by 10 percent by 1985.

6 Alternative Energy/Environment Futures for Wisconsin

I. INTRODUCTION

I.A. ORGANIZATION AND OBJECTIVES

In this chapter the background, key assumptions, and typical results for three alternative energy/environment futures for Wisconsin are presented. A Base Case scenario is presented in some detail to provide a basis for comparison with assumptions and results of other scenarios. Before the presentation of the details of the scenarios starting in section II, a general overview of the initial conditions, data availability, and the character of the three scenarios is given in the next few pages. Following the scenario presentation in sections II and III, sensitivity studies related to critical parameters are discussed in section IV. Finally, some overall conclusions of the Wisconsin studies are presented in section V.

I.B. GENERAL CHARACTERISTICS AND INITIAL CONDITIONS

Chapter 2 presents an overview of demographic, geographic, and energy characteristics of Wisconsin; that information will not be repeated here. Instead, a brief comparison of a few statistics for Wisconsin and the entire United States is given in Table 6.1. The population of Wisconsin is about 2 percent of the national total. The state has a higher population density, greater manufacturing value-added per capita, lower personal income per capita, and lower energy consumption per capita than the U.S. average; however, of these four indices, only population density deviates more than 25 percent from the national average.

The population of Wisconsin is not spread evenly over the state. The 1970

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TABLE 6.1 Comparison of Selected Statistics for Wisconsin and the United States

	Unit	Wis.	U.S.	Ratio: Wis./U.S.
1970 population ($\times 10^6$)		4.4	203.8	.02
Land area	10^3 km^2	141	9,160	.02
Water area	10^3 km^2	4.4	203	.02
Population density (1970)	people per km^2	31	22	1.41
Farms				
Number (1970)	thousands	99	2,730	.04
Area	1,000 km^2	73	4,317	.02
Fishing licenses sold (1972)	licenses per 100 residents	30	12	2.50
Motor vehicle registrations (1970)	registrations per 100 residents	50	53	.94
Manufacturing value-added per capita	$ (1972)	2,086	1,700	1.23
Personal income per capita	$ (1972)	4,290	4,537	.95
Primary energy per capita (1970)	10^9 cal	65	83	.78
Electricity generated per capita (1970)[a]	kWh	6,742	8,046	.84

SOURCES: U.S. Bureau of the Census;[1] Bowman et al.;[2] *The World Almanac and Book of Facts*;[3] U.S. Department of the Interior.[4]
[a] Includes industrial generation as well as electric utilities.

population in each of the 8 districts used in these studies is shown in Figure 6.1. About 40 percent of the total population is found in the southeastern district (District 2 in Figure 6.1), which includes Milwaukee and its suburbs. There are 2 other metropolitan areas with population greater than 200,000 (Table 6.2). In addition, 2 other metropolitan areas that are primarily in other states have a portion of their population in Wisconsin. They are Minneapolis–St. Paul, Minnesota, with 1,965,000 total population and 34,000 in Wisconsin (District 6 in Figure 6.1) and Duluth, Minnesota–Superior, Wisconsin, with 265,000 total population and 45,000 in Wisconsin (District 8).

I.C. THE THREE WISCONSIN SCENARIOS

I.C.1. Description of the Scenarios

Three complete scenarios for Wisconsin, summarized in Table 6.3, have been examined in detail. For purposes of comparison, population growth and economic activity are not varied among these three scenarios. The scenarios can be briefly characterized as follows:

- S1 (Base Case): The assumptions tend to be a continuation of past trends, with

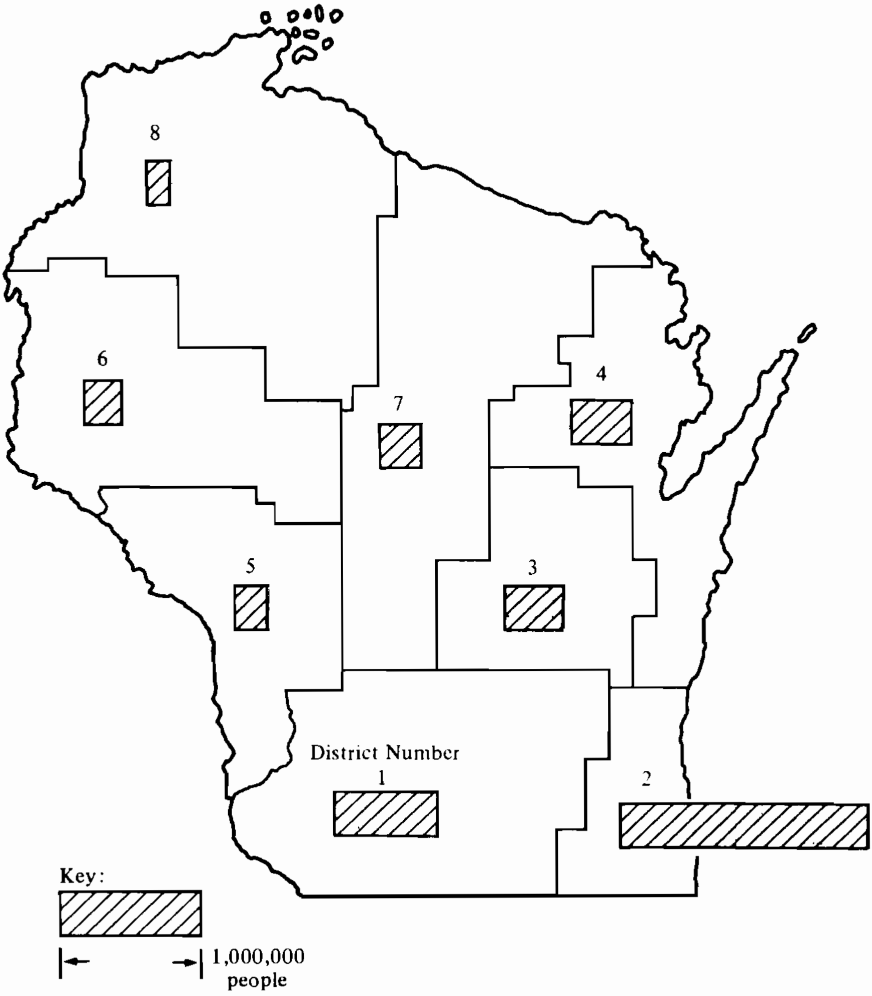

FIGURE 6.1 1970 Wisconsin population by district. The total population of Wisconsin in 1970 was 4.4 million.

some energy-saving methods, such as the construction of more efficient automobiles.

- S2 (High-Energy Case): The assumptions tend to result in significantly higher energy consumption than S1. Electricity is preferred for end-use energy. Emission controls on air pollutants are minimal except for power plants.
- S3 (Low-Energy Case): The assumptions tend to result in lower energy consumption than S1 but by no means the lowest energy consumption that can

TABLE 6.2 Metropolitan Areas in Wisconsin with Over 200,000 People

	Metropolitan Population (× 10^3)	District in Figure 6.1
Milwaukee	1,404	2
Madison	290	1
Appleton-Oshkosh	277	3

TABLE 6.3 Policies and Assumptions for the Three Wisconsin Scenarios

	S1	S2	S3
Growth assumptions			
Population	• Declining growth rate	• Same as S1	• Same as S1
Economy	• Continued expansion of service in relation to industry	• Same as S1	• Same as S1
Policy areas			
Urban Form	• Surburban extension • 25% apartments	• Exurban dispersal • 10% apartments	• Small compact cities • 50% apartments
Energy-Use 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 • More rail shipment of freight
Energy Supply	• Synthetic fuel from coal • Mix of coal and nuclear for electricity	• Synthetic fuel from coal • Mostly nuclear for electricity	• Solar for heating and electricity • No new nuclear • Synthetic fuel from coal
Environment	• Present trends of increasing controls for SO_2 and particulates	• Low controls of SO_2 and particulates	• Stringent controls of SO_2 and particulates

reasonably be expected. Solar energy is developed for both heating and electrical generation. Conservation measures and pollution control are stressed.

An example of the contrasts in the scenarios is the assumed urban form (Table 6.3). Population growth and spatial distribution affects virtually all areas of the model (e.g., the average trip length for personal transportation is related to city size). Population distribution also affects environmental impacts resulting from

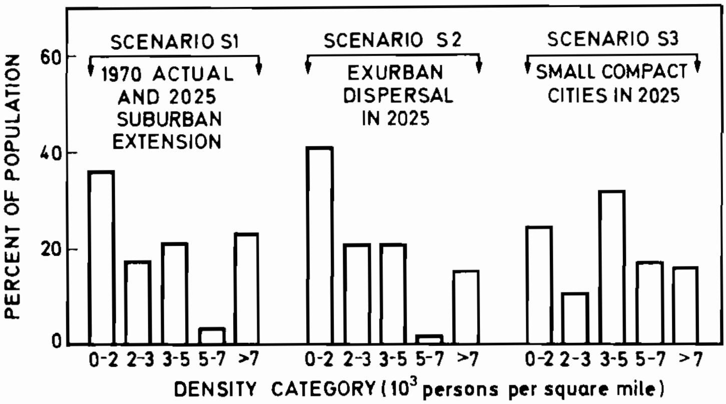

FIGURE 6.2 Wisconsin population by density category.

energy use in ways other than the modification of 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.[5,6] Three of these urban forms with different population density distributions are shown in Figure 6.2. Suburban extension is a continuation of the 1970 density distribution and was used in Scenario S1. The urban form assumed in S2 is exurban dispersal, which indicates a trend of settlement in low-population areas. Growth occurs in low-density urban areas in S3 (the case of small compact cities).

I.C.2. Sensitivity Studies

Several representative sensitivity studies, in which only a single parameter is varied, have been selected for presentation from the numerous possibilities afforded by the multitude of assumptions required for a complete scenario description. The particular sensitivity analyses for the Wisconsin studies are related to solar home heating and water heating, housing type and fuel use, sulfur dioxide control in electrical generation, electricity supply alternatives, and transportation energy for alternative urban forms.

I.C.3. Demand Sectors and Energy Indicators

The energy demand calculations for Wisconsin were based on four demand sectors – residential, service, industrial, and transportation – as described in Chapter 3. The boundaries between these sectors are often not well defined because of some difficulties in data collection procedures. For the scenarios described here, the sectors have been defined as in previous applications of the Wisconsin Regional Energy (WISE) Model,[7] and the period of study has been extended to 2025.

TABLE 6.4 Population Assumptions for Wisconsin Scenarios

	Population ($\times 10^6$)	Average Growth Rate Since 1970 (%/yr)
1970	4.418	
2000	5.78	0.90
2025	6.58	0.73

Some key parameters that have a close relationship with energy consumption in the demand sector models are listed below. Assumptions about population growth affect energy demand in all the models.

Residential
- Type of housing (apartment or single-family home)
- Appliance ownership fractions
- Fuel preference for space heating

Service
- Floor area growth rate
- Energy intensiveness (energy use per unit floor area) by type of fuel

Industrial
- Growth in value-added* for 20 industrial classifications
- Energy intensiveness by type of fuel

Transportation
- Automobile ownership and efficiency
- Distribution of freight between rail and truck

The energy demand results are used to determine total energy supply requirements by fuel type and associated environmental impacts.

I.D. FACTORS COMMON TO THE THREE SCENARIOS

To allow for easy comparison among scenarios, some factors were not varied among the scenarios. However, it should be emphasized that this does not imply certainty for these parameters. The five general areas in which some parameters were held constant over the three scenarios are population growth, economic growth, transportation, energy supply, and environmental impact.

I.D.1. Population Growth

The population estimates used for Wisconsin through 1990 were based on those provided by the Wisconsin Department of Statistical Services. The average annual

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* Value-added is a measure of manufacturing activity derived by subtracting the cost of materials, supplies, containers, fuel, purchased electricity, and contract work from the value of shipments for products manufactured plus receipts for services rendered.

growth rate is approximately 1 percent. From 1990 to 2010, an average annual growth rate of 0.7 percent was used, and from 2010 to 2025, an average annual growth rate of 0.4 percent was used. This approximates the Series X projection of the U.S. Bureau of the Census.[1] Series X reaches zero growth around the middle of the twenty-first century.

The resulting populations for all Wisconsin scenarios are shown in Table 6.4. This estimate is lower than most historical estimates have been[1] but is thought to be a reasonable extension of the recent tendency toward slower population growth. It should also be noted that these growth rates include net migration, which in recent years has increased Wisconsin population by about 0.4 percent annually.

I.D.2. Economic Growth

The scenario methodology required an explicit treatment of economic conditions. Value-added or gross regional product are the typical measures of economic activity. Total value-added includes activity in both the manufacturing and service sectors, which typically have very different energy consumption characteristics.

The level of economic activity in Wisconsin was not varied among scenarios. In addition, the mix of manufacturing and service activity was not varied from scenario to scenario, although it was varied over time. The overall economic growth, measured in terms of total value-added,* used in all Wisconsin scenarios was 3.1 percent per year, which is 2.4 percent per year on a per capita basis.† The overall growth is lower than that of the gross national product since 1950 and is higher than the growth rate since 1910.[1] For comparison, the growth rates used for gross national product in the scenarios developed by the Ford Foundation Energy Policy Project (EPP) for 1975–2000 were 3.3 to 3.4 percent.[8]

The resulting rate of real growth in the Wisconsin manufacturing sector was 2.25 percent per year in the scenarios; this is somewhat lower than the 1958–1971 rate of approximately 3 percent per year.[9] However, the overall growth rate in industry was not a basic assumption; instead, the current rate of change of value-added per capita in 20 industrial classifications was extended into the future,[9] resulting in an overall annual growth rate of 2.25 percent, or 1.5 percent on a per capita basis.

The real rate of growth in the service sector‡ was assumed to be 4.0 percent annually, which was approximately the national growth rate for 1950–1972.[1] Therefore, service value-added represents a larger share of the total value-added as time passes. An additional sector that includes activities such as farming and contract construction is assumed to grow at the same rate as industry. The resultant value-added for all Wisconsin scenarios is shown in Figure 6.3.

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* All value-added figures are in constant dollars to remove the effect of inflation.

† The overall growth was not an assumption itself; instead, growth rates in specific industrial classifications and service sectors were assumed.

‡ This sector includes wholesale and retail trade; finance, insurance, and real estate; services; and government enterprises.

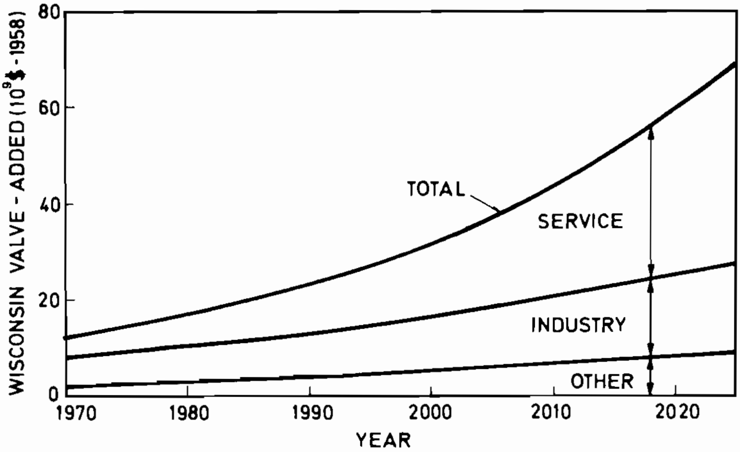

FIGURE 6.3 Assumed value-added in Wisconsin.

For comparison, the Ford Energy Policy Project selected annual growth rates for 1975–2000 of 2.6 percent for U.S. manufacturing and 3.5 percent for service.[8] This is somewhat higher than the assumed rate of growth for Wisconsin industry and somewhat lower than for Wisconsin service. However, the two studies are not easily compared, since time periods, regions, population growth, and the definitions of industry and service are different.

The more recent U.S. National Energy Plan[10] is based on an average growth in GNP of 4.3 percent per year over the period 1976 to 1985. This rate of growth is significantly higher than that used in the scenarios presented here.

I.D.3. Transportation

The freight transportation model is based upon ton-kilometers of freight transported. In all scenarios the number of ton-km is related to economic activity. Since economic activity is the same for all scenarios, the total number of ton-km is the same for all scenarios. However, variations in the distribution between truck and rail tranport are used in the scenarios.

I.D.4. Energy Supply

Wisconsin must import its fossil and nuclear fuels from other regions. Thus, Wisconsin is very dependent on conditions in other states. It has been assumed that required fuel supplies are available from these sources, except for natural gas and petroleum. Acceptable synthetic fuels from coal are assumed to be available in unlimited supply by 2025 as natural supplies of oil and gas diminish.

Wisconsin is assumed to generate exactly the amount of electricity required within its own borders. No net import or export of electricity occurs in any scenario. Although export of electricity is a possibility for the state, this was considered unlikely, and it would be an additional complicating factor that would make results of alternative futures more difficult to compare on a consistent basis. From 1970 through 1974, Wisconsin had a net import of electricity that totaled only 2.1 percent of total electrical generation.[2]

I.D.5. Environmental Impact

In general, the assumptions related to environmental impact are a continuation of the trend toward stricter regulations regarding air pollution, radioactive releases, and waste heat disposal. In all Wisconsin scenarios, control devices and use of low-sulfur coal keep SO_2 emissions from coal-fired electrical generation within U.S. emission standards.* Ash control at coal plants is assumed to retain about 99 percent of the mass of ash.

Reprocessing of fuels from nuclear reactors in order to remove the uranium and plutonium is assumed to take place. Radioactive release from nuclear fuel reprocessing plants is assumed to decline after the year 1990, when equipment that prevents the release of 90 percent of the krypton-85 and tritium (^3H) is installed. These two radionuclides have a long half-life and are expected to be produced in large quantities during normal operation of the plants.

Some other important assumptions that affect environmental impacts have been made. For example:

- Cooling systems for new power plants are mostly closed-cycle evaporative cooling, such as natural-draft wet-cooling towers.
- Occupational fatalities per unit of coal mined decline rapidly to a level that is 30 percent of the 1970 U.S. rate for underground mining and 40 percent of the 1970 value for surface mining.
- New cases of total disability from black lung disease per unit of coal mined underground drops to a level that is nearly 100 times below the 1970 rate.
- The energy input for synthetic fuels is 60 percent from surface-mined Western sub-bituminous coal, 20 percent from bituminous surface mines, and 20 percent from bituminous underground mines.
- The average future power plant (coal or nuclear) is sited within 80 km of 2,250,000 people (this assumption affects population exposures to air pollution and radioactivity).

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* See Appendix C for a discussion of air pollution standards in the three regions.

II. THE BASE CASE SCENARIO

II.A. OVERALL PHILOSOPHY

The primary purpose of the scenario that is presented in some detail in this section is to provide a reference future or Base Case for comparison with the results of other scenarios having different assumptions; the Base Case scenario is not intended to be a prediction of the most likely future for Wisconsin. Assumptions for the near future in the Base Case were established in general by assuming a continuation of current trends, including moderating effects such as slower population growth and more efficient energy use than extrapolation of historical data would indicate. Assumptions over the long run in the Base Case required estimates of what technologies might be available and to what degree they will be used. For example, synthetic fuels that can substitute for some petroleum and natural gas are assumed to be available around the year 2000 in the Base Case. Important assumptions for the Base Case are discussed individually in the following subsections.

II.B. FRAMEWORK FOR SCENARIO S1

In this section the framework for Wisconsin Scenario S1 is presented in some detail. The specific assumptions indicated are the inferred results of implementation of the overall policies shown in Table 6.3.

II.B.1. Assumptions for the Energy Demand Sectors

Transportation Sector Energy use in transportation is categorized into passenger transport and freight transport.

Passenger Transport The demographic characteristics of communities affect the calculated average trip length in the model.[5] The urban form in S1 is a continuation of current growth patterns, designated as suburban extension. The population growth is in suburbs and fringes of the urban areas. In the Base Case, average fuel economy is 40 percent better in 1980 than it was in 1974. Thus, the fuel economy for all types of driving of all 1980 models of autos averages slightly over 8.5 km/liter (20 miles/gal). The current trend toward small cars continues; compact and small cars capture 60 percent of the market after 1980.

Rail, air, and bus passenger service continue at low energy consumption levels relative to passenger auto energy consumption. The assumptions for mass transit fuel use are listed in Table 6.5.

The load factor, the average number of people per vehicle, is assumed to be 1.4 for local and 2.4 for intercity automobile trips. The load factors for buses are 10 passengers per bus for urban travel and 22 passengers per bus for intercity travel.

Freight Transport The freight transport calculations are divided into truck,

TABLE 6.5 Mass Transit Fuel Use

Transport Mode	Energy Use
Urban bus	1.9 km/liter
Intercity bus	2.8 km/liter
Air	555 kcal per passenger-km
Rail	71 kcal per passenger-km
Electric urban bus	645 kcal per passenger-km

SOURCE: Hanson and Mitchell.[5]

TABLE 6.6 Freight Transport Fuel Use

	Energy Use (kcal/metric ton-km)
Truck	485
Rail	118
Air	7,270

SOURCE: Hanson and Mitchell.[5]

rail, and air categories, although air freight is assumed to contribute negligibly to the total energy demand for freight transport. The assumed fuel requirements for the three modes are listed in Table 6.6. Since truck transport requires considerably more energy than rail on a ton-kilometer basis, and since most freight transport is assumed to be by truck, the energy demand for freight shipments by truck is nearly 12 times greater than for rail freight in Scenario S1.

Residential Sector Energy use in the residential sector depends on the type of housing unit, single family or multiple family (apartment), and ownership of energy-consuming devices. Three types of energy consumption are assumed to be a function of housing type for the Wisconsin scenarios; they are space heating, water heating, and central air conditioning. Annual fuel use for and fraction of households owning these three "base appliances" differ considerably for single-family houses and apartments, as shown in Table 6.7. Ownership of secondary appliances, such as refrigerators and television sets, is assumed to be independent of housing type.

The pattern of ownership for new residences shown in Table 6.7 is not the same as for residences that were built before 1970. Therefore, the new and old residences are treated separately in the calculations.

Secondary appliance ownership is assumed to penetrate as indicated in Table 6.7. Essentially all households are assumed to have a refrigerator, television, lighting, and a mixture of small appliances. The only nonelectric secondary appliances that have been included are gas stoves and gas dryers. In 1970 half the households have a gas stove, and about 10 percent have a gas dryer.

The number of occupied households is determined by dividing the population by average family size. Although population only increases by approximately 50

TABLE 6.7 Key Parameters For Wisconsin Residential Energy Use – Scenario S1

Annual Fuel Use for Pre-1970 Residences[a]

	Single Family Home			Apartment		
	Electricity	Gas	Oil	Electricity	Gas	Oil
Space heat	23.1	47.0	47.0	11.0	18.0	18.0
Water heat	4.5	6.9	6.9	3.6	5.6	5.6
Central air conditioning	1.7	3.2		0.66	1.3	

Ownership Fractions for Post-1970 Residences

	Single Family Home			Apartment		
	Electricity	Gas	Oil	Electricity	Gas	Oil
Space heat	0.12	0.86	0.02	0.31	0.59	0.10
Water heat	0.62	0.38	0.0	0.80	0.20	0.00
Central air conditioning	0.20	0.05	0.0	0.80	0.10	0.00

Secondary Appliances

	Fraction of Households That Own Appliance		Electricity Use (10^3 kWh/yr)
	1970	2025	
Refrigerator	0.998	0.999	1.3
Freezer	0.40	0.47	1.4
Dishwasher	0.17	0.67	0.36
Clothes washer	0.59	0.88	0.10
Television	0.97	0.99	0.36
Second television	0.31	0.80	0.50
Room air conditioner	0.26	0.50	0.65
Electric stove	0.49	0.54	1.2
Electric dryer	0.44	0.77	1.0
Lighting	1.0	1.0	0.75
Small appliances	1.0	1.0	0.50
Miscellaneous	0.49	0.54	0.50

SOURCES: Buehring *et al.*[11] and Frey.[12]

[a] Electricity in 10^3 kWh, oil and gas in 10^9 cal.

percent from 1970 through 2025, the number of households nearly doubles over the period because the average family size is assumed to decline from its 1970 value of 3.33.

In 1970, single-family dwellings represented 88 percent of all Wisconsin residences. For Scenario S1, new residences were 75 percent single-family and 25 percent multiple-family dwelling units.

Service Sector Floor area in the service sector is the primary parameter for calculation of energy demand.[13] Based upon the assumption that the ratio of floor area

TABLE 6.8 Key Energy Demand Parameters for Wisconsin Service Sector Calculations – Scenario S1

	Space Heating System Efficiency	Fraction of Total Floor Area Heated	Fraction of Total Floor Area Cooled	Fraction of Total Floor Area Illuminated
Electricity	0.95	0.02	0.60	1.0
Natural gas	0.60	0.60	0.10	0.0
Coal	0.50	0.05	0.0	0.0
Petroleum	0.60	0.25	0.0	0.0

Average growth in service value-added	4.0%/yr
Average fraction of each month that buildings are open for business	0.40 for all months
Average daytime thermostat setting	21.1°C (70°F) for all months
Average nighttime thermostat setting	21.1°C (70°F) for all months
Average building ventilation rate	0.046 $m^3/min/m^2$ floor area for all months
Wall to floor area ratio for new buildings	0.35
Glass to floor area ratio for new buildings	0.15

SOURCE: Buehring.[15]

to service-sector value-added remains constant over time, the service growth was calculated from the value-added growth shown in Figure 6.3.

Some important assumptions by fuel type for Scenario S1 are listed in Table 6.8. In addition to space heating, space cooling, and illumination energy demands, some "process" energy is required for equipment such as elevators, stoves, and water heaters. The calculations have been calibrated to give actual energy demands by fuel type determined from independent analysis of Wisconsin energy use.[14]

Industrial Sector Population growth (discussed earlier), economic activity, and energy intensiveness are the primary parameters for calculation of energy demand in the industrial sector. The primary assumption about economic activity for the Base Case is that there will be an increase in value-added per capita that averages 1.5 percent per year. The increase in value-added per capita, coupled with the assumed population growth, yields a total industrial value-added growth rate that averages 2.25 percent per year over the 55-year period.

The value-added calculations, however, are not based on the overall industrial growth rate but rather on 20 individual industrial categories as shown in Table 6.9. In terms of value-added, the major industries in Wisconsin are food, pulp, fabricated metals, machinery, and transportation equipment. Each industrial category listed in Table 6.9 has an initial value-added per capita, an annual growth rate in value-added per capita, and a rate of change for that growth rate; these initial values are based on historical data.[9]

The energy intensiveness, or energy use per unit of value-added is calculated for five energy sources for each industrial classification. The five energy sources are

TABLE 6.9 Initial Data for Wisconsin Industrial Energy Use

	1970 Value-Added Per Capita (1958 $)	Annual Growth Rate in Value-Added Per Capita 1958–1970
Food and kindred products	178.82	0.54
Tobacco manufactures	0.11	0.70
Textile mill products	16.68	1.95
Apparel and related products	13.76	1.93
Lumber and wood products	21.46	1.08
Furniture and fixtures	16.55	0.54
Pulp and paper products	129.07	1.49
Printing and publishing	59.76	2.49
Chemicals and allied products	54.37	5.55
Petroleum and coal products	3.73	2.25
Rubber products	30.13	3.78
Leather and leather goods	23.63	0.00
Stone, clay, and glass products	21.28	1.74
Primary metal industries	67.25	1.37
Fabricated metal products	100.19	1.53
Nonelectrical machinery	267.30	2.50
Electrical machinery	114.11	1.46
Transportation equipment	90.25	1.00
Instruments and related products	20.92	0.00
Miscellaneous manufactures	17.97	0.56

SOURCE: Shaver et al.[9]

electricity, natural gas, fuel oil, coal, and other miscellaneous fuels such as wood and gasoline. Historical data were used to specify the initial energy intensiveness and their rates of change. The Base Case uses these historical trends with two exceptions:

- The trend away from coal to natural gas reverses so that coal use in industry rises and natural gas growth is not as rapid as a projection of historical data would indicate.
- The overall energy intensiveness growth rate is assumed to be lower than historical trends.

The reason for shifting some emphasis from natural gas to coal is that it appears that the period of rapid expansion of natural gas use in industry has ended in Wisconsin. The overall energy intensiveness in the Base Case is assumed to be nearly constant, rather than the 1.5 percent per year average increase that occurred up to 1970. A reduction in the energy intensiveness growth rate is expected because of increasing energy costs and related conservation measures.

The growth rates for economic activity and energy intensiveness in Wisconsin industry are summarized in Table 6.10. The overall growth rate for electrical intensiveness is somewhat greater than for nonelectrical intensiveness as indicated by historical data.[9]

TABLE 6.10 Annual Growth Rates for Economic Activity and Energy Intensiveness in Wisconsin Industry for Scenario S1

	1970–2025 Average Annual Growth Rate
Industrial value-added per capita (constant $)	1.5%
Total energy intensiveness for industry (energy per $ value-added)	0.34%
Electrical energy intensiveness for industry	0.72%
Nonelectrical energy intensiveness for industry	0.29%

II.B.2. Energy Supply

In general, the nonelectrical energy demanded is assumed to be available. Adjustments were made to some of the demand calculations to reflect expected drifts away from historical trends. For example, the aforementioned rapid growth of natural gas in industry is assumed to slow down.

Production of petroleum and natural gas in the United States may be stimulated in coming years by extensive offshore exploration and development of advanced recovery technologies. However, the likelihood that U.S. production of petroleum and natural gas plus a reasonable quantity of imports will be unable to meet domestic demand, especially by the year 2000 and beyond, is generally thought to be high.[8,16] A potential solution to the shortfall in gas and oil production is synthetic oil and gas produced from coal. In the scenarios, synthetic fuels from coal are assumed to supply significant quantities of energy starting at about the turn of the century. By the year 2025, U.S. production of natural gas and petroleum are assumed to provide Wisconsin with only 80 percent of the 1970 levels of oil and gas consumption; the remaining demand is satisfied by synthetic fuels from coal. The assumed efficiencies for conversion of coal to synthetic gas and to oil are 60 percent and 50 percent. These efficiencies are in reasonable agreement with the projections by the Synfuels Interagency Task Force.[16]

Electricity supply in the Base Case is from a mix of nuclear energy and coal. Half of all new nonpeaking electrical generating capacity is arbitrarily assumed to be nuclear energy after 1982. The mix of nuclear energy sources for new capacity after the year 2000 is approximately 46 percent PWR, 23 percent BWR, 25 percent HTGR, and 5 percent LMFBR.* Coal supplies for electrical generation were assumed to be 25 percent sub-bituminous coal from western states and 75 percent bituminous coal. Hydroelectric capacity and energy production were assumed to remain at current levels.

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* PWR is the pressurized water reactor; BWR is the boiling water reactor; HTGR is the high temperature gas-cooled reactor; and LMFBR is the liquid metal fast breeder reactor. Since these studies were completed, the likelihood of HTGR and LMFBR use in Wisconsin in the near future has decreased considerably.

TABLE 6.11 Control Factors for SO_2 and Particulates – Scenario S1 (percentage removed)

	SO_2		Particulates	
	2000	2025	2000	2025
Residential				
gas	30	40	0	0
oil	50	60	0	0
Service				
coal	0	0	45	60
gas	30	40	0	0
oil	50	60	0	0
Industrial				
coal	15	30	94	95
gas	30	40	0	0
oil	40	50	12	30
Electric power				
coal	65	67	99	99

II.B.3. Environmental Impact

In general the assumptions for environmental impact are extensions of the present trend of increasing controls. Control factors, or the percentage of a pollutant that is kept out of the air, for SO_2 and particulates have been estimated for each sector and fuel type. The factors for the Base Case are shown in Table 6.11. The SO_2 control is generally assumed to be the result of fuel cleaning operations before delivery to the end use sector except for SO_2 control for coal in industry and electric power generation, where complex sulfur removal systems are assumed to be available. Other key assumptions on factors that affect the environment were presented in section I.D of this chapter.

II.C. RESULTS FOR WISCONSIN SCENARIO S1

II.C.1. End-Use Demands

End-use energy includes only energy consumed in end-use processes; therefore, conversion and transmission losses, such as in electrical generation, are excluded from the end-use total. The total end-use energy for the Wisconsin Base Case increased at an average annual rate of 2.4 percent, from 236×10^{15} cal in 1970 to 856×10^{15} cal in 2025.*

The fraction of total end-use energy in each demand sector did not stay constant over time. The service sector increased its share of the total end-use energy from 13

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* Detailed tables showing end-use and primary energy for the scenarios can be found in the appendices at the end of this chapter.

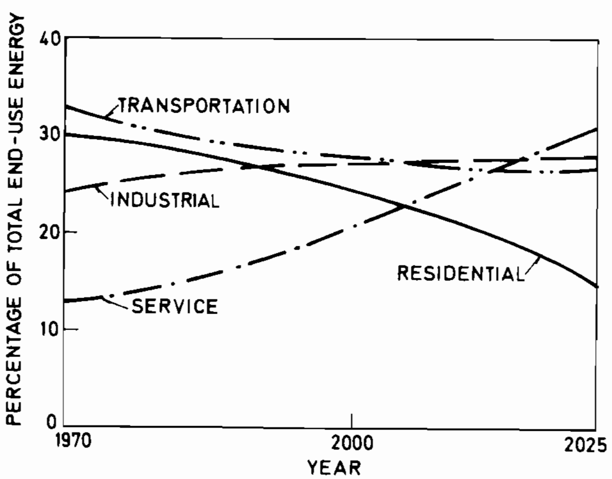

FIGURE 6.4 Distribution of total end-use energy by sector for Wisconsin Scenario S1.

to 31 percent over the 55-year period while the residential sector's share dropped from 30 to 15 percent (Figure 6.4). The percentage of end-use energy in transportation dropped off slightly and the industrial share showed a small increase. The average growth rate in end-use energy varied from a low of only 1.1 percent per year for the residential sector, just slightly higher than the 0.75 percent per year increase in population, to a high of 4.0 percent in the service sector.

The results for end-use energy are shown on a per capita basis in Figure 6.5. The rapid growth of energy use in the service sector relative to the other sectors is evident. Energy consumption per capita in transportation nearly doubles in the 55-year period, although consumption per capita for personal transportation by automobile showed a decline of nearly 18 percent, primarily because of efficiency gains. The energy used for freight transport increased faster than private transportation declined; therefore, total end-use energy in transportation increased as shown in Figure 6.5.

II.C.2. Primary Energy

Primary energy includes both end-use energy and energy losses that occur in processing and transport, such as conversion and transmission losses for electricity. The primary energy supply results for the years 1970, 2000, and 2025, are listed in Table 6.12. The average rate of increase from 1970 to 2025 for primary energy use is 3.1 percent per year. The higher rate of increase for primary energy than for end-use energy (2.4 percent per year) is the result of shifting to electricity and synthetic

TABLE 6.12 Primary Energy Supply for the Wisconsin Base Case (10^{15}cal)

	1970	2000	2025
Petroleum	114.7	168.8	91.8
Natural gas	90.3	149.1	72.2
Synthetic fuel from coal			
end-use fuel	0.0	35.4	473.9
conversion loss	0.0	29.7	403.2
Total	0.0	65.1	877.1
All other coal sources	80.7	130.4	253.4
Nuclear energy	0.1	145.1	225.1
Hydrolectricity	1.6	2.1	2.1
Total	287.4	660.6	1,521.7

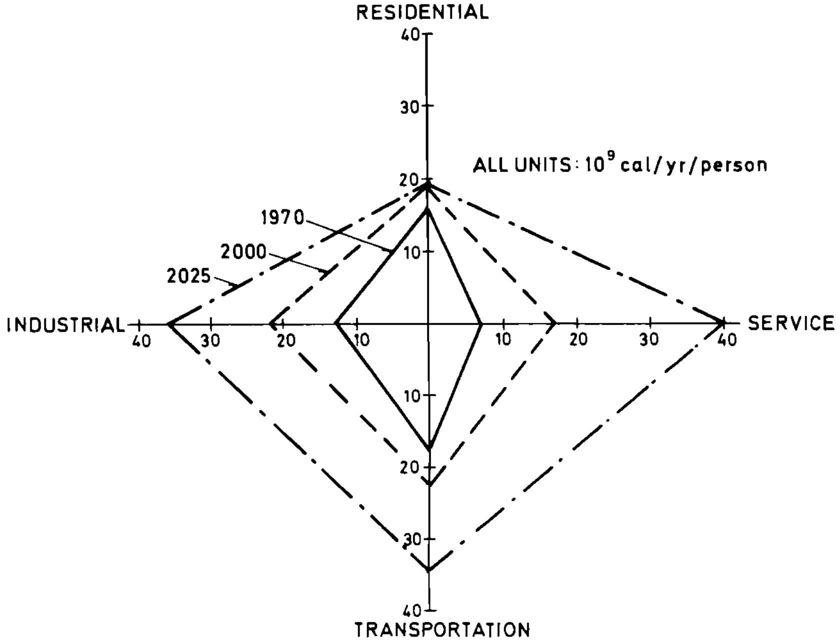

FIGURE 6.5 Annual end-use energy per capita by sector for Wisconsin Scenario S1.

fuels, which both have significant energy losses in conversion. If synthetic fuels from coal were not needed, i.e. if enough petroleum and natural gas were available, the total primary energy use in 2025 would be only about 1,120 x 10^{15} cal, the amount listed in Table 6.12 minus the large conversion loss for synthetic fuels.

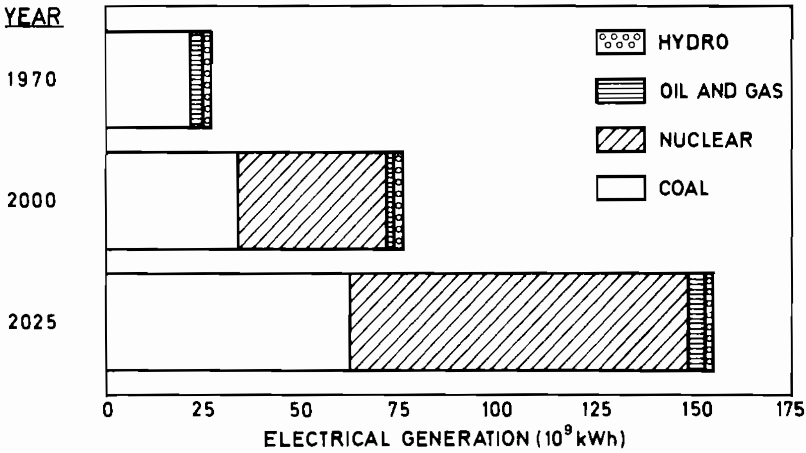

FIGURE 6.6 Sources of electrical generation for Wisconsin Scenario S1.

II.C.3. Electricity

Energy required for electrical generation increased from 72 x 10^{15} cal in 1970 to 383 x 10^{15} cal in the year 2025; this corresponds to an average annual growth rate of 3.1 percent per year. Energy for electricity represented 25 percent of the total primary energy in 1970, 30 percent in 2000, and 25 percent in 2025. The decline is the result of the large energy consumption in the production of synthetic fuels. If enough oil and natural gas were available that the need for synthetic fuels were eliminated, energy for electricity would have been 32 percent of the total energy in 2000 and 34 percent in 2025.

The growth in electrical generation over time and the production of electricity by fuel type is shown in Figure 6.6. Nuclear generation increases from 0.2 percent of all generation in 1970 to 56 percent by the year 2025. Nuclear generation accounted for approximately 25 percent of the electricity in Wisconsin in 1974 and about 33 percent in 1975. However, no new nuclear plants are planned to be operating in Wisconsin before the late 1980s; therefore, the nuclear percentage of total generation will decline until that time if electricity demand continues to increase.

Coal electricity generation in 2025 is nearly three times the 1970 production. Oil and gas do not play major roles in Wisconsin's electricity generation now, nor are these fuels expected to be used as major sources of electrical generation in the future.

The generating capacity in the year 2025 for the Base Case totals approximately 35,000 MW of which 47 percent is coal-fired, 40 percent is from nuclear energy, and 13 percent is hydroelectricity and peaking capacity. Nuclear energy produces more than 40 percent of the electricity (Figure 6.6) because nuclear plants, with their relatively low fuel costs, operate more hours per year than coal plants. Generating capacity in Wisconsin at the end of 1974 was 8,361 MW.[2]

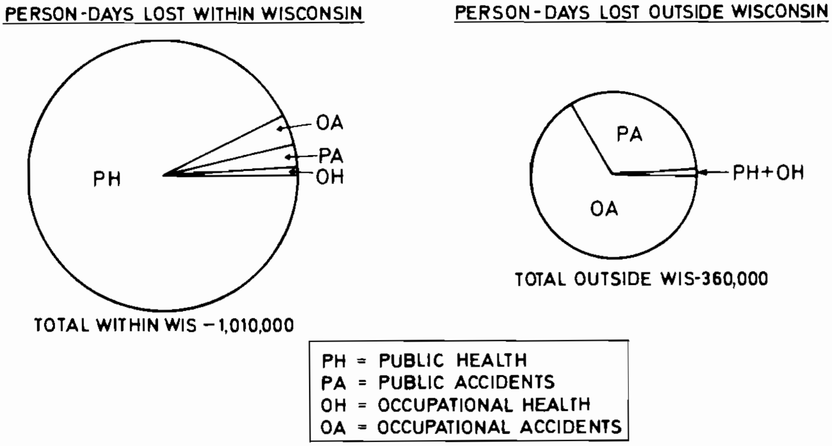

FIGURE 6.7 Quantified human health and safety impact associated with Wisconsin's energy use in 2025 for Scenario S1.

II.C.4. Environmental Impacts

Certain quantified environmental impacts associated with the Base Case energy use are discussed in this section. The impacts selected are only part of the quantified impacts which in turn are only part of the "total" impact. The models used to estimate quantified impact include a broad range of impacts.[17, 18, 19] Examination of these impacts and comparison among scenarios can provide a general impression for certain categories of impacts. A decision analysis methodology for combining quantified impacts with conventional costs and unquantified impacts is presented in Appendix E.

Human Health and Safety The quantified impacts relating to human health and safety in the year 2025 are shown in Figure 6.7. Person-days lost (PDL)* are used as a representation of total quantified human health and safety impact, including fatalities, nonfatal injuries, and illnesses.

Human health and safety impacts can be subdivided into several categories such as those indicated in Figure 6.7. Occupational accidents include impacts such as mining accidents and accidents at the power plants; occupational health includes radiation exposure and black lung disease; public accidents include transportation accidents with vehicles involved in the energy system; and public health includes radiation and quantified air pollution health effects. The health impact of air pollution is the primary contributor to the large public health impact shown in Figure

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* Associating the number of disability days with various accidental injuries is practiced according to methods developed by the American National Standards Institute.[20] This methodology has been extended here to all human health and safety impacts, including death or total disability (6,000 PDL), and nonfatal illnesses.

TABLE 6.13 Quantified Annual Person-Days Lost Resulting From Wisconsin's Energy Use – Base Case Scenario S1[a]

	1970			2025		
	Electric	Nonelectric	Total	Electric	Nonelectric	Total
Within Wisconsin						
Occupational accidents	1,400	5,500	6,900	8,100	21,000	29,000
Occupational health	26	0	26	6,900	0	6,900
Public health	19,000	150,000	170,000	15,000	940,000	950,000
Public accidents	4,400	670	5,100	21,000	6,100	27,000
Total	24,000	160,000	180,000	51,000	960,000	1,000,000
Outside Wisconsin						
Occupational accidents	30,000	50,000	80,000	50,000	190,000	240,000
Occupational health	12,000	4,500	16,000	2,100	1,200	3,300
Public health	7	0	7	680	0	680
Public accidents	13,000	6,100	19,000	62,000	55,000	120,000
Total	55,000	60,000	120,000	120,000	240,000	360,000
Totals						
Occupational accidents	32,000	55,000	87,000	58,000	210,000	270,000
Occupational health	12,000	4,500	16,000	9,000	1,200	10,000
Public health	19,000	150,000	170,000	16,000	940,000	950,000
Public accidents	18,000	6,700	24,000	83,000	61,000	140,000
Grand totals	80,000	220,000	300,000	170,000	1,200,000	1,400,000

[a] One death or case of total disability is associated with 6,000 person-days lost (PDL). Columns and rows may not add to totals because of rounding.

6.7. Occupational accidents are the next largest single category. Two major conclusions may be drawn from Figure 6.7.

- A significant share of the human health and safety impact resulting from energy use in Wisconsin occurs in regions other than Wisconsin.
- Public health impact inside Wisconsin represents nearly all of the total quantified human health and safety impact within Wisconsin.

The quantified human impacts can be further categorized according to whether they are related to electrical or nonelectrical energy and when the energy use occurred. The results for the Base Case for the years 1970 and 2025 are shown in Table 6.13. The PDL calculated by the models are listed in the table in order to avoid rounding difficulties. It is interesting to note that although energy use increases by more than a factor of five from 1970 to 2025 in the Base Case (Table 6.12) the quantified impacts in some categories decline over that period. For example, the PDL in occupational health outside Wisconsin drops from more than 16,000 in 1970 to 3,300* in 2025 primarily because of the assumption that cases

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* Radiation exposure accounts for more than half of the occupational health PDL outside Wisconsin in 2025.

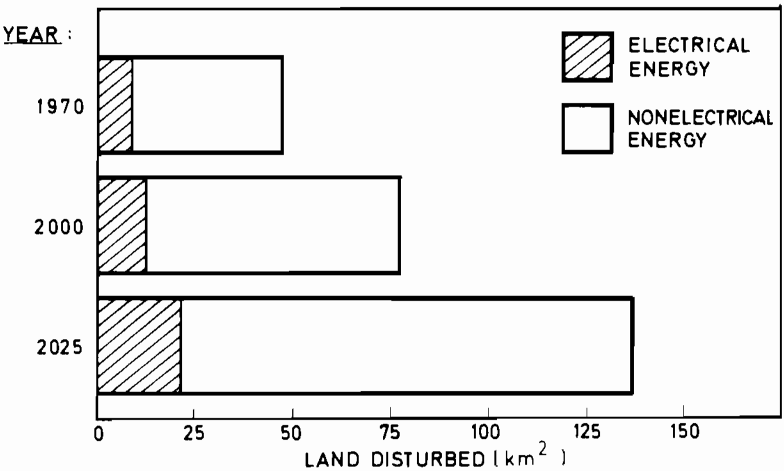

FIGURE 6.8 Land disturbed for fuel resource extraction outside Wisconsin because of energy use within Wisconsin for Scenario S1.

of disability from black lung disease will become rare by 2025. One category that shows a marked increase is public health impact inside Wisconsin from nonelectrical energy use. This is primarily the effect of air pollution on people living in urban areas. Another category that increases over time is occupational health PDL inside Wisconsin from electricity use (26 in 1970; 6,900 in 2025). This is entirely from radiation exposure of workers at nuclear power plants. If all the PDL shown in Table 6.13 were the result of fatalities, the total number of fatalities associated with energy consumption in Wisconsin would have increased from about 50 in 1970 to nearly 230 in 2025.

Land Use for Fuel Resource Extraction The land area disturbed for extraction of energy resources because of energy use within Wisconsin for Scenario S1 is shown in Figure 6.8. The land use plotted in Figure 6.8 is land disturbed to supply energy in the year shown. In most cases the land can be reclaimed for other uses, although reclamation of land mined in the western United States may be limited because of water scarcity. Twenty-five percent of the coal for electrical generation and 60 percent of the coal for synthetic fuels are assumed to be mined in western states. *All* of the land disturbed for resource extraction occurs outside Wisconsin.

Sulfur Dioxide Emission The total emissions of sulfur oxides, expressed in metric tons of SO_2, for the eight districts of Wisconsin are shown in Figure 6.9 for the years 1970 and 2025. The future location of electrical plants was assumed to be such that the fraction of coal-fired electrical generation in each district remains constant after taking into account current capacity and announced plans as of 1975. Sulfur emission controls and use of low-sulfur coal in coal-fired electrical plants is

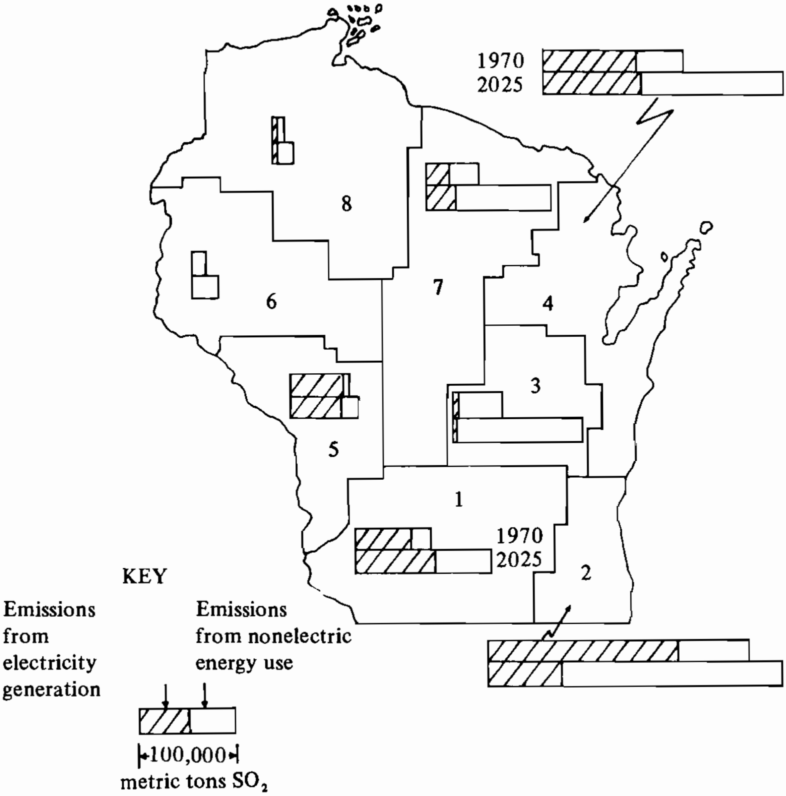

FIGURE 6.9 Total emissions of SO_2 in Wisconsin by district for 1970 and 2025 for Scenario S1.

assumed to reduce the quantity of SO_2 emitted per kilowatt-hour of generation by more than a factor of three over the period 1970 to 2025.

It is obvious from Figure 6.9 that SO_2 emissions in Wisconsin are expected to vary significantly among the eight districts. The corresponding ground-level concentrations can be estimated using the characteristics of the release, such as stack height. Since the ground level concentrations strongly depend on these release characteristics, the average concentrations are not directly proportional to the emissions shown. The effect is clearly shown for Milwaukee, Wisconsin, in Figure 6.10, which has the percentage of emissions on the left half of the chart and the percentage contribution to dose, measured in micrograms per cubic meter ($\mu g/m^3$), on the right half. The relatively low release heights of the residential and service sources result in higher ground-level concentration in the urban area than the emissions from the tall stacks associated with electrical generation plants and industrial sources.

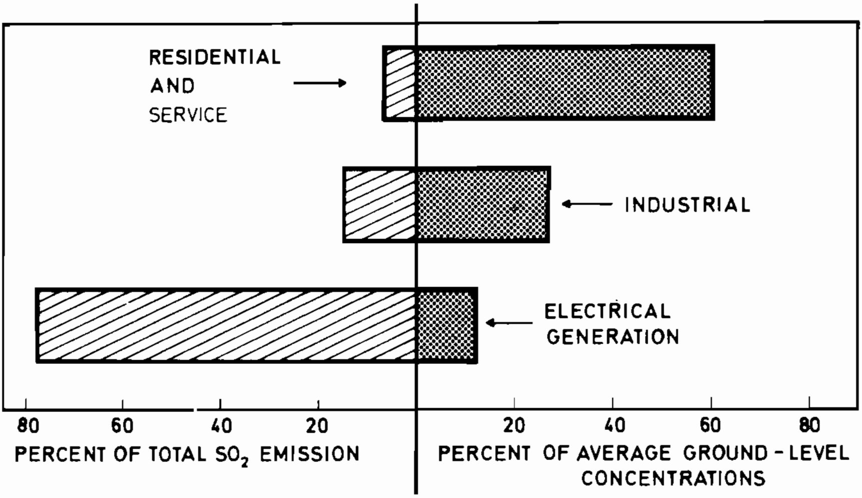

FIGURE 6.10 Sulfur dioxide emissions and concentrations in Milwaukee, Wisconsin, in 1970.

II.D. SOME CONCLUSIONS FOR THE BASE CASE

It is difficult to assess the validity of any scenario that has a time span of more than 50 years. Scenario S1 for Wisconsin is based on what is believed to be a relatively consistent policy set, as presented in section II.B. The guideline used in selecting assumptions for the Base Case was a continuation of current trends in factors related to energy consumption, and, over the long term, including slower population growth and more efficient energy use than extrapolation of historical trends would indicate. One can speculate as to the validity of numerous assumptions for the Base Case. No claim is made about the likelihood of realization for S1; it does, however, provide a point of comparison for other scenarios with some of the key assumptions changed.

The Base Case has demonstrated the problem of growing demand for petroleum and natural gas in the face of declining ability to supply these fuels for U.S. sources. The synthetic fuel (produced from coal) supplies over half the total end-use energy in the Base Case by the year 2025. A supply alternative to synthetic fuel use is a massive conversion to electricity, where coal can also be the primary energy source.

The growth rate in electrical energy generation in the Base Case is significantly below historical trends and some relatively recent projections for Wisconsin,[11] such as the 7.4-percent-per-year growth that occurred in Wisconsin over the 1942 to 1974 period,[2,21] and the 5-percent-per-year growth rate from 1976 to 1995 that was recently predicted by the large electric utilities in Wisconsin. For the period 1970 through 2000 the electricity generation average growth rate in S1 is 3.6 percent per year. The growth in total primary energy over the same period is only 2.8 percent per year, so electricity continues its historical trend of growing somewhat faster than total energy consumption. However, electricity does not play a dominate role in S1.

The quantified impacts that have been estimated for the Base Case show that regions other than Wisconsin will feel the effect of energy consumption in Wisconsin. For example, more than 25 percent of the quantified human health and safety impact associated with Wisconsin's energy use occurs outside Wisconsin. The degree to which the environmental impacts are "exported" to other states and nations is related to the mix of fuel supply systems.

Another observation for the Base Case is that the residential sector has a dramatic decline in its share of the total end-use energy. The service, transportation, and industrial sectors are all roughly equivalent in end-use energy by 2025. Since the service sector in 1970 is the smallest energy consumer of the end-use sectors, the equality with transportation and industry by 2025 represents a rapid expansion in energy consumption in service relative to all other sectors.

Other observations on the Base Case are presented in the final section of this chapter.

III. OTHER SCENARIOS

III.A. THE HIGH ENERGY CONSUMPTION, HIGH ELECTRICITY CASE – SCENARIO S2

The second scenario (S2) has assumptions that tend to result in higher energy consumption in Wisconsin than the Base Case (S1). In addition, electricity is assumed to be preferred for end-use energy. The differences in critical assumptions between Scenarios S1 and S2 are highlighted in Table 6.14.

The growth of population primarily in low-density areas within 20 km of urban areas (exurban dispersal policy) results in more single-family houses (fewer apartments) than the suburban extension policy of the Base Case. Also, the transportation energy is increased because the average trip length is longer with exurban dispersal than with suburban extension.

The use of electricity for space heating and water heating is almost universal in new construction for Scenario S2. Electricity consumption per unit of industrial value-added is assumed to grow even faster than the 2.7 percent annual rate that U.S. industry experienced from 1955 to 1970.[9] The resulting electricity consumption by demand sector for the year 2025 is compared with the Base Case results in Table 6.15 (the 1970 end-use electricity consumption was about 24 x 10^9 kWh). The assumption changes listed in Table 6.14 caused electricity consumption in 2025 to increase by nearly a factor of three over the Base Case. However, end-use demand for natural gas and petroleum was nearly one-third *less* in the high-energy

TABLE 6.14 Wisconsin Scenario S2 in Relation to S1[a]

	Changes in Policy or Assumptions
Urban form	• Exurban dispersal policy (growth in low population density areas but within 20 km of urban areas) instead of suburban extension growth in suburbs and fringes of urban areas).
Transportation sector	• Average automobile efficiency remains at the 1975 level instead of improving 40%. • An urban electric automobile is introduced in 1980 and accounts for about 7% of personal transportation by 2025.
Residential sector	• New residences are 90% single family houses instead of 75% (the remainder of new residences are apartments). • All water heating in new residences is electric. • More than 90% of new residences use electric heat. • New residences cannot use any natural gas.
Service sector	• Commercial buildings are open 45% of the time instead of 40%. • Electric heat and air conditioning is emphasized so that nonelectric fuel use declines from the 1970 levels.
Industrial sector	• Total energy intensiveness (energy consumed per dollar value-added) grows at 1.3%/yr instead of 0.34%/yr. • Electricity intensiveness grows at a rate of 3.4%/yr instead of 0.72%/yr. • Nonelectrical intensiveness grows at 0.89%/yr instead of 0.29%/yr.
Energy supply	• New nonpeaking electrical generating capacity is 70% nuclear energy instead of 50%.
Environmental impact	• Lax controls for SO_2 and particulates from nonelectric fuel use.

[a] Compare with section II.B of this chapter.

TABLE 6.15 End-Use Electricity Consumption in 2025 for Wisconsin Scenarios S1 and S2 (10^9 kWh)

	Base Case (S1)	High-Energy Case (S2)
Residential sector	29.6	74.6
Service sector	77.1	172.6
Industrial sector	33.1	139.5
Transportation sector	0.0	6.4
Total	139.8	393.1

TABLE 6.16 End-Use Petroleum, Natural Gas, and Synthetic Fuels from Coal in 2025 for Wisconsin Scenarios S1 and S2 (10^{15} cal)

	Base Case (S1)	High-Energy Case (S2)
Residential sector	101.5	24.5
Service sector	189.0	6.3
Industrial sector	108.5	155.1
Transportation sector	228.1	248.8
Total	627.1	434.7

TABLE 6.17 Wisconsin Scenario S3 in Relation to S1[a]

	Changes in Policy or Assumptions
Urban form	• Growth in small compact cities resulting in high population densities.
Transportation sector	• Mass transit use doubles from S1. • Urban bus load factor increased to 15 passengers per vehicle. • Urban auto load factor increased to 1.7 passengers per auto. • An urban car captures 30% of the new car market after 1980. This car has fuel economy of nearly 13 km/liter for urban travel and 17 km/liter for intercity travel (30 and 40 miles/gallon). • Compact and small cars capture 45% of the market, leaving only 25% for large and intermediate autos. • The distribution between truck and rail freight transport was assumed to shift to rail so that the metric ton-kilometers of freight shipments in 2025 were the same for rail and truck.
Residential sector	• Only 50% of new residences are single family homes. • Better insulation and conservation reduces heating requirements per house by 30 to 40%. • Solar home heating and water heating, with an electrical auxiliary system, is available starting in 1980. The percentage of new residences using solar increases from 5 in 1980 to 50 in 2000 and stays constant after that. Only new dwelling units use solar energy; no retrofitting of existing units is considered.
Service sector	• Solar energy reduces demand for natural gas and petroleum by 28% in 2025 compared with the same case with no solar energy. • Wall to floor area ratio for new buildings is reduced from 0.35 to 0.30. • Glass to floor area ratio for new buildings is reduced from 0.15 to 0.10. • Better insulation reduces heat transfer through walls and windows. • Lower thermostat settings in winter during the day (18.9°C) and night (15.6°C). • Higher thermostat settings in summer during the day (23.9°C) • Building ventilation rate reduced from 0.046 to 0.037 m^3/min/m^2 floor area for all months. • Cooling system efficiencies increase relative to S1.
Industrial sector	• Total energy intensiveness declines at 0.66%/yr. • Electricity intensiveness declines at 0.36%/yr. • Nonelectric intensiveness declines at 0.70%/yr.
Energy supply	• Solar energy for space heating. • Solar electric power plants account for 30% of the generation and 50% of the capacity by 2025. • No new nuclear plants; all new capacity is either coal-fired or solar energy.
Environmental impact	• Stringent controls for SO_2 and particulates from nonelectric fuel use. Improved SO_2 removal systems at electric power plants.

[a] Compare with section II.B of this chapter and Table 6.14.

TABLE 6.18 Solar Energy Contribution in S3 (percentage of total energy)

	2000	2025
Residential end-use[a]	3.8	16.9
Service-end-use[a]	1.8	8.8
Electrical generation	4.2	30.0

[a] This does not include the percentage of electricity supplied by solar energy. The energy obtained from solar space heating and water heating is divided by total end-use energy for all purposes to obtain the percentages in the table.

case than in the Base Case (Table 6.16) primarily because of electricity substitution in S2.

Other results of the high-energy case are presented in a later section (III.C) that contains a comparison of all three Wisconsin scenarios.

III.B. THE LOW ENERGY CONSUMPTION, HIGH SOLAR ENERGY CASE – SCENARIO S3

The third Wisconsin scenario (S3) selected for presentation has assumptions that tend to reduce energy consumption when compared with Scenario S1. Solar energy is assumed to be developed for both electrical and nonelectrical applications. Nuclear power plants remain at the 1975 level of capacity and generation; all new electrical plants use either coal or solar energy; solar energy grows rapidly after the year 2000. Half of all new residences use solar space heating and water heating. Other differences in important assumptions between the Base Case and S3 are listed in Table 6.17.

Transportation energy demand is significantly lower in S3 than in S1 because of the assumption changes listed in Table 6.17. The shift of some freight from truck to train results in nearly a 25-percent energy savings in freight transport when compared with the Base Case although the number of ton-kilometers of freight is constant in all Wisconsin scenarios.

In S3, population growth is in small compact cities that result in high population densities. This limits solar space heating applications since solar energy can supply less of the total space heating energy needs in a high-density area. However, solar energy does contribute significantly to the total energy requirements in this scenario, as indicated in Table 6.18. Development of solar electricity to such a large degree by 2025 would require very favorable circumstances. Other results of S3 are presented in the next section in which all three Wisconsin scenarios are compared.

III.C. WISCONSIN SCENARIO COMPARISONS

III.C.1. Primary Energy

Primary energy per capita for the three scenarios is displayed in Figure 6.11. Scenario S3 has a 1.5-percent-per-year average increase in per capita primary energy

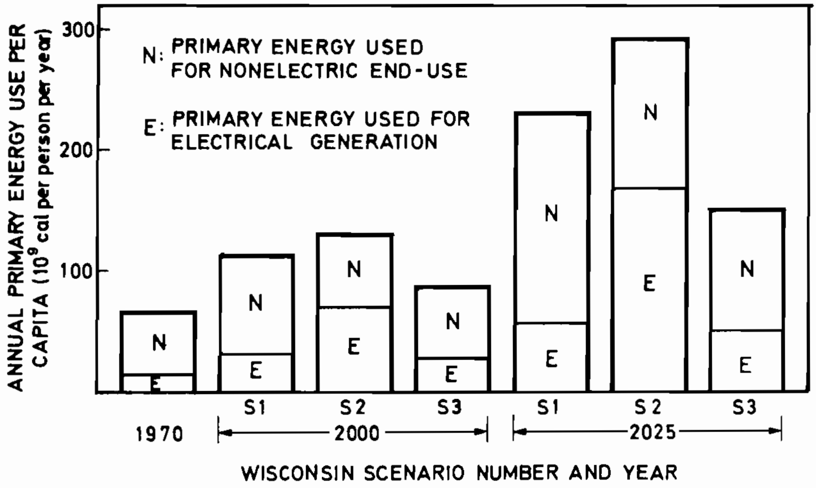

FIGURE 6.11 Primary energy use per capita for the Wisconsin scenarios.

consumption over the period 1970 to 2025. However, if enough oil and gas were available that synthetic fuels from coal were not needed, the per capita primary energy use in 2025 for S3 would be only 120 x 10^9 cal per person. The rest of the energy is losses associated with conversion of coal to synthetic fuels. As indicated in Table 6.19, the average annual increase in per capita primary energy use would be only 1.1 percent if synthetics are not needed. Furthermore, renewable resources (solar energy and hydropower) contribute 20 x 10^9 cal per capita to the primary energy in 2025 for Scenario S3. Excluding these renewable resources, primary energy per capita grows at 1.3 percent per year if synthetics are needed, and only 0.8 percent if synthetics are not needed. Primary energy in S3 grows at only 1.8 percent per year from 1970 to 2000 (0.85 percent per capita annually). One reason S3 exhibits a higher growth rate from 2000 to 2025 than from 1970 to 2000 is that some conservation measures have their major impact before the year 2000. For example, the average fuel efficiency of new automobiles is assumed to improve dramatically between 1970 and 1985, and then remain at that level through the year 2025.

Scenarios S1 and S2 show much higher growth rates in primary energy use, as Table 6.19 indicates. Scenario S2 in particular represents a high-energy future with a total growth in primary energy of 3.3 percent per year from 1970 to 2000. This is close to the average growth in primary energy of 3.5 percent per year that took place in the United States between 1950 and 1973.[4,22] Because of the rise in world oil prices, the rise in other energy prices, economic recession, and general awareness about energy, primary energy consumption in the United States by the year 1976 had not increased above the 1973 level; the average growth rate in U.S, primary energy consumption from 1950 to 1976 was 3.0 percent per year.[23] The Energy

TABLE 6.19 Average Annual Growth Rates in Primary Energy Consumption for the Three Wisconsin Scenarios (%/yr)

	1970–2000			1970–2025		
	S1	S2	S3	S1	S2	S3
Including synthetic fuel conversion losses						
Total	2.6	3.3	1.8	3.1	3.5	2.3
Per capita	1.7	2.4	0.9	2.3	2.8	1.5
Excluding synthetic fuel conversion losses						
Total	2.4	3.2	1.6	2.5	3.3	1.9
Per capita	1.5	2.3	0.7	1.8	2.5	1.1
Excluding synthetic fuel conversion losses and renewable energy resources[a]						
Total	2.4	3.2	1.5	2.5	3.3	1.5
Per capita	1.5	2.3	0.6	1.8	2.5	0.8

[a] Solar energy and hydropower are the only renewable resources in these scenarios.

Policy Project of the Ford Foundation (EPP) found average annual growth rates in primary energy between 1970 and 2000 of 3.5 percent for the high-growth scenario, 2.1 percent for the "Technical Fix" scenario, and 1.3 percent for the zero-energy-growth scenario.[8]* This compares with 3.3 and 1.8 percent per year growth from 1970 to 2000 for the high and low Wisconsin scenarios shown here (see Table 6.19). President Carter's U.S. National Energy Plan called for an annual growth rate of less than 2 percent by 1985.[10]

Primary energy use by fuel type for the three scenarios is shown in Figure 6.12. All scenarios show a significant expansion in coal use. Natural gas and petroleum use declines to 80 percent of the 1970 levels by 2025 because supplies are assumed to be limited. Coal use in 2025 for synthetic fuel production is 78, 62, and 62 percent of the total coal use in S1, S2, and S3.

III.C.2. End-Use Energy

End-use energy for the years 2000 and 2025 for the three Wisconsin scenarios is listed in Table 6.20. It is interesting to note that although S2 is a high-energy scenario, end-use energy in S2 is less than in S1 in, for example, the residential sector. The increased use of electricity in S2 results in less end-use energy, but the primary energy use in S2 is significantly greater than in S1, as Figures 6.11 and 6.12 show.

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* These growth rates are average annual percentage changes over the entire period. They may vary considerably during the period. For example, the EPP zero-energy-growth scenario has a constant energy demand after 1990.[8]

TABLE 6.20 End-Use Energy for the Wisconsin Scenarios (10^{15} cal)

		2000			2025		
	1970	S1	S2	S3	S1	S2	S3
Residential	70.8	109	86	87	127	89	85
Service	29.8	97	63	72	264	155	182
Industrial	57.8	127	160	94	237	409	137
Transportation	77.8	129	144	101	228	254	168
Total[a]	236.0	462	453	352	856	907	572

[a] Columns may not add to totals because of rounding.

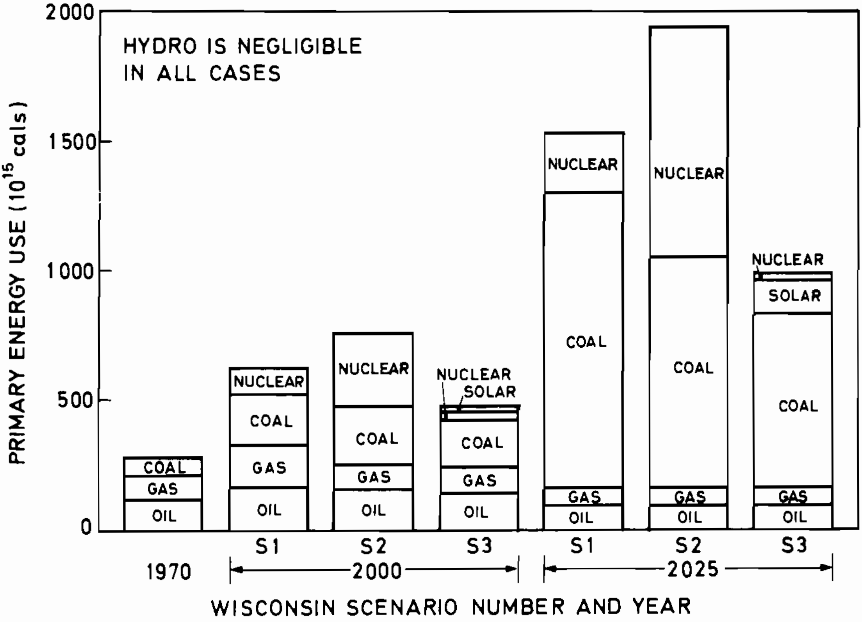

FIGURE 6.12 Primary energy use by fuel type for the Wisconsin scenarios.

The average annual increase in *end-use* energy for the period 1970 to 2000 is

1. 1.4 percent in S1
2. 1.3 percent in S2
3. 0.4 percent in S3

These growth rates increase somewhat after the year 2000, primarily because economic growth continues at the same rate but with lower population growth.

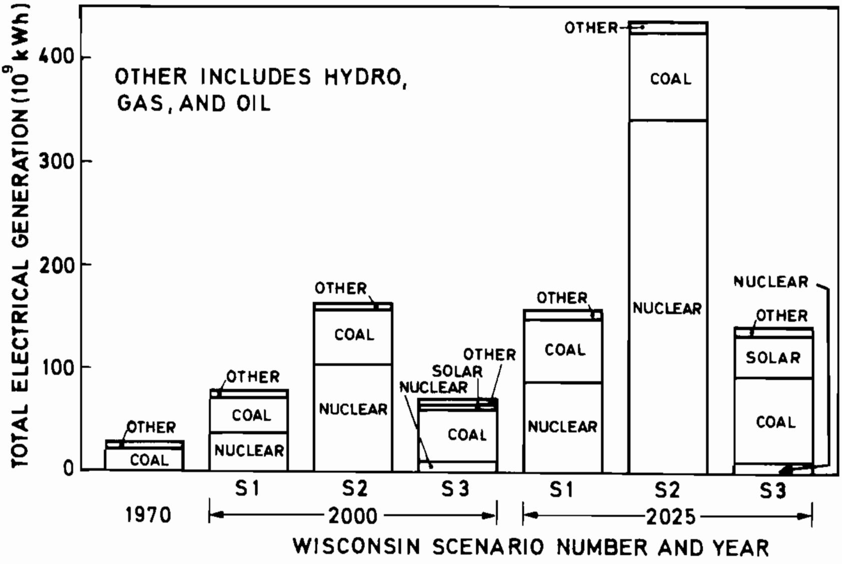

FIGURE 6.13 Electrical generation for the Wisconsin scenarios.

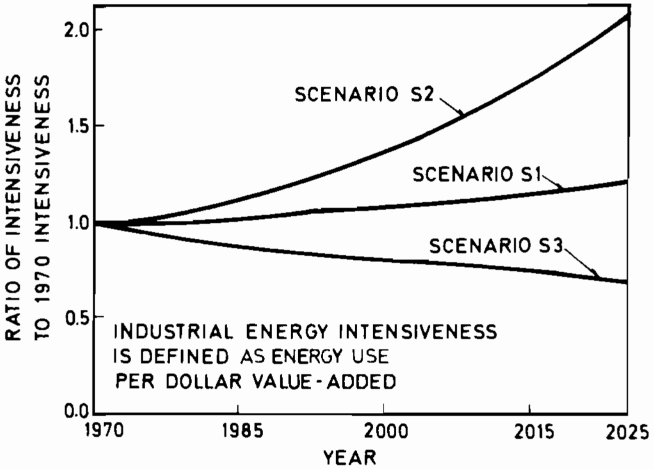

FIGURE 6.14 Wisconsin industrial energy intensiveness for the three scenarios in relation to 1970 intensiveness.

III.C.3. Electrical Generation

The emphasis on electricity in S2 is strikingly clear in Figure 6.13, which shows generation by fuel type as a function of time. Nuclear and coal sources provide all

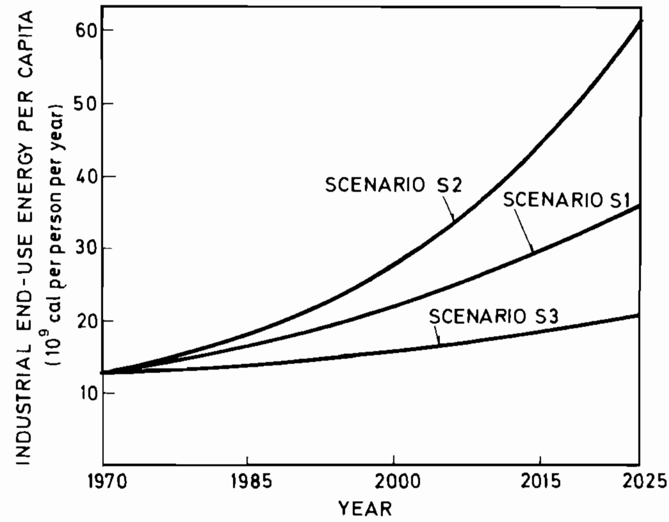

FIGURE 6.15 Industrial end-use energy per capita for the Wisconsin scenarios.

but a small portion of the electricity except in S3 where solar electrical generation provides 30 percent of the total by 2025. The average annual growth rate in electrical generation ranges from 3.1 percent in S3 to 5.2 percent in S2.

III.C.4. Energy Intensiveness in Industry

Each Wisconsin scenario has a different assumption about energy intensiveness in industry, as shown in Figure 6.14. The high-energy scenario assumes that the intensiveness doubles over the 55-year period; the Base Case intensiveness is nearly constant; and the low-energy case has intensiveness declining to about two-thirds of its 1970 value. The average change in intensiveness ranges from − 0.7 percent per year in S3 to + 1.3 percent per year for S2. For comparison, the U.S. industrial energy intensiveness* used by the Energy Policy Project declined at a rate of 0.2 percent per year for the historical growth scenario and decreased at an average rate of 1.5 percent per year in the zero-energy-growth scenario.[8]

The industrial end-use energy per capita for the three Wisconsin scenarios is plotted as a function of time in Figure 6.15. It should be noted that these three scenarios are based on the same population and industrial value-added assumptions. Thus, the curve for S3 in Figure 6.15 indicates that value-added per capita in industry is assumed to increase slightly faster than energy intensiveness declines.

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* Industrial energy intensiveness is estimated by dividing energy use in industry by total manufacturing value-added.

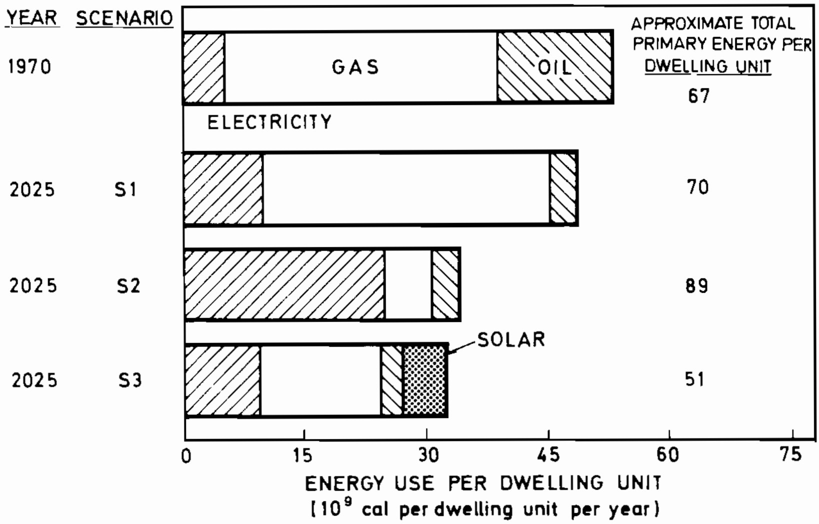

FIGURE 6.16 Annual end-use energy per average dwelling unit for Wisconsin.

III.C.5. Total Energy Use Per Dwelling Unit

The total end-use energy per dwelling unit for the three Wisconsin scenarios is plotted in Figure 6.16. It may seem surprising that the end-use energy in 2025 in the high-energy scenario (S2) is only slightly greater than in the low-energy scenario (S3) and is significantly lower than in the Base Case. The emphasis on electricity in S2 results in relatively low end-use energy but relatively high primary energy as the numbers on the right of Figure 6.16 indicate. Electrically-heated housing units are assumed to have better insulation than oil- or gas-heated units.

Since Figure 6.16 shows energy per average housing unit, it should be noted that the percentage of apartments is not the same in the three scenarios, as shown in Figure 6.17. Single-family houses require more energy than apartments; therefore, the 2025 primary energy use for S1 and S3 in Figure 6.16 would be somewhat higher, but still less than for S2, if the same percentage of single-family houses were used in all scenarios.

III.C.6. Personal Transportation

The end-use energy for personal transportation for the three scenarios is shown in Figure 6.18. Even with the assumed population growth from 4.4 million people in 1970 to 6.6 million in 2025, energy use for personal transportation shows a decline in absolute terms in S3 (21 percent over the same period) primarily because of (1) the introduction of a very efficient urban car, (2) increase in load factors, and (3) urban form (Table 6.17). The high-energy scenario (S2) shows a relatively level energy

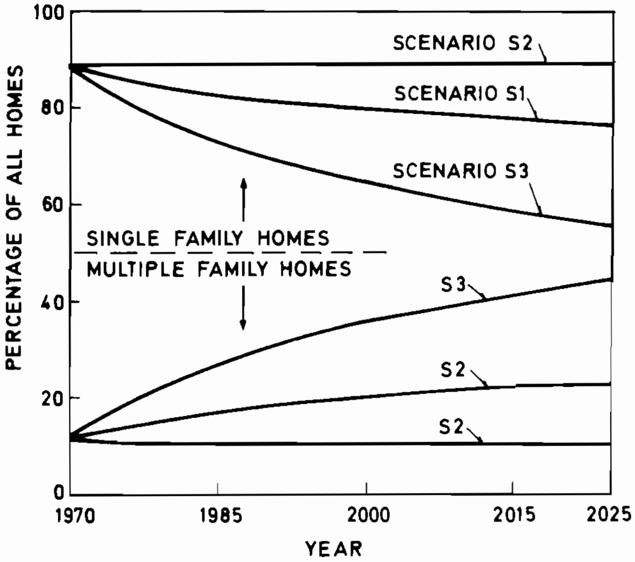

FIGURE 6.17 Type of housing assumed for the Wisconsin scenarios.

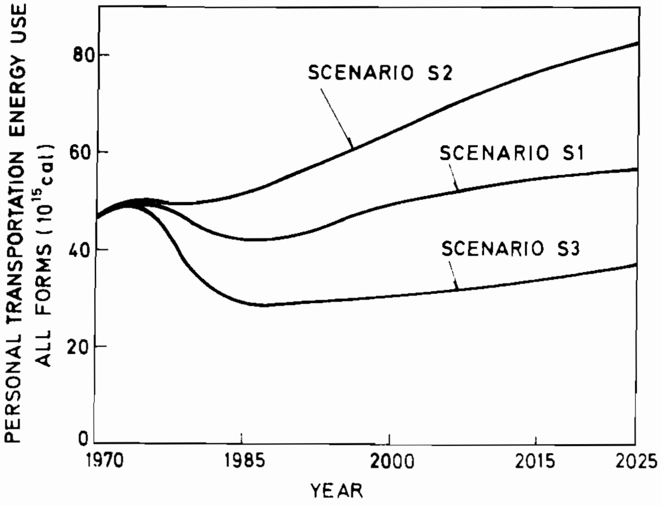

FIGURE 6.18 End-use energy for personal transportation for the Wisconsin scenarios.

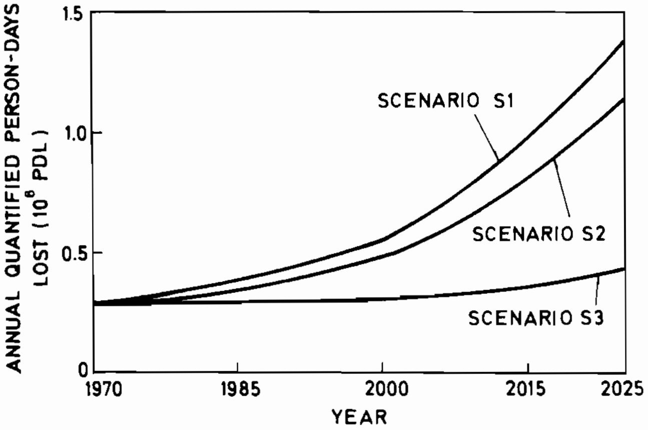

FIGURE 6.19 Quantified human health and safety impacts associated with energy use for the Wisconsin scenarios.

demand in the early years because the compact and small cars are assumed to increase their market share from 40 percent to 60 percent of the new car sales over the period 1970 to 1980.* These results for personal transportation clearly demonstrate that relatively modest measures in the transportation sector may save significant amounts of energy in a supply category where resources are limited.

III.C.7. Environmental Impacts

A comparison of the impacts among scenarios must of necessity be brief and cover only a few of the quantified impacts from the models. A few representative quantified impacts have been selected for description here. More details about the impacts that have been quantified and the models used can be found in Buehring and Foell.[18]

The quantified impact on human health and safety, as measured in person-days lost (PDL), that results from Wisconsin's energy use for the three scenarios is shown as a function of time in Figure 6.19.† The primary contributor is the quantified health impact on the public of air pollution from nonelectric energy use; this single category represents 68, 54, and 18 percent of the total PDL in the year 2025 for

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* Scenario S2 includes some electricity use for electric cars. If this electricity is included as primary energy in the transportation energy use of S2 in 2025, the transportation energy use increases from 83 × 10^{15} cal (Figure 6.18) to 95 × 10^{15} cal.

† At 6,000 PDL per fatality, the total PDL associated with energy use in S1 for 2025 is equivalent to nearly 230 fatalities. Alternatively, if these PDL are associated only with illness, the level of PDL in S1 is equivalent to one extra day of illness per year for 21 percent of Wisconsin's population in 2025.

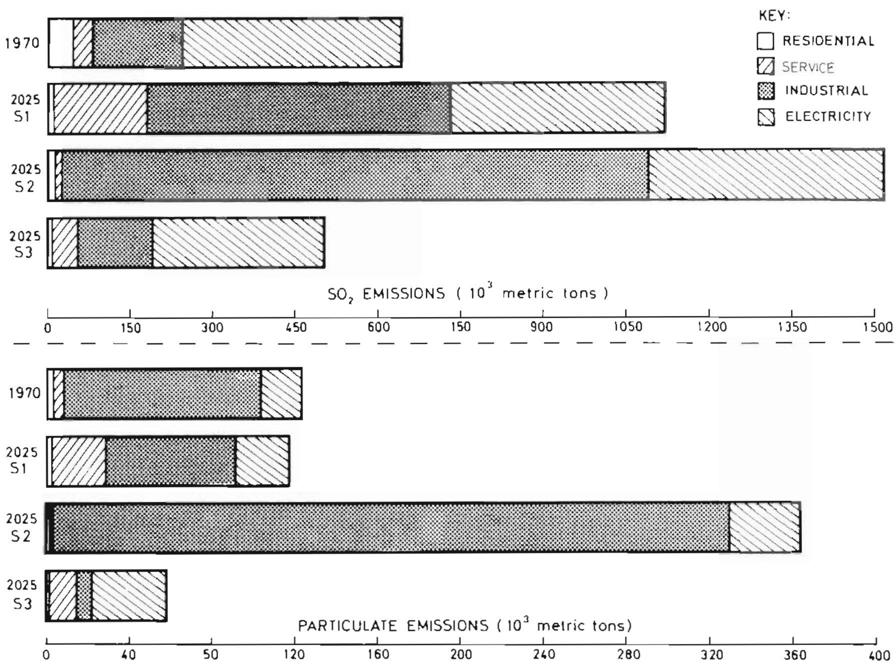

FIGURE 6.20 Sulfur dioxide and particulate emissions by sector for the Wisconsin scenarios.

the three scenarios, respectively.* One surprising result of this analysis is that the total PDL in the Base Case scenario (S1) is greater than the high-energy scenario (S2). One reason that S1 has relatively high PDL is that residential and service SO_2 emissions (Figure 6.20) are relatively high in areas of high population density. As described earlier, residential and service emissions generally have low release heights and therefore cause higher ground-level concentrations per unit emitted than emissions from tall stacks (Figure 6.10).

Residential and service emissions in S2 are less than in S1 because of the substitution of electricity for fossil fuels. Scenario S3 has much lower PDL from air pollution primarily because the industrial emissions are nearly an order of magnitude less than in S2 and the majority of service emissions are away from the main population center of Milwaukee. The quantified health impact of air pollution in the Wisconsin scenarios is strongly related to urban form as well as to the emission characteristics.

In 2025 more than one-fourth of the PDL in each scenario occurred outside

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* Only a portion of the impacts of air pollution have been quantified; these are primarily the result of short-term exposures to high levels of SO_2.[19]

TABLE 6.21 Control Factor Assumptions for SO_2 and Particulates in 2025 for the Wisconsin Scenarios

	Potential Emission That is Retained Because of Emission Control or Fuel Treatment (%)					
	SO_2			Particulates		
	S1	S2	S3	S1	S2	S3
Residential						
oil	60	30	80	0	0	0
gas	40	20	60	0	0	0
Service						
coal	0	0	40	60	40	80
oil	60	30	80	0	0	0
gas	40	20	60	0	0	0
Industrial						
coal	30	0	70	95	90	99
oil	50	0	80	30	0	50
gas	40	20	60	0	0	0
Electricity						
coal	67	67	75	99	99	99

Wisconsin's boundary; in S3 two-thirds of the total quantifed human health and safety impact is in other regions. Thus, it appears that if human health and safety is an important consideration in energy policy decisions, one must take a systemwide perspective and look beyond the impacts that occur in the immediate vicinity of the energy consumption.

The emissions shown in Figure 6.20 depend not only on the fuel used but also on the assumed control factors (Table 6.21). Thus, the industrial SO_2 emissions in 2025 decline by about a factor of 8 between S2 and S3 because the quantity of coal used drops and because the emission per unit of coal used in S3 is only 30 percent of the emission in S2. Electric power plants are assumed to have relatively good controls in all scenarios because they are such large point sources of pollution that extensive control measures are expected to be required.

Total quantified person-days lost are plotted against primary energy use in Figure 6.21. One observation that can be made from Figure 6.21 is that the quantified human health and safety expenditure per unit of primary energy is considerably less in S3 than S1. For example, in the year 2025, the PDL per 10^{18} cal of primary energy are 0.90, 0.59, and 0.43 in S1, S2, and S3, respectively; in 1970, this ratio was 1.0. Another observation is that S2, with its high electricity use, is less costly in terms of *quantified* human health and safety than the Base Case, in spite of the larger energy requirement. These results are influenced strongly by the quantified air pollution person-days lost, by the selection of alternative energy options, and by the assumed gradual reduction in human health and safety impact per unit of coal mined.

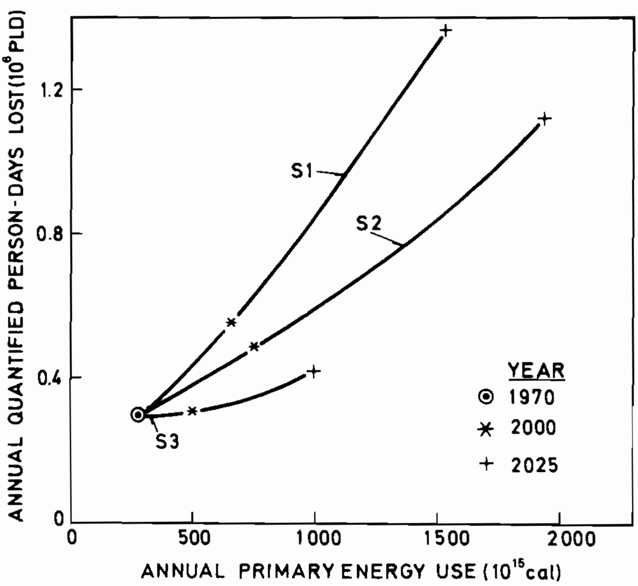

FIGURE 6.21 Quantified person-days lost as a function of primary energy use for the Wisconsin scenarios.

In some categories the low-energy scenario has greater impacts than the other scenarios. For example, land disturbed per unit of primary energy is considerably greater in S3 because of the solar electrical generating plants (Figure 6.22). The land use shown is the sum of all land disturbed, except for electricity transmission,* in order to produce the energy in the year shown. The land use in S3 by 2025 is about 0.3 percent of the area of Wisconsin; however, not all land use is in Wisconsin. The land use for solar energy in 2025 in S3 is 240 km^2. Solar electrical generation in Scenario S3 accounts for 30 percent of the total in 2025. The total land use in 2025 in Scenario S2 is larger than for S3 however; the primary energy requirement is approximately twice as large for S2 as for S3.

No scenario has the lowest environmental impact in *all* categories considered. Therefore, one must make value judgments concerning the tradeoffs among impacts. Of course, the conventional costs of the alternatives and the unquantified impacts must be included in the analysis along with the quantified impacts as discussed in Appendix E.

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* Land for electricity transmission corridors may still be usable, e.g. for agriculture. All land shown in Figure 6.22 is at least temporarily unavailable for other uses. The total land disturbed in 30 yr may be less for a solar plant than for a coal plant since new coal must be mined every year. However, the land used for mining can often be quickly reclaimed for other uses, while the land at the power plant is in use for the lifetime of the plant.

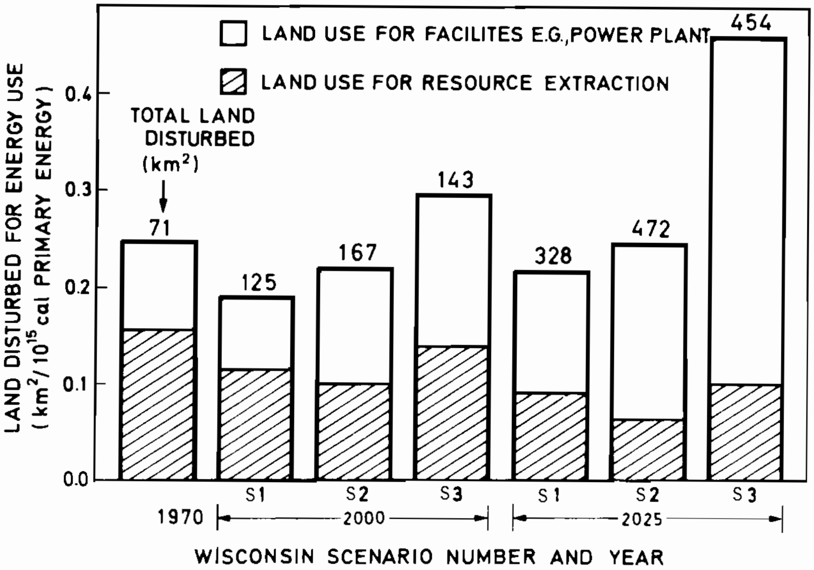

FIGURE 6.22 Land disturbed per unit of primary energy for the Wisconsin scenarios.

IV. SENSITIVITY STUDIES

A thorough sensitivity ansalysis of the scenarios presented in the previous section would require far more space than is available here. Therefore, several representative sensitivity studies have been selected for presentation. Among the topics discussed in this section are solar home heating and water heating, type of housing and fuel consumption, SO_2 controls on power plants, and transportation energy related to urban form.

IV.A. SOLAR HOME HEATING AND WATER HEATING

Solar energy is a major supply source for space heating and water heating in the low-energy scenario (S3). Residences that use solar systems with electrical auxiliary systems are assumed to increase from 5 percent of those constructed in 1980 to 50 percent of those constructed in 2000. After the year 2000, 50 percent of all new housing units are assumed to use solar energy.

The results for residential energy demand in the solar energy scenario (S3) are compared with the results for the same scenario with no solar energy in Table 6.22. Elimination of solar space heating and water heating in 2025 for the low-energy scenario would cause residential demand for (1) natural gas to increase by 56 percent, (2) electricity to decline by 13 percent, and (3) nonsolar end-use energy to

TABLE 6.22 Impact of Solar Energy on Wisconsin's Residential Energy Demand

End-use Residential Energy					Nonsolar Energy Use[b]	
With Solar Homes			Without Solar Homes			
	Electricity (10^9 kWh)[a]	Natural Gas (10^{15} cal)[a]	Electricity (10^9 kWh)	Natural Gas (10^{15} cal)	Solar Scenario (10^{15} cal)[a, c]	No Solar Energy (10^{15} cal)
1970	8.6	44.2	8.6	44.2	70.6	70.6
2000	21.0	50.1	20.2	55.0	81.8	86.0
2025	28.2	39.2	24.4	61.3	70.8	89.6

[a] These columns show results for the S3 low-energy scenario.
[b] Electricity converted at its end-use energy value of 0.86×10^6 cal/kWh.
[c] Solar energy is excluded from the end-use tabulated here. If solar energy absorbed by the collection devices were included, the results would be 85.0×10^{15} cal in 2000 and 85.2×10^{15} cal in 2025.

increase by 27 percent. For the low-energy scenario assumptions, solar energy significantly reduces the residential demand for natural gas, a fuel that is expected to be in short supply. The energy saving associated with solar energy could be even greater if some assumptions listed in Table 6.17 were changed to favor solar energy, e.g. addition of solar facilities to existing homes (retrofitting) could be allowed.

It is interesting to note that the residential nonsolar energy demand in the year 2025 for the case with solar energy is approximately the same as the residential nonsolar energy demand in 1970, in spite of a doubling of the total number of dwelling units over the 55-year period. Other contributing factors are the shift toward apartments with low energy use, better insulation, and other conservation measures.

IV.B. IMPACTS OF HOUSING TYPE ON FUEL USE

An important parameter in the residential model used is the percentage of single-family houses in new construction. In the Base Case, new housing is assumed to be 75 percent single-family houses and 25 percent multiple-family dwellings. The impact on natural gas use of changing the percentage of single-family houses in new construction is displayed in Figure 6.23; the differences are primarily the result of larger space heating requirements for single family houses. Natural gas demand in the residential sector for the case with 90 percent single-family houses is about 11 percent higher than the Base Case by the year 2025. The shapes of the curves in Figure 6.23 are strongly linked to the need for new housing; this in turn is affected by assumptions about population growth, family size, and replacement of old houses. However, it is evident in Figure 6.23 that a major shift to apartments, with no change in other factors such as insulation, would result in significantly lower demand compared to the Base Case scenario for natural gas demand in the residential sector.

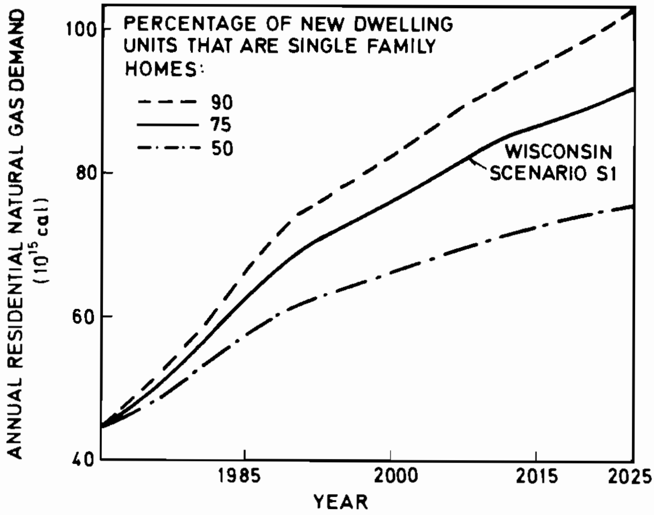

FIGURE 6.23 Effect of the type of housing on residential natural gas use in Wisconsin.

IV.C. SULFUR DIOXIDE CONTROL FOR ELECTRICAL GENERATION

Electrical generation from coal in Scenario S1 results in sulfur dioxide emissions that are at the maximum level permitted by the U.S. Environmental Protection Agency emission standards* (see section II.A. in Appendix B).

The standard is met by using a combination of low-sulfur coal from western states and SO_2 stack gas removal equipment on plants that use high-sulfur midwestern coal. The impact of eliminating SO_2 emission standards and discontinuing use of western coal in Wisconsin's power plants is the subject of this sensitivity study.

The impact on human health and safety in the year 2025 is indicated in Table 6.23. Eliminating SO_2 controls increases the public health impact in the year 2025 by about 34,000 PDL, but the public accident PDL declines by about the same amount.† The increase in public health PDL is primarily increased days of aggravation of heart and lung disease in the elderly. The reduction in public accidents is the result of shifting to coal that must be shipped a shorter distance (midwestern) than the western coal. The overall change in quantified PDL that results is small, but the burden has been shifted somewhat from people who live outside Wisconsin (transportation accidents) to people who live in Wisconsin (public health). The same general conclusions hold for the cumulative totals shown in Table 6.23, except that the magnitudes of the PDL are increased.

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* 1.2 lb SO_2 per 10^6 Btu heat input.

† This quantity of PDL is approximately equivalent to 6 premature fatalities. Total PDL in 2025 for S1 is 1,400,000.

TABLE 6.23 Quantified Person-Days Lost Related to Electrical Generation from Coal[a]

	2025		Cumulative 1970–2025	
	Base Case (S1)	No SO_2 Controls, No Western Coal	Base Case (S1)	No SO_2 Controls, No Western Coal
Occupational accidents (10^3 PDL)	47	46	1,600	1,600
Public accidents (10^3 PDL)	82	45	2,600	1,500
Occupational health (10^3 PDL)	0.3	0.4	100	100
Public health (10^3 PDL)	15	49	600	1,600
Total	144	141	4,900	4,800
PDL inside Wisconsin (%)	28	45	29	44
Total coal-fired electrical generation (10^9 kWh)	62	62	2,056	2,056

[a] Six thousand PDL are associated with each fatality or case of total disability. One PDL is associated with each excess asthma attack or excess day of aggravation for elderly people with preexisting heart and lung disease.

TABLE 6.24 Impacts on Land Related to Electrical Generation from Coal (km^2)

	2025		Cumulative 1970–2025	
	Base Case (S1)[a]	No SO_2 Controls No Western Coal	Base Case (S1)[a]	No SO_2 Controls, No Western Coal
Disturbed by surface mining	12.8	14.6	425	478
Subsidence from underground mining	7.9	9.5	268	312
Ash disposal at power plant	0.22	0.20	7.3	6.6
Sulfur sludge disposal at power plant	0.37	0.0	10.4	0.0
Solid waste from underground mining	0.03	0.03	1.0	1.1
Solid waste from coal cleaning plants	0.11	0.13	3.7	4.3

[a] There also is land disturbed in connection with the limestone needed for the sulfur removal system. In Scenario S1 the limestone needed is 1.3 million metric tons in 2025 and the cumulative (1970 to 2025) total is 38 million metric tons.

The impacts on land in the year 2025 that result from eliminating power plant SO_2 controls and discontinuing use of western coal are shown in Table 6.24. Western coal is generally found in much thicker seams than midwestern coal; therefore, more land is disturbed for surface mining and subsidence if midwestern coal is used. Of course, elimination of SO_2 controls also eliminates land needed for sulfur sludge disposal. The sludge is the product of the desulfurization system and is assumed to be piled in waste banks approximately 7.5 m high for wet limestone removal systems. The elimination of western coal results in more land disturbed for mining

TABLE 6.25 Impact of Electricity Supply Change for the Wisconsin High-Energy Scenario (S2)

	S2 as presented	S2 with No New Nuclear Plants
Annual electricity generation (10^9 kWh)		
2000 – nuclear energy	106	10
2000 – coal	53	149
2025 – nuclear energy	341	10
2025 – coal	85	416
Annual land use outside Wisconsin for Wisconsin's electricity generation (km^2)		
1970	9	9
2000	19	50
2025	31	139
Annual quantified public person-days lost from SO_2 radiation exposure resulting from electrical generation		
1970	10	10
2000	1,500	140
2025	5,700	170
Annual quantified public person-days lost from SO_2 exposure resulting from electrical generation		
1970	19,000	19,000
2000	13,000	37,000
2025	20,000	97,000
Annual water evaporated for electrical generation (10^6 m^3)		
1970	27	27
2000	320	250
2025	920	690
Cumulative (1970 through 2025) fuel resource use for electricity (10^6 metric tons)		
Uranium oxide (U_3O_8)	0.140	0.012
Thorium oxide (ThO_2)	0.0017	0.0001
Uranium and Thorium ore		
At 0.2% grade	71.	6.
At 0.01% grade	1,400.	120.
Coal	1,140.	3,340.

in midwestern states. However, the long-term impact may be less because midwestern land generally can be reclaimed faster and with less costly measures.

The difference between the total cumulative impacts for the Base Case and for "No SO_2 Controls" shown in Table 6.24 indicates that nearly 100 km^2 of additional land would be disturbed for mining if SO_2 controls are eliminated. However over 10 km^2 of land would have sulfur sludge piles by 2025 if the controls remain. The land for sludge piles may have more permanent effects than the nonwestern land disturbed for mining.

In summary, some effects of elimination of SO_2 controls on power plants and discontinuing use of western coal in power plants are:

- Some of the human health and safety impact related to electrical generation in Wisconsin is shifted from people who live in other states to the people who live in Wisconsin and are the electricity consumers.
- Land disturbed for mining is increased in areas where reclamation is easiest, but land for sulfur sludge waste piles is eliminated.

Of course there are many other factors that need to be considered before one can decide whether SO_2 emission standards for Wisconsin power plants are needed.

IV.D. ELECTRICITY SUPPLY MIX FOR THE HIGH-ENERGY SCENARIO

The electricity supply in the high-energy scenario (S2) is based on the assumption that 70 percent of the new non peaking electrical generating capacity added after 1982 is nuclear and the remainder is coal-fired. Some effects of having all new capacity be coal-fired are reviewed in this section.

The annual electricity generation that is nuclear and coal-fired for the years 2000 and 2025 is listed in Table 6.25 for S2 as presented earlier and for the same scenario with no new nuclear plants. Nuclear generation in the case with no new nuclear plants is about the current level of nuclear generation in Wisconsin.

The annual land use outside Wisconsin that results from electricity generation in Wisconsin includes:

- Land disturbed for surface-mined uranium
- Uranium mill tailings storage area
- Radioactive waste burial area
- Land disturbed by and subsidence from coal mining
- Coal mining waste disposal area
- Coal cleaning plant waste disposal area

Most of the land disturbed by mining can be reclaimed for other uses. The land used for waste disposal is generally a more permanent commitment, especially in the case of radioactive wastes. The land use tabulated here does not include land used for siting fuel industry buildings or any of the land used at the power plant itself (inside Wisconsin). The results shown in Table 6.25 indicate that the switch to coal increases the land use outside Wisconsin by over 100 km^2 in the year 2025. In general, electricity from coal requires more land disturbance than electricity from nuclear energy. However, this conclusion could be reversed by assuming that all coal were mined from very thick western subbituminous seams and all uranium from surface mining of very low-grade ores.*

The quantified public PDL from radiation is reduced approximately in proportion to the reduction in nuclear generation. The PDL level in 2025 in the high nuclear energy case is approximately equivalent to one radiation fatality per year. The quantified occupational PDL from radiation is about six times greater than the public PDL shown in Table 6.25.

When coal-fired plants meet SO_2 emission standards that were announced after 1970, the quantified public PDL from SO_2 exposure increases approximately in proportion to the coal generation. The primary contributors to this category of PDL are excess asthma attacks (one PDL is assumed per attack) and excess days of aggravation of heart and lung disease in the elderly. If there were no SO_2 removal systems assumed in these cases, public PDL from SO_2 would be increased by approximately a factor of three in the years 2000 and 2025.

The total water evaporated from power plant cooling systems is about 30 percent higher in the case with new nuclear plants than in the case with no new nuclear plants. In general, nuclear reactors have a larger quantity of heat to reject to the condenser cooling water than a similarly-sized coal plant because the nuclear plant has a lower thermal efficiency (advanced reactors may have efficiencies about equal to coal plants) and because a coal plant emits some waste heat directly to the atmosphere via the stack. Therefore, a nuclear reactor will evaporate more water than a coal plant of the same size with the same cooling system. The total fresh water consumed for all purposes (evaporated, transpired, or incorporated into products) in Wisconsin in 1970 was only 250 million m^3, so the quantities of water consumption indicated in Table 6.25 may be more than can reasonably be allowed. Some form of dry or nonevaporative cooling system, which usually has a large thermal efficiency penalty and cost, may be required. Even the Base Case scenario (S1), with its lower electricity demand, has about 300 million m^3 of water evaporation for electrical plant cooling in the year 2025.

The cumulative fuel resource consumption for these scenarios with high energy and electricity demands are also shown in Table 6.25. If nuclear power is accepted as the major electricity supplier in other states and electricity demand per capita is about the same all over the United States, then the U.S. cumulative uranium requirements through the year 2025 would be about 7 million tons. The U.S. Energy Research and Development Administration (ERDA) has recently estimated domestic U.S. uranium resources under $30/lb as approximately 3.5 million tons.[24] If this estimate were correct, then the extensive nuclear power development described in the high-energy scenario S2 might have to be more heavily dependent on the breeder reactor, with its extremely low uranium consumption rate; in S2 as currently

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* Low-grade concentrations of uranium are at levels of 100 or less ppm while high-grade concentration is about 2,000 ppm.

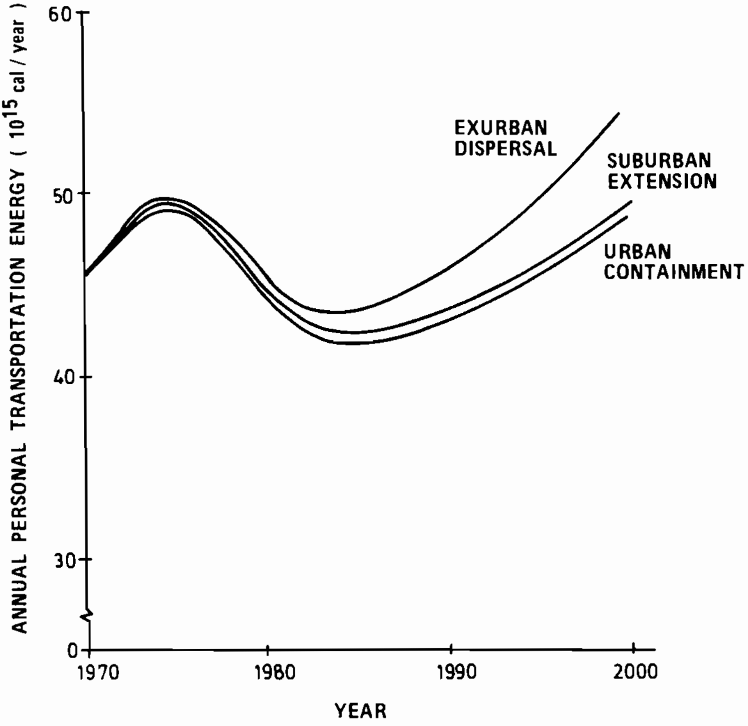

FIGURE 6.24 Urban form and resultant transportation energy use.

described, the breeder was only 5 percent of new nuclear capacity after 1995. On the other hand, if U.S. domestic uranium reserves are considerably more plentiful, and need only additional incentives for exploration and development as argued by the most recent Ford Foundation study,[25] even this high-energy nuclear future might not require significant contributions by the breeder during the time period considered.

The cumulative coal resource requirements are 1.1 billion metric tons in the low nuclear variation of S2. Total recoverable coal resources in the United States have been estimated to be in the range of 1 to 1.8 billion tons.[26] Coal reserves in the United States are sufficient to withstand high-energy growth scenarios for decades, but other factors, such as associated environmental effects, may limit this fuel's use.

Other impacts with long-term implications, such as radioactive waste production by nuclear plants and CO_2 production from the use of coal, increase or decrease approximately in proportion to the energy produced from the respective sources.[27] It is clear that value judgments concerning tradeoffs between impacts and costs are necessary to decide on the most acceptable electricity supply future.[28]

IV.E. TRANSPORTATION ENERGY AND URBAN FORM

The final sensitivity study shows the relationship between alternative population growth patterns and personal transportation energy use.[5] The Base Case scenario uses the suburban extension growth pattern, which is an extension of current trends. The other alternatives shown in Figure 6.24 are an exurban dispersal case, in which the population growth is mainly in rural areas, and an urban containment case with small compact cities, in which growth occurs in small urban areas (20,000–100,000 people). The exurban case results in an 11-percent increase in energy use over the Base Case by the year 2000. Considering that only incremental population is affected, this is a substantial increase that would remove over half the savings resulting from the assumed increase in fuel economy (see the discussion of transportation in section II.B.). The small compact cities case results in a 9-percent energy savings over the Base Case by the year 2000.

These studies have indicated that variation of city size, population density, and the mix of surrounding communities can significantly alter the personal transportation energy demand.

V. OVERALL CONCLUSION FOR THE WISCONSIN SCENARIOS

The process of scenario writing and evaluation is an iterative process in which the scenario writers learn something about inconsistencies, data problems, and what assumptions other people feel are more realistic than the ones in the scenario. During the workshop when the preliminary results of the Wisconsin scenarios were presented for the first time, several workshop participants suggested assumption changes that would result in scenarios they felt would better span the options available for Wisconsin.* Workshop participants also commented on which information was and was not of particular interest; these comments have helped to shape the presentations in the previous sections, and to develop new scenarios that reflected the perceptions of some of these participants and use more recent policies and data.†

A few general conclusions drawn from the Wisconsin scenarios are listed below for each of the policy areas. Needless to say, additional policies related to population growth and economic activity will also affect energy and environmental

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* Workshop on Integrated Management of Regional Energy/Environment Systems held November 10–14, 1975, at the International Institute for Applied Systems Analysis in Laxenburg, Austria.

† Summary descriptions of such policies and data are given in: The Potential Impact of the National Energy Plan on Wisconsin's Energy Future, Institute for Environmental Studies Report (Madison, Wisconsin: The University of Wisconsin-Madison, June 1977); and J. R. Peerenboom *et al.*, Alternative Energy Futures for Wisconsin, In W. K. Foell (ed.), *Proceedings of the 1978 Conference on Alternative Energy Futures for Wisconsin* (Madison, Wisconsin: Energy Research Center, University of Wisconsin-Madison, 1978).

systems. Several of the following statements are based on value judgments and should be recognized as such.

Urban Settlements

- Energy use and environmental impacts are strongly related to urban form. Land use planning, zoning, and other policy-setting actions need to consider these factors.
- Energy efficient transportation planning must account for future urban forms.

Transportation

- Large energy savings are possible if relatively modest policy shifts are directed toward more efficient automobiles and more rail shipment of freight. This is especially important if saving is needed in petroleum consumption.

Energy Intensity

- Conservation measures or more efficient use of energy per unit of activity in several of the 20 industrial categories and for the service sector would favorably affect Wisconsin's energy/environment future.

Energy Supply

- If a long-term shortage of natural gas and petroleum develops, strong conservation measures, synthetic fuel from coal, solar energy, and a shift to electricity can help alleviate the shortfall.
- Coal and nuclear power, and possibly solar energy after a few decades, are the basic electricity supply options. Each has its long term and short-term advantages and disadvantages.
- Solar space heating and water heating has the potential for significantly reducing natural gas and petroleum demand.
- Electricity supply options are not tied strongly to the growth in demand except through resource limitation and environmental impacts. For example, solar electric power may be developed faster in a high-energy scenario but may be limited by its land requirement.

Environmental Protection

- Coal is better utilized by converting to a low-sulfur form as a synthetic fuel, or for electric generation, than for direct residential and commercial applications that typically result in high ground level pollution concentrations.
- Significant environmental effects from Wisconsin's energy use occur in regions other than Wisconsin.
- Land use may limit solar electric applications.
- Tall stacks are better than no stacks, but reducing sulfur emission is an even better way to reduce health impacts from sulfur dioxide.
- If electricity consumption continues to grow, power plants may have to turn to nonevaporative cooling systems.

- Energy transport systems do not result in insignificant environmental impacts.
- Quantified human health impact from air pollution is a significant consideration in all scenarios examined.
- Quantified environmental impacts cannot be considered in isolation, but must be combined with conventional costs, unquantified impacts, and other factors in the decision process.

The three Wisconsin scenarios selected for presentation are not considered the best or only alternatives facing the state. No judgments have been made on the probability of occurrence for the scenarios. However, the scenarios have demonstrated that there is a spectrum of futures open to Wisconsin and that management related to a small piece of the energy/environment system would be aided by a view of the entire energy system and related environmental impacts. The scenarios also provide an opportunity to study and display the fundamental components of the Wisconsin energy/environment system and contribute to a better basis for choosing among Wisconsin's energy paths into the future.

APPENDIX

ENERGY TABLES FOR WISCONSIN SCENARIO S1

TABLE 6A.1 Primary Energy Supply (10^{15} cal)

	1970 (for comparison)	2000	2025
Petroleum	114.7	168.8	91.8
Natural gas	90.3	149.1	72.2
Synthetic fuel from coal			
End-Use fuel	0.0	35.4	473.9
Conversion loss	0.0	29.7	403.2
Total primary energy	0.0	65.1	877.1
All other coal	80.7	130.4	253.4
Nuclear energy	0.1	100.4	225.1
Hydropower	1.6	2.1	2.1
Total	287.4	615.9	1521.7

TABLE 6A.2 End-Use Energy Consumption (10^{15} cal)

	Coal	Gas	Oil	Electricity	Total	Electricity (10^9 kWh)
2000						
Industrial	48.3	54.6	8.2	15.8	126.9	18.4
Residential		76.4	13.9	19.0	109.3	22.1
Service	3.1	33.8	35.3	24.6	96.8	28.7
Transportation			129.2		129.2	
Total	51.4	164.8	186.6	59.4	462.2	69.2

TABLE 6A.2 – Continued

	Coal	Gas	Oil	Electricity	Total	Electricity (10^9 kWh)
2025						
Industrial	100.0	95.7	12.8	28.5	237.0	33.1
Residential		92.5	9.0	25.4	126.9	29.6
Service	8.3	90.9	98.1	66.3	263.6	77.1
Transportation			228.1		228.1	
Total	108.3	279.1	348.0	120.2	855.6	139.8

TABLE 6A.3 Fuels for Electricity

	Generation (10^9 kWh)			Primary Energy (10^{15} cal)		
	1970	2000	2025	1970	2000	2025
Hydropower	1.6	2.1	2.1	1.6	2.1	2.1
Petroleum	0.6	0.9	1.7	2.0	2.9	5.6
Gas	2.4	0.9	1.6	7.9	2.9	5.2
Coal	21.8	33.9	62.3	60.3	79.0	145.1
Nuclear energy	0.04	38.7	86.8	0.1	100.4	225.1
Total	26.4	76.5	154.5	71.9	187.3	383.1

TABLE 6A.4 1970 End-Use Energy (10^{15} cal)

	Coal	Gas	Oil	Electricity	Total	Electricity (10^9 kWh)
Industrial	19.5	27.9	4.8	5.6	57.8	6.5
Residential		44.2	19.0	7.4	70.6	8.6
Service	0.9	10.3	11.1	7.5	29.8	8.7
Transportation			77.8		77.8	
Total	20.4	82.4	112.7	20.5	236.0	23.8

ENERGY TABLES FOR WISCONSIN SCENARIO S2

TABLE 6A.5 Primary Energy Supply (10^{15} cal)

		2000		2025
Petroleum		155.0		91.8
Natural gas		95.1		72.2
Synthetic fuel from coal				
End-use fuel	27.8		292.3	
Conversion loss	24.2		260.6	
Total primary energy		52.0		552.9
All other coal		179.7		331.8
Nuclear energy		273.7		879.3
Hydropower		2.1		2.1
Total		757.6		1,930.1

TABLE 6A.6 End-Use Energy Consumption (10^{15} cal)

	Coal	Gas	Oil	Electricity	Total	Electricity (10^9 kWh)
2000						
Industrial	55.8	66.4	9.5	28.8	160.5	33.5
Residential		30.2	13.7	42.3	86.2	49.2
Service	0.5	5.2	5.9	51.4	63.0	59.8
Transportation			138.8	4.8	143.6	5.6
Total	56.3	101.8	167.9	127.3	453.3	148.1
2025						
Industrial	133.5	137.8	17.3	120.0	408.6	139.5
Residential		15.8	8.7	64.2	88.7	74.6
Service	0.3	2.9	3.4	148.4	155.0	172.6
Transportation			248.8	5.5	254.3	6.4
Total	133.8	156.5	278.2	338.1	906.6	393.1

TABLE 6A.7 Fuels for Electricity

	Generation (10^9 kWh)		Primary Energy (10^{15} cal)	
	2000	2025	2000	2025
Hydropower	2.1	2.1	2.1	2.1
Petroleum	1.3	3.3	4.3	10.8
Gas	1.2	3.3	123.4	198.0
Nuclear energy	106.1	340.8	273.7	879.3
Total	163.6	434.4	407.4	1,101.0

ENERGY TABLES FOR WISCONSIN SCENARIO S3

TABLE 6A.8 Primary Energy Supply (10^{15} cal)

		2000		2025
Petroleum		131.0		91.8
Natural gas		105.0		72.2
Synthetic fuel from coal				
End-Use Fuel	26.2		216.3	
Conversion Loss	22.3		191.6	
Total primary energy		48.5		407.9
All other coal		159.1		254.6
Nuclear energy		27.3		27.3
Hydropower		2.1		2.1
Solar energy		11.3		128.2
Total		484.3		984.1

TABLE 6A.9 End-Use Energy Consumption (10^{15} cal)

	Coal	Gas	Oil	Electricity	Solar	Total	Electricity (10^9 kWh)
2000							
Industrial	34.5	42.5	5.8	11.2	0.0	94.0	13.0
Residential		50.1	13.6	18.1	3.2	85.0	21.0
Service	2.1	21.8	22.8	24.5	1.3	72.5	28.5
Transportation			101.0			101.0	
Total	36.6	114.4	143.2	53.8	4.5	352.6	62.5
2025							
Industrial	55.8	58.2	7.1	15.7	0.0	136.8	18.2
Residential		39.2	7.3	24.3	14.4	85.2	28.2
Service	5.5	44.3	47.0	69.1	16.0	181.9	80.3
Transportation			168.0			168.0	
Total	61.3	141.7	229.4	109.1	30.4	571.9	126.7

TABLE 6A.10 Fuels for Electricity

	Generation (10^9 kWh)		Primary Energy (10^{15} cal)	
	2000	2025	2000	2025
Hydropower	2.1	2.1	2.1	2.1
Petroleum	0.7	1.4	2.3	4.6
Gas	0.7	1.4	2.3	4.6
Coal	52.6	83.0	122.5	193.3
Nuclear energy	10.1	10.1	27.3	27.3
Solar energy	2.9	42.0	6.8	97.8
Total	69.1	140.0	163.3	329.7

	2000	2025
Total capacity (MWe)	15,777	31,964
Solar contribution (MWe)	1,120	15,982

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7 Cross-Regional Comparison of Energy/Environment Futures

I. INTRODUCTION

I.A. PURPOSE

With so much energy data available from the three regions, it is an irresistible temptation to make comparisons and draw conclusions concerning energy consumption patterns. Although many problems and pitfalls with such comparisons are recognized, this section is an attempt to highlight some cross-regional comparisons that the IIASA research team felt were both meaningful and interesting. Structural differences related to the climate, natural resources, past economic and social development of the region, as well as policy differences are considered in their influence on energy consumption and environmental impact. It is in the expectation of developing a greater understanding of the complex interactions and interdependencies in the energy supply and demand system and socioeconomic development that the comparisons are made, rather than to imply that any region is "better" or "worse" than any other region in total or in any particular respect. We hope this section will be read in the same spirit.

It is only within the framework of the differing political and administrative structures of the three regions and their physical, economic, and social characteristics that comparison can be made and understood. Frequent reference will be made to material discussed previously in the sections describing the regions and their institutional structures. Descriptions of the scenarios being compared can be found in the previous three chapters. This chapter also provides a good opportunity to examine the consistency and plausibility of assumptions made by the research team and to explain the differences.

Chapter 7 was written by Jacqueline Buehring and William Buehring – IIASA; and Wesley K. Foell – Energy Research Centre, University of Wisconsin – Madison.

I.B. SPECIAL CONSIDERATIONS

The scenarios for the regions are described in detail elsewhere. Briefly, they are: (1) the Base Case, (2) a high-energy case, and (3) a low-energy conservation case.

The German Democratic Republic (GDR) plans long-term development over a 20-year period in a centrally planned economy.* The Base Case for the composite Bezirk X therefore represents the "plan" through 1995 and an extrapolation of the plan from 1995 to 2025. For the state of Wisconsin, on the other hand, with its diffuse decision-making apparatus, no coherent plan is available. The system is complicated not only by decisions made under multiple conflicting objectives but also by decisions made by several decision-makers each with his or her own set of conflicting objectives. The Base Case scenario for Wisconsin is a continuation of present trends with restraints, limits, and new technologies imposed according to the best judgment of the IIASA team. The Base Case for the Rhone-Alpes region is defined from past economic trends and the current energy plans of the government, essentially in the same manner as the Wisconsin Base Case scenario.

The high-energy scenario and the conservation scenario for each region were also written within the constraints imposed by the political and economic systems and physical resources of the regions. The result is that the alternative scenarios are not defined identically across the regions, and care must be taken in drawing conclusions from comparisons of both assumptions and results.

The initial reference year for the scenarios is 1970. This year was chosen because the energy data were more complete than for subsequent years and consequently calibration was more readily achieved. However, data from later years were used in specifying parameters in the scenarios and in the models.

Data were available in varying quantity and with varying reliability from the regions. Wisconsin, Rhone-Alpes, and Bezirk X in the GDR are all regions embedded within a larger political unit. Since the GDR is a centrally planned economy, a large quantity of data is available to the central authorities and planners. Bezirk X is, however, a hypothetical bezirk with characteristics chosen to represent a typical industrial area of the GDR. Appropriate, although composite, data are therefore available, but consistency problems sometimes arise. Wisconsin is a distinct political unit within the United States, with its own legislative, judicial, and administrative apparatus. Many decisions relating to energy are made at the state level, so a great deal of data is available. The planning regions within France, of which Rhone-Alpes is one, are recent creations with no government of their own. Consequently, few data have been collected on a regional basis and much of the Rhone-Alpes data for this study was deduced from data for France as a whole.

Another obvious result of the political structures is that only in Wisconsin are many energy-related decisions made at the regional level. Therefore, one might expect to see more decisions made in Wisconsin "for the good of the region" (rather

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* As noted in section I. in Appendix B, a 20-year plan is not developed in the same sense of the word as the official 1- and 5-year plans.

than "for the good of the country") than in either Rhone-Alpes or Bezirk X. The goals of the planning process in both Bezirk X and Rhone-Alpes are likely to be the goals of the country as a whole with the region playing the part assigned to it. Wisconsin has much more autonomy with respect to setting its goals and carrying out plans to implement those goals. One result of this may be that Wisconsin is unlikely to tolerate any very large adverse environmental effect, especially one that would harm the very important tourist industry of northern Wisconsin.

Another difference between the regions, possibly influenced by the political structure described above, is the role envisioned for each region within the national economy. Rhone-Alpes and Bezirk X are both heavily industrialized, as is the southeastern area of Wisconsin. Plans for future development show very large expansion of industrial activity in Bezirk X compared with the planned growth for the GDR as a whole. In Rhone-Alpes, both past trends and plans for the future indicate a higher growth rate for Rhone-Alpes than for the whole of France. The Wisconsin economy, on the other hand, is expected to grow at a rate comparable to or slightly less than the growth rate of the United States as a whole. Thus, the anticipated roles of the regions in their countries must be considered when looking at the scenario cross-regional comparisons dealing with industry, transportation, energy supply, and environment.

II. SOCIOECONOMIC COMPARISONS

II.A. POPULATION

The population, the population distribution by size of city, and the population density are important factors in energy demand and the human health impacts of pollution. Population remains nearly constant in Bezirk X and grows slowly in both Rhone-Alpes and Wisconsin for the 55-year period of the study. Total population and overall population density are graphed in Figure 7.1. The projections shown were used for all scenarios. A relatively large proportion of the population is in older age groups in the GDR (see Table 8.2). It is therefore very unlikely that population will grow in the next 55 years and that has been reflected in the hypothetical Bezirk X. The constant population in turn restricts employment.

In addition to the total population, the density distribution and the distribution of the population by city size also have an important impact on per capita energy consumption and health effects of air pollution. The calculation of the population densities is described in Chapter 3. The fractions of the population in high density areas in Rhone-Alpes and the Bezirk are greater than in Wisconsin, the result of differences in historical patterns of growth between the three regions. Obviously, the structure of cities changes only gradually and the urban scenarios presented in the scenario chapters are attempts to explore the possibilities and effects of different types of urban development.

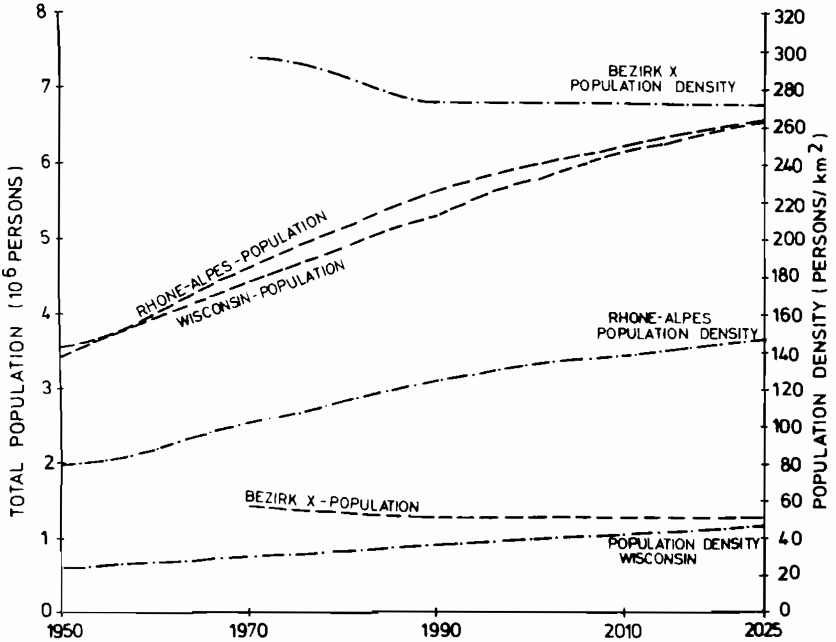

FIGURE 7.1 Population and population density in the three regions (actual figures until 1970, projected thereafter).

II.B. ECONOMY

Comparison of economic indicators is complicated by a lack of consensus on the proper currency exchange rates and by different definitions of the industrial and service sectors. Therefore, economic activity is described in relationship to the 1970 value in each country rather than analyzed on an absolute basis. Then comparison can be made across the regions on the change in productivity or energy intensiveness per unit of output.

The value-added or net production in a particular year for a particular region did not vary across the scenarios, except for Scenario 3 for Rhone-Alpes. Figure 7.2 shows the change in economic activity per capita in the industrial and service sectors that formed the basis for the scenarios. It must be emphasized that the value-added is a variable exogenous to the energy models. In Rhone-Alpes it is a continuation of current economic trends resulting in growth rates that start at 5 percent per year in 1970 and decline to 3.5 percent per year by 2025. Scenario S3, the low-energy scenario, includes a shift from industrial to service sector activity and a reduction in the value-added growth rate. Total value-added in 2025 for S3 is approximately 60 percent of that used in S1 and S2. In Wisconsin the overall economic growth is

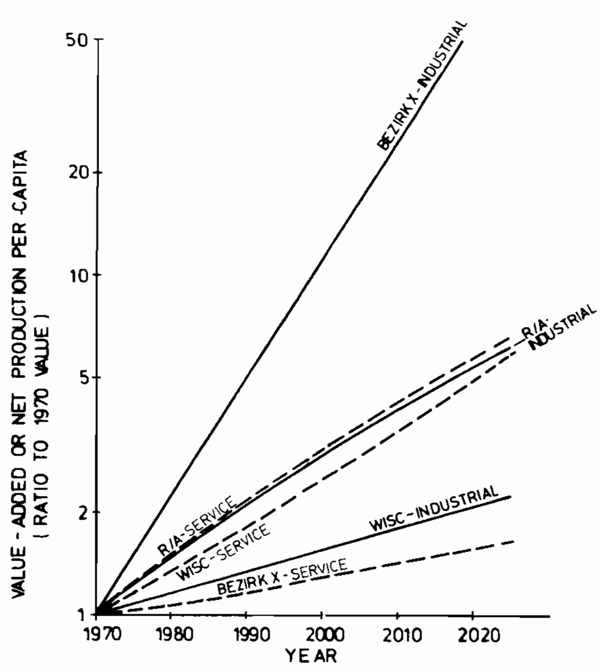

FIGURE 7.2 Economic activity indicators (ratio to 1970 value).

projected at 3.1 percent per year, somewhat lower than historical trends, with a continuing trend toward greater activity in the service sector. Only the southeastern area around Milwaukee is heavily industrialized and Wisconsin is not now, or expected to be in the future, a large industrial center. Industrial activity in Wisconsin more than doubles from 1970 to 2025; service sector activity increases by a factor of approximately 6.

The data from the Bezirk are from the 20-year "plan" through 1995 and from an extrapolation of the plan after 1995. Economic growth is 8.3 percent per year or a factor of 75* over the 55-year time period in the industrial sector, but the service sector grows linearly and grows much less than either Wisconsin or Rhone-Alpes service sectors. Such a large growth in production naturally raises many questions about the corresponding social and political consequences. Unless the increase in production is exported from the region without equivalent compensation for the workers involved, one would expect the personal income in the area to grow commensurately with the increase in production since industrial employment does not increase. Such a large increase in income could be expected to alter the lifestyles and expectations of the people in the areas of personal transportation and housing.

* Somewhat greater on a per capita basis since population declines slightly over the period.

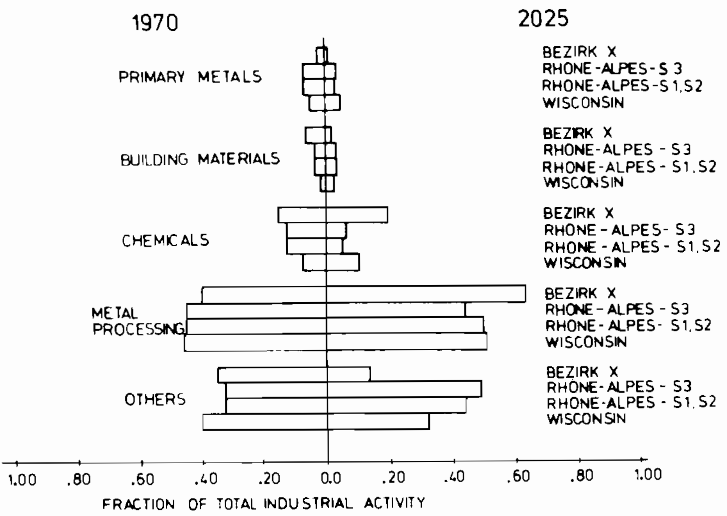

FIGURE 7.3 Industrial activity by industrial sector (all scenarios unless otherwise indicated).

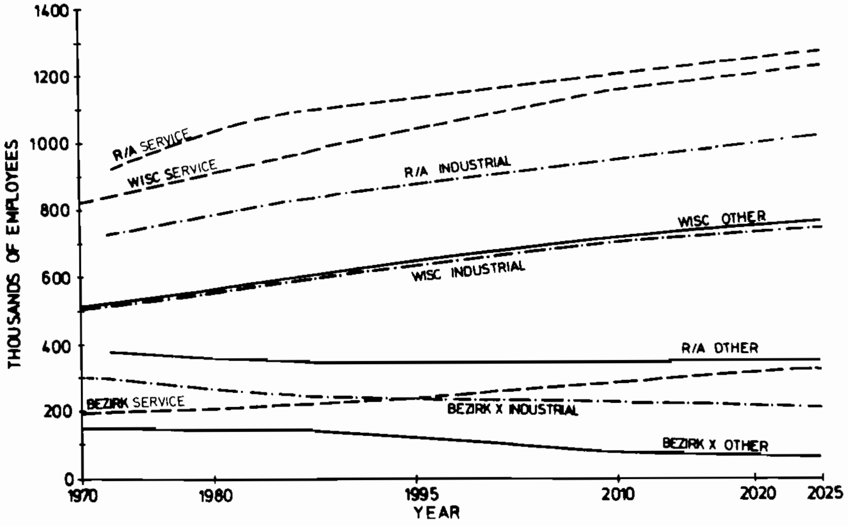

FIGURE 7.4 Employment by economic sector (all scenarios).

Secondary questions may also be asked about the effect on energy demand of the consumer or of the industrial goods produced.†

The distribution of industrial activity by industry is shown in Figure 7.3. The

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† See the Prologue to this chapter for comments on this economic growth.

distribution is quite similar among the three regions in 1970; Wisconsin has a slightly larger fraction of metal fabrication and a smaller fraction of chemicals.

By the year 2025, the fractions of the very energy intensive metal processing and chemical industries have increased slightly in Wisconsin, decreased slightly in Rhone-Alpes, and increased considerably in the Bezirk. This factor would tend to increase overall energy intensiveness in Bezirk X with respect to Wisconsin and Rhone-Alpes. This increase, however, is more than offset in the energy use results of the scenarios by assumed improvements in technology that will be discussed later.

Employment in the service and industrial sectors is compared in Figure 7.4. In the projections for all three regions, the percentage of the population that is employed remains fairly constant; only Rhone-Alpes shows a change of as much as 3 percent. In 1970, approximately 42 percent of the population is employed in Rhone-Alpes and Wisconsin and approximately 46 percent in Bezirk X. In Bezirk X, the population is nearly constant so that the size of the work force is nearly the same in 2025 as in 1970. Rhone-Alpes and Wisconsin with their slowly growing populations have a larger work force at the end of the period. It is interesting to note that although industrial value-added is increasing at a very high rate in Bezirk X, the industrial sector is losing employees to the service sector where productivity (economic activity per employee) is assumed not to increase. In Rhone-Alpes and Wisconsin where activities such as insurance, consulting and computer service companies are increasingly influencing the service sector, that sector is not only assumed to grow faster than the service sector in Bezirk X, but productivity is also assumed to increase. Figure 7.5, with value-added or total production plotted against employment, gives an idea of employment and economic activity changes over the 55-year period, and indicates changes in productivity as well. Reference lines representing constant productivity, a tripling of productivity, and a tenfold increase in productivity, are also plotted. For example, any point, independent of the year, that falls on the line labeled "tripling of productivity" implies a threefold increase in productivity over the 1970 value. Bezirk X industrial productivity crosses that line well before the year 2000. Rhone-Alpes industrial productivity crosses that line about the year 2000, and Wisconsin's industrial productivity does not triple even by the year 2025.*

There are additional factors that must be considered in comparing the assumed productivity changes. One is that the three regions do not start at the same level of productivity, and as no comparison has been made on absolute values of production or value-added, no absolute comparison can be made on productivity. Productivity in the industrial sector by 2025 is projected to increase by factors of over 100 in the Bezirk (calculated from production and employment figures supplies by the Institut für Energetik in the GDR) by a factor of approximately $2\frac{1}{2}$ in Wisconsin, and by a factor of slightly over 6 in Rhone-Alpes. The consensus of the IIASA research group is that the Bezirk-X estimate is probably overly optimistic for the

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* A tripling of productivity over the 55-year period can be attained by an average annual increase of 2 percent.

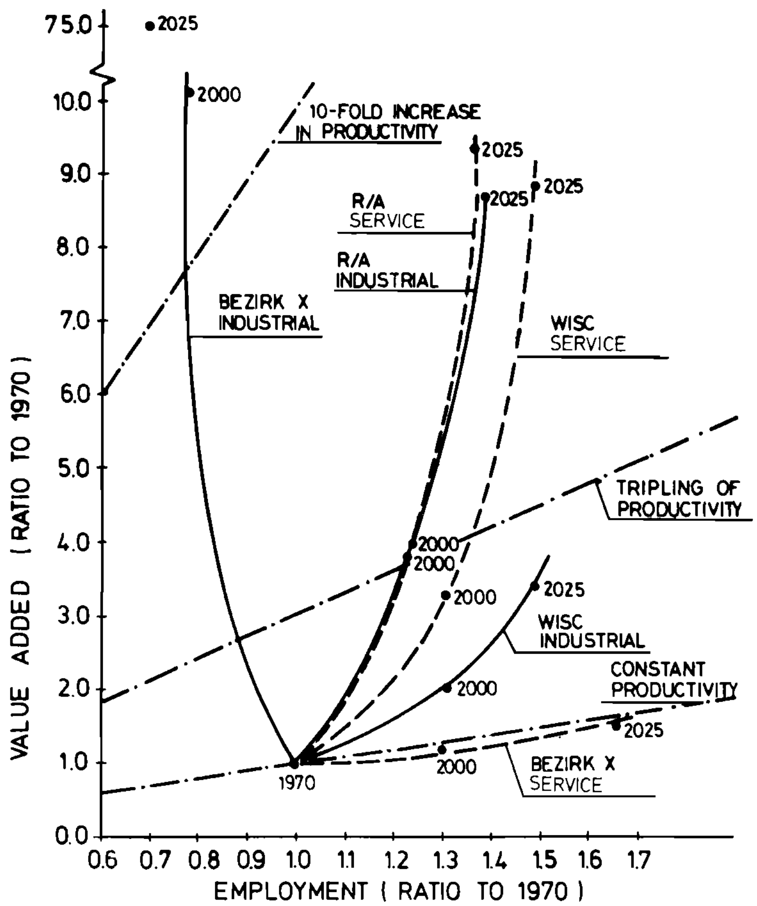

FIGURE 7.5 Value-added plotted against employment (ratio to 1970 value).

period after 2000, and that in any event, the differences in growth rates between the regions in both production and productivity will probably not be as extreme as indicated by these scenarios.

In summary

- Economic activity is assumed to increase at approximately 3.1 percent per year in Wisconsin, 3.5 percent to 5 percent in Rhone-Alpes, and 8.2 percent in Bezirk X, with most of the Bezirk's growth occurring in the industrial sector.
- Employment patterns are not assumed to change drastically in any of the regions. In Wisconsin and Rhone-Alpes the service sector is the largest employer; in Bezirk X the industrial sector employs the greatest number of workers in 1970 but by 1995 the service sector passes the industrial sector in number of employees.

TABLE 7.1 Annual End-Use Energy

		Bezirk X			Rhone-Alpes			Wisconsin		
	Scenario	1970	2000	2025	1970	2000	2025	1970	2000	2025
Annual end-use energy (10^{15} cal/yr)	S1	29	48	96	117	236	398	236	462	856
	S2	29	62	223	117	277	500	236	453	907
	S3	29	47	80	117	238	297	236	352	572
Annual end-use energy/capita (10^9 cal/person/yr)	S1	20	37	73	25	39	60	53	80	130
	S2	20	48	171	25	46	76	53	78	138
	S3	20	36	61	25	40	45	53	61	87
Density of annual end-use energy (10^{12} cal/km^2)	S1	6	10	20	3	5	9	2	3	6
	S2	6	13	43	3	6	11	2	3	6
	S3	6	10	17	3	5	7	2	3	4

- By 2025, productivity declines in the Bezirk service sector; approximately doubles in the Wisconsin industrial sector; increases by a factor of 5 or 6 in the Rhone-Alpes service and industrial sectors and in the Wisconsin service sector; and increases by a factor of over 100 in the Bezirk industrial sector.

III. END-USE ENERGY DEMAND*

End-use energy includes only energy consumed in end-use processes; conversion and transmission losses, such as in electrical generation, are excluded from the end-use energy total. Each sector will be discussed in detail in this section, but first a summary of total annual end-use energy for all three scenarios is shown in Table 7.1. For reference, the Wisconsin average annual end-use energy consumption per capita in 1976 was 57×10^9 cal/yr or about 23 percent less than the 1976 U.S. average.[10] Wisconsin uses more than twice as much energy per capita as Rhone-Alpes or Bezirk X in 1970 and this relationship continues to 2025 in the Base Case, although the higher economic growth for Bezirk X provides a greater energy demand increase in that region. Since the population density in Wisconsin is so much lower than in the Bezirk or Rhone-Alpes, the energy use per square kilometer is lower on the average than for the other regions. However, Wisconsin population and industry are clustered in the southeastern corner of the state so that some Wisconsin citizens enjoy no advantage with respect to pollution effects despite the lower average density of energy use. Environmental effects are discussed further in section V.

The broad range of policy measures and/or economic growth assumptions leads to a wide range of future energy use in the regions. Table 7.2 presents the average annual growth rates of end-use energy over time for the scenarios.

Both Wisconsin and Rhone-Alpes experience somewhat less than historical growth

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* Purchased fuels and electricity consumed by user.

TABLE 7.2 Average Annual Growth Rates of End-Use Energy Over Time

	Bezirk X		Rhone-Alpes		Wisconsin	
Scenarios	1970–2000	2000–2025	1970–2000	2000–2025	1970–2000	2000–2025
S1	1.7%	2.8%	2.4%	2.1%	2.3%	2.5%
S2	2.6%	5.2%	2.9%	2.4%	2.2%	2.8%
S3	1.6%	2.2%	2.4%	0.9%	1.3%	2.0%

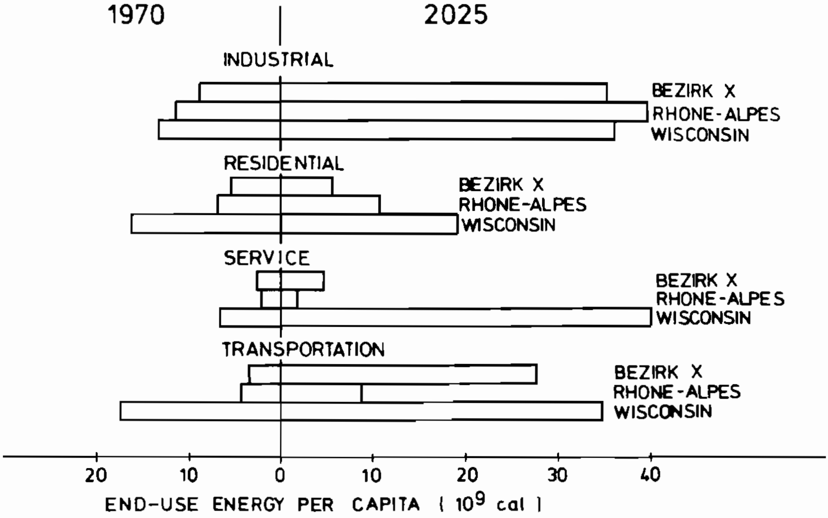

FIGURE 7.6 End-use energy per capita by economic sector (Scenario S1).

rates in the Base Case and high-energy scenario (S1 and S2) through 2000.* In contrast, the end-use energy growth by 2025 in Bezirk X increases by more than a factor of 8 in S2; this growth results primarily from the postulated 8.3 percent per year industrial growth. The dramatic increase in S2 as compared to S1 and S3 is a direct result of a slackening of the rate of improvement of efficiency of industrial use.

End-use energy per capita by economic sector is shown in Figure 7.6. Each sector will be discussed in more detail later; however, it is worth noting now the relative importance of the transportation and residential sectors in Wisconsin compared with the other regions at the beginning of the time period. The difference can in part be attributed to more personal transportation in Wisconsin, especially by less energy efficient means of transportation such as large automobiles, and to larger dwelling units with more appliances. The increasing importance of the transportation sector in energy use in Bezirk X is a result of freight transportation necessitated by

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* In Wisconsin, the energy growth rate increases slightly after the year 2000, primarily because economic growth continues at the same rate, despite lower population growth.

FIGURE 7.7 End-use energy per capita in the transportation sector.

the growth in industrial output. The increase in the demand for transportation in Wisconsin is also related to freight rather than passenger transportation. The energy use in the service sector increases dramatically in Wisconsin, an effect that will be discussed in the service sector comparisons.

The rest of this section contains more specific comparisons of the transportation, residential, service, and industrial sectors of the economy.

III.A. TRANSPORTATION

The transportation sector is very different in each of the regions. Table 4 in Chapter 2 shows a key reason – the great differences in motor vehicle stocks. The auto ownership comparison is most striking; autos per 1,000 inhabitants in 1972 range from 82 in the GDR, to 270 in Rhone-Alpes, to 436 in Wisconsin.

The transportation sector is divided into two main categories: passenger transport and freight transport. Transportation energy use per capita in each category is shown in Figure 7.7. Freight increasingly dominates transportation in both Bezirk X and Wisconsin. Differences in freight transportation are largely attributable to the location, type, and amount of industrial and service sector activity in the regions. Passenger transportation demand is affected by income and employment as well as city size and structure.

II.A.1. Passenger Transportation

Intracity personal transportation is generated by the need of transportation for employment, for shopping, and for pleasure. Auto ownership and the number of trips depend in part upon per capita personal income and the amount of income left for pleasure trips after the basic necessities are provided. A less obvious but equally important determinant of personal travel is the size and structure of the cities. Wisconsin cities tend to be less dense with fewer local or neighborhood shopping

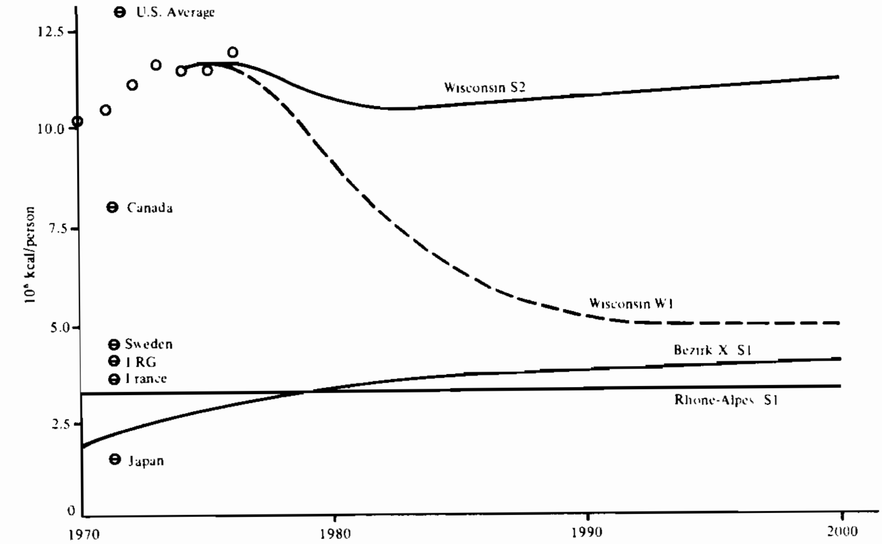

FIGURE 7.8 Personal transportation energy use per capita.

areas than GDR or Rhone-Alpes cities and therefore the average trip length is longer. Thus, although the fraction of the population employed is greatest in the Bezirk, the more energy efficient structure of the cities keeps the urban passenger travel low. To account for possible city structure changes over time, Scenarios S2 and S3 have differing assumptions on the future growth pattern of cities in the three regions. However, a sensitivity study (Chapter 6, section V.F.) indicates that even a strong urban containment policy would not bring per capita energy use for personal transportation in Wisconsin into the range of Bezirk X and Rhone-Alpes.

The penetration of mass transit systems into the city passenger transportation market is also an important determinant of energy demand since most urban mass transit systems are more energy efficient than private automobile transport. The use of mass transit is influenced not only by income and the relative prices of mass and personal transit, but also by the structure of the cities. A high-density area can be served more efficiently by mass transit since there are more potential customers per vehicle-mile; these high-density areas are also less attractive for large numbers of private automobiles because of increased congestion. Hanson and Mitchell[1] have shown, however, that given current city structure, a shift to more energy-efficient automobiles has a greater potential for energy savings in Wisconsin than a shift to mass transit. The trend toward smaller autos has been incorporated into the Wisconsin Scenarios S1 and S3 and explains the decrease in energy use per capita for passenger transportation. Energy intensiveness for private passenger transportation is assumed to remain constant in Bezirk X and in Rhone-Alpes.

Figure 7.8 compares personal transportation energy use per capita for several scenarios. Important characteristics of these are:

- Bezirk X (S1): Car ownership rises to approximately 240 cars per 1,000 persons by 2025; fuel economy remains approximately constant.
- Rhone-Alpes (S1): Ownership and efficiency do not greatly change.
- Wisconsin (S2): Fuel efficiency remains at level of 1975 new cars; ownership and travel level unchanged.

The contrasts are great between both the initial use levels and the scenarios; with no improvements in fuel economy, the Wisconsin values would remain far higher than the other regions. Scenario S2 for Wisconsin does not include the standards of the U.S. Energy Policy and Conservation Act (EPCA) which mandates an average yearly standard that reaches 8.6 liter/100 km for the 1985 model fleet. Scenario W1, shown by a dashed line, has recently been developed at the University of Wisconsin to include EPCA and some additional conservation measures;[13] by the year 2000 the Wisconsin per capita use is only 20 percent greater than in Bezirk X (Scenario S1).

II.A.2. Freight Transportation

Freight transportation is partially the result of industrial and service activity and consumer needs within the region. Bezirk X had a growth in industrial output that is nearly double the growth in freight transportation. This is partially explained by a reduction in the export of briquettes. In Wisconsin, on the other hand, freight transportation was found to grow at a faster rate than industry partly as a result of the large increase in the service sector. Freight transportation increases very slowly in Rhone-Alpes. Freight transportation within the regions is, however, not solely dependent upon the service and industrial activity in the area since freight that passes through the region with both departure point and destination outside the region is also counted as ton-kilometers while within the region. A lower growth rate in freight transportation may also result from a shift to manufactured products with a higher value per unit weight or from a policy to locate factories nearer to their source of raw materials or to the destination of the manufactured goods.

The fraction of freight by each mode of transportation (truck, rail, and barge) with associated energy intensiveness is shown in Table 7.3 for Scenario S1. The present mix of freight transportation is assumed to remain unchanged in Wisconsin, while the trend from rail to truck continues in the Rhone-Alpes. In the Bezirk all intercity freight transport is assumed to be by rail. The energy intensiveness of rail freight transport also improves dramatically because of the gradual replacement of steam locomotives with diesel and eventually electric engines.* Since diesel engines are already in use in Wisconsin and both electric and diesel engines are in use in Rhone-Alpes, the energy intensiveness of rail freight transport is assumed to remain constant in these regions.

An overall picture of the fuel efficiency of the freight transportation systems

TABLE 7.3 Freight Transportation by Mode and Associated Energy Intensiveness

		Fraction of Total Ton-km			Energy Intensiveness (kcal/ton-km)		
		Bezirk X	Rhone-Alpes	Wisconsin	Bezirk X	Rhone-Alpes	Wisconsin
Rail	1970	.77	.38	.26	360	110	118
	2025	.81	.29	.26	80	110	118
Truck	1970	.23	.54	.74	335	710	485
	2025	.19	.64	.74	375	710	485
Barge	1970		.08			160	
	2025		.06			160	

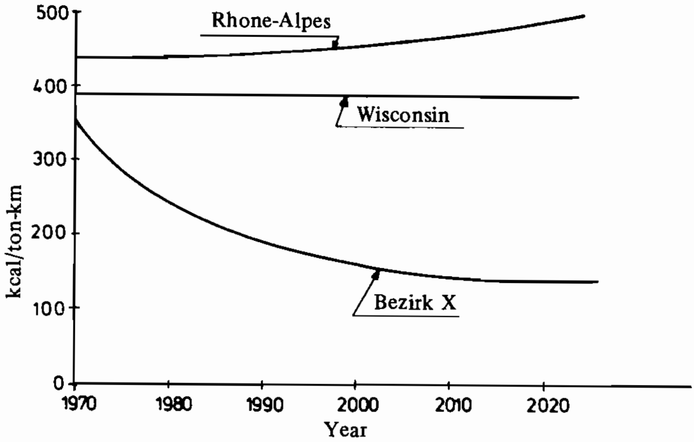

FIGURE 7.9 Energy intensiveness of freight transportation.

in the regions can be obtained from Figure 7.9 showing the energy use per ton-kilometer of freight transportation. If the primary energy used for electricity generated were also included, the overall energy intensiveness for Bezirk X would be about 280 kcal/ton-km. The heavy reliance on rail and the decreasing intensiveness of the new locomotives account for the substantial improvement in Bezirk X. Rhone-Alpes actually increases in overall energy intensiveness per ton-kilometer because of increasing use of truck transport, which is more energy intensive than rail transport.

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* The energy intensiveness of electric engines does not include the energy needed to produce electricity. Therefore in terms of primary energy required per ton-kilometer, improvement is not so striking.

TABLE 7.4 Single-Family Dwelling Units in the Three Regions for Each Scenario (% of total housing stock)

	1970	2025		
	All Scenarios	S1	S2	S3
Bezirk X[a]	62	54	56	48
Rhone-Alpes	47	41	72	26
Wisconsin	88	77	90	56

[a] Two-family dwelling units are counted as single-family dwelling units in the Bezirk-X data.

III.B. RESIDENTIAL SECTOR

The number, size, and characteristics of the dwelling units in a region as well as the appliances in those dwelling units are major factors determining the energy use in the residential sector. Table 7.4 gives the current and projected percentages of single-family dwelling units in the total housing stock for the three scenarios. Wisconsin has the largest percentage of detached homes in all scenarios, a significant factor since detached homes tend to be larger and to have a greater heat loss through the roof and walls (they do not have common walls with other dwelling units). A discussion of the energy required to heat typical single-family homes and apartments in the three regions may be found in Appendix C, section II, which deals with building practices.

In all three regions, space heating consumes the most residential energy. Wisconsin's larger residential floor area, colder climate, and high fraction of households with many applicances, all contribute to a residential energy use between two and three times larger than in the other regions.

Assumptions about the type of heating system for future dwelling units posed a difficult problem for the IIASA team, particularly in achieving consistency across the regions. Table 7.5 is a summary of the types of energy assumed for use in residential space heating. Very little coal is used for residential space heating in Wisconsin and Rhone-Alpes and use of this fuel is expected to decline even more. In Bezirk X in 1970, direct use of coal is the main source of fuel for residential space heating. In the future, the Bezirk's abundant supply of coal will instead be used for coal district heating where the air pollution problems can be minimized with pollution control equipment and high stacks. In all three regions, oil is considered to be an undesirable alternative because of the need to rely on imports, although a high level of dependence on oil use continued in Scenario S2 for Rhone-Alpes. Gas is also in increasingly short supply although both Rhone-Alpes and Bezirk X plan to introduce it to some extent. Wisconsin is heavily dependent on natural gas in 1970, but all scenarios except the Base Case call for a decrease in use. Where demand for such fuels exceeds what could realistically be expected to be supplied in Wisconsin, the gap is filled by synthetic fuels. High use of electricity for home heating is examined in Scenario S2 for Wisconsin and Scenario S1 for Rhone-Alpes. Some advantages of

TABLE 7.5 Fraction of Housing Units Using Each Type of Energy Source for Space Heating

	Fractions of Housing Units			
		2025		
	1970	S1	S2	S3
Coal				
Bezirk X	.91	.22	.24	.22
Rhone-Alpes	.055	.0	.0	.0
Wisconsin	.0	.0	.0	.0
Gas				
Bezirk X	.005	.16	.18	.13
Rhone-Alpes	.07	.219	.145	.178
Wisconsin	.64	.74	.20	.48
Oil				
Bezirk X	.0	.0	.0	.0
Rhone-Alpes	.6	.292	.6	.267
Wisconsin	.33	.13	.11	.14
Electricity				
Bezirk X	.001	.16	.17	.08
Rhone-Alpes	.015	.423	.138	.017
Wisconsin	.02	.12	.68	.13
Solar energy				
Bezirk X	.0	.0	.0	.12
Rhone-Alpes	.0	.011	.054	.263
Wisconsin	.0	.0	.0	.25
District heat[a]				
Bezirk X	.08	.46	.4	.45
Rhone-Alpes	.03	.048	.051	.166
Wisconsin	.0	.0	.0	.0
Geothermal district heat				
Bezirk X	.0	.0	.0	.0
Rhone-Alpes	.0	.007	.012	.109
Wisconsin	.0	.0	.0	.0

[a] Primarily oil for Rhone-Alpes and coal for Bezirk X.

electricity use are in moving pollution problems to the power plant and in enabling sources such as nuclear energy to be used for heating; disadvantages include the higher primary energy use resulting from conversion and transmission losses, and the myriad of environmental impacts and social costs involved in generating electricity. However, since the cost per unit of energy is higher for electricity than for most other types of energy, electrically heated homes are usually better insulated (except in Rhone-Alpes where standards are very high for all homes) resulting in decreases in end-use energy. Scenario S3, the energy conservation scenario, also includes solar heating in each of the regions.

Wisconsin is the only region with a significant residential air conditioning load. In addition Wisconsin homes have more "secondary" appliances, i.e. dishwashers,

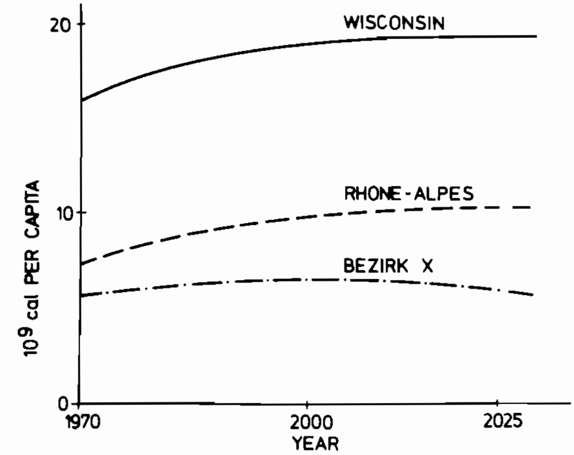

FIGURE 7.10 Residential end-use energy per capita.

washing machines, televisions, refrigerators, and they are in general larger and more energy intensive than the Rhone-Alpes and GDR appliances. In 1970 the average electricity use per home for secondary appliances was approximately 5,200 kWh in Wisconsin, 1,000 kWh in Bezirk X, and 900 kWh in Rhone-Alpes.* By 2025 these figures were projected to be 6,400, 2,000, and 3,100 kWh.

Total residential end-use energy per capita is shown in Figure 7.10. Rhone-Alpes uses only half as much energy per capita as Wisconsin but about 30 percent more than the Bezirk in 1970 and the differences increase by 2025. One of the major conclusions for the residential sector is that demands for energy are not expected to increase significantly over the time period studied, and under some conditions may decrease. Vigorous implementation of improved insulation practices would have major conservation impacts on all regions, particularly in Wisconsin with its larger dwelling size and colder climate.†

III.C. SERVICE SECTOR

Since definitions of service sector activity vary among the regions, comparisons are difficult. In addition, data for the service sector were the most difficult to obtain. Service floor area in both the Bezirk and Rhone-Alpes was assumed to grow proportionately to employment in the service sector. Reasonable projections of employment could be made. In Wisconsin, floor area was assumed to grow proportionately to value-added in the service sector. Since value-added, especially in

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* One kWh is equivalent to 0.86 million cal.

† In December 1978, Wisconsin instituted its first building construction code for new 1- and 2-family dwellings. See section II.C. in Appendix C.

TABLE 7.6 Space Heating in the Service Sector by Source of Energy

	Percentages of Each Fuel Type			
		2025		
	1970	S1	S2	S3
Coal				
Bezirk X	64.2	43	19.5	35.4
Rhone-Alpes	4	0	0	0
Wisconsin	5	5	1	5
Gas				
Bezirk X	1.7	1.7	1.7	1.7
Rhone-Alpes	11	10	45	60
Wisconsin	60	60	2	43
Oil				
Bezirk X	0	0	0	0
Rhone-Alpes	61	5	30	10
Wisconsin	25	25	.8	18
Electricity				
Bezirk X	.2	7.6	31	7.6
Rhone-Alpes	21	80	5	10
Wisconsin	2	2	88	2
Solar energy				
Bezirk X				7.6
Rhone-Alpes (In S3, solar substitutes in part for each heating fuel.)				
Wisconsin				24
District heat				
Bezirk X	33.9	47	47	47
Rhone-Alpes	3	5	20	20
Wisconsin				

the Wisconsin service sector, is growing much faster than employment (Figure 7.5), i.e. productivity is increasing, a much larger growth rate in floor area and consequently in energy use appears in the Wisconsin service sector than in either Rhone-Alpes or Bezirk X. In retrospect, the assumption that floor area grows proportionately to value-added may not have been justified in the Wisconsin case, especially since the larger growth is assumed to take place in insurance companies, consulting firms, and so on, where the ratio of floor area to value-added is less than in more traditional service industries.* If the assumptions had been that floor area grows proportionately to employment as in the other two regions, Wisconsin's consumption in the service sector would have been more similar to the Bezirk's and Rhone-Alpes'. In Rhone-Alpes the assumption was also made that new service sector buildings would be much more energy efficient than existing buildings.

Space heating accounts for most of the energy use in the service sector and, as in the residential sector, the fuel mix (Table 7.6) was a subject of much discussion.

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* A more recent study of the impact of the U.S. National Energy Plan on Wisconsin has assumed that floor area grows more slowly than value-added.[11]

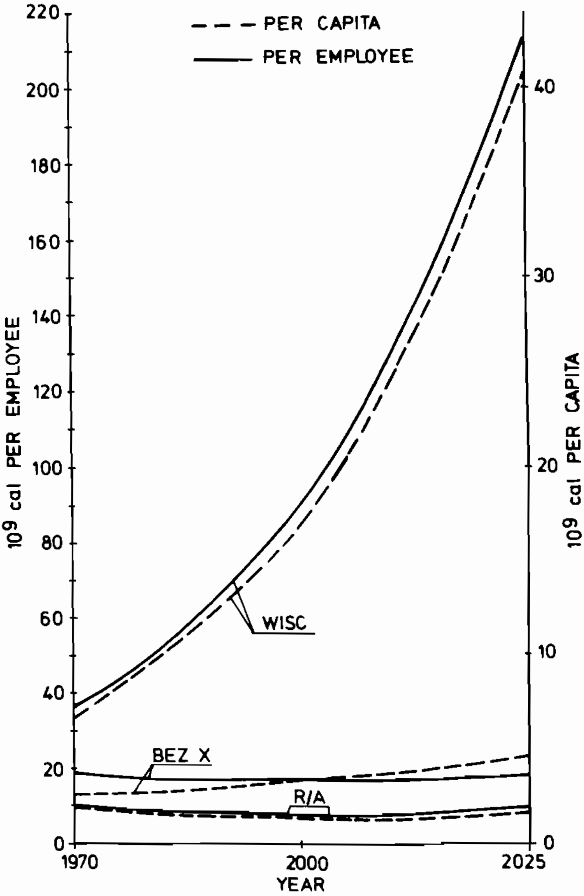


FIGURE 7.11 Service end-use energy per capita and per employee.

Space air conditioning is much more prevalent in Wisconsin in 1970, but by 2025 50 percent of Rhone-Alpes service floor space is also projected to be air conditioned. The GDR does not plan to install air conditioning in service sector buildings.

Results in terms of end-use energy per capita and end-use energy per employee in the service sector are compared in Figure 7.11. The differences between Rhone-Alpes and Bezirk X may be partially attributed to a milder climate in the Rhone-Alpes region that requires less energy for space heating.

III.D. INDUSTRIAL SECTOR

In all of the three regions, the industrial sector is a major consumer of energy (Table 2.8 in Chapter 2). However, each of the collaborating regional institutions in this study brought widely differing views of future industry development and energy consumption in its region. The alternative industrial energy demand patterns showed a strong divergence in the long run.

The diversity of these patterns can be discussed in terms of three important determining factors:

- The rate of industrial economic growth and the resulting mix of industry between energy-intensive and less energy-intensive activities, i.e. between processes which require more or less energy
- The energy intensiveness in terms of energy per unit of activity (e.g. cal/$ or cal/ton) for individual industrial subsectors
- The distribution of the energy consumption in an industrial subsector among the various energy forms (fuel mix)

Because the economic growth patterns were summarized previously in section II.B, the major attention in this section is devoted to energy intensiveness. The energy intensiveness factor was the focus of our industrial energy demand and conservation analysis. This analysis has been based in part on historical trends in sectoral intensiveness, and in part on examination of conservation potentials and incentives for major technical processes used within these sectors. Among the regions, the energy analysts from the GDR were the most optimistic about the likelihood of continuing long-term reductions in energy intensiveness. Based upon the results of the past two five-year plans, and their long-term planning, they expect a five percent annual decrease in the overall industrial intensiveness. This suggests not only a continued implementation of currently available conservation measures but a constant development of new measures and technologies.

Industrial classifications in the three regions have been consolidated into five categories: (1) building materials, (2) primary metals, (3) metal fabrication, (4) chemicals, and (5) others. Industrial activity by category for the three regions is described in section II.B. above and is summarized in Figure 7.3. Energy intensiveness (end-use energy per unit of output) is shown in Figure 7.12. Bezirk X plans a drastic reduction in energy intensiveness, especially in chemicals and primary metals, combined with an exponential increase in industrial activity during the time period. The change in energy intensiveness and worker productivity (see Figure 7.5) for the Bezirk industrial sector implies that the GDR would far surpass France and the United States in both industrial productivity and efficiency of industrial processes by 2025. The energy intensiveness figures for Wisconsin result from a study of past trends modified by the best judgment of the researchers. Perhaps the current increasing cost of energy was not adequately accounted for in the projections since historical data are from a period of decreasing energy costs. It seems more reasonable that trends that would result from improved industrial processes and shifts to different products would be seen in all three regions. The magnitude of the differences in this case can only be explained by greater optimism on the part of the GDR researchers than the Rhone-Alpes and Wisconsin researchers could muster.

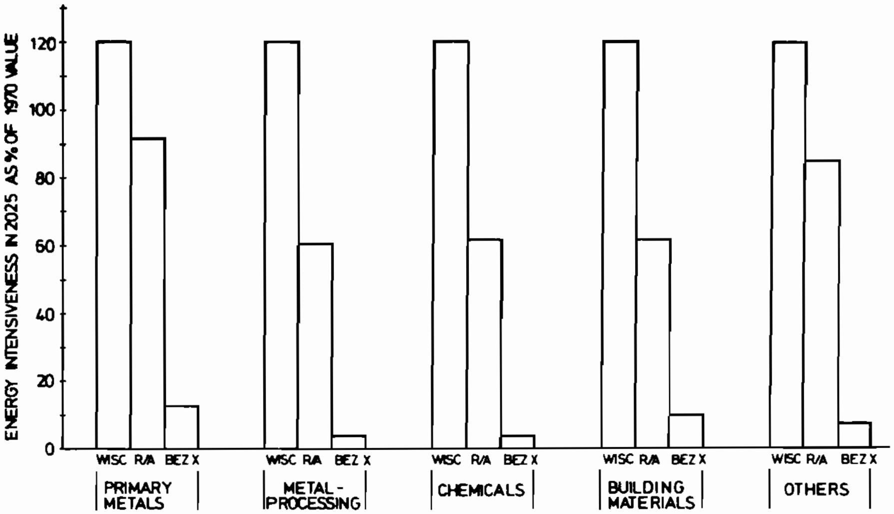


FIGURE 7.12 Energy intensiveness by industry.

Figures 7.13 and 7.14 show the overall industrial energy intensiveness for the Base Case and low-energy Scenario. It must be emphasized that these values incorporate the industrial structures of these scenarios and the associated fuel mixes for each industrial sector. All scenarios shown here except the Wisconsin Base Case show decreasing intensiveness. Subsequent analysis for Wisconsin, based upon more recent data, indicates that the decreases shown for S3 best represent current trends and future potential.[12]

The effects of the decreasing energy intensiveness and increasing production offset each other in the Bezirk X Base Case scenario, so that the trends in total industrial end-use energy per capita (Figure 7.15) are roughly similar to those in Wisconsin and Rhone-Alpes. The Base Case scenarios all yield an industrial energy use that grows more slowly than it has historically, except for the GDR, where the high economic growth more than compensated for the continuing decrease in energy intensiveness. The low-energy scenarios all yielded growths in demand that were significantly lower than historical growths; in Wisconsin, the demand in the industrial sector grew less rapidly than in the service sector, and by the year 2025, the service sector used more energy than the industrial sector.

Industrial end-use energy is broken down by energy source in Table 7.7. Coal district heat is the primary source of industrial energy in Bezirk X in 1975 and that is expected to continue in all scenarios. Coal is also an important source in Wisconsin and, except for scenario S2 where electricity is more heavily used, becomes even more important in the future despite the pollution control problems. Rhone-Alpes, which presently gets 11 percent of its industrial energy from coal, expects coal use in industry to be negligible by 2025 because there is no readily available supply of

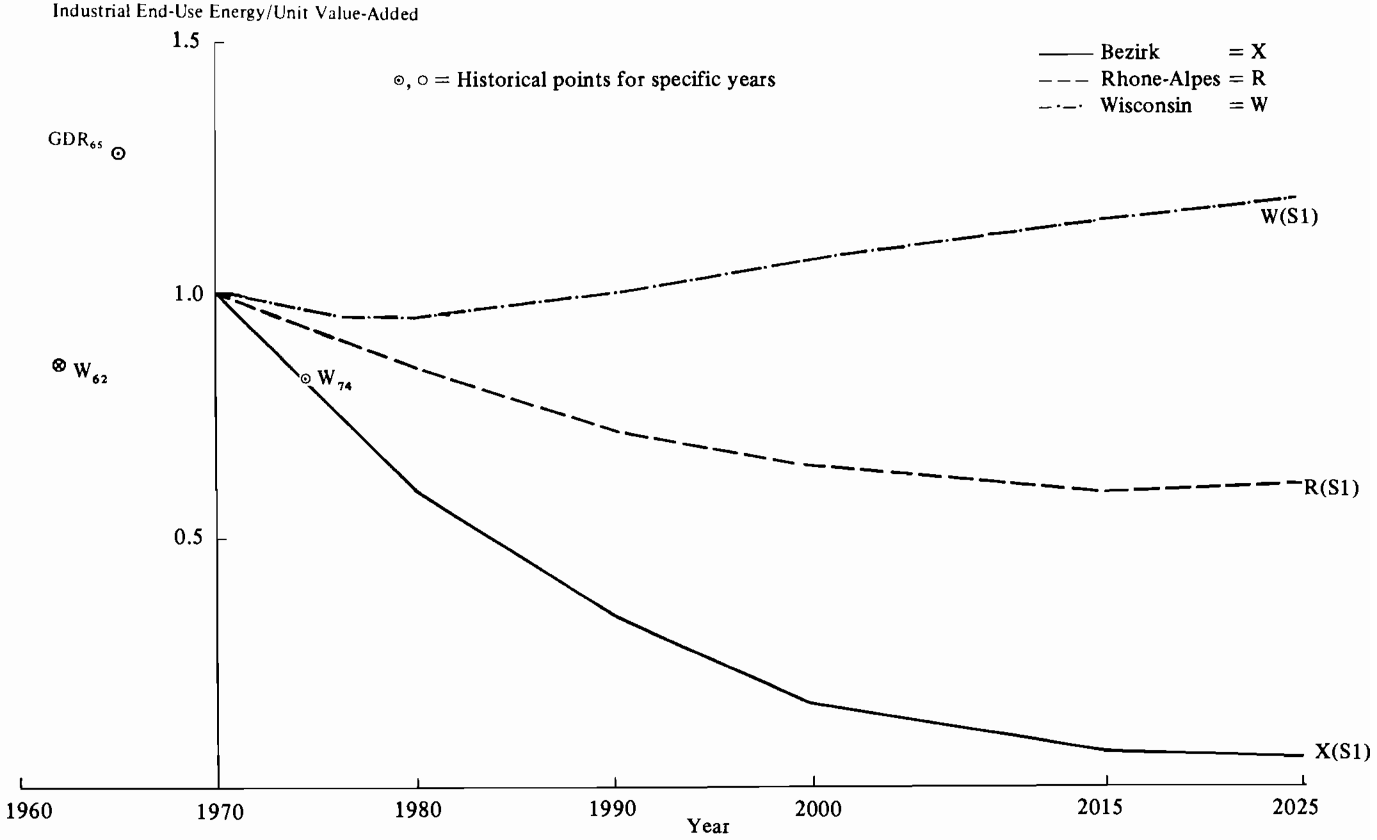


FIGURE 7.13 Cross-regional comparison of end-use energy per unit of industrial activity for Scenario S1 (Base Case). For Bezirk X, the unit of the vertical axis is Industrial End-Use Energy/Unit Net Production.

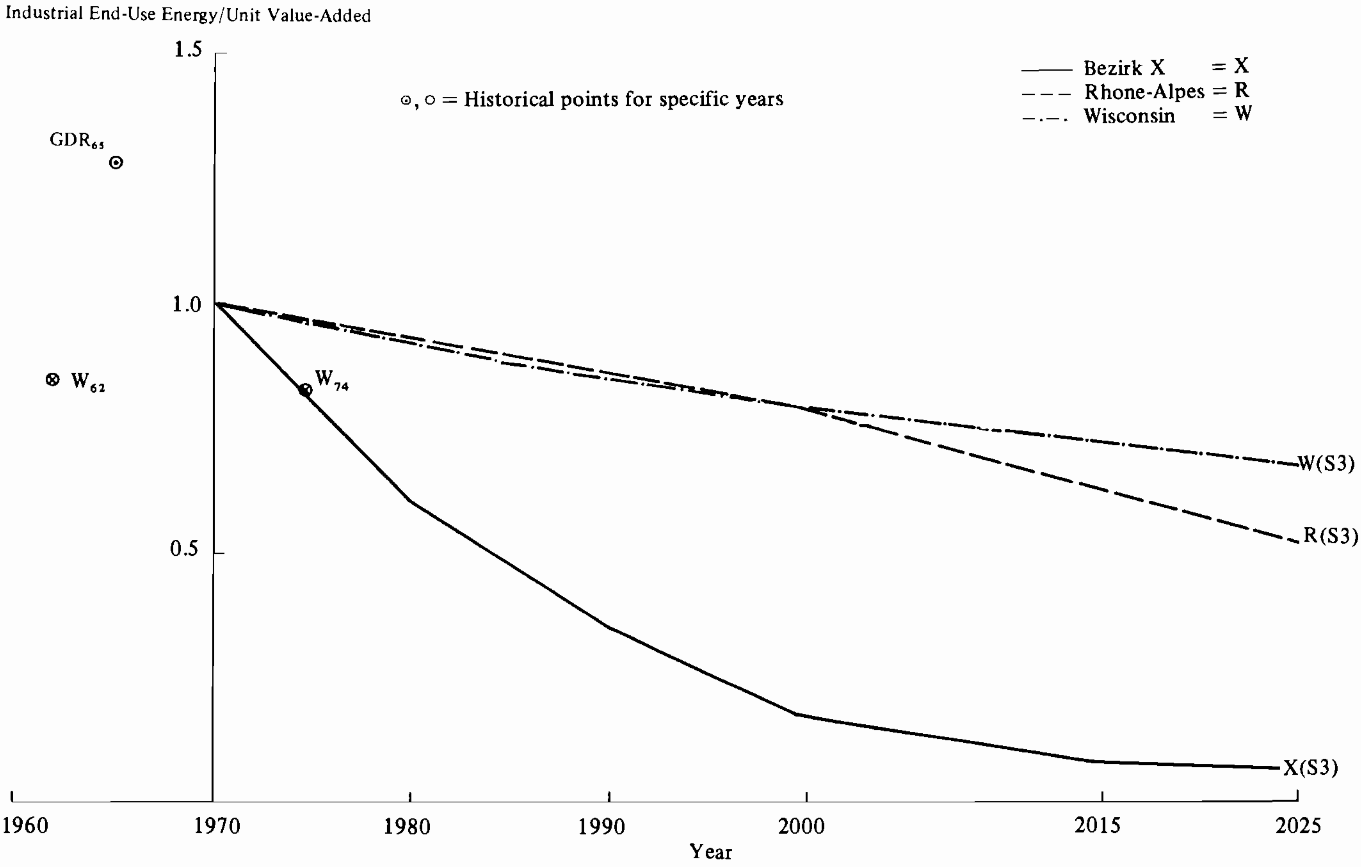


FIGURE 7.14 Cross-regional comparison of industrial end-use energy per unit of industrial activity for Scenario S3 (low-energy scenario). For Bezirk X, the unit of the vertical axis is Industrial End-Use Energy/Unit Net Production.

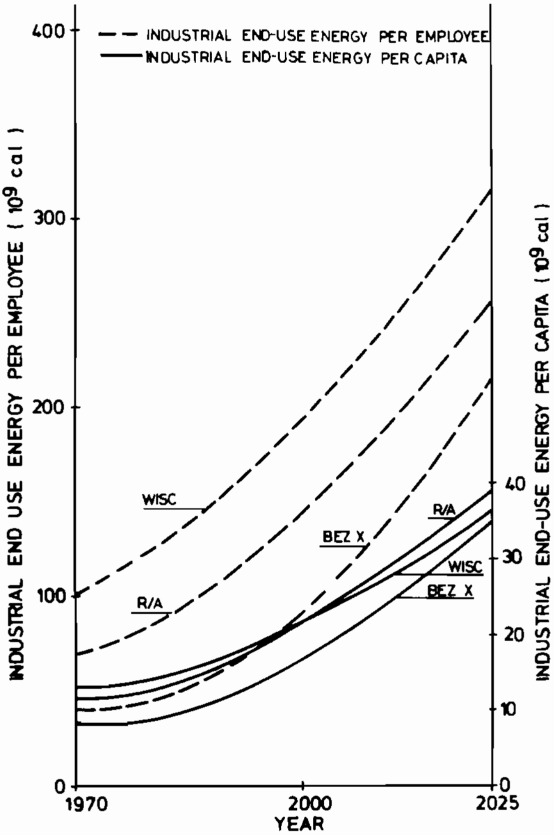


FIGURE 7.15 Industrial end-use energy per capita and per employee.

high-grade coal. Only Wisconsin currently uses a large amount of gas for industrial uses. Natural gas is not expected to be available in those quantities in the future, but gas manufactured from coal has been assumed to be available. Rhone-Alpes is very dependent on imported oil for its industry. Except for Scenario S2, the dependence is decreased but still remains a factor of importance. The decrease in oil and coal use is to be offset by an increase in use of electricity in Rhone-Alpes. Electricity use for industry also increases in all scenarios in Bezirk X and Wisconsin.

IV. ENERGY SUPPLY

Choices of alternative fuels and supply technologies are among the most important of the long-term strategies being debated in the regions studied. Resource availability and economic considerations played a major role in shaping the end-use energy

TABLE 7.7 Industrial End-use Energy by Source

	Fraction of Total Industrial Energy Use			
		2025		
	Initial Values[a]	S1	S2	S3
Coal				
Bezirk X	.17	0	0	0
Rhone-Alpes	.11	.01	.01	.01
Wisconsin	.34	.42	.33	.41
Gas				
Bezirk X	.05	.04	.04	.05
Rhone-Alpes	.09	.11	.18	.17
Wisconsin	.48	.40	.34	.43
Oil				
Bezirk X	.05	.01	.01	.01
Rhone-Alpes	.55	.22	.43	.15
Wisconsin	.08	.05	.04	.05
Electricity				
Bezirk X	.14	.39	.25	.32
Rhone-Alpes	.25	.66	.38	.67
Wisconsin	.10	.12	.29	.11
District heat				
Bezirk X	.59	.56	.69	.62
Rhone-Alpes	0	0	0	0
Wisconsin	0	0	0	0

[a] For Rhone-Alpes and Wisconsin, 1970 values; for Bezirk X, 1975.

demands described in the previous section, but perhaps to an even greater degree they influence the energy-supply strategies for a region. This section describes end-use and primary energy flows by fuel type, and discusses other supply considerations such as electricity generation, district heating, and use of renewable resources.

IV.A. ENERGY BY FUEL TYPE

IV.A.1. Initial Conditions

A slightly different perspective on end-use energy consumption within the region is given in Figure 7.16. The fraction of end-use energy by fuel type is shown with the fraction of each type of fuel used in each sector of the economy for 1970. Perhaps the distinction between end-use and primary energy should be made again at this point. End-use energy is energy that is consumed within the region for heat, light, or mechanical or chemical processes. Primary energy is the energy in its original form. In practice, in this study, "primary energy consumed within the region" is identical to end-use energy except for district heat, electricity, and synthetic gas and oil. In these cases, the primary energy is the hydropower, solar energy, nuclear

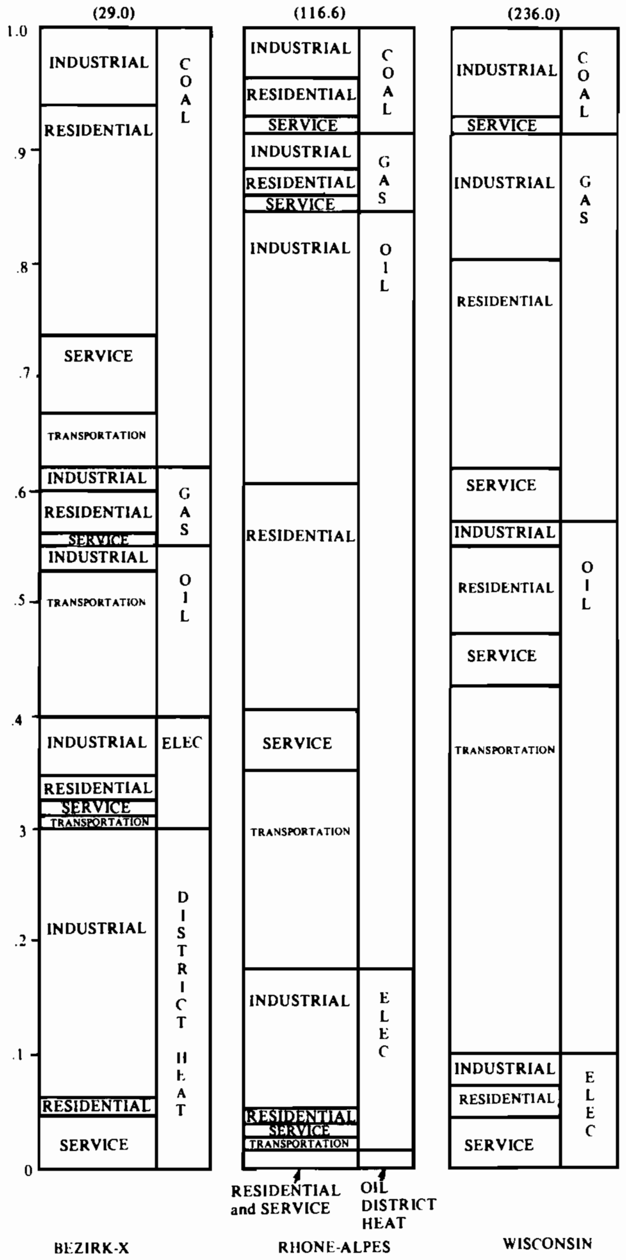


FIGURE 7.16 Annual end-use energy by fuel and economic sector (1970). Numbers in parentheses indicate total end-use energy in 10^{15} cal/yr.

energy, geothermal energy, coal, or oil that produced the district heat, electricity, or synthetic fuel. The end-use energy from these sources does not include losses from conversion at the plant or distribution of the energy. Primary energy that is exported from the region is also tabulated.

In 1970, the only region with a significant fraction of end-use energy supplied by district heat is Bezirk X, where coal district heat is the major source of energy for industry and is also used in small amounts in the residential and service sectors. Rhone-Alpes also has a minor amount of oil district heat for the residential and service sectors. One can theorize that in the GDR economic system, where industry is state-owned, district heat is easier to develop than in France or the United States where different companies would have to cooperate or a new energy supply system, perhaps similar to the American electric utilities or the French state-owned utility, would have to be developed. Because of its primary reliance on coal in a densely populated country, the GDR also has an incentive to make efficient use of its abundant supply of low-grade coal without adversely affecting the health and welfare of its citizens. District heat provides a convenient means of exploiting the coal resource while minimizing the local health impacts.

Direct use of coal provides less than 10 percent of the energy use in Rhone-Alpes and Wisconsin where its main use is for industry; minor amounts are used for space heating in the residential and service sectors. Bezirk X, on the other hand, obtains nearly 40 percent of its end-use energy with the direct combustion of coal. It is the primary fuel for residential space heating (about 50 percent of the total) and is also used for industry, steam locomotives, and space heating of service sector buildings. The direct use of coal in situations where pollution control devices or high stacks are infeasible, especially in densely populated areas, is a major source of concern in the GDR.

Gas is used in minor amounts in the residential, service, and industrial sectors of Bezirk X and Rhone-Alpes. In Wisconsin, however, it is the primary energy source for residential home heating and is also used in the service and industrial sectors, accounting for over one-third of the total end-use energy. Natural gas is expected to be in increasingly short supply at higher prices in the future and presents a problem for Wisconsin's decision-makers. The Wisconsin scenarios have dealt with supply problems in gas and oil by postulating that synthetic fuels from coal will be available.

Oil must be imported into all three regions. Because of well-known political problems, both the supply and prices of oil are unpredictable, although perhaps Wisconsin feels the pressure least since the United States has some oil resources of its own. Oil is used almost exclusively for transportation in Bezirk X and accounts for only about 15 percent of the energy supplied. Oil is the primary fuel for transportation in Wisconsin also. About one-third of Wisconsin's end-use energy is used for transportation and another 15 percent is oil used in the other three sectors; over 45 percent of its end-use energy is from oil. Rhone Alpes has an even worse situation with almost two-thirds of its end-use energy in the form of oil, a result of the

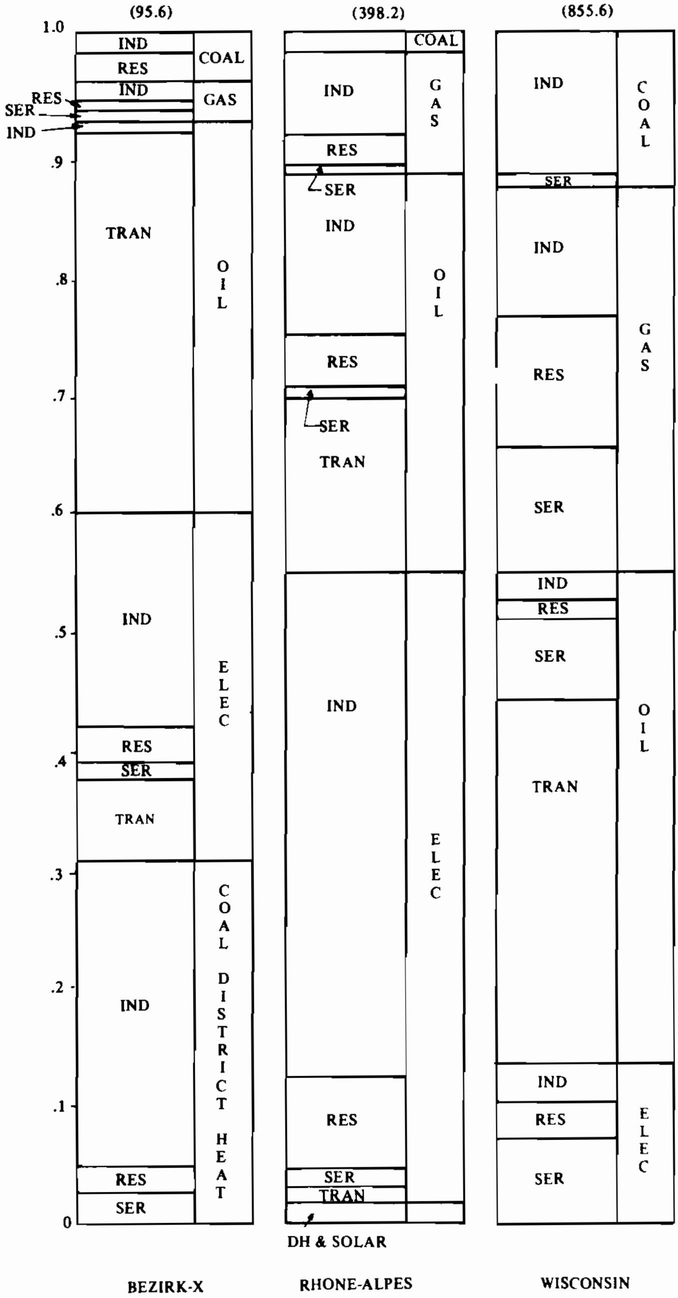


FIGURE 7.17 Annual end-use energy by fuel and economic sector (Scenario S1 – 2025). Numbers in parentheses indicate total end-use energy in 10^{15} cal/yr.

previous easy availability of low-priced Middle-East oil. Oil is not only the primary fuel for transportation, but also is used for residential and service space heating and industrial production.

Electricity accounts for less than 10 percent of end-use energy in Bezirk X and Wisconsin. It is divided among the residential, service, and industrial sectors somewhat evenly in Wisconsin. The industrial sector uses a larger fraction of the total electricity (and total energy) in Bezirk X than in Wisconsin. A small amount of electricity is also used in the transportation sector. Over 15 percent of the end-use energy in Rhone-Alpes is from electricity, the majority of which is used in the industrial sector. Electricity has been a more attractive source of power in Rhone-Alpes than in the other regions because of the availability of hydro power.

IV.A.2. Scenario S1

End-use energy in Scenario S1, shown in Figure 7.17, was defined as a successful implementation of the 20-year plan in the Bezirk and a combination of current plans, present trends, and the judgment of the researchers in Wisconsin and Rhone-Alpes. In Bezirk X the overall strategy is to phase out the direct use of coal, which presents a significant air pollution problem, in favor of coal district heat and electricity, both of which can exploit the coal resource while minimizing the impact of the air pollution. The implied goal in the Rhone-Alpes Scenario S1 is the replacement of imported oil with nuclear generated electricity. The results of the Wisconsin Scenario S1 in 2025 do not differ from the initial conditions as dramatically as either Rhone-Alpes or Bezirk X, perhaps because of a lack of a clearly articulated energy policy in Wisconsin. Gas and oil remain the primary sources of energy although the assumption is that a significant fraction of these will be synthetic fuels produced from coal by 2025.

In all three regions the fraction of energy from coal used directly in the residential, service, and transportation sectors is greatly reduced. Only in Wisconsin is the direct use of coal increased and that is in the industrial sector where the use of high stacks and some pollution control devices is assumed.

Gas is not assumed to significantly increase its share of the market in either Rhone-Alpes or Bezirk X. In Wisconsin its share of the market decreases slightly but is still about a third of the total end-use energy. A decline in the fraction used for residential space heating is nearly offset by the rapidly growing service sector.

One of the most alarming results of Scenario S1 is the heavy dependence on oil in 2025 in all three regions despite efforts to control its use. No satisfactory substitute for oil, except synthetic oil, was foreseen in any of the regions for the transportation sector. One conclusion of this result may be that a high priority should be placed on finding an alternate fuel that can be used for transportation. There are several alternatives of varying degrees of feasibility to supply heat and process energy in the other sectors of the economy, but the research team did not believe that any other form of energy with currently foreseeable technology could reasonably be

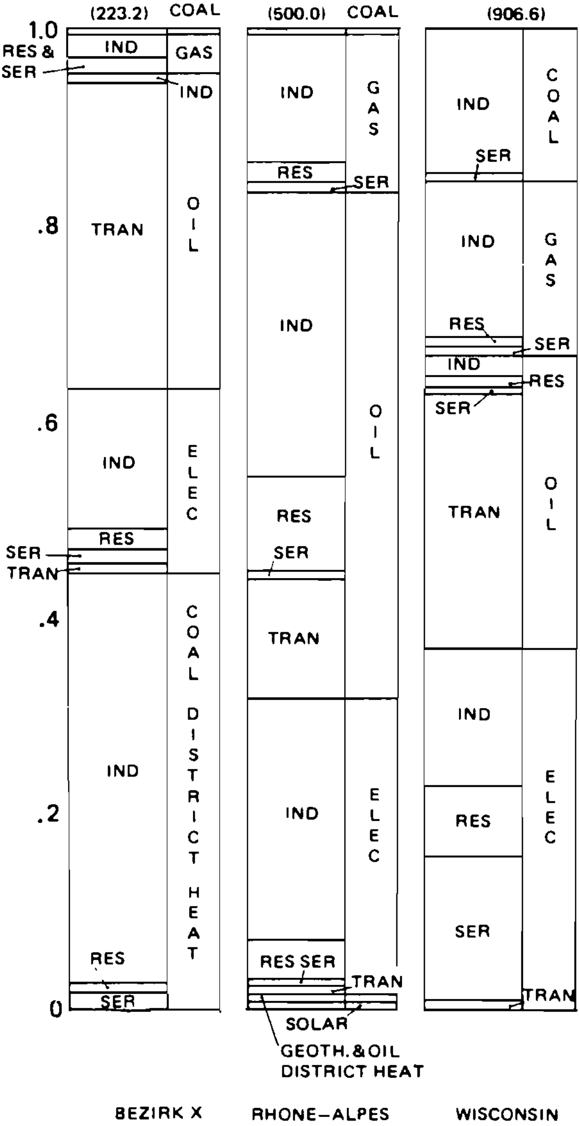


FIGURE 7.18 Annual end-use energy by fuel and economic sector (Scenario S2 – 2025). Numbers in parentheses indicate total end-use energy in 10^{15} cal/yr.

substituted for oil in the transportation sector. The Bezirk nearly eliminates oil for all uses except transportation, but oil still increases to nearly one-third of end-use energy in 2025. Rhone-Alpes decreases the fraction of end-use energy from oil from over two-thirds in 1970 to just over one-third in 2025, mainly by encouraging the use of electricity for industry and for residential and service space heating. The transportation sector uses a smaller fraction of the total end-use energy in Rhone-Alpes than in the other two regions, another factor that keeps oil at only one-third of the end-use energy. In Wisconsin, the fraction of end-use energy from oil decreases only slightly, mainly as a result of a decrease in oil-based residential space heating and a slight decrease in the importance of the transportation sector in end-use energy consumption.

The use of electricity increases greatly in both Bezirk X and Rhone-Alpes, especially in industry; electricity even supplies a significant amount of energy for freight transportation in Bezirk X. In Wisconsin, electricity increases from less than 10 percent to nearly 15 percent of the total end-use energy and the rapidly growing service sector accounts for the increase. More will be said about electricity and about the supply of primary energy in section IV.B.

District heat continues to be developed in the Bezirk and in Rhone-Alpes but its impact on the total end-use energy supply does not change appreciably.

IV.A.3. Scenario S2

The results of Scenario S2, defined as a high-energy case, are shown in Figure 7.18, once again in terms of the allocation of total end-use energy among the competing fuels and economic sectors.

The direct use of coal is very similar to Scenario S1 in all three regions. Coal use almost disappears in Rhone-Alpes and Bezirk X and increases slightly in terms of the fraction of total end-use energy in the industrial sector in Wisconsin.

Wisconsin Scenario S2 assumes that gas will not be available in the future to the same extent as in the past, and gas is phased out for service and residential space heating. Energy use in industry, however, grows at a faster rate relative to the other sectors than in Scenario S1, the gas supplies a large fraction of this demand. Perhaps a more likely policy would be that the available supplies of gas are reserved for residential and service space heating, forcing industry to use other fuels. Gas accounts for approximately the same fraction of end-use energy in Bezirk X and Rhone-Alpes in Scenario S2 as in S1.

Use of oil in Bezirk X and Wisconsin does not vary much from Scenario S1, although for space heating in the service sector it is largely replaced by electricity. The Rhone-Alpes Scenario S2, however, is not as successful as S1 in replacing oil with electricity and over half of the end-use energy in 2025 is still supplied by oil. Oil supplies about one-third of the end-use energy in Rhone-Alpes in S1. Since S2 is is also higher in total end-use energy than S1, this represents a substantial additional amount of oil that must be obtained.

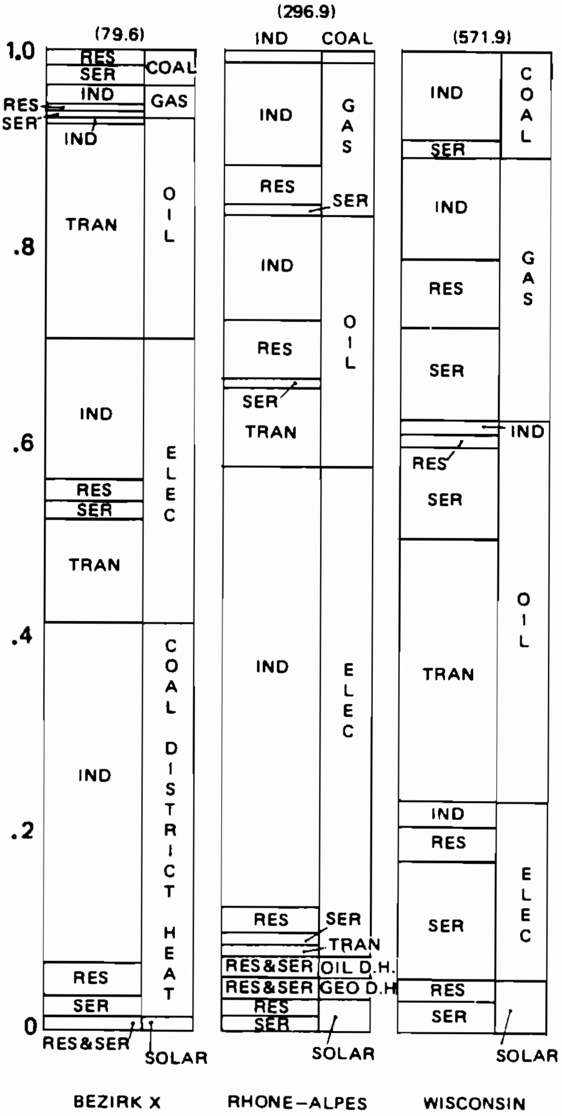


FIGURE 7.19 Annual end-use energy by fuel and economic sector (Scenario S3 – 2025). Numbers in parentheses indicate total end-use energy in 10^{15} cal/yr.

Electricity does not capture as large a fraction of the market in Scenario S2 as in S1 in Rhone-Alpes and Bezirk X. In the Bezirk, the decrease in the share of electricity in the transportation sector is made up by oil because of the importance of truck freight transport; in the industrial sector it is made up by coal district heat. In

Rhone-Alpes Scenario S2, the decrease in the share of electricity compared with S1 is from the low penetration of electricity into industry. For Wisconsin, Scenario S2 is the high energy, high electricity case. Electricity captures nearly 40 percent of the total end-use energy including most of the residential and service space heating markets, a large fraction of the industrial energy use, and even a small amount of mass transit.

In Bezirk X, the industrial sector grows even faster in S2 in relation to the other sectors than in S1 and coal district heat provides most of the additional energy required, resulting in 45 percent of the end-use energy being supplied by district heat.

IV.A.4. Scenario S3

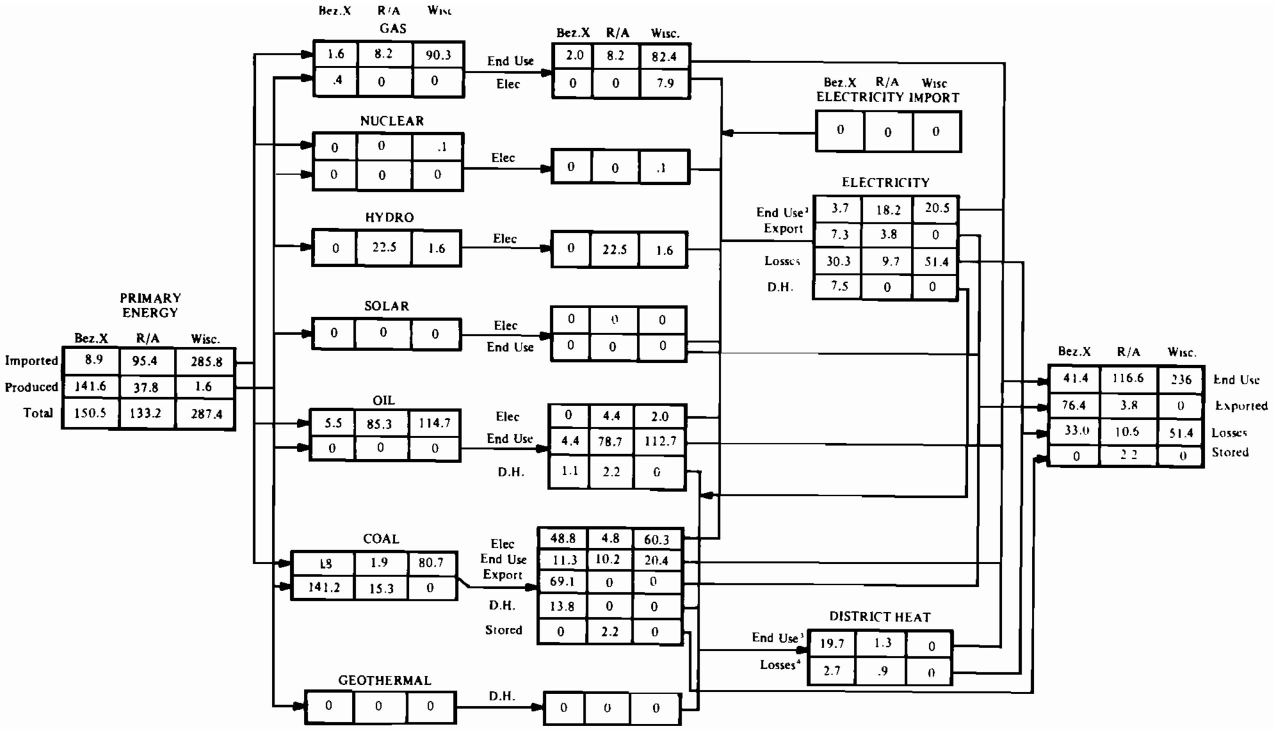
Scenario S3 was defined as an energy-conservation case with emphasis on more speculative sources of energy and a high degree of environmental control. Perhaps one of the most interesting results of Scenario S3 was the demand that could be met by solar and geothermal energy as a result of quite vigorous programs to introduce them (Figure 7.19).

In terms of the fuel mix, Scenario S3 is very similar to S1 in Bezirk X except that coal district heat for industry supplies an even larger share of the total energy. Solar space heating is also introduced but accounts for less than 1 percent of the total by 2025. The Rhone Alpes picture is also very similar to S1. Solar and geothermal district heat together account for slightly over 5 percent of the end-use energy in 2025, a substantial contribution but certainly a long way from solving the energy problem. The result is very much the same in Wisconsin where solar space heating accounts for just over 5 percent of the total end-use energy needs by 2025.

IV.B. ENERGY FLOWS

IV.B.1. Initial Conditions

Primary Energy The primary energy flows in 1970 for the three regions are shown in Figure 7.20. Bezirk X is an energy producer, exporting directly or after conversion over half of the coal mined in the region in 1970. The coal is exported mostly in the form of briquettes, but also as electricity. Of the energy used in the Bezirk, only approximately 12 percent must be imported to supply the needs for coke, gas, and oil. To meet its energy needs, Rhone-Alpes must import about 70 percent of its total requirement, primarily Middle Eastern oil. The abundant supply of hydro power supplies 17 percent of its total primary energy requirement and allows Rhone-Alpes to export nearly 20 percent of the electricity produced in the region. Rhone-Alpes also has a limited amount of coal that provides another 10 percent of the primary energy requirement. The coal reserves, however, are not large and are not expected to be a significant source of energy for Rhone-Alpes in the future.



[1] Losses include both conversion and distribution.
[2] Includes 1. × 10^{15} cal. used for raw lignite and briquette production in Bezirk X.
[3] Includes 11.1 × 10^{15} cal. used for briquette production in Bezirk X.
[4] Losses from district heat (D.H.) produced in power plants are counted as losses in the electricity category rather than district heat.

FIGURE 7.20 Primary energy flows for all scenarios: 1970 (× 10^{15} cal).

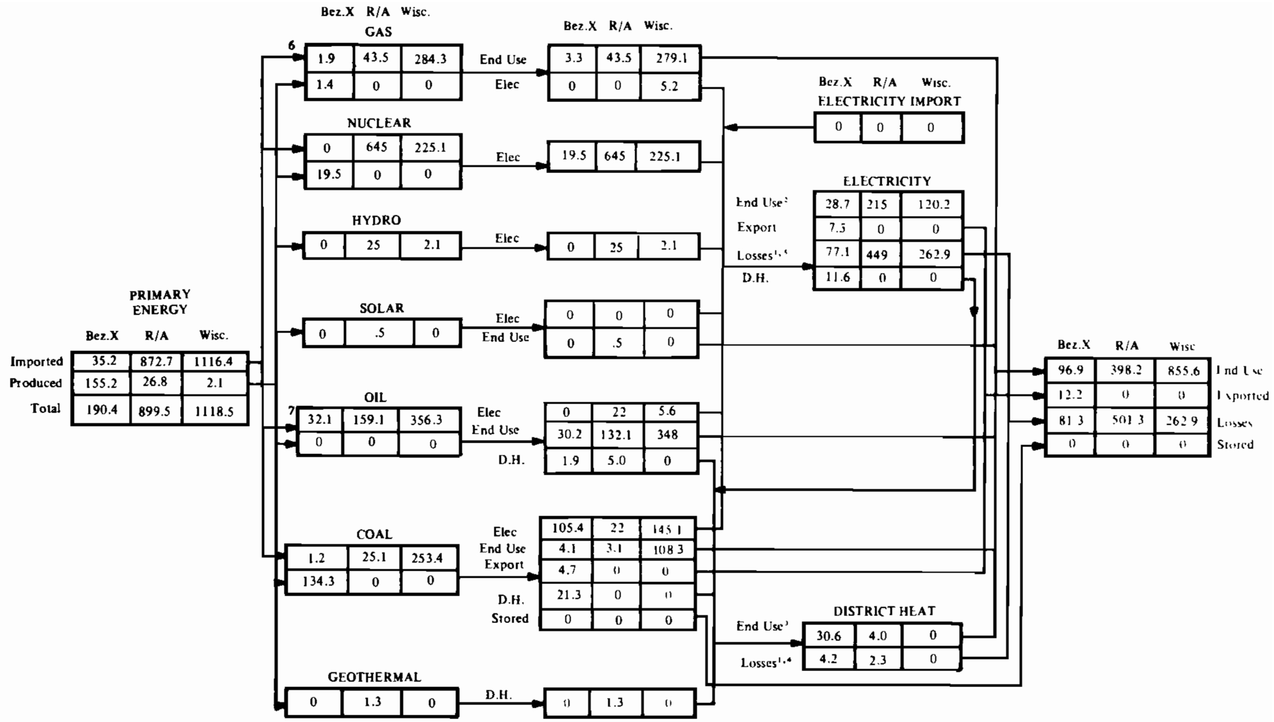
Wisconsin is in the worst position; except for about .5 percent of its primary energy supplied by hydro power, its entire supply was imported in 1970.

Electricity Generation and District Heat Electricity generation and district heat production provide convenient methods of utilizing the low grade, high sulfur lignite that is found in the GDR. Excluding exported briquettes, 60 percent of the primary energy is used in electric power plants that both generate electricity and produce district heat and another 18 percent is used in pure district heating plants. The penalty that must be paid of course is the losses that occur in conversion and in transmission and distribution of the new form of energy. In the Bezirk, conversion, transmission, and distribution losses are 44 percent of the total primary energy, excluding again exported briquettes. Both Wisconsin and Rhone-Alpes use about 25 percent of their primary energy for electricity generation. Rhone-Alpes uses another 3 percent for district heat, resulting in losses in total primary energy of 18 percent for Wisconsin and, because of the high efficiency of hydro power, of only 8 percent for Rhone-Alpes. In all regions, losses associated, for example, with the combustion of fuels in a house furnace are included in end-use energy rather than losses. Losses are defined solely as conversion, transmission, and distribution losses associated with electricity or district heat production.

District heat is a significant energy option in Bezirk X, already supplying 30 percent of the end-use energy; 38 percent of the district heat is produced in electric power plants with an overall efficiency (electricity plus district heat) of 39 percent. The remainder is produced in coal and oil-fueled district heating plants at 82 percent efficiency. Rhone-Alpes also has a limited amount of oil-fueled district heat produced at 60 percent efficiency.

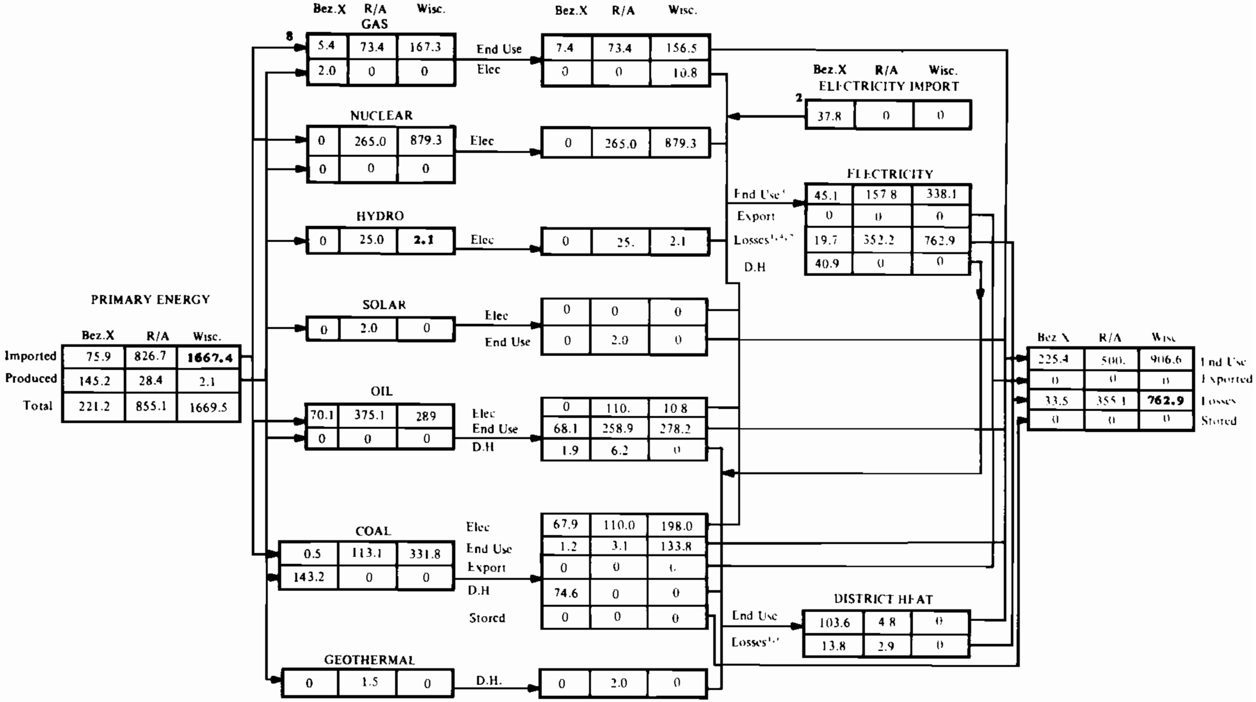
IV.B.2. The Scenarios

Primary Energy Figures 7.21 through 7.23 show the primary energy flows in 2025 for the three basic scenarios. Bezirk X remains relatively energy self-sufficient producing between 66 percent and 86 percent of its own energy, again excluding exported briquettes. By 2025, however, in all three scenarios, exports must be drastically curtailed as the Bezirk needs a larger percentage of its coal to supply its own needs. Increasing amounts of foreign oil are also required primarily to meet transportation requirements. The energy self-sufficiency of Rhone-Alpes declines rapidly to only about 3 percent of its primary energy needs by 2025 in Scenarios S1 and S2 as the coal reserves dwindle and no more suitable sites are available for hydro plants. In Scenario S1, however, 70 percent of the energy is nuclear, a source that the French policymakers hope will be cheaper and more reliable than the coal, oil, and gas of Scenario S2. Wisconsin, whose only energy resource is a small amount of hydro power (Wisconsin Scenarios S1 and S2 have no solar energy), can produce only a small fraction of 1 percent of its energy needs by 2025 in S1 and S2. In Scenario S3, with the introduction of energy conservation measures, solar and



[1] Losses include both conversion and distribution.
[2] Includes .8 × 10^{15} cal used for raw brown coal and briquette production in Bezirk X.
[3] Includes .6 × 10^{15} cal used for briquette production in Bezirk X.
[4] Losses from district heat produced in power plants are counted as losses under electricity rather than district heat.
[5] 25.8 × 10^{15} cal counted as losses in Rhone-Alpes electricity generation is actually used for a uranium enrichment plant that supplies all of France.
[6] Wisconsin gas includes 212.1 × 10^{15} cal of imported synthetic gas produced from coal at a conversion efficiency of 60%.
[7] Wisconsin oil includes 261.8 × 10^{15} cal of imported synthetic oil produced from coal at a conversion efficiency of 50%.

FIGURE 7.21 Primary energy flows in Scenario S1: 2025 (× 10^{15} cal).



[1] Losses include both conversion and distribution.

[2] Nine percent of imported electricity is counted as losses in transmission and distribution. The electricity is generated at 33% efficiency resulting in a primary energy use of 113 × 10^{15} cal. This primary energy has *not* been included in the primary energy figure for Bezirk X.

[3] Includes .8 × 10^{15} cal used for raw lignite and briquette production in Bezirk X.

[4] Note that losses are so low in Bezirk X because most electricity generation is outside the Bezirk and therefore conversions are not accounted for.

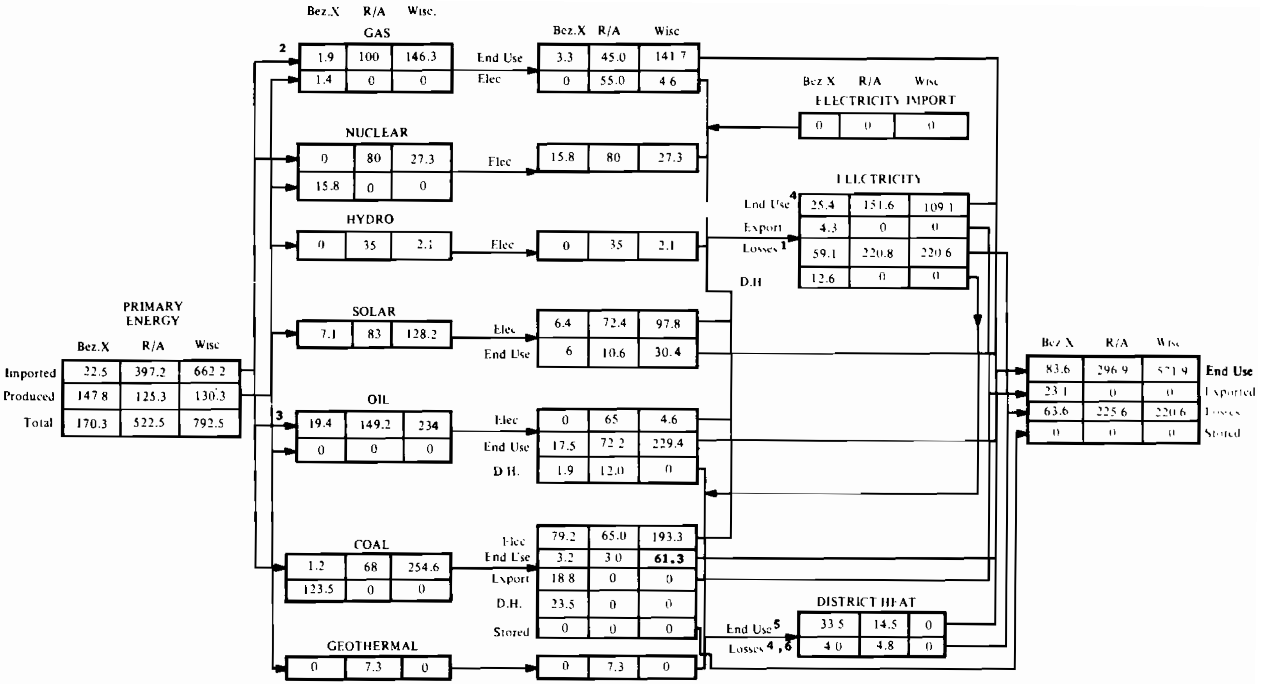
[5] Includes 1.6 × 10^{15} cal used for briquette production in Bezirk X.

Losses from district heat produced in power plants are counted as losses under electricity rather than district heat.

21.5 × 10^{15} cal counted as losses in Rhone-Alpes is actually used for a uranium enrichment plant that supplies all France.

[8] Wisconsin gas includes 9.5 × 10^{15} cal of imported synthetic gas produced from coal at a conversion efficiency of 60%.

FIGURE 7.22 Primary energy flows in Scenario S2: 2025 (× 10^{15} cal).



[1] Losses include both conversion and distribution

[2] Wisconsin gas includes 74.1 × 10^{15} cal of imported synthetic gas produced from coal at a conversion efficiency of 60 percent

[3] Wisconsin oil includes 142.2 × 10^{15} cal of imported synthetic oil produced from coal at a conversion efficiency of 50 percent

[4] Includes .7 × 10^{15} cal used for raw lignite and briquette production in Bezirk X.

[5] Includes 3.2 × 10^{15} cal used for briquette production in Bezirk X.

[6] Losses from district heat produced in power plants are counted as losses under electricity rather than district heat.

FIGURE 7.23 Primary energy flows in Scenario S3: 2025 (× 10^{15} cal).

TABLE 7.8 Average Annual Increase in Electricity Consumption and Percentage of Total Primary Energy Devoted to Electrical Generation

		1970–2000		
Annual average percentage increase in electricity consumption[a]	1970	S1	S2	S3
Bezirk X	4.8[b]	4.2	5.4	3.9
Rhone-Alpes	5.3[c]	5.3	4.4	4.8
Wisconsin	7.2[d]	3.6	6.3	3.3
		2000		
Percentage of Primary Energy Used for Electrical Generation[e]	1970	S1	S2	S3
Bezirk X	32	42	48	41
Rhone-Alpes	24	66	48	50
Wisconsin	25	30	54	34

[a] Excludes exports and transmission losses; includes electricity import.
[b] Average for 1960–1972 period.
[c] Average for 1969–1972 period.
[d] Average for 1961–1972 period.
[e] Includes primary energy used for electricity export as well as primary energy used for electricity import.

geothermal energy, Wisconsin and Rhone-Alpes manage to supply 6 percent and 24 percent of their own needs.

Electricity Generation and District Heat Bezirk X continues to rely heavily on electricity and district heat in all three scenarios. The percentage of total primary energy used for electricity and district heat ranges from 66 to 75. Rhone-Alpes and Wisconsin also increase their reliance on electricity in all three scenarios with a corresponding increase in energy lost in conversion, especially in Rhone-Alpes where new power plants must be nuclear or fossil-fueled rather than the very efficient hydro plants.

One of the major conclusions inferred from the range of futures is that future growth of electricity generation will be much lower than historical rates. Table 7.8 shows the average annual growth rates for the selected scenarios in comparison with historical values. Also shown are the percentages of primary energy used for electrical generation. The significant slowing of electricity growth in these industrialized regions indicates the need for a continuous examination of the requirements for future generating facilities.

In terms of efficiencies, district heat is better than electricity and Bezirk X achieves its best overall efficiency of close to 70 percent in Scenario S2 (including the generation losses associated with the imported electricity). The high electricity cases result in low efficiencies, especially Scenario S1 for Rhone-Alpes with 72 percent of its primary energy coming from nuclear energy for electric power plants. However, since nuclear energy is used only for electricity generation, it is not really consistent to compare losses from nuclear energy with losses from fossil fuels, except in the consideration of environmental effects such as the impact of waste heat discharges.

TABLE 7.9 Solar Energy Contribution to Energy Requirements in Bezirk X, Rhone-Alpes, and Wisconsin for Scenario S3 in 2025

	Bezirk X	Rhone-Alpes	Wisconsin
Residential end-use	5%	10%	17%
Service end-use	6%	41%	9%
Total end-use energy[a]	3%	12%	11%
Electricity generation	7%	16%	30%

[a] These figures include solar-generated electricity used in the end-use sectors.

Sources of electricity are primarily coal for all three scenarios in Bezirk X; nuclear energy for Rhone-Alpes Scenarios S1 and S2 and Wisconsin Scenario S1; coal and nuclear energy for Wisconsin Scenario S2; a combination of solar energy, oil, gas, coal, and nuclear energy for Rhone-Alpes Scenario S3; and coal and solar energy for Wisconsin Scenario S3.

Solar Energy One strategy examined in the scenarios for reducing petroleum requirements was the development of renewable resources such as solar power. Vigorous development of solar power for heating was examined in the residential and service sectors, and to a more limited extent in electricity production. As stressed in the scenario descriptions in the three previous chapters, the scenario assumptions about solar penetration were not meant to be a prediction of technological progress: rather they were included to assess the impact of a given penetration rate on end-use energy demands and on resource requirements in the time frame of the scenarios.

The potential solar contribution to the energy needs of the three regions in 2025 is shown in Table 7.9. Its contribution is significant, especially in Rhone-Alpes where solar energy provides 41 percent of service energy needs and in Wisconsin where it provides 17 percent of residential needs. One must keep in mind that in the scenarios, the utilization of solar power was restricted to new construction, and even during a 50-year period the turnover of a stock of buildings is slow. Should retrofitting of existing buildings with solar equipment become economical, the impact of the solar strategy would be even greater. It must be emphasized too that in the scenarios only technology that is currently operational, such as space heating and water heating, was considered. The scenarios could be radically altered if inexpensive mass production of the photovoltaic cell and solar energy systems for producing intermediate temperatures for industry became feasible.

IV.C. SOME CONCLUDING COMMENTS ON ENERGY SUPPLY

In concluding the discussion on energy supply systems in the three regions, the following observations can be made:

- Despite vigorous conservation measures and alternative fuel strategies, the scenarios demonstrated the difficulty that could be experienced well before the end of the century in avoiding severe constraints or shortfalls of petroleum supplies if petroleum production begins to decline in that period.

- Although conventional and environmental costs could be appreciable, coal represents a major option for decreasing dependence on scarce petroleum and gas, and is a major competitor to nuclear power.
- In general, future growth of electricity generation in the regions will be much lower than historical rates.
- The potential of energy savings through application of district heating or cogeneration is significant in all of the regions. The GDR is well on its way to the widespread implementation of district heating.
- Solar energy has the potential to appreciably reduce the long-term, nonrenewable energy resource requirements in all of the regions.

V. SELECTED ENVIRONMENTAL IMPACTS

The analysis of environmental consequences was one of the major objectives of scenario building. A wide range of quantified environmental indicators have been used to characterize the environmental implications. *Quantified* here refers only to those impacts included in the models used in this research. The choice of this set of impacts is to some extent subjective; in addition, some degree of uncertainty (and perhaps controversy) is associated with some of the impact factors. There are also many indicators which are recognized but remain unquantified; there are others that are unrecognized and hence unquantified. An approach to coping with this uncertainty and subjectivity is described in Appendix E.

The impacts presented in this section are only a fraction of those studied with the methodology described in Chapter 3, and described in the scenarios for each of the regions in Chapters 4, 5, and 6. Representative impacts have been selected from several categories as shown below:

- Impacts on water: Water evaporated by power plant waste heat
- Impacts of land: Land use for energy resource extraction and energy-related facilities
- Impacts on air: Sulfur dioxide emissions
- Impacts on people: Quantified human health and safety impacts
- Potential long-term impacts: Carbon dioxide production and radioactive waste production

The first three categories are primarily regional or local impacts. The fourth category, human health and safety impacts, includes some quantified global impacts as well as the local effects. The final category has impacts that are representative of the potential long-term risks that are global in nature.

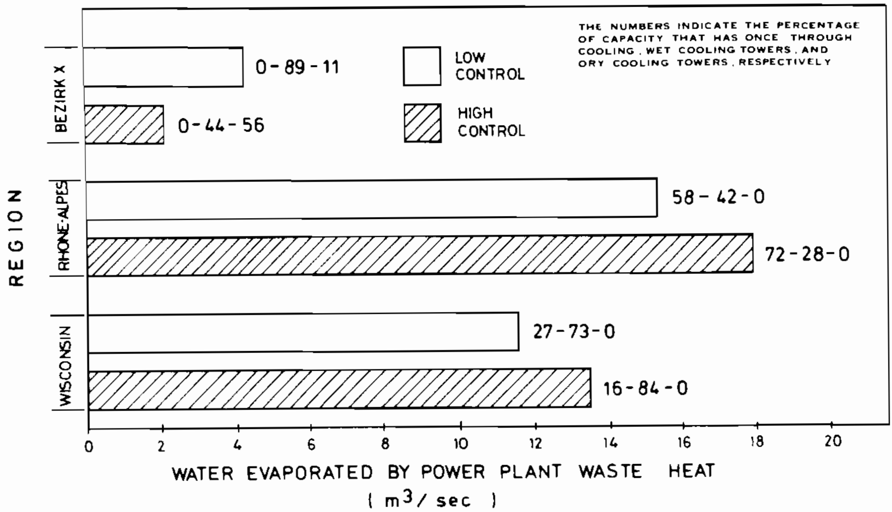


FIGURE 7.24 Water evaporated by power plant waste heat in 2025 for two control options (electrical generation as in Scenario S1).

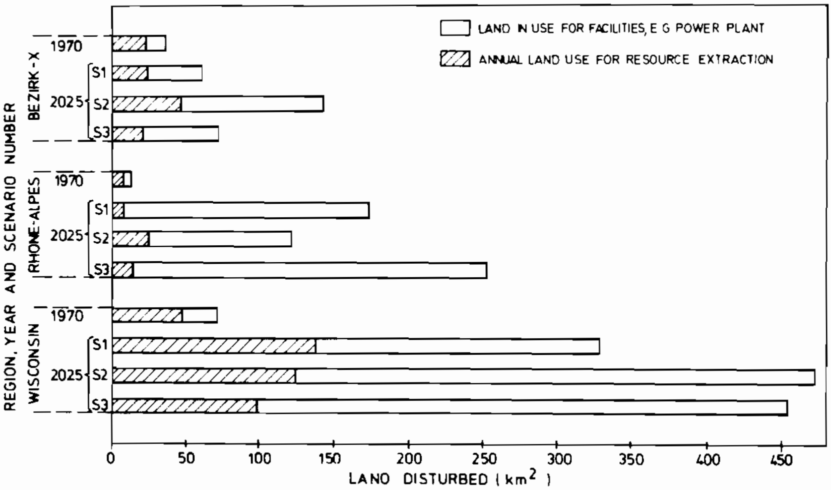


FIGURE 7.25 Cross-regional comparison of annual land use for energy production. Note that land in use for facilities does not include land used for hydropower plants.

V. HEAT DISCHARGE FROM POWER PLANTS

Waste heat from electrical generation presents a problem that varies in magnitude among the three regions. Three categories of cooling options have been considered for power plants: once-through cooling on rivers; evaporative cooling such as provided by wet cooling towers; and dry (nonevaporative) cooling towers. A high control and a low control case for each region were based on different allowable temperature increases for rivers. Since Rhone-Alpes and Wisconsin have sizable water resources, once-through cooling and wet cooling towers are the only options considered. For Bezirk X the water resources are very limited, and once-through cooling is not an option.

Calculation of water evaporated for the 2025 levels of electrical generation in Scenario S1 have been made for each region. The results for low control and high control cases are shown in Figure 7.24. The high control case for Bezirk X has less evaporation (more dry cooling), while the high control case for Rhone-Alpes and Wisconsin requires more evaporation (less once-through cooling). If strict environmental standards are imposed, dry cooling may also eventually be required in Rhone-Alpes and Wisconsin. Current designs for dry cooling systems are avoided because of large efficiency penalties and costs.

The total fresh water consumed for all purposes (evaporated, transpired, or incorporated into products) in Wisconsin in 1970 averaged approximately 9.5 m^3/sec. This is less than the evaporation from Wisconsin power plants for either control option shown in Figure 7.24.

V.B. LAND USE

The annual land use for energy production is shown in Figure 7.25. The land being used may be divided into facilities land use, such as at power plant sites, and resource extraction land use, such as at uranium or coal surface mines (land use for hydropower plants was not included in this study). Therefore, not all the land use shown in Figure 7.25 is within the region since some fuels are imported and some fuel system facilities, such as uranium mills, are located in other regions.

Even if it is assumed that all land disturbed for past resource extraction is reclaimed so that the total quantity of land disturbed because of energy activities is just what is shown in Figure 7.25, the quantities of land use are not insignificant. For example, the scenario with the largest land use in 2025 amounts to the following percentage of total land areas in each region:

- Bezirk X – 2.9 percent (S2)
- Rhone-Alpes – 0.6 percent (S3)
- Wisconsin – 0.3 percent (S2)

V.C. SO_2 EMISSIONS

Sulfur dioxide (SO_2) is generally thought to have unfavorable effects on human health, vegetation, and structures. Coal is a major source of SO_2 emissions in Bezirk X and Wisconsin, and to a lesser degree, in Rhone-Alpes. Table 7.10 indicates typical

TABLE 7.10 Assumed Typical Coal Characteristics for Electricity Impact Calculations

	Heating Value (kcal/kg)	Percent Sulfur	Grams SO_2 per 10^6 cal (No Control)	Percent Ash	Grams Ash per 10^6 cal (99% Control)
Bezirk X					
lignite (thru 1985)	2,300	1.4	12.2	10	0.43
lignite (after 1985)	2,200	1.4	12.7	10	0.45
Rhone-Alpes					
bituminous	7,000	0.7	2.0	10	0.14
Wisconsin[a]					
bituminous	6,650	2.5	7.5	10	0.15
subbituminous	4,700	0.6	2.6	10	0.21

[a] United States Environmental Protection Agency (USEPA) emission standard for SO_2 from power plants is 1.2 lb/10^6 Btu, or 2.2 g/10^6 cal.

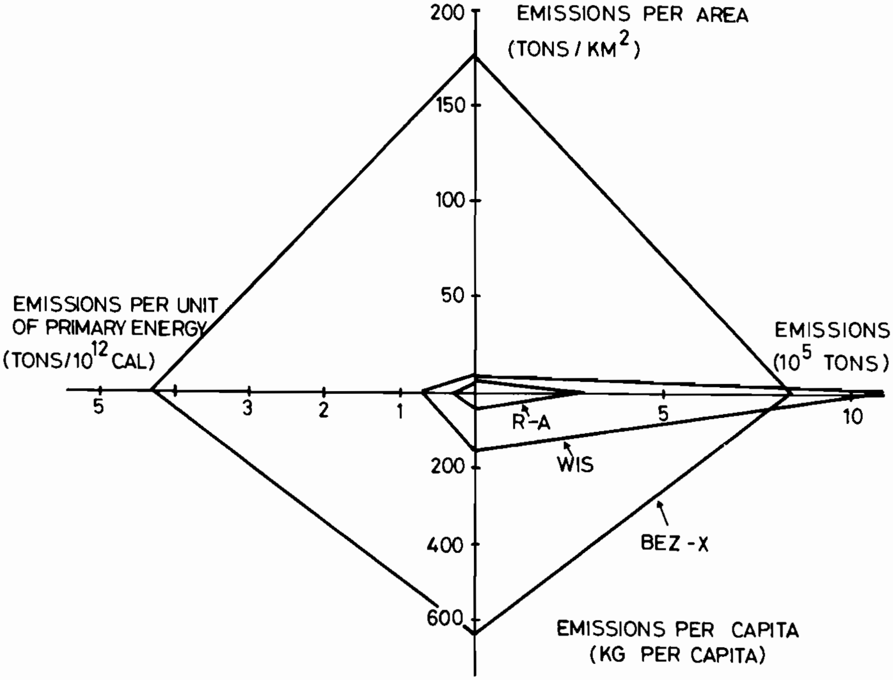


FIGURE 7.26 Sulfur dioxide emissions in 2025 for Scenario S1.

coal characteristics assumed for the three regions. With no SO_2 control measures, the Bezirk coal produces about twice as much SO_2 per unit energy as a blended U.S. coal, or nearly 5 times as much as low-sulfur western subbituminous coal. The table demonstrates the wide variability in energy resource characteristics in the three regions.

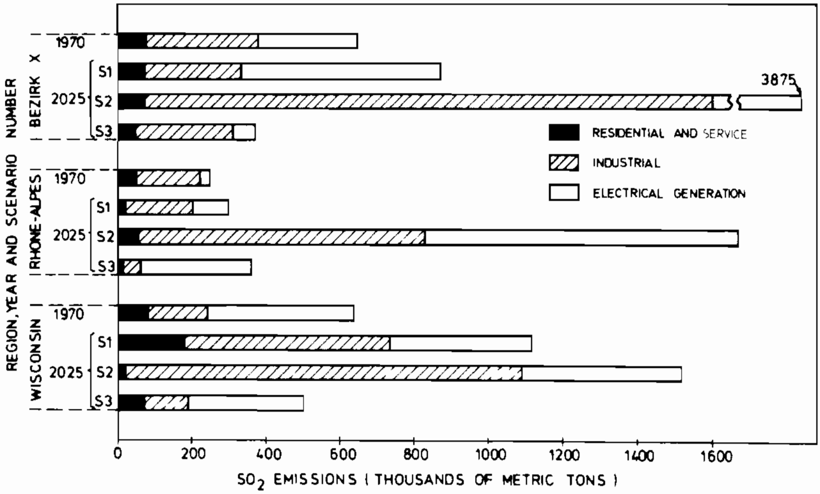


FIGURE 7.27 Cross-regional comparison of SO_2 emission resulting from energy use and energy export.

The SO_2 emissions for Scenario S1 in the year 2025 are compared for the three regions in Figure 7.26. Four different indices for the emissions are shown: total absolute emissions, emissions per unit area, emissions per capita, and emissions per unit of primary energy use. Wisconsin has the largest total emissions, but Bezirk X has the greatest impact on the other three scales. The Bezirk is a highly industrialized region that uses lignite for most of its energy.

The SO_2 emissions for the years 1970 and 2025 for all scenarios are compared in Figure 7.27. It is clear that residential and service sector emissions are a small fraction of total emissions in all scenarios considered. The very large total emission for the Bezirk in Scenario S2 is the result of expansion of energy-intensive industry, emphasis on electricity, and no SO_2 emission controls. Some of the emission for Bezirk X in S2 occurs in other regions because the Bezirk imports a significant quantity of electricity.

In general, the SO_2 emission controls were assumed to be minimal in S2, maximum in S3, and in the middle for S1. These assumptions, coupled with the widely varying energy demands in some scenarios, result in total SO_2 emissions in 2025 that are near 1970 levels (Rhone-Alpes S1 and S3) or even decline from 1970 levels (Bezirk-X S3 and Wisconsin S3).

Expected emissions of particulates, nitrogen oxides, carbon monoxide, and hydrocarbons have also been computed for the scenarios. Only SO_2 is presented because it is the only pollutant with which some quantified health effects have been associated in the models used here. However, it should be noted that the transportation sector, which includes private autos, is a large contributor of some of these other pollutants but is not a significant contributor of SO_2.

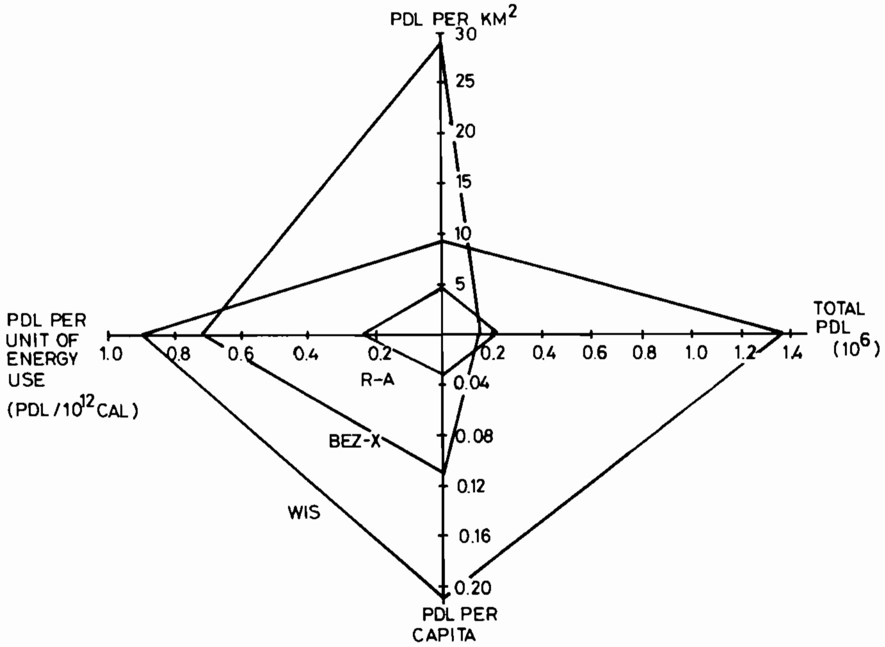


FIGURE 7.28 "Quantified" human health and safety impacts (Scenario S1 – 2025; PDL = person-day lost).

V.D. HUMAN HEALTH AND SAFETY

The total "quantified" human health and safety impacts in the year 2025 for Scenario S1 are shown in Figure 7.28, which is similar in format to Figure 7.26. Person-days lost (PDL) are used to combine the effects of mortality and morbidity. 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 to waste disposal. In contrast to SO_2 emissions for Scenario S1, Bezirk X has the largest impact only on the scale showing PDL per unit area. Quantified impacts of air pollution are a major share of the total PDL for Wisconsin.

To provide some perspective on these numbers, the PDL per capita in Figure 7.28 are compared with the PDL per capita that result from all accidental fatalities in the United States. The risk of fatality from all accidents (autos, falls, burns, drowning, firearms, and so forth) was 49 per 100,000 in the United States in 1974.[2] This is equivalent to 2.9 PDL per person per year.* The quantified PDL per capita in 2025 that results from Wisconsin energy use in Scenario S1 is about 7 percent of the PDL per capita from all fatal accidents at current incidence levels.

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* One accidental fatality is equivalent to 6,000 PDL in this accounting system.

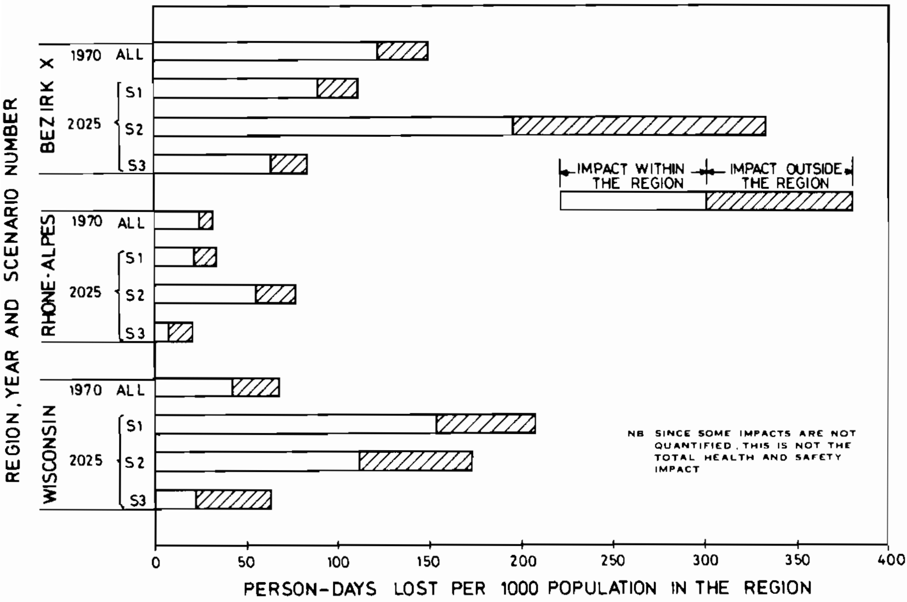

FIGURE 7.29 Cross-regional comparison of quantified human health impacts.

The quantified health and safety impacts are not spread evenly over all population groups. For example, nearly 30 percent of the quantified PDL in 2025 for Wisconsin Scenario S1 are imposed on less than 1 percent of the total population, namely, 53,000 elderly people who live in the industrialized Milwaukee area and had heart or lung disease before the period of the study.

The total PDL per 1,000 people in the region is displayed in Figure 7.29 for the years 1970 and 2025 for all scenarios. It is interesting to note that there is at least one scenario in each region that has fewer PDL per capita in 2025 than in 1970. Also, it is clear from the figure that a significant fraction of the total PDL is imposed on regions other than where the energy is consumed. Impacts in other regions result from consumption of fuels that must be mined elsewhere and transported into the regions, or from the expected global health effects from radioactive releases and so on. The quantified health impacts of air pollution are a significant consideration in all scenarios examined in this study.

V.E. CARBON DIOXIDE EMISSIONS

Carbon dioxide emissions are of concern on a global scale since the atmospheric concentration of CO_2 affects average global temperature.[3,4,5,14] Burning of fossil fuels has produced enormous quantities of CO_2, about 10.8 x 10^9 metric tons in 1960,[3] for which there are three main reservoirs: the oceans, the biosphere (defined

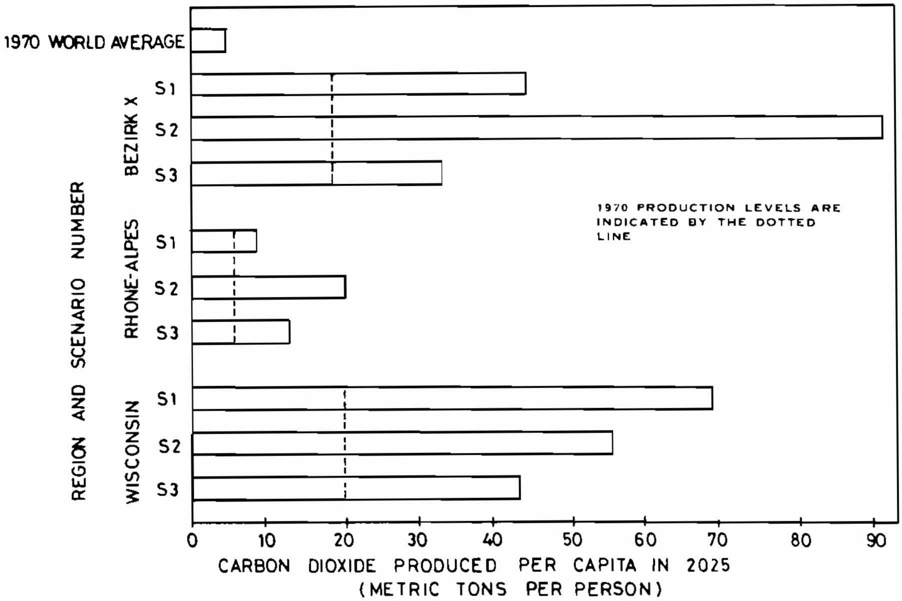

FIGURE 7.30 **Carbon dioxide production per capita in 1970 and 2025.**

as the mass of living and nonliving organic matter), and the atmosphere. About half of the CO_2 liberated by fossil fuel combustion has remained in the atmosphere.[3,4] Calculations have shown that the CO_2 concentration in the atmosphere may increase from about 320 parts per million (ppm) by volume in 1970 to from 370 to 380 ppm in 2000; the resulting global temperature increase may be nearly one degree Celsius. Global temperature changes of this magnitude may have serious implications for agriculture, global sea level, and global precipitation patterns. Thus, CO_2 emissions that result from burning of fossil fuels may involve a significant long-term risk to future generations.

The per capita CO_2 emissions in the year 2025 for the three scenarios in each region are shown in Figure 7.30 along with the 1970 emission levels. All three regions have greater CO_2 emissions in 2025 for all three scenarios than they had in 1970. The total CO_2 emissions in Wisconsin in 2025 for Scenario S1 are more than a factor of 5 greater than the 1970 emissions (population increases by about 50 percent from 1970 to 2025). Bezirk X relies on coal for a large fraction of its energy in all scenarios; the total emissions for the high-energy scenario (S2) in the Bezirk are nearly 5 times greater than the 1970 emissions. In Rhone-Alpes, the availability of fossil fuels is more limited and a significant fraction of the energy comes from other sources, such as hydropower or nuclear energy.

The emissions resulting from Wisconsin's energy use in 2025 for S1 are approximately 4 percent of the total emissions for the world in 1960. If all regions of the

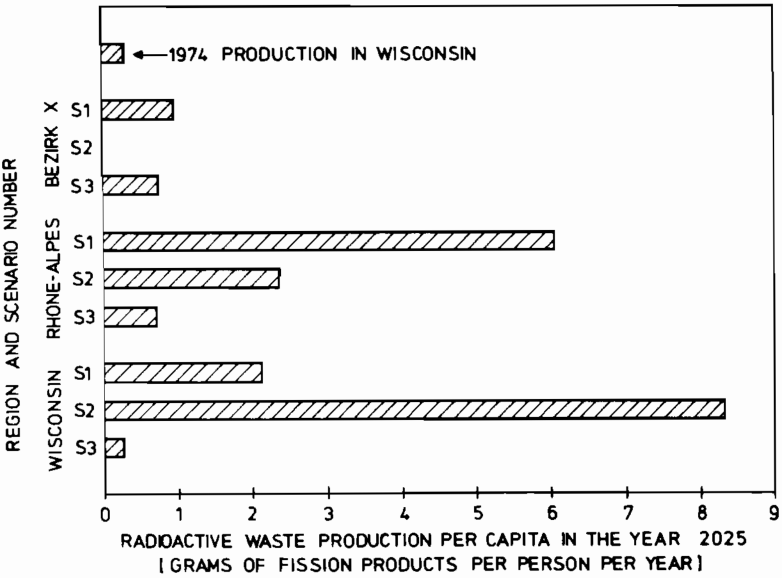

FIGURE 7.31 Radioactive waste production per capita in 2025 for all scenarios.

world were to increase their CO_2 emissions as in these scenarios, methods for reducing CO_2 emissions to the atmosphere, e.g., Marchetti's disposal method,[6] or even CO_2 removal from the atmosphere, may be required, or the fossil fuel option might be unacceptable.

V.F. RADIOACTIVE WASTE

Radioactive wastes produced during reprocessing of nuclear fuel are highly radioactive and must be stored in isolation for long time periods.[7,8] The safety and reliability of waste management alternatives are among the recognized potential long-term risks related to nuclear power.

The mass of radioactive waste that is produced annually to provide nuclear electricity in each of the three regions is shown in Figure 7.31 for the three scenarios. The large commitment to nuclear power in Rhone-Alpes Scenario S1 and Wisconsin Scenario S2 is evident. The Bezirk relies heavily on coal (lignite) for its electricity, and nuclear power is not introduced until after the year 2000 in Scenarios S1 and S3; there is no nuclear power at all in Scenario S2. Wisconsin has a significant quantity of nuclear energy in Scenario S1 but nuclear generation in Wisconsin Scenario S1 is only about one-third of the production in Rhone-Alpes Scenario S1. The 2025 nuclear generation in Rhone-Alpes Scenario S1 is greater than 3 times the 83 x 10^9 kWh (gross) produced from nuclear plants in the United States in 1973.[2]

Radioactive wastes could have both global and regional impacts. Accidents at reprocessing plants, waste storage facilities, or during transportation could cause severe local radioactive contamination. A worldwide heavy commitment to nuclear power, such as in Scenario S1 for Rhone-Alpes, would present a formidable waste management problem, one that would require global cooperation. In concluding this section on the environment, it should be noted that no scenario has the lowest environmental impacts in all categories considered. Therefore, one must make value judgments concerning tradeoffs between impacts. Some impacts are local and short-term, while others are global and long-term. Some are quantified, others are recognized but unquantified, still others are unrecognized and therefore unquantified. Local government controls over the localized impacts may be adequate to keep local impacts at a tolerable level; in contrast, some of the potential long-term impacts may require cooperation among nations to avoid "the tragedy of the commons"[9] on a global scale.

VI. CONCLUDING COMMENTS

The alternative futures compared in this chapter are clearly not intended as forecasts; no probabilities of occurrence have been associated with them. In the time since the scenarios were written, it has become clear that some of the parameters, assumptions, and policies embodied in them would have to be changed, were the scenarios to be rewritten. However, because of their emphasis on the mid- to long-term, the examination of these futures is a valuable process for analysis of the policy issues treated here; if anything, these issues are of even more importance today than at the beginning of the research project.

The preceding sections have only highlighted some of the results of the comparative analysis. One of the important aspects not described here is an analysis of the relationship between the decision structures of a region and the formal models and planning tools that are used. This work is presented in Appendixes B and C of this book.

In closing, it should be emphasized that this study was made with the objective of developing a greater understanding of the regions and their futures. No region should be judged as "better" or "worse." We hope that our results are read in that spirit and that they contribute to improved management of energy and environmental systems.

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Appendixes

BACKGROUND PAPERS

The appendixes of this book provide a detailed picture of the three regions. Appendix A, which contains a description of socioeconomic, geographic, and energy-use characteristics of the regions, has much more detail than Chapter 2. Appendixes B and C provide an overview of the administrative and institutional structure of energy management as well as a description of selected energy and environmental practices in each of the three regions. Appendix D describes energy system models employed in each of the regions and an appraisal of these models by specialists from the two other regions. Finally, Appendix E presents an approach used by IIASA to find the preferences of decision makers with regard to energy/environment strategies.

A Description of the Three Regions

I. THE GERMAN DEMOCRATIC REPUBLIC

Alois Hölzl – IIASA

I.A. PHYSICAL CHARACTERISTICS

I.A.1. Geography

The German Democratic Republic (GDR) is a middle European country; in the north it borders on the Baltic Sea (Its coastline is 901 km.) and it has common boundaries with the Federal Republic of Germany (FRG) in the west and southwest (1,381 km), with Czechoslovakia in the southeast (430 km), and with Poland in the east (456 km). The area of the GDR is 108,178 km^2, and its population was about 17.1 million in 1970. The capital is Berlin, which had about 1.1 million residents in 1970. Figure 1 gives an idea of the size and location of the GDR.

Geographically, the country consists of two regions: the northern part of the GDR is part of the North German lowland, while the southern part belongs to the German low mountain area. The highest elevation in this area is the Fichtelberg (1,214 m) in the Erzgebirge. The main river of the GDR is the Elbe which enters the country from Czechoslovakia at the southeast border and leaves the country in the northwest (at the border with the FRG). The length of the GDR section of the river is 566 km (49 percent of the total length of the river), and its drainage area covers 77 percent of the total land area of the GDR. The second important river is the Oder which forms part of the border with Poland. Here, the GDR section is 162 km (18 percent of the total length of the river). Including a number of smaller rivers and several canals (such as the Oder–Spree Kanal) the inland waterway system of the GDR has a total length of approximately 2,500 km.

Natural resources in the GDR are very scarce. The most important minerals mined are iron, uranium, and potassium; even taking these into consideration, the country is not self-sufficient. Within the energy sector, lignite is practically the only primary energy source supplied in the country itself; it supplied about 75 percent of the total energy demand in 1970. Other fossil fuels, such as hard coal, crude oil, and natural gas, have to be supplied almost exclusively by imports. Due to the

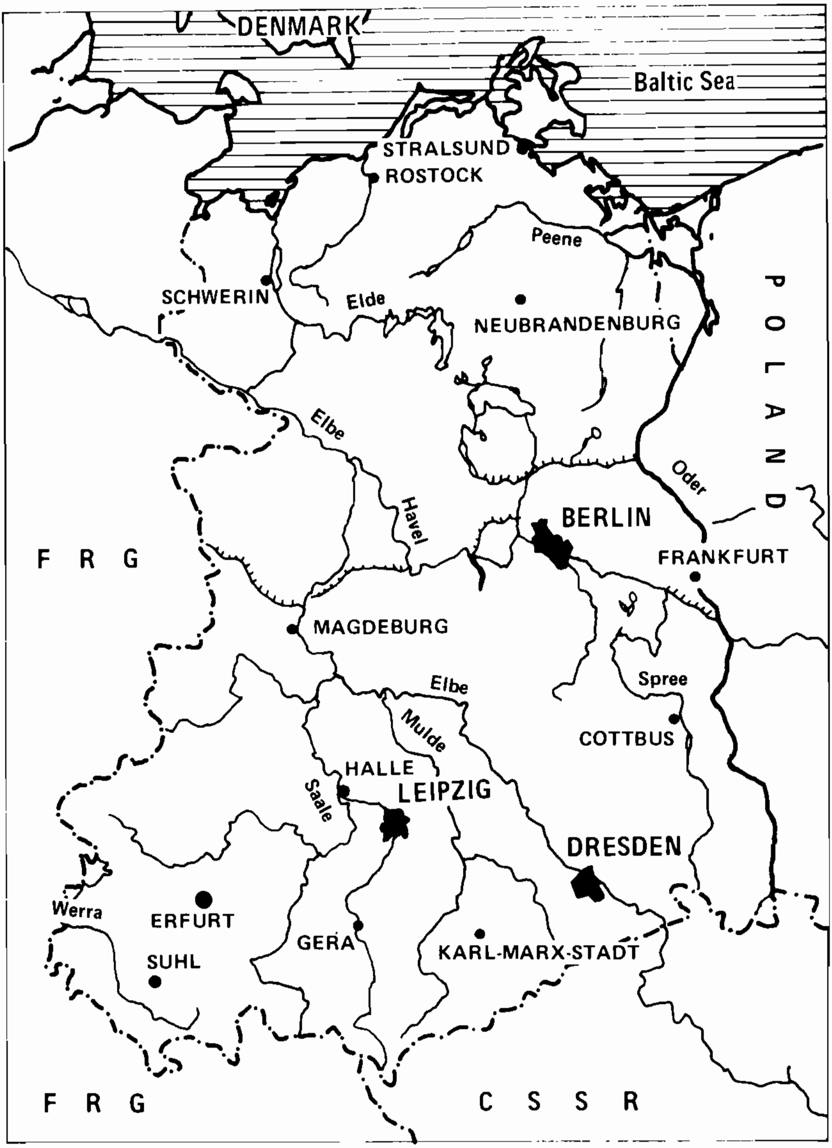

FIGURE A.1 Map of the German Democratic Republic.

geographic characteristics, the climate, the location of raw materials, and historical factors, the northern part of the GDR is dominated by agriculture, whereas the southern part is highly industrialized. The most important branches of industry are the lignite industry, the chemical industry, iron and steel, construction of machinery

TABLE A.1 Area, Population, and Population Density of the Regions in the GDR

	Area (km²)	1970 Population (× 10³)	1970 Population Density (people/km²)
Berlin	403	1,086	2,695
Cottbus	8,262	863	104
Dresden	6,738	1,877	279
Erfurt	7,348	1,256	171
Frankfurt/Oder	7,185	681	95
Gera	4,004	739	185
Halle	8,771	1,925	219
Karl-Marx-Stadt	6,009	2,047	341
Leipzig	4,966	1,491	298
Magdeburg	11,525	1,320	115
Neubrandenburg	10,793	638	59
Potsdam	12,572	1,133	90
Rostock	7,074	859	121
Schwerin	8,672	598	69
Suhl	3,856	553	143

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; pp. 3, 77–106.

and equipment, the fine mechanical and optical industry, and the textile industry. In the north, the only industrial centers are Berlin (electrical equipment) and the seaports Rostock and Stralsund (shipbuilding).

I.A.2. Climate

The GDR has a moderate continental climate. The temperature ranges are slightly less in the north due to the influence of the Baltic Sea. For instance, the average annual minimum and maximum temperatures in Cottbus (69 m above sea level in the southern part of the GDR) are – 10.4°C and 4.9°C in January, and 15.8°C and 20.7°C in July. The corresponding values for Schwerin (59 m above sea level, near the Baltic Sea) are – 8.6°C and 4.5°C in January, and 14.2°C and 19.9°C in July. The figures are average values over the period 1901 to 1973. The number of degree-days calculated on the basis of these data give a measure of the heating requirements. A degree-day is defined as the difference between the average of the daily maximum and minimum temperatures and the normal room temperature (18.3°C), accumulated during the heating season. Assuming that the heating season lasts from October through April, the average number of degree-days is 3,342 for Cottbus and 3,335 for Schwerin. Apart from the coastline and a few elevated points, the climate is rather dry. The average annual amount of precipitation ranges between 500 mm and 650 mm.

I.B. POPULATION CHARACTERISTICS

The GDR is divided into 15 regions (*Bezirke*) broken down into 27 urban and 191 rural districts (*Kreise*), which in turn consist of 8,868 communities (*Gemeinden*). Table 1 gives a listing of the 15 regions along with their area, population, and density (see Figures A.2a and A.2b).

The population changes in the GDR have been very unusual. In 1939, 16.7 million

FIGURE A.2a Regions (*Bezirke*) and districts (*Kreise*) of the GDR – 1974.

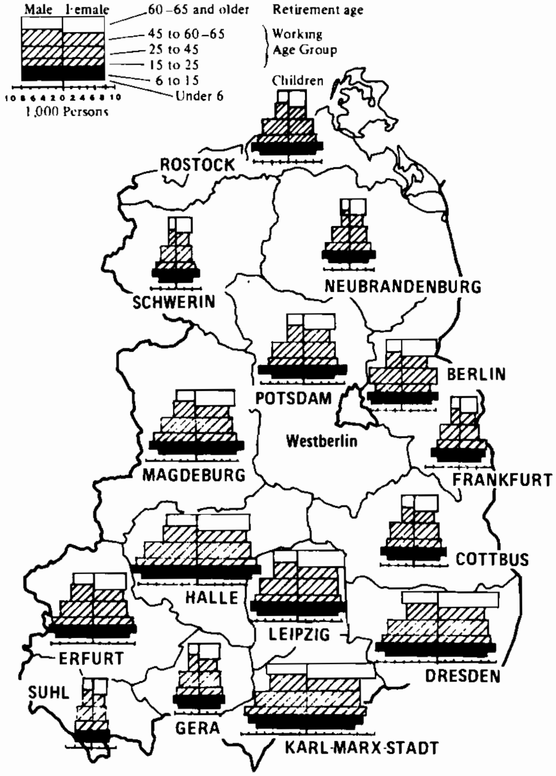

FIGURE A.2b Population of the GDR regions by age and sex – 1972.

people lived in the GDR area. Due to the inflow of refugees, this number increased to 18.6 million by 1946. From 1946 to 1964, the population dropped to 17.0 million. Currently, the population is stable. The major reasons for the stability are an extremely high proportion of older people, a surplus of women in the total population due to war losses, and migration of many in the labor force to the FRG before 1961 (Table A.2). The labor shortage is compensated in part by the rather large number of working women and by a high number of people working beyond the retirement age.

The regional distribution of the population within the GDR is not very homogeneous. Roughly speaking, the line Magdeburg-Dessau-Görlitz is the boundary between the densely populated southern part, with average densities between 100 and 500 persons/km^2, and the more sparsely populated northern part, with densities of less than 100 persons/km^2. In the southern part of the GDR there are three urban areas with densities higher than 475 persons/km^2. These areas are

- Halle-Leipzig (2 million people)
- Karl-Marx-Stadt (1.6 million people)
- Dresden (1 million people)

TABLE A.2 Structure of the GDR Population by Age and Sex (%)

Age group	1950	1960	1973
$A \leqslant 6$	7.0	9.4	7.6
$6 < A \leqslant 15$	15.9	12.0	14.7
$15 < A \leqslant 25$	13.7	14.9	15.1
$25 < A \leqslant 45$	25.4	22.2	26.2
$45 < A \leqslant 65$	27.5	27.7	20.3
$65 < A$	10.5	13.8	16.1
Total	100.0	100.0	100.0
Male	44.4	45.1	46.3
Female	55.6	54.9	53.7

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 419,

TABLE A.3 GDR Population by Size of Community

	Percentage of Total Population			
	1950	1960	1970	1973
Rural communities (< 2,000 people)	29.0	28.0	26.2	25.3
Urban communities				
$2{,}000 < R \leqslant 20{,}000$	31.9	31.5	29.7	29.2
$20{,}000 < R \leqslant 100{,}000$	18.4	19.1	22.1	22.2
$100{,}000 < R$	20.7	21.4	20.0	23.3
Total	100.0	100.0	100.0	100.0

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 10.

One-third of the total GDR population lives in Berlin or one of these three urban areas, which account for one-tenth of the total land area. The natural population change is negatively correlated with the density: in the northern part, there are more births than deaths, whereas in the southern part there are more deaths than births (especially in Dresden and Karl-Marx-Stadt). In the middle of the country there is a stable zone. This stability is modified by the migration to the industrialized areas in the south, and to the east-central part of the GDR, where new chemical factories are being built.

The distribution of the GDR population by community size reveals a shift from rural and small urban communities to medium-size cities; the percentage of the population living in cities with more than 100,000 residents has remained fairly constant since 1950 (see Table A.3).

I.C. TRANSPORTATION CHARACTERISTICS

Before World War II, the main transportation routes in the GDR area were constructed from east to west. Therefore, basic changes in the traffic network were necessary in order to connect the industrial centers in the south with the agricultural areas and seaports of the northern GDR after the separation from the western part of Germany.

The railway network of the GDR is fairly dense (14,317 km in 1973), despite the

TABLE A.4 Motor Vehicles in the GDR

	Absolute Figures (10^3 vehicles)				Average Annual Growth Rate (%)		
	1950	1960	1970	1973	1950–1960	1960–1970	1970–1973
Autos	75.7	298.6	1,159.8	1,539.0	14.7	14.5	9.9
Motorcycles	197.5	848.0	1,374.0	1,360.9	15.7	4.9	– 0.3
Mopeds		477.4	1,538.0	1,813.3		12.5	5.6
Buses	1.9	9.3	16.7	19.1	4.9	6.0	4.6
Trucks	93.5	117.8	185.9	216.3	2.3	4.7	5.2
Special-purpose vehicles	3.3	13.9	43.0	53.5	15.5	12.0	7.6
Traction vehicles	11.6	85.6	194.0	204.1	22.1	8.5	1.7
Trailers		163.5	491.3	633.0		11.6	8.8

SOURCES: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 245.

closing of several lines in the last few years. The main railway lines are the connections between Berlin and the seaports Rostock and Stralsund in the north, and those connecting Berlin with the industrial centers in the south (Dresden, Halle/Saale, Leipzig, Frankfurt/Oder). Currently, about 10 percent of the railroad networks are electrified (especially the main routes). In 1973 the rail service (measured in gross ton-kilometers and including both passenger and freight transportation) was divided among the three traction types as follows: steam – 33 percent, electricity – 16 percent, diesel – 51 percent. Currently, steam engines are being replaced mainly by diesel engines.

Expansion of the road system began on a large scale in 1968; the total length of roadways in the GDR in 1973 was 126,667 km. The number of private cars in the GDR is still rather low, but is increasing very rapidly. Although there is apparently a strong trend towards more private transportation, as can be seen in Table A.4, the official plans are to emphasize public transportation.

In the public transportation sphere, a significant trend is a shift away from the tramway in favor of buses in intracity mass transit. Buses are also becoming increasingly important in intercity mass transit, replacing the train as a favored mode of travel. Summary statistics on the volume (number of passengers) and service (number of passenger kilometers) of mass transportation by mode are given in Tables A.5 and A.6. The data reflect the continued importance of public transportation in the GDR. In 1973, for example, the average number of trips per person on public transportation facilities was 218 (17 percent rail, 33 percent intercity buses, 49 percent intracity mass transit), and the average distance traveled was 2,864 km (43 percent rail, 37 percent intercity buses, 14 percent intracity mass transit).

In the freight transportation sector, one can observe a shift from railways to trucks, but the relative decline of the railway service is not as strong as in the case of mass transportation. An overview of the volume (number of tons) and service (number of ton-kilometers) of freight transportation by mode is given in Tables A.7 and A.8. The items "factory vehicles" and "sea boats" cause some distortion in the statistics: the former category accounts for a large fraction of the total tonnage transported, but since the average length of a haul is very short, its contribution to the total freight transportation service is rather small; conversely, the latter category represents only a small percentage of the total tonnage transported but a large part of the total freight service.

I.D. ECONOMIC STRUCTURE

The GDR has a centrally planned economy, making the concept of measuring economic activity (net material product) different from the concept used in free-market economies. The main difference is the fact that the definition of the net material product (NMP) excludes economic activities not contributing directly to material production, such as public administration and defense, personal and professional services, and similar activities. An estimation of the gross national product (GNP) of the GDR made by the West German Institute for Economic Research (DIW), by calculating the contribution of the "nonproductive" services, indicates that the GNP in 1960 was about 18 percent higher than the NMP in that year. In 1970 the GNP was about 15 percent above the NMP. Tables A.9 and A.10 show the difference between the two concepts; it affects mainly the so-called service sector.

The percentage of the labor force employed in the most important sectors is given in Table A.11. One may note a decline in the percentage of people working in agriculture, and an increase in the percentage of people in the service sectors.

TABLE A.5 Volume of Mass Transportation by Mode

		Percentage of Total Passengers				Number of Passengers (× 10^6)	Annual Average Rate of Change (%)		
		1950	1960	1970	1973	1973	1950–1960	1960–1970	1970–1973
Rail		33.7	26.1	18.0	17.1	633	– 0.1	– 4.0	0.4
Bus	intercity	3.9	18.5	31.8	32.7	1,213	19.7	5.2	3.1
	intracity	62.1	54.5	49.2	48.9	1,814	1.1	–1.4	1.9
Riverboat		0.2	0.2	0.2	0.2	8	1.3	0.0	0.0
Ship			0	0	0	.0105		5.8	– 12.7
Airplane			0	0	0	.09117		12.6	2.7
Subtotal[a]		100.0	99.4	99.1	98.9	3,669	2.4	– 0.4	2.0
Factory vehicles			0.6	0.9	1.1	40		4.1	10.1
Total	%	100.0	100.0	100.0	100.0		2.5	– 0.3	2.1
	10^6 passengers	2,830	3,607	3,486	3,709	3,709			

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 239.

[a] Columns may not sum to totals because of rounding.

TABLE A.6 Mass Transportation Service by Mode

	Percentage of Total Passenger-kilometers				Number of Passenger-kilometers ($\times 10^6$)	Annual Average Rate of Change (%)		
	1950	1960	1970	1973	1973	1950–1960	1960–1970	1970–1973
Rail	68.2	54.6	41.5	42.8	20,851	1.4	− 1.8	5.7
Bus intercity	7.0	24.0	38.3	37.4	18,228	17.2	5.7	3.8
intracity	24.2	18.9	14.8	14.1	6,863	1.1	− 1.5	2.9
Riverboat	0.6	0.5	0.5	0.5	234	2.7	1.6	0.3
Ship		0.1	0.2	0.1	48		[a]	[a]
Airplane		0.4	2.2	2.3	1,120		19.1	5.8
Subtotal[b]	100.0	98.5	97.7	97.2	47,344	3.5	0.8	4.5
Factory vehicles		1.5	2.3	2.8	1,345		5.6	10.5
Total %	100.0	100.0	100.0	100.0		3.7	0.9	4.6
10^6 passenger-km	27,234	39,004	42,525	48,689	48,689			

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 239.

[a] Because of the strong fluctuations it is not meaningful to give average growth rates.

[b] Columns may not sum to totals because of rounding.

TABLE A.7 Volume of Freight Transportation by Mode

	Percentage of Total Tonnage				Total Tonnage (10^6 tons)	Annual Average Rate of Change (%)		
	1950	1960	1970	1973	1973	1950–1960	1960–1970	1970–1973
Rail	56.9	45.5	34.4	32.9	280.6	6.3	1.0	2.2
Truck	19.6	25.2	23.6	20.9	178.5	11.5	3.2	– 0.3
River barge	4.4	2.4	1.8	1.5	12.7	2.4	0.8	– 2.5
Ship		0.3	1.1	1.3	11.5		20.0	10.5
Airplane		0	0	0			14.2	4.6
Pipeline			2.0	2.9	24.5			16.8
Subtotal[a]	81.0	73.4	62.9	59.6	507.8	7.7	2.3	1.9
Factory vehicles	19.0	26.6	37.1	40.4	344.9	12.4	7.4	6.7
Total %	100.0	100.0	100.0	100.0		8.7	3.9	3.7
10^6 tons	225.8	522.1	764.0	852.6	852.6			

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 237.

[a] Columns may not sum to totals because of rounding.

TABLE A.8 Freight Transport Service by Mode

	Percentage of Total Ton-kilometers				Total Ton-kilometers (10^6)	Annual Average Rate of Change (%)		
	1950	1960	1970	1973	1973	1950–1960	1960–1970	1970–1973
Rail	81.0	64.9	32.4	32.3	46,829	8.1	2.4	4.1
Truck	5.2	5.2	4.8	4.8	6,980	10.5	8.9	4.0
River barge	8.5	4.4	1.8	1.3	1,884	3.6	0.5	– 7.2
Ship		20.8	54.5	54.1	78,542		20.8	4.1
Airplane		0	0	0	30.8		18.9	5.0
Pipeline			1.7	2.4	3,512			17.7
Subtotal[a]	94.8	95.3	95.3	95.0	137,778	10.6	9.7	4.1
Factory vehicles	5.2	4.7	4.7	5.0	7,317	9.3	9.8	6.6
Total %	100.0	100.0	100.0	100.0		10.5	9.7	4.3
10^9 ton-km	18.6	50.6	128.0	145.1	145.095			

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 238.

[a] Columns may not sum to totals because of rounding.

TABLE A.9 Contributions by Sector in the GDR to the Net Material Product (NMP)[a] (%)

		1960	1970	Average Annual Growth Rate, 1960–1970 (%)
Agriculture		16.4	11.7	0.96
Industry		56.4	60.7	5.26
Construction		7.0	8.2	6.19
Trade, catering		13.0	12.6	4.17
Transport, communication		5.5	5.2	3.96
Other activities[b]		1.6	1.6	4.14
Total	%	100	100	4.35
	10^6 marks	73.0	113.3	

SOURCE: *United Nations Yearbook of National Accounts Statistics.*[4]

[a] Prices in 1967 used as basis.

[b] Excluding economic activities not contributing directly to material production.

TABLE A.10 Contributions by Sector in the GDR to the "Gross National Product"[a] (%)

		1960	1970	Average Annual Growth Rate, 1960–1970 (%)
Agriculture		13.1	9.7	1.50
Industry		47.1	50.6	5.35
Construction		5.7	6.6	6.14
Trade, catering		9.9	10.0	4.70
Transport, communication		5.1	5.0	4.39
Other activities[b]		18.8	18.1	4.20
Total	%	100	100	4.60
	10^6 marks	92.8	145.0	

SOURCE: *Meyers Enzyklopädisches Lexikon*[2]; p. 509.

[a] Prices in 1967 used as a basis.

[b] Including economic activities not contributing directly to material production (public administration and defense, personal and professional services, and so on).

Currently, a high proportion (48 percent) of the total population is employed (including apprentices). Further information about each economic sector is provided in the following sections.

Agriculture The agricultural acreage of the GDR is about 10.83 million hectare (58 percent of the total land area of the GDR); a further 27 percent of the land area is woodland. Of the agricultural acreage, 73 percent is arable land and 27 percent are pastures and meadows. Due to geographic characteristics and soil properties, arable farming is dominant in the northern part of the country, whereas in the south there are mainly stock breeding farms. Self-sufficiency has been achieved in livestock products, but not yet in crops. The dominant legal form of farms is the agricultural cooperative, in which all means of production, including domestic cattle, are used in common. These farms occupied 86 percent of the total land area in 1970. Additional agricultural statistics are given in Table A.12.

TABLE A.11 GDR Working Population by Economic Sector

	Percentage of Total Working Population[a]		
	1955	1960	1973
Agriculture	22.3	17.0	11.7
Industry[b]	39.5	41.4	42.0
Construction	5.6	6.1	6.9
Transport, communications	6.9	7.2	7.6
Trade, catering	10.9	11.6	10.7
Other sectors	15.2	16.7	21.1
productive[c]		1.2	2.7
nonproductive[c]		15.5	18.4
Total %	100	100	100
10^6 workers	7.7	7.7	7.8

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; p. 57.

[a] Excluding trainees; in 1973 the total number of trainees was about 0.46 million, and their distribution among the sectors reported above was as follows: agriculture – 5 percent, industry – 50 percent, construction – 14 percent, transport and communications – 8 percent, trade and catering – 9 percent, other productive sectors – 2 percent, nonproductive sectors – 11 percent.

[b] Including minor (craft) industry.

[c] This distinction is made with respect to their contribution to the net material product.

TABLE A.12 Agricultural Activity in the GDR

	1965	1970	1973
Employment (10^3 people)	1,178	997	918
Total land area (10^3 ha)	6,358	6,286	6,287
Arable land (10^3 ha)	4,718	4,618	4,634
Livestock (10^3 tons)	1,578	1,800	2,094
Milk (10^3 tons)	6,371	7,091	7,738
Eggs (10^6)	3,935	4,442	4,554
Corn (10^3 tons)	6,730	6,456	8,503
Potatoes (10^3 tons)	12,857	13,054	11,401
Sugar beets (10^3 tons)	5,804	6,135	6,682

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; pp. 187 ff.

Industry In the industrial sector, almost all production is by nationalized enterprises or cooperatives, as is evident from Table A.13. Industrial gross production in the GDR grew by 80 percent during the period 1960–1970, which is equivalent to an annual growth rate of 6 percent. As is seen from Figure A.3, the fastest growing branches are

- Electrical, fine mechanical, and optical products
- Chemicals
- Machinery and transportation equipment

The building materials sector is growing at approximately the same rate as the industrial sector as a whole. The growth rates of the other branches are below

TABLE A.13 GDR Industry by Legal Form of Property

	Percentage of All Plants			Percentage of Total Industrial Gross Production[a]			
	1950	1960	1970	1950	1960	1970	1973
Nationalized enterprises and cooperatives	25.6	31.8	23.6	76.5	88.7	88.7	99.9
Semigovernmental		27.8	48.7		7.5	9.9	
Private	74.4	40.4	27.5	23.5	3.8	1.4	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

SOURCE: *Meyers Enzyklopädisches Lexikon*[2]; p. 509.
[a] At constant prices.

TABLE A.14 Gross Production of GDR Industry by Branch

	Percentage of Total Industrial Gross Production			Percentage of Total Employment in Industry
	1960[a]	1970[a]	1970[b]	1973[b]
Energy sector	6.8	5.6	5.0	6.4
Chemicals	12.1	14.5	15.0	11.0
Primary metals	8.4	7.8	8.0	4.2
Building materials	2.0	2.1	2.1	3.0
Machinery and transportation equipment	22.1	24.9	24.6	28.5
Electrical machinery and equipment, electronics instruments	6.8	9.5	10.5	14.0
Consumer goods (excluding textiles)	12.0	11.2	11.0	16.6
Textiles	8.8	7.0	6.7	8.3
Food	21.0	17.4	17.2	7.9
Total	100	100	100	100

SOURCES: [a] *Meyers Enzyklopädisches Lexikon*[2], p. 509; [b] *Statistisches Jahrbuch 1974 der DDR*[1], pp. 116, 118.

average. Table A.14 shows the relative importance of the individual branches in various years.

The regional distribution of industrial production is markedly uneven. In 1973, the most important regions in terms of gross industrial production were Karl-Marx-Stadt (14.6 percent), Halle (14.4 percent), and Dresden (12.3 percent). The contribution of the other southern regions varied between 5 and 9 percent, whereas the share of the northern regions was only on the order of 1 to 4 percent, with the exception of Berlin (5.9 percent).

Service Sector The major branches included in the service sector are

- Construction
- Transportation, communication
- Trade, catering (hotels and restaurants)

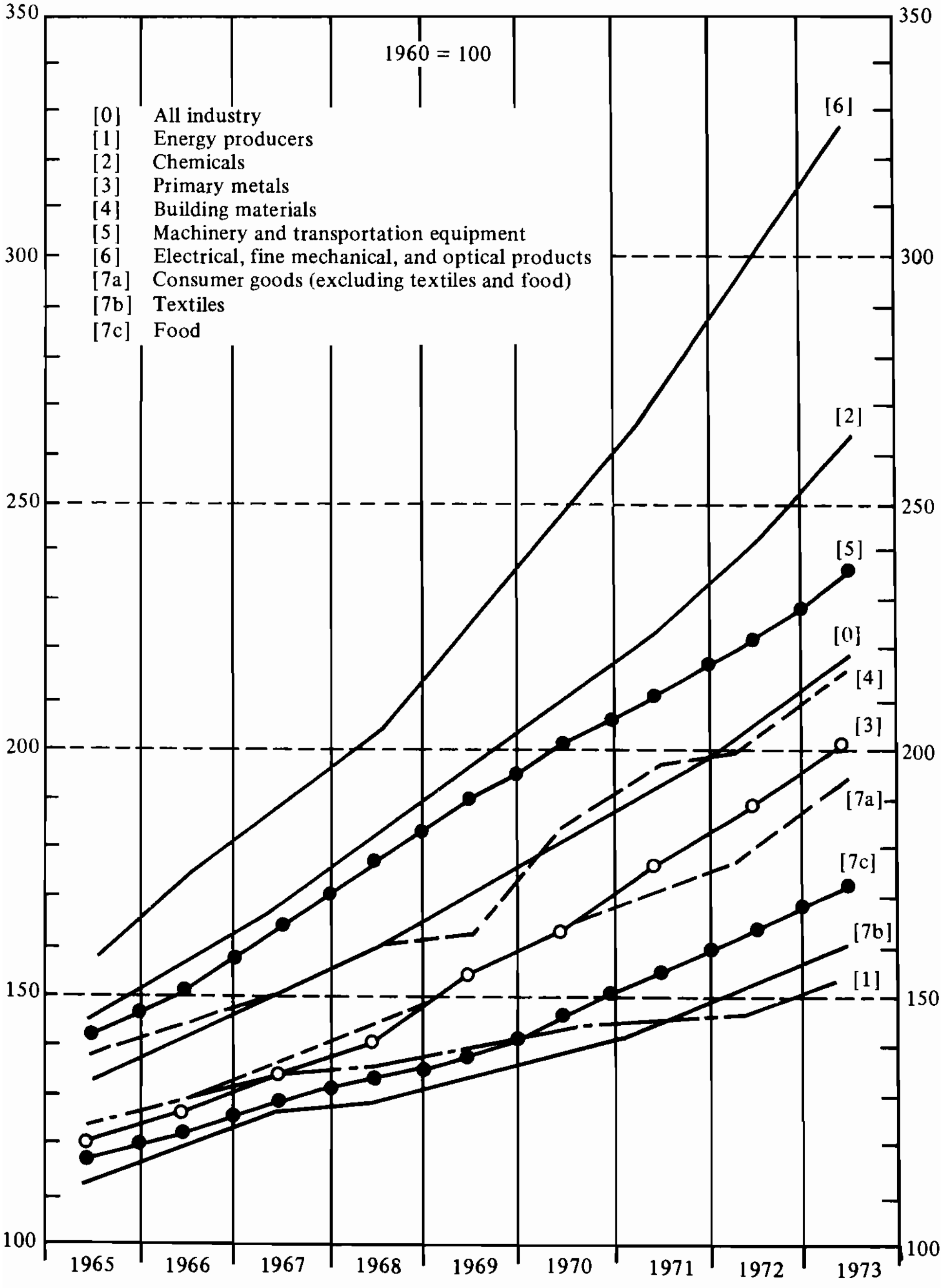

FIGURE A.3 Index of the industrial gross production by sector.

TABLE A.15 Summary Statistics for the GDR Service Sector

	1965	1970	1973
Construction[a]			
Establishments	22,795	18,618	16,234
Employment (10^3 people)	446	533	549
Total production (10^6 mark)	11,371	16,979	19,169
Industrial production (10^6 mark)[d]	8,377	11,735	14,818

	1968	1973
Production subcategories		
Industrial complexes	25.0%	28.7%
Water supply	9.5%	8.2%
Agriculture	6.0%	3.1%
Communication	15.1%	12.1%
Construction of new houses	17.3%	18.2%
Retrofitting of houses		0.7%
Cultural buildings	13.8%	16.3%
Repair work	12.5%	12.1%
Demolition	0.9%	0.5%

Trade, Catering[b]	
Employment (10^3 people)	
Wholesale (nationalized) (1973)	100
Retail trade (nationalized) (1973)	403
Total sales in retail trade (10^6 mark)	
– 1965	51,086
– 1970	64,059
– 1973	74,601
Shops (1971)	97,269
Total floor space (10^3 m^2) (1971)	4,705
Restaurants (1968)	34,035
Total sales in restaurants (10^6 mark) (1968)	5.721

Other services[c e]	Expenditure (10^6 mark)			
	1950	1960	1970	1973
Education	1,136	3,613	5,812	7,275
Culture	312	649	1,082	1,451
Public health and social security	1,394	4,240	5,877	6,940
Social insurance	4,575	9,600	14,976	19,848

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1]; [a] pp. 144 ff.; [b] pp. 261 ff.; [c] p. 310.

[d] Refers to the legal form.

[e] The employment figures in Table A.11 show that this is a rapidly growing sector. It includes both productive services and services for education, social security, and administration. Government expenditures indicate the importance of such services.

- Other services (education, culture, public health and social security, social insurance)

The activities of the transportation sector were described in section IV.A.4. Summary statistics about the other branches are given in Table A.15.

TABLE A.16 Electricity Generation by Source in the GDR

	Percentage of Total Generated Electricity		
	1960	1970	1973
Hard coal	4.4	1.4	1.2
Lignite	72.7	83.2	83.0
Lignite briquettes	6.8	1.8	1.0
Hydropower	1.5	1.8	1.6
Fuel oil	0.1	2.6	3.6
Gas, nuclear energy	14.5	9.1	9.6
Total %	100	100	100
10^6 kWh	40,304.8	67,650.0	76,908.0

SOURCE: *Statistisches Jahrbuch 1974 der DDR*[1], p. 141.

I.E. ENERGY SYSTEM

The energy supply of the GDR is based mainly on lignite. There are rich deposits in the southern part of the country i.e. in the regions Halle-Leipzig-Cottbus. The annual lignite production increased continuously until 1964; since that time the production level varied between 240 and 260 million tons per year. Because of the low heat content, the lignite is practically all converted. In 1973, for instance, 40.8 percent of the total lignite available for home consumption was converted to briquettes, and 57.4 percent was used for electricity generation and/or district heating. Other fossil fuels such as hard coal, crude oil, and natural gas have to be supplied almost exclusively by imports. In the case of hard coal, the percentage supplied by home production dropped from 22 in 1963 to 10 in 1973, while the consumption level remained fairly constant. The annual supply of crude oil is almost exclusively imported; however, a large fraction of refined products, especially light products, is exported. Natural gas was introduced only in the late 1960's, but since that time the annual consumption has been increasing at a very high rate. Until 1972, natural gas was supplied entirely by home production. In 1973 however, 23 percent of the natural gas was imported and this fraction will increase due to the scarcity of home deposits and their low energy content. Other forms of primary energy such as electricity from hydropower or nuclear plants, are rather insignificant. In 1970, only about 0.4 percent of the total primary energy supply was provided in these forms.

In the energy conversion sector, the most important types of conversion are the generation of electricity and district heat. According to an energy flow chart for 1970 provided by the Institut für Energetik in Leipzig, 29 percent of the total primary energy was converted to electricity or, in combined cycle plants, to steam and hot water. Table A.16 shows the fuel mix for electricity generation. The most important energy source is lignite; gases (coke-oven gas and natural gas) and fuel oil are also used to some extent.

The growth rate of electricity production is declining: between 1960 and 1970, the average annual growth rate was 5.3 percent; between 1970 and 1973 it was only 4.4 percent.

Manufactured gas is becoming less important. The production of coke-oven gas and blast furnace gas is decreasing and the production of city gas (mainly from lignite gasification) is increasing slightly.

To summarize these remarks, primary energy consumption and end-use energy

TABLE A.17 Primary and End-Use Energy Consumption in the GDR

Primary Energy Consumption in 1970 (%)[a]

	Coal	Petroleum	Natural Gas	Other	Total
Electrical generation	27.3	0.9	0.3	0.4	28.9
Other consumption	58.3	12.1	0.5	0.0	71.1
Total	85.6	13.0	0.8	0.4	100.0

End-use energy consumption in 1970 (%)

	Residential Sector	Transportation	Industry and Internal Consumption	Total
Electricity	2.0	0.2	4.5	6.7
Other fuels	27.0	4.2	19.8	51.0
Total	29.0	4.4	24.3	57.7

Energy losses (% of total production)

Production and transportation of electricity	22.5
Fuel use	
Residential sector	10.4
Transportation sector	1.7
Industry, internal uses	7.7
Total	42.3

[a] The total consumption in 1970 was 714×10^{12} kcal.

consumption (after conversion losses) are presented in Table A.17. The figures were taken from the 1970 energy balance prepared by the Institut für Energetik in Leipzig. Finally, end-use energy consumption is provided in detail for 1973 in Table A.18.

II. RHONE-ALPES

Alois Hölzl – IIASA

II.A. PHYSICAL CHARACTERISTICS

II.A.1. Geography

Rhone-Alpes is one of the 22 regions into which France is divided. It is located in the eastern part of the country and is surrounded by the regions Franche-Comté and Bourgogne in the north, Auvergne and Languedoc-Roussillon in the west, and the Mediterranean region Provence-Cote d'Azur in the south; in the northeast, Rhone-Alpes borders on Switzerland (between Lake Geneva and Mont Blanc), and in the east it has a border with Italy (see Figure A.4). With an area of 43,694 km^2 or 8 percent of the total area of France, it is the second largest region; it also ranks second with respect to population (4.5 million people or about 9 percent of the entire population of France in 1970).

TABLE A.18 End-Use Energy Consumption in the GDR in 1973 by Sector and Fuel Type (10^9 kcal)

	Energy Production	Other Industries	Transportation	Residential Sector	Distribution Losses	Total
Hard coal		7,504	10,297	3,500	14	21,315
Lignite	3,199	4,410		2,205	217	10,031
Peat	28	602		399	7	1,036
Lignite briquettes	1,617	26,551	1,493	101,290	476	131,432
Coke-over-coke		20,503		875	14	19,250
Gas coke	84	4,431	105	2,706	7	6,594
Total solid fuels	4,928	64,001	11,900	110,971	735	189,658
Crude oil					1,526	1,526
Light petroleum products[a]	56	14,658	8,981	8,981	182	55,461
Heavy petroleum products[b]		21,462	5,145	3,857		30,464
Refinery fuel[c]					308	308
Total liquid fuels	56	36,120	14,126	12,838	2,751	87,759
Natural gas	1,071	4,494		35	455	6,055
Derived gases	6,062	17,456	28	8,362	841	33,055
Total gases	7,133	21,959	28	8,407	2,296	39,796
Total electricity	13,349	29,099	1,155	18,949	4,501	67,051
Total steam, hot water	57,302	76,272	2,401	12,712	6,426	155,120
Grand total	82,768	227,451	29,610	163,912	16,709	539,441
Estimated conversion losses[d]						205,219
Estimated primary energy consumption						744,660

SOURCE: ***Annual Bulletin of General Energy Statistics for Europe 1973.***[5]

[a] Light products: gasoline, jet fuel, kerosene, naphtha.

[b] Heavy products: diesel, residual fuel oil.

[c] Refinery fuel: total consumption of petroleum products at refineries.

[d] The losses were calculated from data on total energy converted by applying the following efficiency factors: coal–gas: 0.6; coal–briquettes: 0.95; fossil fuels–steam: 0.8; steam–electricity: 0.4; gas reforming: 0.9.

FIGURE A.4 Regions and departments in France.

The Rhone-Alpes region is composed of three very distinct geological formations: the Saone-Rhone plain (which crosses the region from north to south), the area to the west of this plain (which belongs to the Massif Central), and the eastern part of the region which contains the western spur of the Alps (Europe's highest mountain, Mont Blanc, with an elevation of 4,807 m, is located in this section).

In the French economy, mining and quarrying plays an important role. There is mining of minerals such as coal, iron, salt, potassium, bauxite, and sulfur from methane deposits. However, only two relatively poor coal mines, the so-called Bassin de la Loire (near St. Etienne) and Bassin du Dauphine (south of Lyon) are located in Rhone-Alpes. Since 1967, production in these mines has been reduced considerably in favor of richer deposits in the north of France, which are also advantageously located near iron deposits. Important for the economy of Rhone-Alpes are the bauxite deposits in the south of France, i.e., in the region Provence-Cote d'Azur. To a large extent, this bauxite is refined in Rhone-Alpes because of the abundance of sources of electricity in this region.

The South European Pipeline (Marseille–Strasbourg–Karlsruhe) passes through Rhone-Alpes and provides the refinery Feyzin (near Lyon) with crude oil. The output of this refinery amounts to about 5 percent of the total French production. A fact that may be important for the economic situation of Rhone-Alpes in the future is that the abundance of cooling water provided by the Rhone River makes the region a desirable site for nuclear power plants (currently the uranium production in France is about 10 percent of the total production in the western hemisphere). The water resources of Rhone-Alpes have also been exploited by numerous hydropower plants.

II.A.2. Climate

Due to the diversity of the geographical formations, the climate of Rhone-Alpes is also very heterogeneous, ranging from alpine in the northern and eastern parts of the region, to continental in the western section, and nearly Mediterranean in the south-central part. In Lyon, which may be considered the capital of Rhone-Alpes, the average daily minimum and maximum temperatures are -0.9°C and 5.4°C in January; the corresponding figures for July are 14.8°C and 26.6°C. The annual average precipitation in Lyon is 813 mm. The number of degree days (which is a measure of heating requirements), is 2,664 for Lyon (the number has been calculated using 30-year average figures); it is higher for all other parts of the region with the exception of Drome, which has a more Mediterranean climate, i.e. the number of frost days (days with a minimum below 0°C) is only around 30 in the capital of Drome, compared with about 50 in Lyon, and approximately 70 in the capitals of the other departments.

II.B. POPULATION CHARACTERISTICS

France was subdivided into regions comparatively recently. A region is not yet an administrative entity but rather an aggregation of departments; only the latter have administrative authority. It must be said, however, that the Rhone-Alpes region has a clearly dominant economic center, the metropolitan area of Lyon.

On the other hand, the departmental structure is rather old: these administrative entities were established in the year 1789 and have remained almost unchanged. Currently there are 94 departments in France of which eight are in Rhone-Alpes. A department is further subdivided into *arrondissements* (25 in Rhone-Alpes) and *cantons* (268 in Rhone-Alpes). The smallest administrative unit is called a *commune* (there are 2,372 of them in Rhone-Alpes). For each department, the capital city, the land, the population and the population density are listed in Table A.19. The figures show that the population is distributed very unevenly within Rhone-Alpes: almost 60 percent of the total population is concentrated in the 3 industrial regions of Loire, Isere, and particularly Rhone, which together cover only 35 percent of the total area.

Population change in Rhone-Alpes and its departments is summarized in Table A.20. The average annual growth rate (1.61 percent between 1962 and 1968, and 1.67 percent between 1968 and 1974) is higher than in France, mainly because of immigration. Of the total increase in the population between 1965 and 1974 (460,000 people) about 30 percent can be attributed to immigration, 20 percent to the interregional migration surplus, and the rest to the excess of births over deaths. In 1971, for example, the birth rate was 1.74 percent and the death rate was 1.02 percent.

TABLE A.19 Area and Population of the Rhone-Alpes Departments

	Capital	Area (km^2)	Population (1970; 10^3 people)	Density (persons/km^2)
Ain (01)[a]	Bourg-en-Bresse	5,797	343.8	59
Ardeche (07)	Privas	5,523	258.1	47
Drome (26)	Valence	6,525	352.2	54
Isere (38)	Grenoble	7,789	782.4	100
Loire (42)	St. Etienne	4,774	725.7	152
Rhone (69)	Lyon	2,859	1,372.4	480
Savoie (73)	Chambery	6,036	294.6	49
Haute-Savoie (74)	Annecy	4,391	392.8	89
Rhone-Alpes		43,694	4,522.0	103

SOURCE: *Meyers Enzyklopädisches Lexikon*^{2}, vol. 9, p. 256.

[a] Numbers in parentheses refer to the number of the department.

TABLE A.20 Population Change in Rhone-Alpes

	Population (10^3 people)			Average Annual Growth Rate (%)	
	1962	1968	1974	1962 to 1968	1968 to 1974
Ain	314.5	339.3	366	1.27	1.27
Ardeche	248.5	256.9	261	0.56	0.26
Drome	304.2	342.9	371	2.02	1.32
Isere	678.0	768.5	855	2.11	1.79
Loire	696.3	722.4	745	0.62	0.51
Rhone	1,181.1	1,325.5	1,435	1.94	1.33
Savoie	266.7	288.9	307	1.34	1.02
Haute-Savoie	329.2	378.6	427	2.36	2.03
Rhone-Alpes	4,018.6	4,423.0	4,767	1.61	1.26
France	46,459.0	49,755.8	52,340	1.15	0.85
Rhone-Alpes as % of France	8.65	8.89	9.3		

SOURCE: *Annuaire Rhône-Alpes 1974*[7], p. 25.

TABLE A.21 Urban Population in Rhone-Alpes

	Population in 1968 (10^3 people)	Average Annual Growth Rate, 1962–1968 (%)
Lyon	1,074.8	2.2
Grenoble	332.4	4.0
St.-Etienne	331.4	0.8
city size > 100,000 people	1,738.6	2.3
Valence	92.1	3.4
Annecy	81.5	4.2
Roanne	77.9	1.0
St.-Chamoud	77.0	0.8
Chambery	75.5	3.0
city size > 50,000 people	404.0	2.5
city size > 20,000 people	476.9	2.9
other population	1,803.5	0.5
Total	4,423.0	1.6

SOURCE: *Annuaire Rhône-Alpes 1974*[7], pp. 25, 27.

Some other population statistics reflecting the urban–rural split and average family size and their historical trends are given in Tables A.21 and A.22 and Figure A.5; these factors exert an important influence upon energy demand in the residential and transportation sectors.

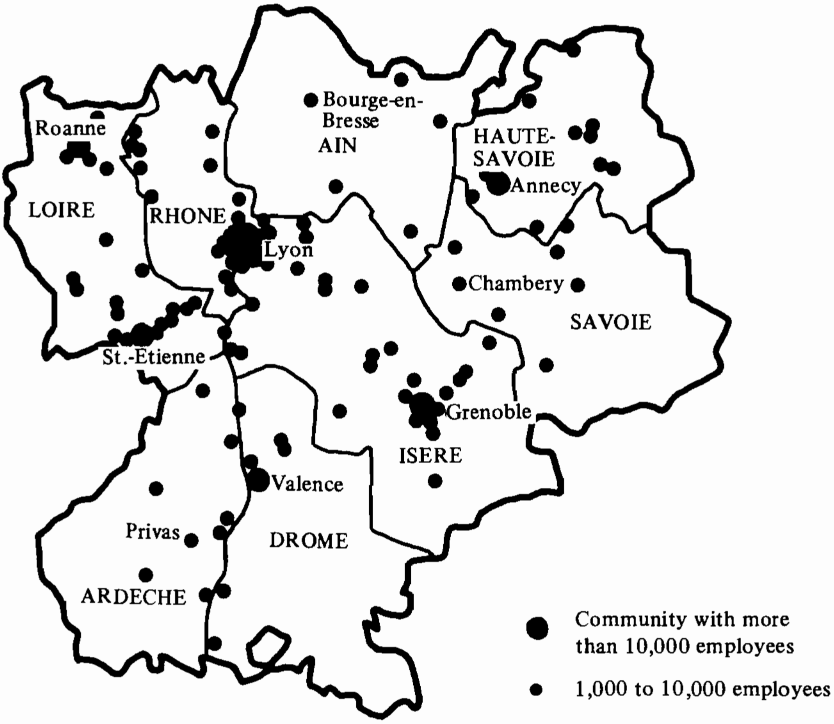

FIGURE A.5 Industrial locations in the Rhone-Alpes region (1964).

TABLE A22 Average Family Size in the Departments of Rhone-Alpes and in Their Capital Cities

Department	1962	1968	1974	Capital City	1968
Ain	3.09	3.14	2.87	Bourg-en-Bresse	3.31
Ardeche	3.27	3.19	3.06	Privas	[a]
Drome	3.27	3.22	3.11	Valence	3.14
Isere	3.09	3.26	3.15	Grenoble	3.28
Loire	3.01	3.00	2.91	St.-Etienne	2.89
Rhone	3.23	3.09	2.98	Lyon	2.68
Savoie	3.40	3.33	3.09	Chambery	3.31
Haute-Savoie	3.47	3.33	3.17	Annecy	3.24
Rhone-Alpes	3.19	3.16	3.03		

SOURCE: *Annuaire Rhône-Alpes 1974*[7], pp. 25–28.
[a] Not available.

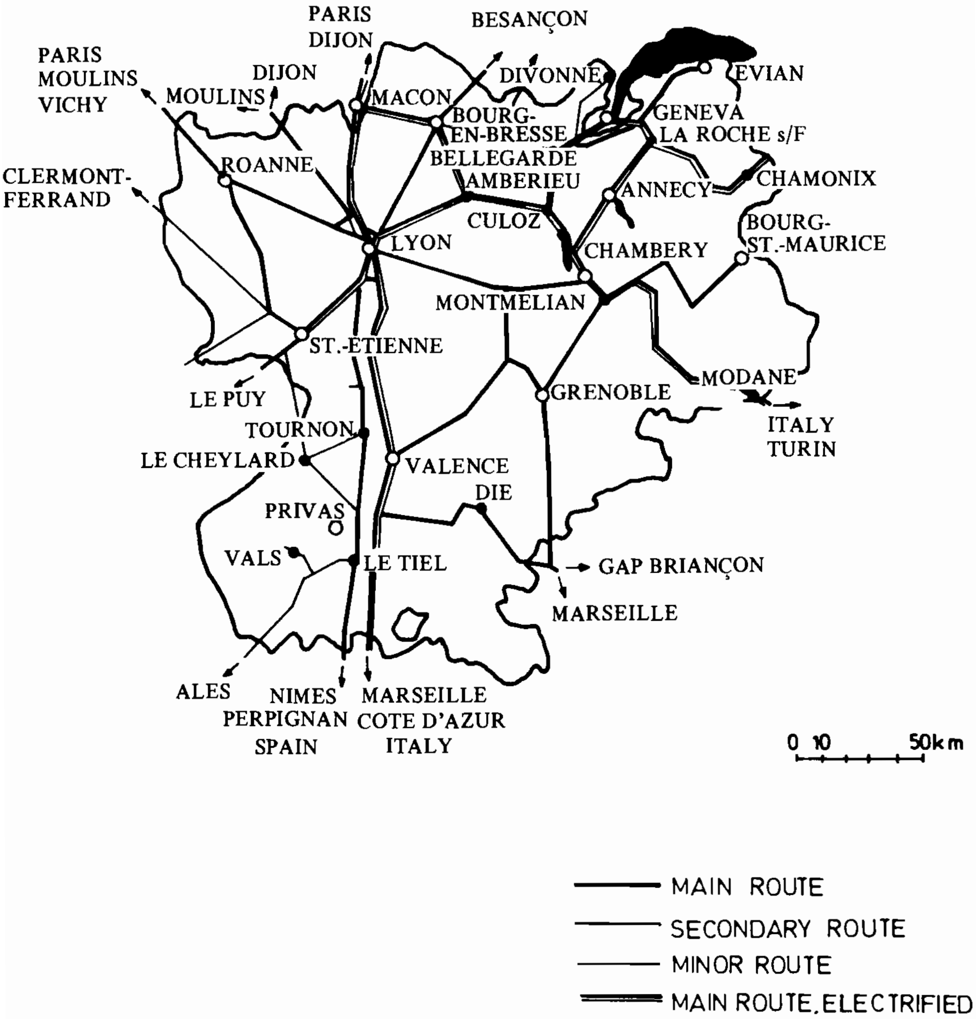

FIGURE A.6 Railway network in Rhone-Alpes.

II.C. TRANSPORTATION CHARACTERISTICS

The traffic system of Rhone-Alpes is determined by the region's geographical characteristics. Most important is the Saone-Rhone valley, which forms one part of the main traffic artery of France, the connection Paris–Dijon–Lyon–Marseille. Another important connection is the Lyon–St.-Etienne–Roanne–Paris route in the west of the Saone-Rhone valley; in addition, the Lyon–Geneva, Lyon–Turin, and the Grenoble–Marseille routes in the eastern part of the province cross the Alps

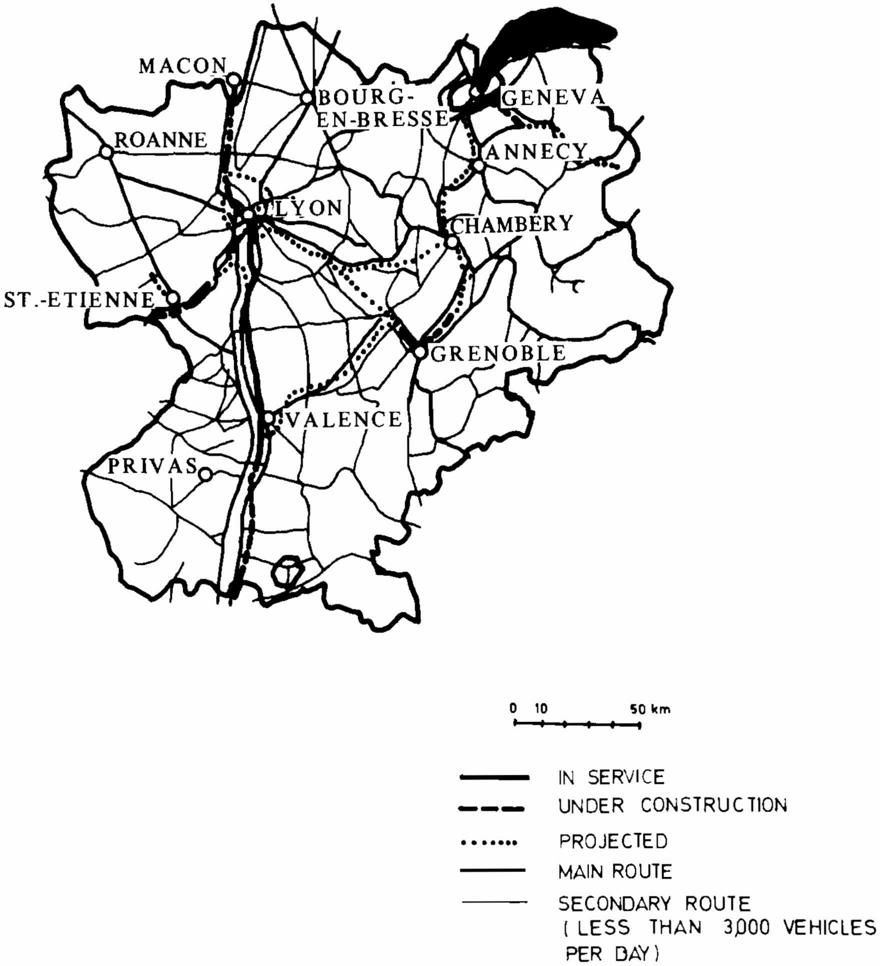

FIGURE A.7 Road network in Rhone-Alpes.

from west to east and north to south. All these connections are in the form of major railway lines and roads. The rivers Saone (north of Lyon) and Rhone (south of Lyon) also form an important inland waterway. In addition, air traffic has shown a significant increase during the 1960s in the whole of France, especially in Rhone-Alpes. Here, interregional rather than international traffic is important. The main airport is Lyon-Bron. Figures A.6 and A.7 show the rail and road network in Rhone-Alpes.

One factor which influences the energy demand for personal transportation in the Rhone-Alpes region is car (and motorcycle) ownership. In the year 1972, about 260 cars (private and commercial) and 95 motorcycles/1,000 people were registered in France as a whole. These figures can be used as an approximation of the private vehicle ownership level in Rhone-Alpes. In the same year, about 32 new cars per

TABLE A.23 Selected Transportation Statistics for Rhone-Alpes

Road system (km; 1972)[a]	
Limited access highways	322
Other highways	6,844
Provincial roads	22,353
Urban roads	42,584
Rural roads	51,203

Motor vehicle registration (1972)[b]	10^3 Vehicles	Vehicles/10^3 people
Cars	1,214.2[i]	259[i]
Motorcycles	438.6[i]	94[i]
Buses	8.8	
Trucks and special transport vehicles	315.8	
Other transport vehicles	36.4	
Tractors for nonroad use	128.7[i]	27[i]

Intraurban public transportation (1971)[c,j]	Length of Network (km)	Number of Passengers (10^6)
Bus	851	162
Trolley bus	93	69
Tramway	7.5	22
Total	951.5	253

Interurban public transportation (1971)[d,k]	Length of Network (km)	Number of Bus Kilometers (10^6)
Regular service	66,000	72.8
Occasional service		25.4
Transport of school children		15.2

Truck transportation (10^6 tons)[e]	1967	1971
Intraregional	129.6	120.3
Interregional	17.3	21.7
International	3.6	4.2
Total	150.5	146.2[m]

Railway transportation (1971)[f]	
Total length of network (km)	1,746
with electricity	914
Passenger transportation (10^6 passengers)	
Normal tickets	9.2
Commuter tickets	5.3
Freight transportation (10^6 tons)	
Intraregional	1.6
Interregional	11.4
International	3.2

TABLE A.23 – Continued

River barges (1971)[g]	
Length of waterways (km)	454
Freight transportation (10^6 tons)	
Intraregional	2.8
Interregional	1.4
International	0.4

Air transportation (1970)[h]	Passengers ($\times 10^3$)	Freight (10^3 tons)	Mail (10^3 tons)
Lyon–Bron	870.6	6.8	8.3
Grenoble–St. Geoirs	105.5	0.1	
St.-Etienne–Bouthion	43.8	0.1	

SOURCES: *Annuaire Statistique de la France 1974*[6]; [a] p. 368; [b] pp. 377, 379. *Annuaire Statistique Régional des Transports*[8], [c] pp. 58; [d] pp. 70, 71; [e] pp. 147, 148, 156, 157; [f] pp. 44, 46, 52, 53, 156, 157; [g] pp. 20, 36, 37, 156, 157; [h] pp. 8, 13.

[i] Estimated from average figures for France.

[j] Includes the cities Annecy, Annemasse, Bourg-en-Bresse, Chambery, Grenoble, Lyon, Roanne, St.-Chamond, St.-Etienne, and Valence.

[k] Does not include railway transportation.

[m] The corresponding figure for 1970 is 162.4 million tons. The 1971 figure is exceptionally low.

1,000 people were registered in Rhone-Alpes. To give a quantitative picture, selected statistics about the transportation systems in Rhone-Alpes, as well as the volume of freight and mass transportation, are listed in Table A.23. It should be noted, however, that these data reflect only the transportation related to the economic activity within the region; transit traffic is not included unless otherwise noted. The actual traffic density is therefore considerably higher than indicated by these figures.

II.D. ECONOMIC CHARACTERISTICS

Because of the centralized structure of the French economy, it is necessary to use employment as an indicator of economic activity within Rhone-Alpes. Table A.24 shows changes in the distribution of the working population in 3 major economic sectors in France and Rhone-Alpes. One notes a heavy decline in the population engaged in agriculture and forestry; this is compensated for by growth in the so-called "secondary" sectors (industry in the narrowest sense, electricity, gas and water supply, construction, transportation) as well as in the "tertiary" (commercial and service) sectors. The regional distribution of the working population in 1968 is displayed in Figure A.8. The aggregation used here and in the following statistics differs from the one used in Table A.24: electricity, gas and water supply is included in industry, transportation and construction are considered as service sectors (the construction sector is sometimes accounted for separately). This aggregation is based on the classification called "*Nomenclature des Branches de la Comptabilité Nationale*,"[11] which distinguishes 37 sectors (1: agriculture; 2–23: industry; 24: construction; 25–37: commerce and services).

Figure A.8 shows that in 1968 about 63 percent of the working population of Rhone-Alpes was concentrated in the 3 departments of Rhone (30 percent), Isere (17 percent) and Loire (16 percent). The departments Isere and Loire are more industry-oriented (over 40 percent of the working population is employed in industry) whereas the commerce and service sector is dominant in Rhone (50

TABLE A.24 Changes in the Working Population in Rhone-Alpes

	Percentage of Total Working Population			
	1954[a]	1962[a]	1968[b]	1974[b]
Agriculture	24.8	17.2	12.2	8.5
Industry, building, transportation	47.7	51.5	49.9	49.5
Commerce, services	27.5	31.3	37.9	42.0
Total	100.0	100.0	100.0	100.0
10^3 people	(1,960)	(1,710)	(1,819)	(2,071)
(% of total population)	(46.6%)	(42.8%)	(41.1%)	(42.4%)

SOURCES: *L'Economie de la Région Rhône-Alpes*[9], p. 14, *Annuaire Rhône-Alpes 1974*[7], pp. 37–38.

percent of the working population is employed in this sector). Selected statistics about the activity level in these sectors and the importance of the sectors in the national economy are presented in Tables A.25 and A.26. The industrial output data in Table A.24 show that Rhone-Alpes leads in the production of aluminum (38 percent of French production) iron-alloys (56 percent of national production), as well as in the production of some fabricated metal products such as hydroturbines and mechanical tools. The employment data also indicate the significance of some other industrial branches (textiles and apparel, chemicals, and electrical devices and fine machinery) in the Rhone-Alpes economy.

To give an idea of the amount of value-added which can be attributed to economic activities within Rhone-Alpes, national productivity figures (value-added in a given sector divided by the number of people employed in this sector) are presented along with regional employment data for 4 major sectors in Table A.27. By using this presentation, one may obtain a rough estimate of the value added in these sectors in Rhone-Alpes.

The implied growth rates (7 percent per year for the total value-added, 7.25 percent for industry, 8 percent for commerce and services) are much higher than the growth rates in the national economy (5.7 percent per year for the total value-added between 1963 and 1972, 6.4 percent for industry, and 5.4 percent for commerce and services). Currently, Rhone-Alpes contributes between 10 percent and 11 percent of the GNP of France.

II.E. ENERGY SYSTEM

In the following description of the energy use in Rhone-Alpes, only 4 fuel types will be considered: solid mineral fuels, gas, electricity, and petroleum products. The disaggregation of energy use by consumer corresponds in principle to the categories which are generally used in the statistics of France, i.e., industry, household and small consumers (*foyers domestiques et petite industrie*), transportation; agriculture is included in the household and small consumer sector. Table A.28 shows the share of each energy source over time in the final energy consumption, or end-use energy (this term is used when the conversion losses in the generation of electricity are not counted). The change in the fuel mix is typical: there is a movement away from solid mineral fuels in favor of petroleum products. While the share of gas and electricity is decreasing slightly, it is important to note the high level of electricity

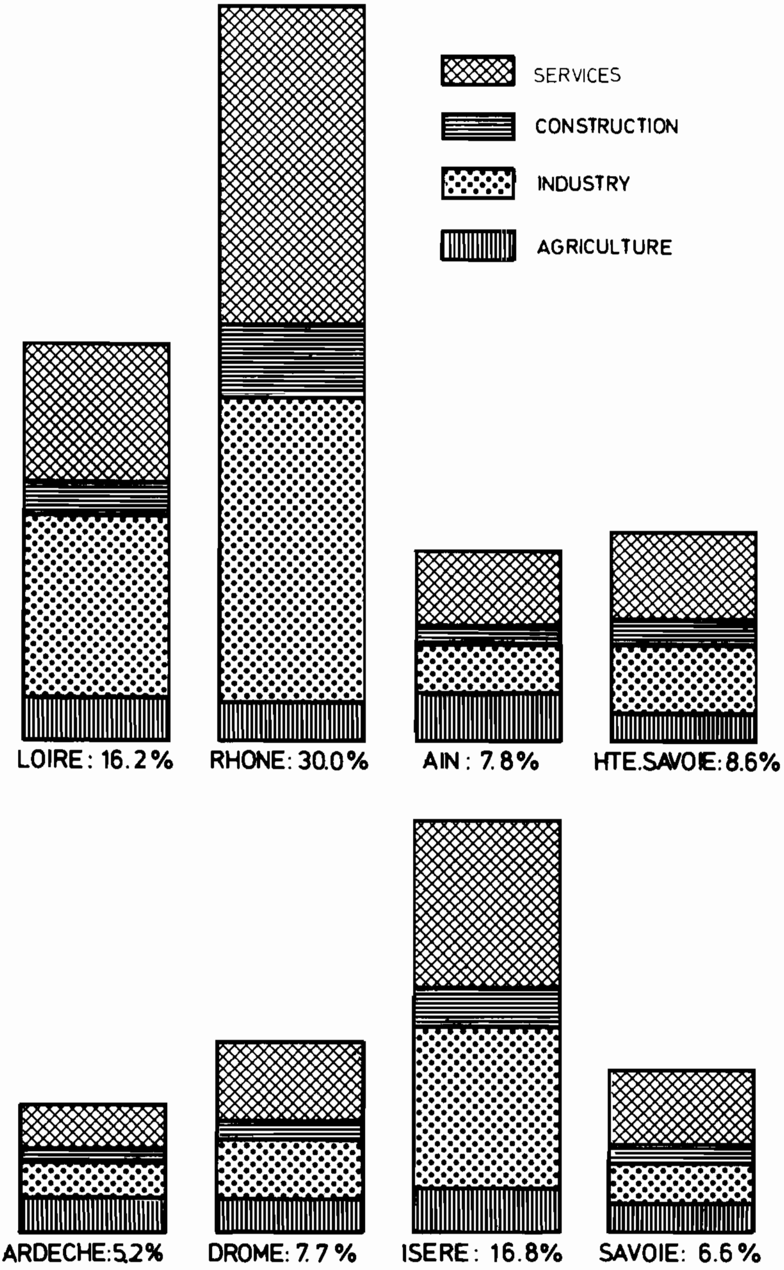

FIGURE A.8 Regional distribution of the working population in Rhone-Alpes (1968).

TABLE A.25 Selected Statistics on Economic Activities in Rhone-Alpes

	Rhone-Alpes	Percentage of France	Year
Agriculture[a]			
Establishments ($\times 10^3$)	141.7	8.9	1973
Agricultural land (10^3 km^2)	1,754.4	5.8	1973
Value of products (10^9 F)			
Livestock and by-products	3.3	6.6	1972
Crops	1.8	5.1	1972
Agricultural working population (10^3 people)	175		1974
Percentage of total working population	8.5		1974
Industry[b]			
Iron and steel production			
Establishments	33		1973
Employees	16,000		1973
Steel production (10^3 tons)	585	3.0	1966
	736	3.1	1972
Nonferrous metal production			
Establishments	37		1973
Employees	6,676		1973
Aluminum production (10^3 tons)	145	39.9	1966
	150	37.8	1972
Primary transformation of metals			
Establishments	165		1973
Employees	32,083		1973
Production of iron-base alloy (10^3 tons)	149	54.0	1966
	219	55.6	1972
Forging and casting			
Establishments	1,006		1973
Employees	45,147		1973
Value of hydroturbine production (10^6 F)	91	60.6	1966
	108	78.9	1972
Value of water pipe production (10^6 F)	54	22.9	1966
	100	25.6	1972
Machinery and mechanical equipment			
Establishments	977		1973
Employees	50,890		1973
Value of mechanical tool production (10^6 F)	170	31.1	1966
	340	39.8	1972
Diverse metal products:			
Establishements	3,092		1973
Employees	59,900		1973
Production of vehicles:			
Establishments	2,422		1973
Employees	57,342		1973
Electrical, fine mechanical, and optical equipment			
Establishments	1,503		1973
Employees	84,049		1973

TABLE A.25 – Continued

Chemical, rubber and plastics		
Establishments	1,178	1973
Employees	73,029	1973
Textiles and apparel (including shoes)		
Establishments	4,127	1973
Employees	139,795	1973

Commerce and Services (1974)[c]	Employment (10^3 people)	Percentage of Total Working Population
Construction	192.3	9.3
Transportation	70.6	3.4
Communication	32.4	1.6
Trade	233.2	11.3
Banking, insurance	32.4	1.6
Hotels, restaurants, housing	288.2	13.9
Government	153.4	7.4
Public services	131.4	6.3
Total	1,133.9	54.8

SOURCE: *Annuaire Rhône-Alpes 1974*[7], [a] pp. 5, 12; [b] pp. 76–105; [c] p. 37.

consumption: more than 30 percent of the total end-use energy is consumed in the form of electricity (the corresponding figure for France as a whole is only 20 percent). In Table A.29, the actual energy consumption is listed for the year 1972 by sector and by fuel type. In the following sections, the consumption of each source of energy will be considered in more detail.

II.E.1. Electricity

In French statistics, the electricity consumption is recorded for 2 categories: low voltage (mainly for residential use) and high voltage (for industry and transportation).

In the low-voltage category, Rhone-Alpes accounted for about 10 percent of the total national consumption in 1972. This is slightly more than its share of the total population (9 percent). But the growth rate in low-voltage consumption in Rhone-Alpes (8.22 percent per year between 1966 and 1972) was significantly lower than that which occurred in France as a whole during that period (10.07 percent). Therefore, it seems reasonably certain that per capita residential energy use in Rhone-Alpes will approach the national average in the near future. The breakdown of total low-voltage electricity consumption in Rhone-Alpes in 1971 is shown in Table A.30.

The level of high-voltage electricity consumption in Rhone-Alpes is extremely high; the province accounted for 18.3 percent of total national consumption in 1971. The growth rate in consumption in Rhone-Alpes was between 5 percent and 6 percent per year between 1966 and 1972 (the growth rate for France as a whole was 5.49 percent per year within this period). The breakdown of the total high-voltage electricity consumption in Rhone-Alpes by major sectors in 1971 is listed in Table A.31.

TABLE A.26 Industrial and Service Enterprises in Rhone-Alpes (1971)

Companies

Size (Employees)	Enterprises	Percentage of all French companies
0 or not declared	85,382 (48.99%)	10.22
1–2	50,775 (29.13%)	9.39
3–5	17,105 (9.81%)	9.63
6–9	7,957 (4.57%)	10.26
10–19	10,632 (6.10%)	10.52
50–199	1,910 (1.10%)	9.58
200–999	471 (0.27%)	9.26
1,000 and over	53 (0.03%)	5.99
Total	174,285(100.00%)	9.91

Plants

Size (Employees)	Plants	Percentage of all French plants
0 or not declared	87,937 (46.30%)	10.15
1–2	57,393 (30.22%)	9.49
3–5	19,385 (10.21%)	9.69
6–9	9,200 (4.84%)	10.27
10–19	12,818 (6.75%)	10.51
50–199	2,469 (1.30%)	9.80
200–999	659 (0.35%)	10.91
1,000 and over	49 (0.03%)	8.18
Total	189,910(100.00%)	9.92

SOURCE: *Annuaire Statistique de la France 1974*[6], pp. 608, 609.

II.E.2. Gas

In 1972 the Rhone-Alpes industries consumed about 5,497 × 10^9 kcal of gas. The largest consumers were the chemical industry (52 percent), the iron and steel industry (11.3 percent), producers of mechanical and electrical machinery (10.6 percent) and the textile, leather and apparel sectors (7.5 percent). The total gas consumption by industry in Rhone-Alpes in that year was only 5.3 percent of the total industrial gas consumption in France. The gas consumption in the residential and commercial and service sectors was 3,790 × 10^9 kcal in 1972; from this amount, about 60 percent was consumed by households, 25 percent by commercial establishments, and the remaining 15 percent by small industrial establishments. The level of gas consumption in the residential sector of Rhone-Alpes is low relative to the national consumption level (it accounts for only 4.5 percent of total non-industrial gas consumption in France).

II.E.3. Petroleum

A preliminary breakdown of consumption of petroleum products by major sector can be based on the product mix. This is given in Table A.32 for the year 1972. Statistics about fuel oil consumption by industry sector are only available at the national level. An estimation using national fuel oil intensiveness figures (defined as

TABLE A.27 Employment and Value-Added in France and Estimation for Rhone-Alpes

France

	Employment (10^3 Workers)			Value-Added (10^9 F – 1963)		
	Mar. 1962	Mar. 1968	Dec. 1971	1963	1968	1972
Agriculture	3,793.2	2,998.7	2,576.1	34.6	40.0	40.8
Industry	5,749.8	5,869.8	6,126.2	156.9	210.3	274.8
Construction	1,533.9	1,910.9	1,925.6	34.0	49.7	61.8
Commerce, service	7,979.0	9,182.4	10,204.9	134.8	169.3	216.3
Total	19,055.9	19,961.8	20,832.8	360.3	469.3	593.7

Rhone-Alpes

	Employment (10^3 Workers)			Value-Added (10^9 F – 1963)		
	Mar. 1962	Mar. 1968	Dec. 1973	1963	1968	1972
Agriculture	294.5	221.6	175.5	(2.7)	(3.0)	(2.8)
Industry	667.7	667.5	761.5	(18.2)	(23.9)	(34.2)
Construction	156.2	176.5	192.3	(3.5)	(4.6)	(6.2)
Commerce, service	591.6	753.3	941.7	(10.0)	(13.9)	(20.0)
Total	1,710.0	1,818.9	2,071.0	(34.4)	(45.4)	(63.2)

SOURCES: *Annuaire Statistique de la France 1974*[6], pp. 54, 55, 596; *Annuaire Rhône-Alpes 1974*[7], p. 37; *L'Economie de la Région Rhône-Alpes*[9], pp. 13–15.

TABLE A.28 Final Energy Consumption in Rhone-Alpes and France by Fuel (%)

	1966		1970		1972	
	Rhone-Alpes	France	Rhone-Alpes-	France	Rhone-Alpes	France
Solid mineral fuels	17.8	27.9	9.6	17.4	6.2	12.4
Gas	6.4	6.8	6.1	6.9	5.9	8.0
Electricity	34.9	20.9	33.9	20.6	33.7	21.1
Petroleum products	40.9	44.4	50.4	54.1	54.2	58.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

SOURCE: *Annuaire Rhône-Alpes 1974*[7], p. 53.

fuel oil consumption per unit of value added) and regional value-added figures for each industry sector, indicates the following consumption pattern for Rhone-Alpes: building materials – 26 percent; mechanical and electrical machinery and equipment – 22 percent; chemicals – 14 percent; food production – 11 percent; paper and pulp – 4 percent; primary metals – 2 percent; other industry sectors – 22 percent.

TABLE A.29 Final Energy Consumption in Rhone-Alpes in 1972 by Sector and Fuel Type (10^{15} cal)

Industry	
Solid fuels	4.6
Gas	5.7
Electricity	38.7
Petroleum	20.5
Total	69.6
Households and Small consumers	
Solid fuels	4.8
Gas	3.3
Electricity	11.5
Petroleum	41.9
Total	61.5
Transportation	
Solid fuels	0.0
Electricity	1.5
Petroleum	20.7
Total	22.2
Total of all sectors by fuel type	
Solid fuels	9.5
Gas	9.1
Electricity	51.7
Petroleum	83.1
All fuels	153.3
Total of all fuels by sector	
Industry	69.6
Households and small consumers	61.5
Transportation	22.2
All sectors	153.3

SOURCE: *Annuaire Rhône-Alpes 1974*[7], p. 53.

II.E.4. Solid Mineral Fuels

Coal is the second most important indigenous primary energy resource in Rhone-Alpes (hydropower is first), but the output of the region's two mines (Bassin de la Loire and Bassin du Dauphine) has gone down drastically since 1967; this is in line with the decreasing demand for coal, as shown in Table A.33. The total coal consumption by Rhone-Alpes industries in 1972 was 700,000 tons; the most important consumers were the electrometallurgical industry (28 percent), building industry (24 percent), chemical industry (18 percent), and the textiles, leather and apparel

TABLE A.30 Distribution of Total Low-Voltage Electricity Consumption in Rhone-Alpes (1971)

	Consumption in Rhone-Alpes (10^6 kWh)	Percentage of National Consumption
Residential and agricultural sectors	2,379.2	10.07
Trade and business	982.1	10.38
Public lighting	201.7	12.34
Local public services	85.6	8.78
Internal consumption (distribution losses)	22.6	8.65
Total	2,671.2	10.21

SOURCE: ***Annuaire Statistique de la France 1974***[6], pp. 190, 191.

TABLE A.31 Breakdown of Total High-Voltage Electricity Consumption in Rhone-Alpes (1971)

	Consumption in Rhone-Alpes (10^6 kWh)	Percentage of National Consumption
Railways	580.0	9.93
Mines	248.8	11.19
Coal	159.9	5.84
Other minerals	88.9	5.35
Electrochemical and electrometallurgical industry	5,074.5	46.72
Iron alloys	1,877.6	61.13
Aluminum	2,323.1	35.72
General metal industry and other industries	12,586.4	15.77
Iron, Steel	805.9	8.73
Paper, pulp	723.5	14.81
Textile, leather, apparel	1,168.6	24.50
Total	18,489.7	18.32

SOURCE: *Annuaire Statistique de la France 1974*[6], pp. 188, 189.

TABLE A.32 Consumption of Petroleum Products by Major Sectors (1972)

	Consumption in Rhone-Alpes	Percentage of National Consumption
Gasoline (10^3 m^3)	1,839.7	9.40
Diesel (10^3 m^3)	679.7	9.82
Domestic fuel oil (10^3 m^3)	3,606.9	10.72
Light fuel oil (10^3 tons)	181.8	8.52
Heavy fuel oil (10^3 tons)[a]	1,970.4	10.56
Propane and butane (10^3 tons)[b]	180.2	8.49

SOURCE: *Annuaire Statistique de la France 1974*[6].

[a] Excluding sales to the national railway company, Société nationale des Chemins de fer Français (SNCF), to the national electricity company, Electricité de France (EDF), and to builders.

[b] Excluding sales to gas plants.

TABLE A.33 Coal Demand in Rhone-Alpes

	1966	1970	1972
Production (10^3 tons)	2,899	2,184	1,533
Percentage of national production	5.5	5.4	4.7
Deliveries (10^3 tons)	1,898	1,865	856
EDF power plants; (10^3 tons)	469	705	201
Industry (10^3 tons)	959	651	371
Households, small consumers (10^3 tons)	456	244	165

SOURCE: *Annuaire Rhône-Alpes 1974*[7], p. 54.

TABLE A.34 Production of Electricity in Rhone-Alpes and France (10^6 kWh)

	Rhone-Alpes			France		
	1966	1970	1972	1966	1970	1972
Hydropower plants	20,184	22,471	16,650	51,695	56,612	48,657
Thermal power plants	1,908	4,187	8,741	54,416	84,096	114,995
Total	22,092	26,658	25,391	106,111	140,708	163,652
Proportion of hydropower in total electricity production	91%	84%	66%	49%	40%	30%
Proportion of French electricity produced in Rhone-Alpes	20.8%	19.0%	15.5%			

SOURCE: *Annuaire Rhône-Alpes 1974*[7], p. 57.

industry (15 percent), which together account for 85 percent of the total coal consumption.

To obtain the primary energy consumption in Rhone-Alpes, the fuel mix used for electric generation must be taken into account. Table A.34 shows the electricity production in Rhone-Alpes and, for comparison, in France as a whole. The data show the importance of hydropower for the energy supply of Rhone-Alpes.* Adding the conversion losses in thermal power plants (about 15×10^{15} cal in 1972) to the final energy consumption, the total primary energy consumption in the Rhone-Alpes region in 1972 is estimated to be about 171.2×10^{15} cal, which is 11.7 percent higher than the final energy consumption.

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* The amount of hydropower which remains to be exploited in Rhone-Alpes is currently being examined. Between 1974 and 1979 construction of new plants should result in an additional annual generation of 2077 GWh (9.5 percent of total 1973 generation). Potential sites which could yield as much as 9,015 GWh are also being surveyed.[10]

FIGURE A.9 Wisconsin and surrounding area in the United States.

III. WISCONSIN

William Buehring – IIASA

III.A. PHYSICAL CHARACTERISTICS

III.A.1. Geography

Wisconsin is located in the north-central United States and has common borders with the states of Minnesota, Iowa, Illinois, and Michigan and with two of the Great Lakes, Lake Superior and Lake Michigan (Figure A.9). The total area of Wisconsin is 145,439 km^2 of which 4,377 km^2 is water.* There are over 8,500 lakes, of which Winnebago with an area of 557 km^2 is the largest. Major rivers include the Wisconsin River and the Mississippi River, which forms Wisconsin's border with Iowa and southern Minnesota. Public parks and forests occupy one-seventh of the land area; and there are 49 state parks, 9 state forests, and 2 national forests.

Wisconsin is a state of diverse physical features. The northern topography is relatively irregular with moderate or few changes in elevation. In the southwestern portion of the state the tributaries of the Mississippi River have cut into the sandstone to provide local relief approaching 150 m. The upland portion of this area is gently rolling. The central and eastern portions are predominately rolling plains. Elevation in the state ranges from 177 m above sea level along the Lake Michigan shoreline to a maximum of only 595 m at Tim's Hill.

Mineral production in Wisconsin is relatively small. The total value of all minerals produced in 1972 was $89 million; only 12 of the other 49 states had a lower dollar

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* Unless otherwise noted, data in the text are from *The World Almanac and Book of Facts* and *Statistical Abstract of the United States*.[12,13]

FIGURE A.10 Wisconsin counties and their 1970 population (× 1,000).

value production. Sand and gravel, stone, cement, iron ore, and zinc are the principal minerals produced. Recently, copper deposits have been discovered in the northern part of the state. There are no known mineral fuel resources.

III.A.2. Climate

Wisconsin's humid continental climate results in great variation in seasonal average temperatures. For example, an average January day in Madison has a maximum temperature of — 3°C and an average minimum temperature of — 13°C; in July the average daily maximum is 28°C and the average minimum is 16°C. An important

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* The number of heating degree-days for any day is computed by averaging the daily high and low temperatures and then subtracting the average from 18.3°C, the standard used for comfortable room temperature. The degree-days are accumulated over the heating season to obtain annual values.

TABLE A.35 Major Cities in Wisconsin

	County[a]	1970 Population (10^3 people)
Milwaukee	Milwaukee	717
Madison	Dane	169
Racine	Racine	95
Green Bay	Brown	88
Kenosha	Kenosha	79
West Allis	Milwaukee	72
Wauwatosa	Milwaukee	59
Appleton	Outagamie	56
Oshkosh	Winnebago	53
LaCrosse	LaCrosse	51

SOURCE: Newspaper Enterprise Association, Inc.[13]
[a] See Figure A.10.

TABLE A.36 Selected Population Statistics for Wisconsin

Total population	1960	3,952,000
	1973	4,569,000
Total employment	1973	1,979,000
Manufacturing	1973	529,000
Trade	1973	364,000
Government	1973	276,000
Services	1973	264,000
Median age	1970	27.4 yr
Birth rate/1,000 residents	1960	25.2/yr
	1973	13.7/yr
Death rate/1,000 residents	1960	9.7/yr
	1973	9.0/yr
Heart diseases	1973	3.7/yr
Malignant neoplasm	1973	1.6/yr
Cerebrovascular diseases	1973	1.0/yr
Accidents	1973	0.5/yr
Urban population	1970	2,910,000
Rural population	1970	1,507,000

SOURCE: U.S. Bureau of the Census.[12]

consideration for heating requirements is the number of degree-days* Madison has had an annual average of 4,150 degree-days in recent years. Average precipitation at Madison is 77 cm/yr. Snowfall in Milwaukee averages 111 cm/yr.

III.B. POPULATION CHARACTERISTICS

Wisconsin's population, which totaled 4,568,000 in 1973, has exhibited a declining growth rate in recent years. The average annual percentage change was 1.4 from 1950 to 1960, 1.1 from 1960 to 1970, and 1.0 from 1970 through 1973. Net migration into the state accounted for nearly 40 percent of the net increase in population of 152,000 from 1970 to 1973.

TABLE A.37 Selected Transportation Data for Wisconsin

Motor vehicle registrations		
Autos, Trucks, and Buses	1960	1,600,000
	1970	2,181,000
	1975	2,591,000
Automobiles	1974	2,084,000
Trucks	1974	408,000
Motorcycles	1974	106,000
Trailers	1974	86,000
Buses	1974	11,000
Road network (km)		
Rural	1974	145,000
Urban	1974	24,000
Total	1974	169,000
Surfaced	1974	160,000
Auto, truck, and bus drivers	1975	2,721,000
Commerce at principal Wisconsin ports (tons)		
Duluth-Superior (Minnesota and Wisconsin)	1974	36,677,000
Milwaukee	1974	3,876,000
Green Bay	1974	2,301,000
Kewaunee	1974	1,165,000
Railroad network (km)	1972	14,314

SOURCES: U.S. Bureau of the Census,[12] Newspaper Enterprise Association, Inc.,[13] Wisconsin Legislative Reference Bureau,[15] Bowman *et al.*[16]

The state is divided into 72 counties, as indicated in Figure A.10. The 1970 population of each county is also shown in the figure; it is evident that the southeastern area (Milwaukee) has relatively high population densities and that the northern part of the state has relatively low densities. The 1970 population density for the state as a whole was 31 people per km^2, for Milwaukee County it was 1,718 people per km^2, and for Florence County, which borders on Upper Michigan, only 2.6 people per km^2.

The Wisconsin cities with 1970 populations greater than 50,000 are listed in Table A.35. Milwaukee is by far the largest city with 16 percent of the state population and nearly one-third of the state total in the metropolitan area. Approximately half of Wisconsin's 1970 population lived in cities and towns of 10,000 population or more.

Other population statistics for Wisconsin are listed in Table A.36. The birth rate dropped 44 percent from 1960 to 1972, while the death rate showed a decline of only a few percent over that period.

III.C. TRANSPORTATION CHARACTERISTICS

The number of registered motor vehicles has increased approximately 3 times faster than the population since 1960 (Table A.37). The dominance of the automobile in Wisconsin's transportation system can be demonstrated by dividing the registration by total population; there are approximately 450 autos per 1,000 people.

TABLE A.38 Service Sector Activity in Wisconsin

	1963	1967	1972
Retail trade			
Establishments (× 10^3)	44.3	45.1	47.2
Sales (10^9 \$)	5.2	6.6	9.7
Percentage of U.S. sales	2.1	2.1	2.1
Employees (× 10^3)		214.7	259.4
Wholesale trade			
Establishments (× 10^3)	6.74	6.63	7.20
Sales (10^9 \$)	5.5	7.3	10.4
Percentage of U.S. sales	1.8	1.6	1.5
Employees (× 10^3)	55.1	63.1	69.5
Services (establishments with payroll)			
Establishments (× 10^3)		10.4	11.1
Total receipts (10^9 \$)	0.57	0.73	1.16
Percentage of U.S. receipts	1.4	1.3	1.4
Employees (× 10^3)	50.2	57.2	76.0
Consumer Price Index (1967 = 100)	91.7	100.0	125.3
Government			
Employees, total (× 10^3)			288
Employees, federal (× 10^3)			26
Employees, state (× 10^3)			67
Employees, local (× 10^3)			195
Payroll (10^9 \$)			0.16
State and local government expenditures (10^9 \$)			3.76
Percentage of total for all states			2.3

SOURCE: U.S. Bureau of the Census.[12]

III.D. ECONOMIC CHARACTERISTICS

For this discussion of the Wisconsin economy, *service* denotes the service, retail, wholesale, and public sectors; *industrial* refers essentially to the entire manufacturing sector. A brief overview of these two sectors and agriculture follows.

III.D.1. Service Sector

The diverse activities that are classified under the service sector accounted for approximately 1.2 million of Wisconsin's total employment of 1.9 million in 1972.[16] Some other statistics for the retail trade, wholesale trade, selected services (e.g. hotels, auto repair, amusement, and recreation services), and government are listed in Table A.38. The rapid growth of these sectors is demonstrated by the growth rates in sales and receipts from 1963 through 1972: 7.2 percent per year for retail trade, 7.3 percent for wholesale trade, and 8.2 percent for selected services. Since the rate of inflation, as measured by the consumer price index, was 3.5 percent per year over this period, real growth for these sectors was approximately 4 percent per year.

Employment also increased over this period but not as rapidly as sales. Total employment in Wisconsin, excluding manufacturing and farming, increased at 5.2 percent per year from 1968 through 1973.[15]

TABLE A.39 Industrial Activity in Wisconsin

	1963	1967	1972
Establishments (X 10^3)	7.94	7.84	7.84
Employees (X 10^3)	462	512	501
Payroll (10^9 \$)	2.78	3.58	4.72
Value added by manufacturing (10^9 \$)	5.36	7.01	9.44
Ranking of value-added among the 50 states	11	11	12
Largest industries in terms of value-added (10^9 \$)			
Machinery, except electrical	1.40	1.59	2.01
Food and kindred products	0.75	0.91	1.32
Fabricated metal products	0.38	0.57	0.95
Paper and allied products	0.50	0.66	0.82
Electrical equipment	0.60	0.70	0.80
Transportation equipment	0.73	0.56	0.79
Percentage of total for these 6 industries	78	71	71

SOURCES: U.S. Bureau of the Census,[12] Wisconsin Legislative Reference Bureau.[15]

III.D.2. Industrial Sector

Wisconsin has considerable industrial activity, as indicated in Table A.39. The total industrial output, as measured by value-added, ranks Wisconsin twelfth among the 50 states. The growth in Wisconsin's total value-added by manufacturing from 1963 to 1972 was 6.5 percent per year. The wholesale price index for industrial commodities increased 2.5 percent per year over this period, so real industrial growth was about 4 percent per year over this period. Employment increased at only 0.9 percent per year, somewhat less than the 1.1 percent per year growth of total population over this period.

Industrial activities are often categorized into 20 Standard Industrial Classifications (SIC). The 6 categories with the largest value-added account for more than 70 percent of the total in all 3 years shown in Table A.39. Other categories that have shown rapid growth in recent years include printing and publishing (7.3 percent per year from 1963 to 1972), chemicals and allied products (9.9), lumber and wood products (10.4), rubber and plastic products (13.6), and furniture and fixtures (10.6). These 5 rapid-growth industries accounted for 15 percent of the total value-added in 1972.

III.D.3. Agriculture

Agriculture is an important part of Wisconsin's economy, as indicated in Table A.40. Total cash receipts from farm marketing of over \$2 billion in 1973 placed Wisconsin eleventh among the 50 states. Total workers on Wisconsin farms have dropped steadily from 282,000 in 1960 to 173,000 in 1973.

Known as America's Dairyland, Wisconsin produces more bulk milk and cheese than any other state.[13] Dairy products account for \$1.2 billion of the \$1.9 billion receipts from livestock and products in 1973. Wisconsin is also a leading producer of butter, beets, snap beans, corn, oats, peas, cranberries, alfalfa hay, honey, and maple syrup.

TABLE A.40 Agricultural Activity in Wisconsin

	1964	1970	1973
Employment, farm (10^3 people)	246	193	173
Total cash receipts (10^9 \$)	1.18	1.60	2.29
Livestock and products	1.01	1.38	1.89
Crops	0.17	0.22	0.40
Land area of farms (10^3 km^2)	82.5		79.7

Leading agricultural products (% of U.S. production)	1968	1971	1973
Butter	19.4	17.7	19.5
Cheese	43.6[a]	41.6[a]	39.9[a]
Milk	15.5[a]	15.9[a]	16.0[a]
Beets for processing	34.3[a]	35.7	30.2
Snap beans for processing	14.5	21.8[a]	18.6
Cabbage	7.7	17.4	11.6
Sweet corn for processing	22.2	26.3[a]	23.5
Cranberries	29.8	31.7	36.4
Green peas for processing	26.7	28.1[a]	24.8[a]

SOURCE: Wisconsin Legislative Reference Bureau.[15]

[a] Wisconsin ranked first among the 50 states for these products.

III.E. ENERGY DEMAND

In this section, end-use energy is tabulated by fuel type and sector. The difference between end-use and primary energy (given in the next section) is that energy losses in electricity generation and transmission are not included in end-use energy. It should also be noted that the definition of the sectors (service, industrial and so on) used here because of the data recording traditions are not the same definitions as for the demand models that were used in the scenario development.

The end-use energy by sector for the years 1970 through 1974 are shown in Figure A.11 and Table A.41. A few comments on each sector follow.

III.E.1. Industrial Sector

Industry consumed 28 percent of Wisconsin's end-use energy in 1974. The breakdown by fuel type shows that industrial coal use in 1974 was only one-third of the 1970 use. Many firms have switched from coal to alternate fuels, such as natural gas or electricity, because of air quality regulations, prices and availability. It should be noted that the industrial coal data for 1970 to 1972 include service coal use, but this was probably a small fraction of the industrial coal use, as the 1974 data indicate.

Industrial natural gas use reached a peak in 1972 and declined about 7 percent in the next 2 years. Economic conditions, conservation, fuel availability, weather conditions and other factors all contributed to the decline in gas use.

Industrial electricity consumption increased at an average rate of 6.0 percent per year over the 5-year period. However, the 1973–74 increase was only 1.4 percent. Industrial electricity accounted for 38 percent of Wisconsin's total electricity consumption in 1974.

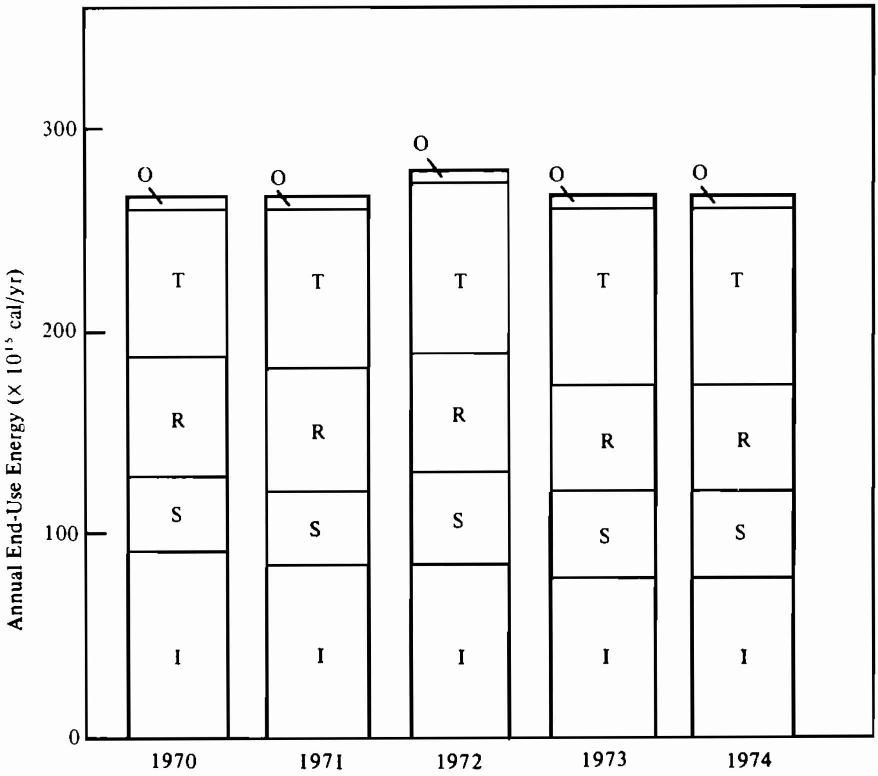

FIGURE A.11 Total end-use energy by sector. I = industrial; S = service; R = residential; T = transportation; O = other. (After Bowman *et al.*[16])

III.E.2. Service Sector

The service sector has been increasing its consumption of total end-use energy and used 15 percent of Wisconsin's end-use energy in 1974. The tabulation of fuel use in Table A.41 indicates that natural gas demand increased by 28 percent over the 5-year period. This may be partly attributable to the inclusion in the service sector of some multifamily dwellings with more than 4 units; this classification problem occurs because of natural gas tariff structures.

Electricity use in the service sector increased at nearly the same rate as natural gas use, and petroleum consumption remained nearly constant.

III.E.3. Residential Sector

The residential sector consumed 25 percent of Wisconsin's end-use energy in 1974. The residential energy consumption remained almost constant over the 5-year period (Table A.41), while the state's population increased by 2.4 percent. Natural gas accounted for about half of the total residential consumption in 1974. Petroleum

TABLE A.41 End-Use Energy in Wisconsin (10^{15} cal)

	1970	1972	1974
Industry			
Natural gas	34.2	44.1	41.1
Coal	35.7[a]	21.8[a]	11.4
Petroleum	5.4	5.5	5.1
Electricity	7.9	9.0	9.9
Total end-use energy	83.2	80.4	67.5
Service			
Natural gas	13.2	13.9	16.9
Coal	b	b	b
Petroleum	15.2	15.6	15.0
Electricity	4.4	5.1	5.6
Total end-use energy	32.8	34.6	38.1
Residential			
Natural gas	27.4	31.6	30.1
Coal	1.2	0.6	0.3
Petroleum	24.4	23.0	21.2
Electricity	8.2	9.2	9.7
Total end-use energy	61.2	64.4	61.3
Transportation			
Gasoline	56.5	62.7	63.9
Diesel	6.9	8.2	10.0
Other petroleum	2.0	2.3	2.5
Total end-use energy	65.4	73.2	76.4
Total end-use energy by sector			
Industrial	83.2	80.4	67.5
Service	32.8	34.6	38.1
Residential	61.2	64.4	61.3
Transportation	65.4	73.2	76.4
Miscellaneous	5.6	5.4	4.8
Total	248.2	258.0	248.1
Total end-use energy by fuel			
Natural gas	74.8	89.6	88.1
Coal	36.9	22.4	12.3
Petroleum	115.4	121.9	121.7
Electricity	21.1	24.1	26.0
Total	248.2	258.0	248.1

SOURCE: Bowman *et al.*[16]

[a] Includes service coal use.

[b] Included in industrial coal use.

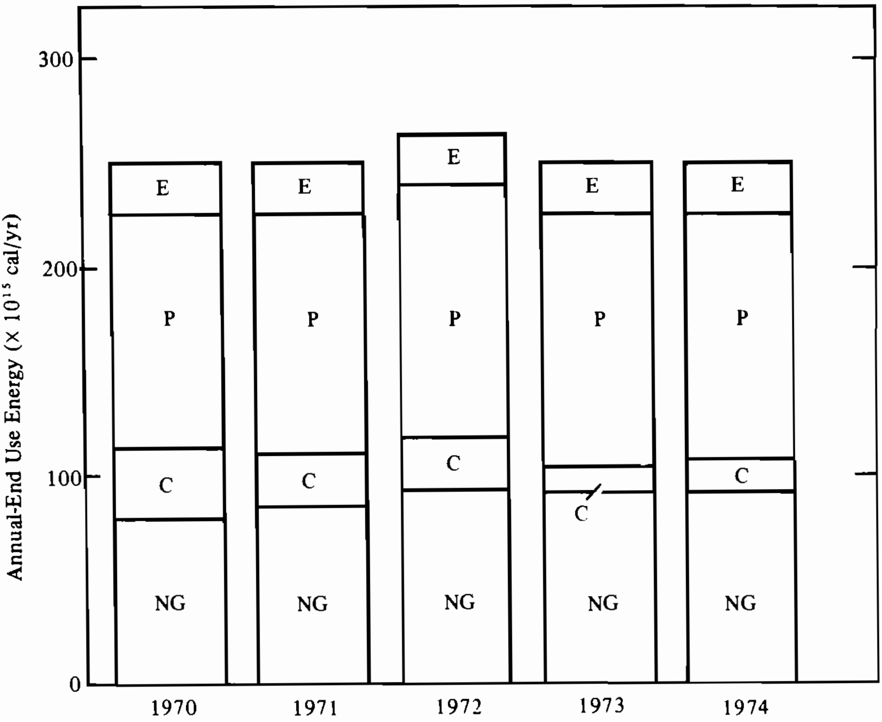

FIGURE A.12 Total end-use energy by fuel. NG = natural gas; C = coal; P = petroleum; E = electricity. (After Bowman *et al.*[16])

consumption steadily declined over this period as electricity and natural gas became more widely used. Electricity increased by 18 percent from 1970 to 1974; this corresponds to an annual growth rate of 4.2 percent. Residential electricity consumption was 37 percent of Wisconsin's electricity use in 1974.

III.E.4. Transportation

Transportation had the largest energy consumption of any sector in 1974; it amounted to 31 percent of Wisconsin's total energy consumption. Furthermore, petroleum consumption for transport in 1974 was 62 percent of Wisconsin's total consumption of petroleum. Personal travel resulted in 56 percent of the total transportation energy use and 17 percent of all end-use energy in the state.[16]

The overall rate of growth in transportation energy use has been large since World War II and the trend continued in the years 1970–1973 at a rate of 5.5 percent.[16] In 1974, however, the increase in gasoline prices, the economic recession, and conservation efforts resulted in a small decline in transportation energy use.

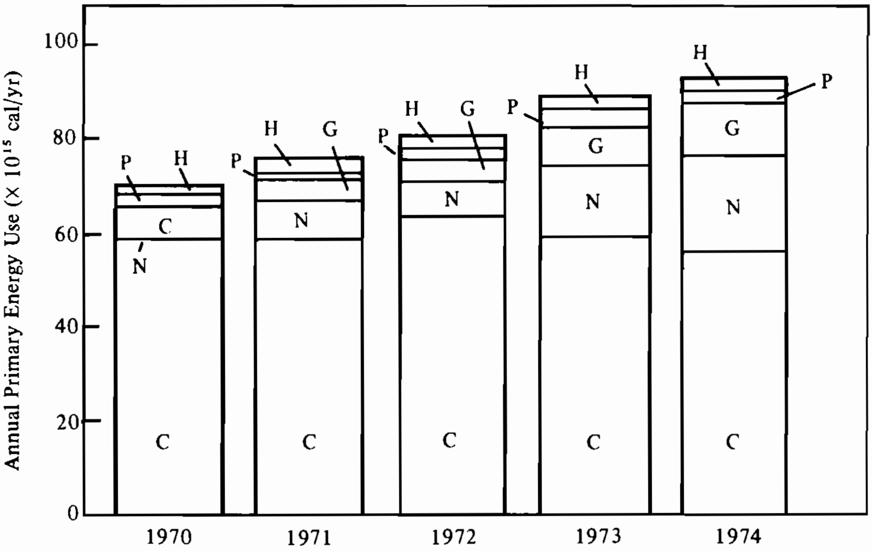

FIGURE A.13 Primary energy use in Wisconsin for electrical generation. C = coal; N = nuclear energy; G = gas; P = petroleum; H = hydropower. Hydropower is used at approximately 100 kcal/kWh; this is *not* equivalent to the fossil fuel that would have been consumed if hydropower were not available. (After Bowman *et al.*[16])

III.E.5. Total End-Use Energy

As shown in Figure A.11, Wisconsin's total end-use energy was nearly the same in 1974 as in 1970. The transportation and service sectors increased end-use energy consumption from 1970 to 1974, while the residential sector had stable consumption and the industrial sector consumed less.

The end-use energy by fuel type in Figure A.12 shows a steady growth in electricity consumption, a rapid decline in coal use, and a leveling of natural gas and petroleum use.

III.F. ENERGY SUPPLY

In order to determine the total primary energy, the electricity fuel supply and losses must be combined with the end-use energy discussed in the previous section. The use of fuels used for electricity generation, shown in Figure A.13, increased at an average annual rate of slightly over 6 percent, while total generation increased from 27.4 to 32.6 × 10^9kWh. Coal and nuclear power account for nearly 90 percent of the total fuel use. Nuclear power's contribution grew from virtually nothing in 1970 to 26 percent in 1974. However, the 1974 nuclear energy totals are approaching the maximum that can be expected from the state's 1,600 MW nuclear capacity.* All major new facilities for the next few years are planned to be coal-

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* Nuclear generation in 1975 was about 20 percent above generation in 1974.[17]

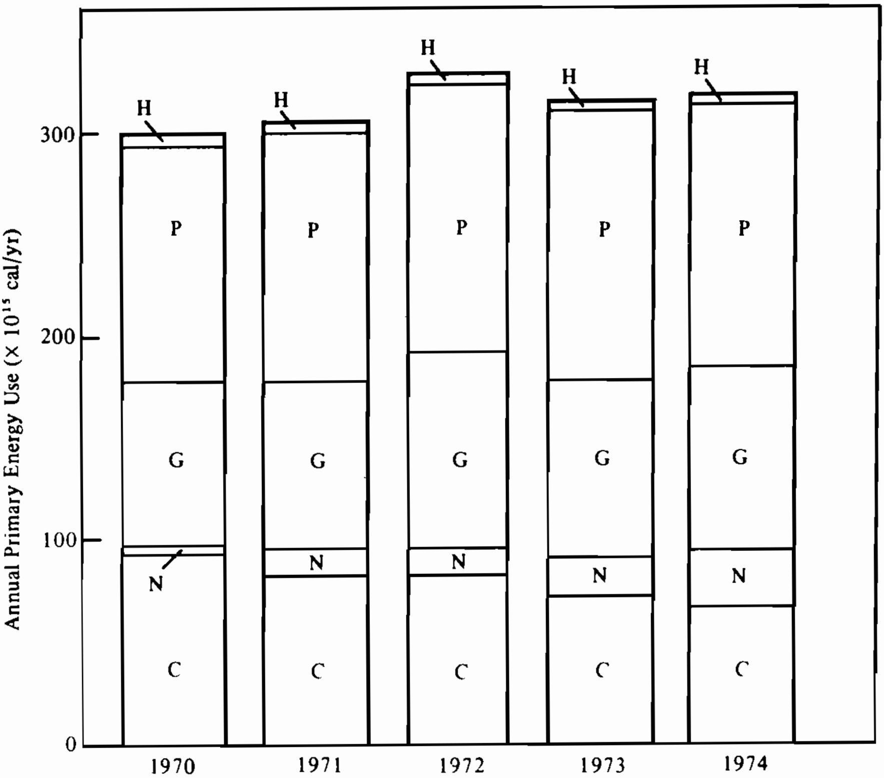

FIGURE A.14 Total primary energy use in Wisconsin by fuel type. C = coal; N = nuclear energy; G = gas; P = petroleum; H = hydropower. (After Bowman *et al.*[16])

fired. No new nuclear capacity is planned before the mid-1980s. Therefore, coal can be expected to increase its share of the total electrical fuel supply if electricity demand continues to grow.

Natural gas and petroleum are not major sources of fuel for electricity nor are they expected to be in the future. Use of hydropower is relatively small and is expected to remain almost constant.

Total primary energy consumption is obtained by adding the electrical fuel supply results in Figure A.13 to the end-use fuel results in Figure A.12. The total primary energy use in Figure A.14 shows a slight increase of approximately 1.1 percent per year over the period. As noted previously, the end-use energy remained almost constant over this period; the slight increase in primary energy use is attributable to the increased use of electricity during the period.[16]

With the exception of coal, there were increases in all of Wisconsin's energy sources from 1970 to 1974. Natural gas and petroleum provided over 70 percent of the state's primary energy use. Wisconsin has no fuel resources, other than hydropower, so all these fuels must be imported.

IV. ENERGY FLOWS IN THE THREE REGIONS

Jean-Pierre Charpentier – International Atomic Energy Agency (IAEA)

Before describing energy flows in the GDR, France, and Wisconsin, their respective average energy consumption per capita, and relative position in world energy consumption will be summarized. Figure A.15 gives the distribution of world energy consumption per capita in kilowatt-year-thermal per year (kWy_{th}/y). This distribution, using data from 178 countries throughout the world shows that countries can be divided into 3 classes:

- The first class includes countries which consume more than 7 kWy_{th}/y. Only 3 percent of the countries belong to this class. It is essentially composed of the United States, Canada, and some exceptional consuming countries such as Kuwait.
- The second class includes all European countries. It is composed of those countries in which the average level of energy consumption per capita is between 2 and 7 kWy_{th}/y. This group represents 22 percent of the countries of the world.
- The third group includes all developing countries or countries consuming less than 2 kWy_{th} per capita per year. This last group is the largest one, in which are 75 percent of the countries of the world.

It is also worthwhile mentioning that if population, rather than the number of countries, is taken as the studied variable, the distribution remains roughly the same. The first class has 6 percent of the world population instead of 3 percent of the countries; the second class has the same percentage of people and countries, and the third class has 72 percent of the population in comparison with 75 percent of countries.

The mean value of this energy distribution per capita in the world for 1971 is 1.64 kWy_{th}/y. The GDR, Rhone-Alpes, and Wisconsin, are *three "rich" energy con-*

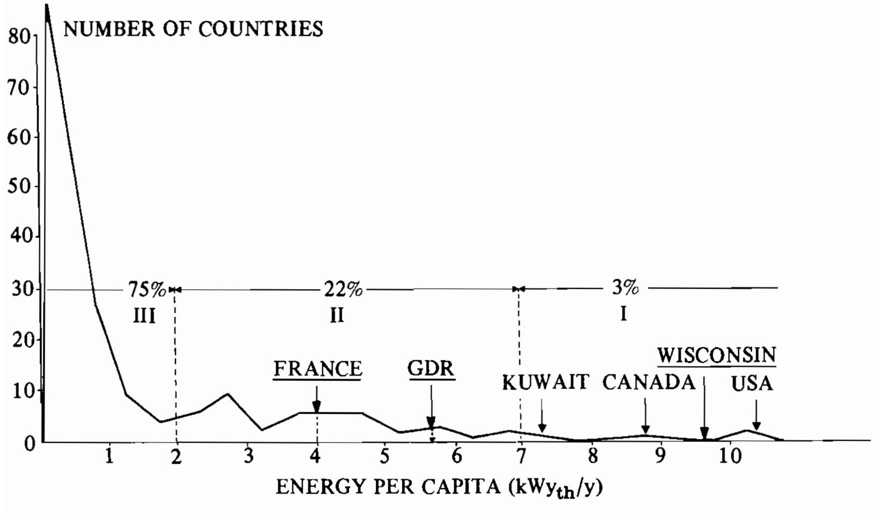

FIGURE A.15 Distribution of energy consumption in the world in 1971 for 178 countries. (After *Statistical Yearbook*[20])

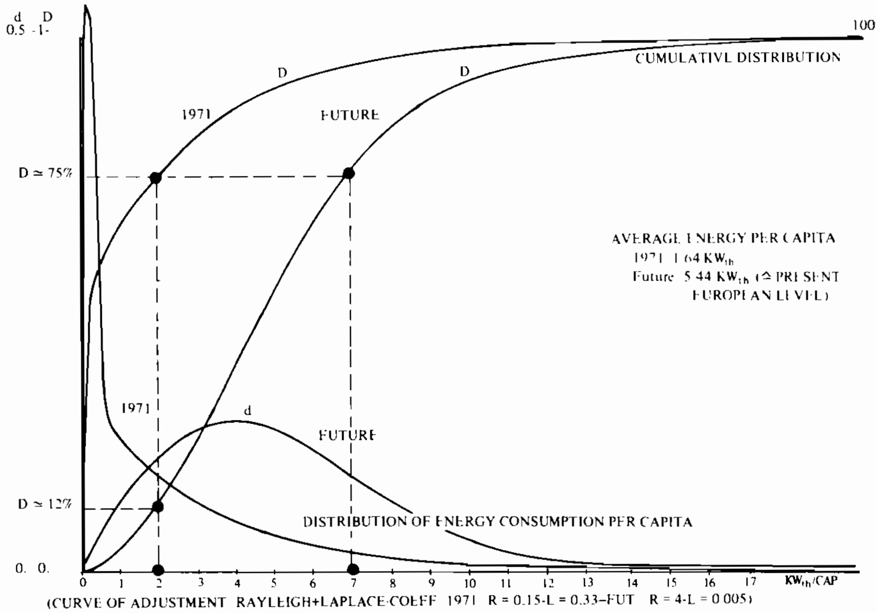

FIGURE A.16 1971 and possible future distribution of energy consumption per capita in the world.

sumers because their average energy consumptions for 1970–71 were, respectively, 5.6 $\mathrm{kWy_{th}/yr.}$, 4.0 $\mathrm{kWy_{th}/yr.}$ and 9.3 $\mathrm{kWy_{th}/yr.}$ Therefore, the conclusions drawn about the 3 countries are applicable to only 25 percent of the countries of the world. This clearly shows the necessity of continuing development and implementation of this kind of study in order to improve our knowledge of energy consumption at the global level.

Figure A.16 shows the first step in what seems a promising method of research for analyzing the development of energy consumption both globally and within countries.[18] The general idea is to analyze how a country (or people) shifts from one class of consumer to another through time. This mainly requires analysis of how technological knowledge spreads and is applied from country to country over time. The analysis has not progressed past the preliminary stage. For Figure A.16 it was assumed that the distribution of energy per capita in the world will remain the same in the future, and only its parameters will change. Roughly speaking, this could mean that the historical trends related to the speed of technological progress in countries will remain the same. There are, however, two normative assumptions:

- The average world energy consumption per capita will reach the present European level.
- Of the countries of the world, 75 percent will reach the upper limit of the second class of consumers and use 7 $\mathrm{kWy_{th}}$ per year and per capita.

Based on these assumptions, the "future" distribution of energy consumption per capita in the world will have the form of curve *D*.

In order to determine a date for this so-called future energy distribution, it was necessary to study the growth rates of this energy consumption per capita. This situation could occur by the year 2040 if the growth rate of energy per capita is around 2 percent per year, or the year 2000 if the annual growth rate per capita is 4 percent.

If the average energy growth rate per capita were 2 percent per year, the energy consumption in the three regions would be 7.5 kWy_{th}/yr for the GDR, 5.5 kWy_{th}/yr for France, and 12.5 kWy_{th}/yr for Wisconsin.

It would be worthwhile to carry out the same kind of study within each country in order to have a better understanding of energy distribution across the population and among its different groups: those living in urban areas, those in rural areas, and so on.

Figures A.17, A.18, and A.19 summarize in a standard form, the energy flows of the 3 regions for the year 1970. All numbers indicated on these energy patterns are in percentages either of total energy consumed or by sector. The relative orders of magnitude are interesting to note. It is clear that only Wisconsin's consumption of primary energy fuel is well balanced among natural gas (28.5 percent), coal (31.5 percent), and liquid fuels (38.9 percent). The other two countries are mainly dependent on only one primary fuel: coal for the GDR (85.8 percent) and fuel oil for France (62 percent). These great dependencies on one primary fuel lead to less flexibility and could lead to great difficulties for the country if any shortage in this fuel appears. In addition, in such a country, any kind of replacement by another fuel would need more time because the technical structure related to this primary fuel is extensive and more difficult to change.

If we now look at electricity production, the ranking of the countries appears quite different. We see that the GDR is a high electricity producer; approximately 30 percent of its primary fuels are devoted to electricity production. Roughly 20 percent of primary fuels are for electricity production in each of the other two regions.

In all 3 regions there is a highly unbalanced distribution among the primary fuels used for this electricity production. The GDR produces 94.5 percent of its electricity from coal, Wisconsin 79 percent from coal, and in France 46 percent of its electricity is from fuel oil. In the case of France, it is interesting to note that 20 percent of the electricity was supplied from hydropower in 1970, in comparison with a very small percentage in the other two countries.

In all countries, nuclear energy did not play a major role in 1970, generally accounting for less than 1 percent in the primary energy balance.*

If we look at end uses by economic sector, industry, transport, and "other sectors" (household, commercial, service, and agricultural), 3 totally different structures appear. Table A.42 summarizes this structure of end uses. Wisconsin has the characteristics of an agricultural area with only 29 percent of its energy used in the industrial sector in contrast to more than 40 percent in the GDR and France. The part of its total energy used by the GDR in transport is very small compared with the 2 other regions: 8 percent in the GDR and 20 and 25 percent in France and Wisconsin.

The energy structure for the 3 regions is presented in a triangular graph in Figure A.20. These 3 regions follow 3 *totally different energetic developments* when compared with other countries. By cross-section analysis, one sees that according to their economic evolution, countries are moving along the line *ABCD* in Figure A.20.

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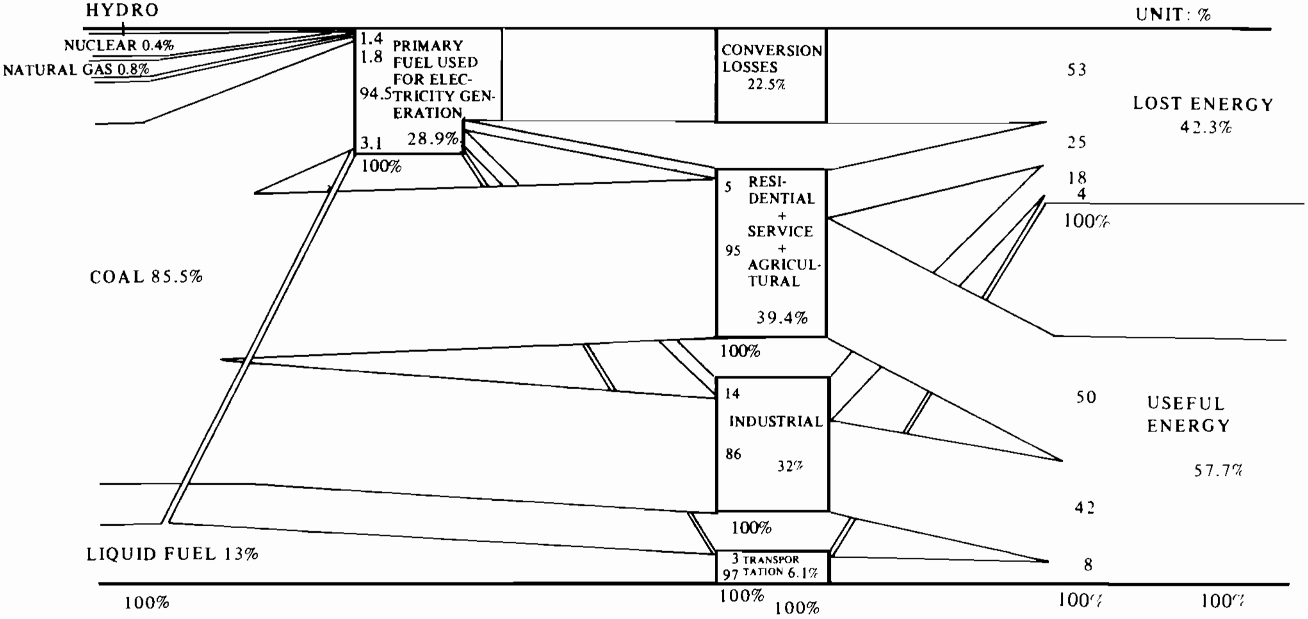
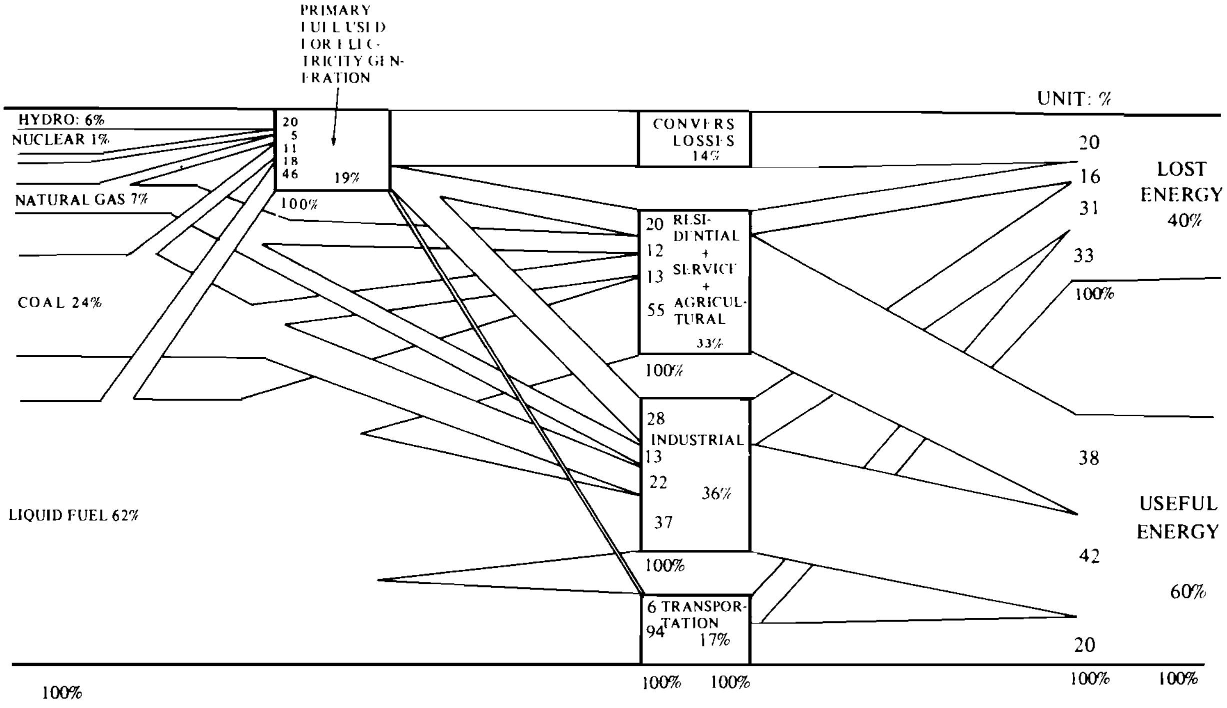
* In 1976, nuclear energy supplied approximately 9 percent of Wisconsin's primary energy use.



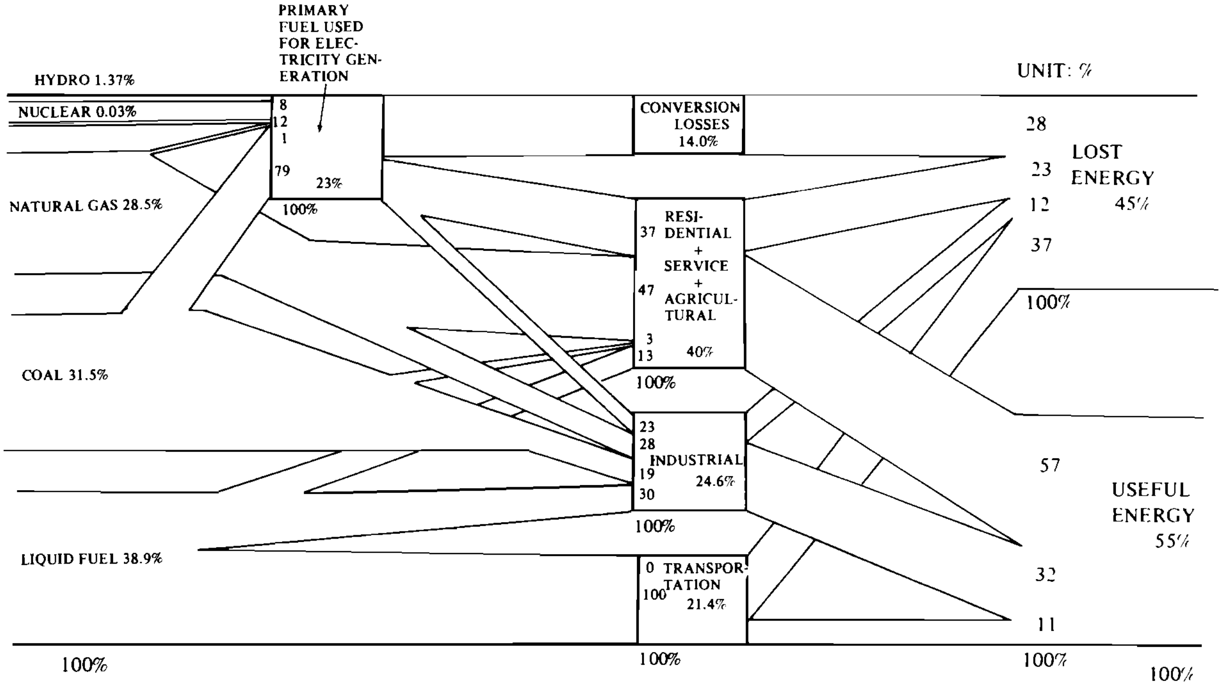
TOTAL PRIMARY ENERGY USED IN 1970: $95 \cdot 10^6$ kWy_{th}
ENERGY PER CAPITA IN 1970: 5.6 kWy_{th}

FIGURE A.17 Energy flows in the GDR (1970).



{ TOTAL PRIMARY ENERGY USED IN 1970: $212 \cdot 10^6$ kWy_{th}
{ ENERGY PER CAPITA IN 1970 : 4 kWy_{th}

FIGURE A.18 Energy flows in France (1970).



TOTAL PRIMARY ENERGY USED IN 1970: $43 \cdot 10^6 \, kWy_{th}$
ENERGY PER CAPITA IN 1970 : $9.3 \, kWy_{th}$

FIGURE A.19 Energy flows in Wisconsin (1970).

TABLE A.42 End-Use Energy by Sector (%)

	Wisconsin	GDR	France
Industry	29	41	42
Transportation	25	8	20
Other sectors	46	51	38
Total	100	100	100

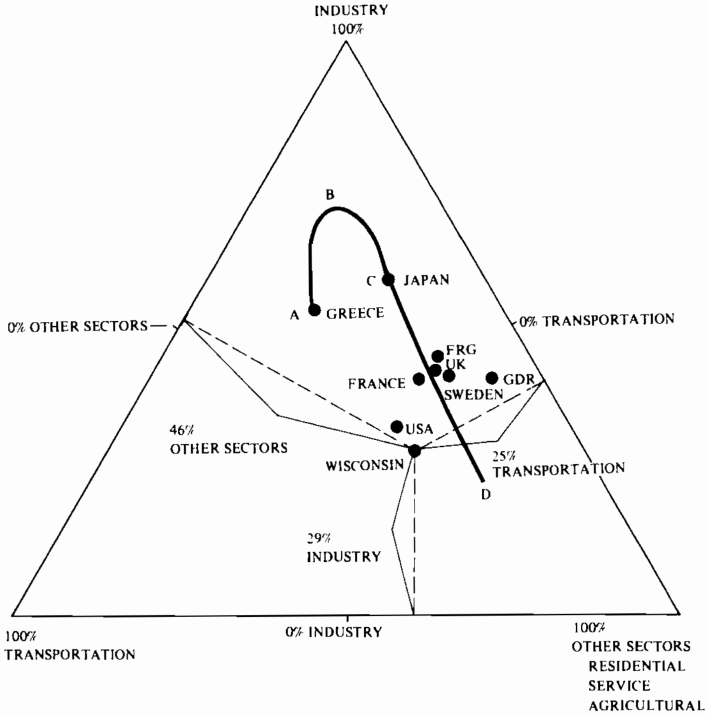


FIGURE A.20 Structure of energy consumed by sector (1970).

The line *AB* corresponds to such countries as Greece, Portugal, and Turkey which used a disproportionally large amount of energy in transport, with corresponding development of their industry. The line *BC* refers to such countries as Japan or Spain which are engaged in a rapid development of their industry. But after a given point *C* (corresponding to the present Japanese situation) it seems that countries are moving on parallel lines which correspond to:

- A fixed proportion of energy used in the transportation sector
- A decreasing proportion of energy used in industry and more energy used in the tertiary and residential sectors

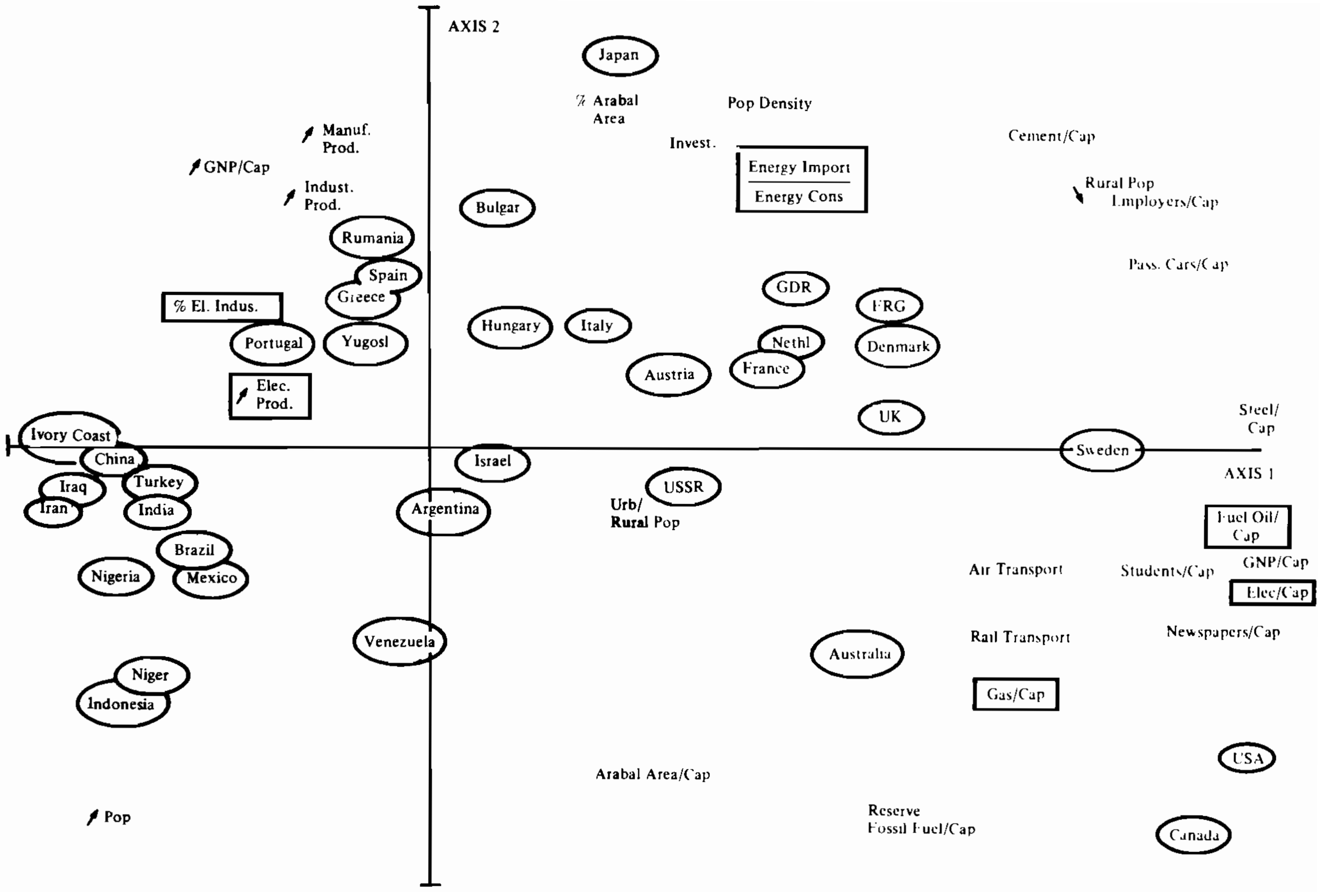


FIGURE A.21 Factor analysis: energy versus growth (1971).

Most of the European countries are moving along a straight line which shows that roughly 20 percent of their energy is consumed in the transport sector. For 10 years the United States has also moved on a parallel line but with a greater amount of energy used in transport (25 percent), and Wisconsin seems to be on the same line. The GDR used a much lower share of its energy for transportation (8 percent).

Examining the fuel mix at the level of end-use, the GDR's link to coal is noted: 86 percent of fuels used in industry come from coal and 95 percent of energy consumed in the service and residential sectors is also supplied by coal. For the 3 regions, 55 to 60 percent of primary energy is transformed into useful energy.

To conclude, there will be a description of the results of a factor analysis made not only with these 3 countries but with 35 countries, each characterized by a vector of 27 parameters (dimensions).[19] Factor analysis is a method for summarizing and clarifying a set of data. In order to give a general idea of its objective, consider the following example: You are living in Austria and you want boxes of a certain size built by people in an industrialized country such as Japan. Let us suppose that neither you nor your agent in Japan have any knowledge of geometry, so in order to obtain your boxes you must send to your contact person a great deal of information (perhaps too much; e.g. volume of boxes, external surface area, length of each side, angle of each corner). If your Japanese agent has a knowledge of factor analysis (though he is ignorant of geometry!) he will find that only three factors are needed: length, width, and height. No single parameter determines a factor or axis, rather they are determined by the combined influence of the parameters which characterize the 35 countries. The first two axes, typically restricted to be at right angles, indicate the strongest common "directions" or patterns in the data.* The coordinate of a given variable, with respect to an axis, is proportional to the correlation coefficient between the variable and the axis. The variables (either parameter or countries) that are grouped along an axis must be interpreted so as to identify what the axis represents.

In this study, the first axis (or factor), which corresponds to the economic level of development, explains 41 percent of the variance of the initial information (the matrix of 35 countries and 27 parameters).

Figure A.21 shows a summary of a factor analysis. Axis 1, corresponding to economic development, depicts the high correlation between such variables as steel consumption, electricity consumption, primary energy consumption, newspapers, and cars per capita. The United States is clearly at a high level of economic development, followed closely by Canada and Sweden; then come the FRG, Denmark, the United Kingdom, followed by the GDR, the Netherlands and France. The second axis is related more to the notion of space and population density. This analysis is described in more detail by Charpentier and Beaujean.[19]

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* The axes are the eigenvectors of the variance–covariance matrix between the different parameters. It can be shown that the most important factor loadings are given by the eigenvectors corresponding to the longest eigenroots of the variance–covariance matrix.

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B Institutional Structures of the Three Regions

An analysis of energy and environment management tools in a region cannot be undertaken without an understanding of the institutional framework within which they are used. This framework, in turn, is best viewed within the overall economic and political framework of the region. The socioeconomic and political structures have shaped the quantitative tools and the planning and decision practices used in the three regions. The following three sections briefly describe the institutional settings for energy (and in some cases environmental) planning and decision making in the three regions. The contrasts are vivid and revealing.

I. THE GERMAN DEMOCRATIC REPUBLIC*

Dietmar Ufer – Institut für Energetik

In the German Democratic Republic (GDR) the people own the productive equipment in all industries. The fact that the socialist title to the means of production is undivided, renders product-line planning possible by the public, but it makes it necessary, at the same time, to organize, plan, and control the socialist development according to consistent principles. The energy sector must also be planned. Full particulars about the energy industry in the GDR will be given. First, however, the organizational chart of the energy industries will be outlined to give a better understanding of the planning policy applied.

The energy economy covers all the utilities and facilities for the production, conversion, transportation and use of all forms of energy (see Figure B.1). The energy systems penetrate all processes in public life, in production, and consumption, and are therefore planned with great care. The Ministry for Coal and Energy

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* This section describes planning in the energy sector only; a description of practices in air pollution control is given in section I of Appendix C. For further information on the GDR, see also K. Hanf's report, "Policy and Planning in the German Democratic Republic – an Interorganizational Perspective," (Internationales Institut für Management und Verwaltung, Berlin, 1975) – ED.

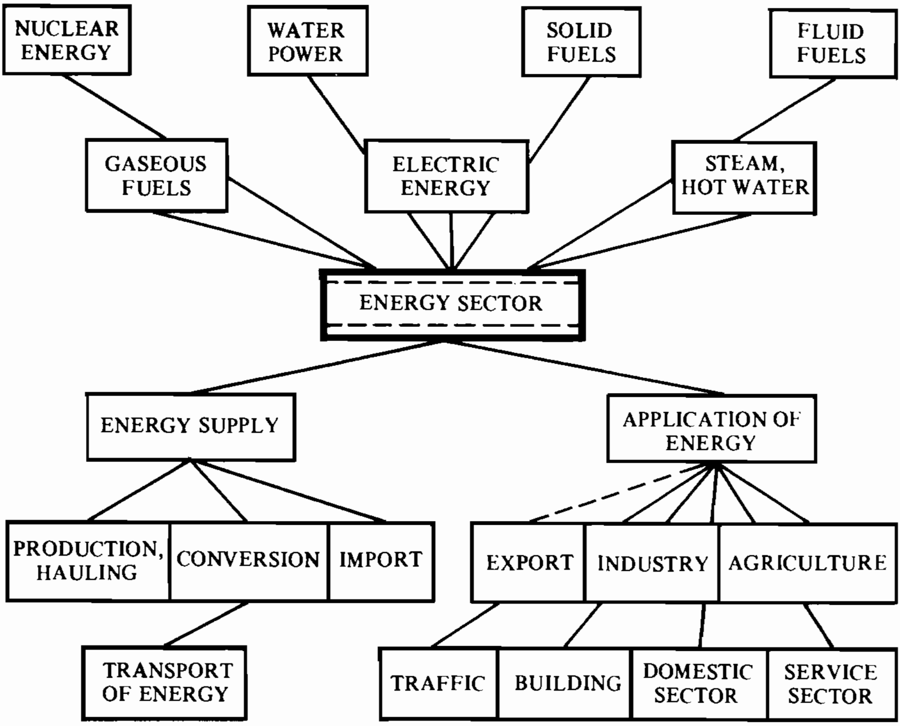

FIGURE B.1 The energy sector in the GDR.

is held responsible for working out and implementing the national energy policy. The decisions made by the United Socialist Party of Germany are the basis of these activities. The Ministry for Coal and Energy operates according to the principles of the national economic policy accepted by the Council of Ministers and is subordinate to this Council. The structure of the GDR hierarchy is shown in Figure B.2. The State Planning Commission, also subordinate to the Council of Ministers, is the most important staff organization which outlines the strategy of development of national industry and is therefore considered to be an important partner in the process of planning the energy industry.

All the authorities that regulate the economy are subordinate to the Ministry of Industries. In the case of the Ministry of Coal and Energy, the authorities concerned are the Association of Nationally-Owned Enterprises (VVB) for Hard Coal, Brown Coal, Power Plants, and Energy Supply, as well as the Gas Manufacturing Group (Gaskombinat Schwarze Pumpe; see Figure B.3). The Institute of Energetics is also under the direct control of the Ministry for Coal and Energy.

The single-product factories, scientific centers, and, to some extent, the planned enterprises are also under the control of the Association of Nationally-Owned Enterprises. For example, as shown in Figure B.4, the Association of Nationally-Owned Enterprises for Power Plants controls the large-scale power plants operated with lignite, the nuclear power stations, the gas turbine power plants, the storage pumping stations, and the Institute of Power Stations. The Association of

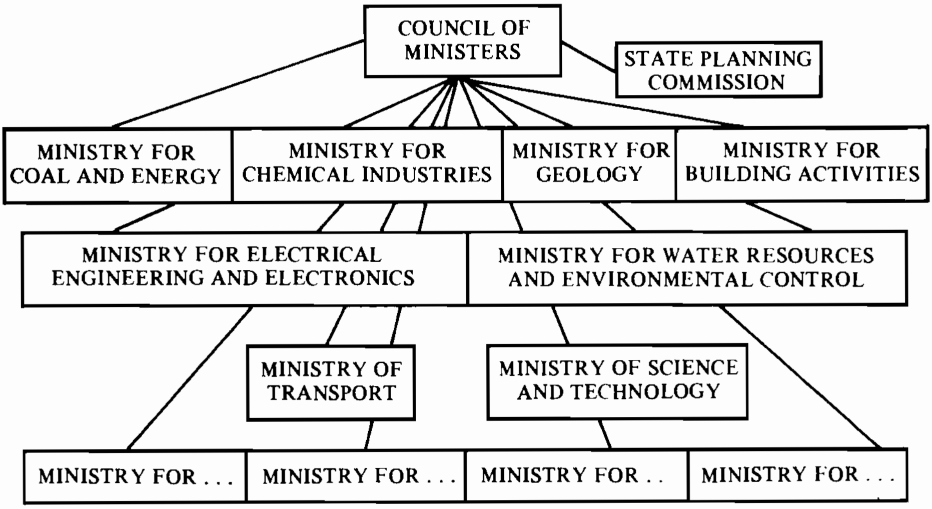

FIGURE B.2 The structure of the government in the GDR.

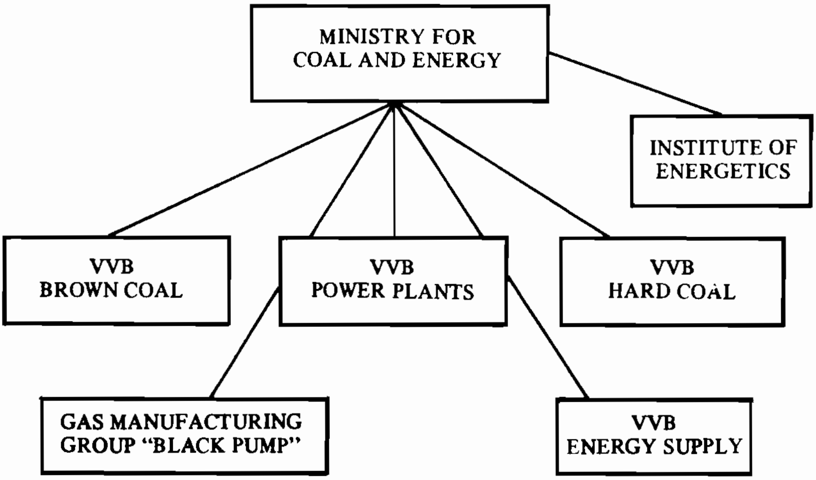

FIGURE B.3 The GDR Ministry for Coal and Energy and its subordinates. VVB is the Association of Nationally Owned Enterprises.

Nationally-Owned Enterprises for Brown Coal and the Gas Manufacturing Group have been organized analogously. In contrast, the Association of Nationally-Owned Enterprises for Energy Supply has been divided into territories. The energy supply authorities in the districts comprise the combined heating and power stations, larger heating stations, gas works, and the stations for the distribution of electricity, gas,

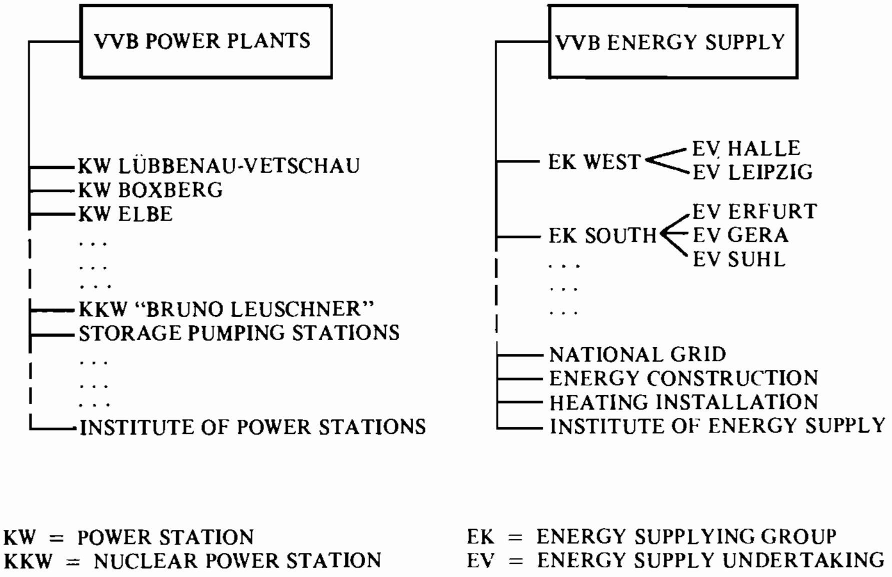

FIGURE B.4 The structure of the Associations of Nationally Owned Enterprises (VVB).

and district heat. They constitute the marketing units in the energy industries for these forms of energy.

Thus the Ministry for Coal and Energy is responsible for the greatest part of the energy supply. The only exceptions are (1) the primary processing of petroleum, which falls within the sphere of the Ministry of Chemical Industry; (2) the extraction of natural gas, which is controlled by the Ministry of Geology; and (3) the industrial power plants in the different branches of industry as well as the municipally-owned heating plants and other plants of only local significance. With regard to the responsibility for the development strategies for the energy industry, the Ministry for Coal and Energy has to fulfill a double function:

- It is responsible for the supply of energy by the economic units under its control, i.e. about 78 percent of total primary energy.
- It is responsible for the realization of rational principles of energy use, and thus for energy policy in all spheres of national industry and social life (with respect to all forms of energy).

In order to translate the latter function into practice, a whole system of executive bodies has been set up in recent years:

- In all the Ministries controlling industry, and in the authorities controlling the economy, there are energy specialists supervising the economical use of energy who are responsible for the development of energy plans. This, of course, includes the responsibility assumed in the overall operating management by the managers and ministers for the energy consumption in their own sectors.

- Under the direction of a deputy chairman of the District Council, county energy commissions which take care of the national energy policy in the political regions have been established. They cooperate closely with the regional energy supply authorities and central government authorities.

The most important instrument for the implementation of energy policy is the Plan, more particularly, the Energy Plan. This Plan has been worked out for ten years by all energy intensive large-scale enterprises and facilities in conjunction with the one-year and five-year Plans. The Plans are coordinated centrally and an account is given annually. The implementation of the policy for efficient energy use is given support by a pricing policy as scheduled for the various forms of energy.

It is not possible here to describe the overall planning process in detail. Some principles in socialist planning, and some phases of long-range energy planning will be outlined. The planning of the energy economy forms part of the overall planning of the national economy. Its goal is the consolidation and steady development of the socialist community as well as the continual supply of the growing necessities of life, and the fulfillment of the intellectual desires of its members by a continuous and rapid rise in production in all sectors. Since the objectives in the planning process are important interests of the whole community, the process is controlled centrally by the government. It is reviewed at all levels of the government up to the Enterprise Associations, where the people employed participate in the determination of the indices in the Plans of the Enterprises.

The GDR is a member of the Council for Mutual Economic Assistance (CMEA). The Plans of the member countries, especially the five-year plans, are closely coordinated in order to gain a steady and quick development of national industries in all socialist countries.

Planning is carried out by means of coordination over different periods: annual planning, five-year planning, and long-term planning, which usually covers several decades and is especially important in the energy industry. The forecasting of the scientific and technical development of single processes and procedures within them is presupposed to be of great importance. The planning for one and five year Plans is done according to a centrally designed practice which also applies to energy planning. The methods of long-range planning vary and depend on which economic sphere and which time period are to be examined. However, three methodological principles apply in each case:

- The starting point is the demand, either national or subnational, depending on the planning.
- The leading consideration in planning is balancing, i.e. to balance the demand and supply capacity, the economic requirements, and the economic potentials.
- Planning is carried out with consideration for all essential interrelations with other activities.

With reference to the energy sector this means that the forecasting of the demand for energy is the starting point for energy planning. The quantity and the structure of the energy supplied depends closely on the development of the national economy and on living standards. The forecasting of energy supply requires, on the one hand, the awareness of the future economic trends, especially the production volume of energy-intensive products, such as steel, aluminum, and glass, not to mention railway transportation service, the number of flats requiring heating, and so on. On the other hand, it is necessary to have information on the specific energy consumption trends for these products and services. For this purpose, investigations into the technological and economic development of the individual processes are made in cooperation with the experts from the appropriate sectors. In certain cases, suggestions are made by the energy economists, suggestions appropriate to an advanced technological development promising exceptionally efficient consumption of energy, or which permit the use of domestic energy instead of imported sources. In long-range planning for 1 to 2 decades, approximately 40 percent of the total demand for energy is estimated with the aid of detailed indices on specific consumption. This percentage, of course, will decrease with a longer planning period. The remaining consumption of energy is assessed by applying global methods such as trend and correlation calculations.

The selection of the most effective alternative is of special significance in the long-range planning of energy supply. With the advanced development of production techniques such as those applied in the steel or cement industries, there is always a great variety of technological capabilities and possibilities for employing energy. The sole intention is not to realize the alternative representing the least demand for energy. Together with the appropriate branch, we hope to find technological solutions that facilitate the required results at the lowest social expenditure. This will also be in the interest of the entire national economy.

Such isolated calculations of alternatives for the individual processes show the drawback that an energy structure which cannot be realized for economic reasons may be established (e.g. the calculation of the excessive consumption of natural gas or another limited energy source). For this reason we have developed a model that takes into consideration the substitution of energy forms. Thus, it has been rendered possible to distribute the forms of energy among the individual processes such that there will be maximum economic benefit not for the individual processes, but for the processes together. The model in question is the so-called substitution optimization model (SOM).

Apart from these detailed techniques for the determination of energy consumption arising from the individual products and services, global methods are also used in order to calculate the total consumption and demand of the individual sectors. Such methods have priority over mere trend determinations resulting from the correlation between production, national income, other economic variables, and energy consumption. These global methods are best applied to the consumption figures and then verified by applying other methods. They must also be considered as the only methods suitable for the calculation of consumption variables for very long periods.

In the next phase of the planning process, the total production and importation of all energy forms and the primary energy is calculated. In long-range planning for a period of around two decades, an optimization model that takes into account the interdependence of the various forms of energy is used. Application of this model, the so-called production optimization model (POM), provides for the selection of alternative combinations of energy forms and extraction and conversion systems by which the demand for energy can be met at the lowest social expenditure. These calculations are supplemented by computations with global methods (methods for handling the totality of energy-related problems), especially beyond the year 2000. Experience has shown that at least rough investigations must be made when interdependence is assumed. As an example, a pure trend extrapolation for electricity will show results which are untenable for technological and economic reasons.

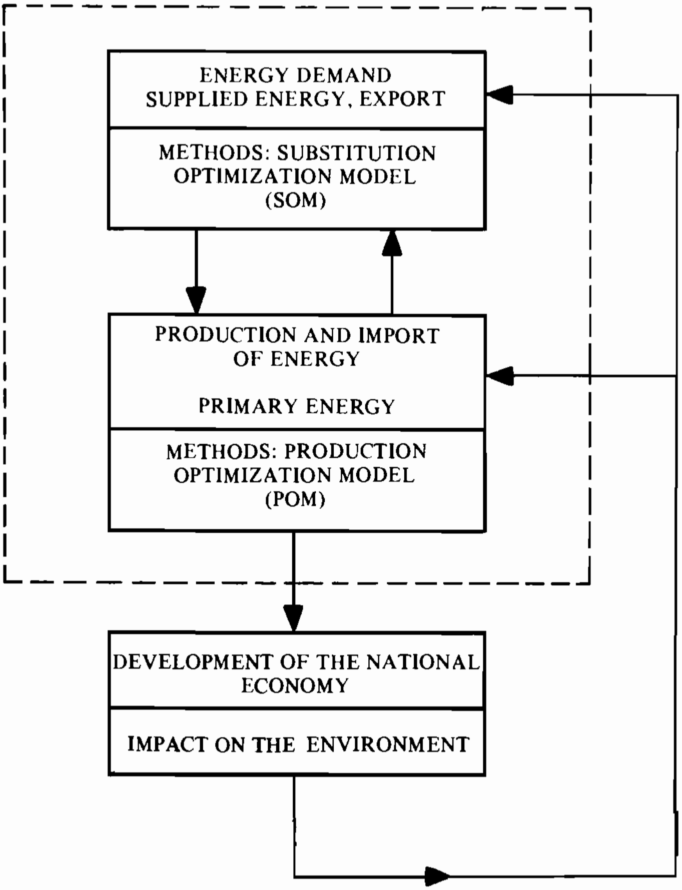

FIGURE B.5 Planning of the energy sector in the GDR.

This phase in the planning process is linked with studies of the scientific and technological development of energy production, transportation, and power conversion. The computations require a great deal of knowledge about available energy resources, both domestic and foreign. Economic variables such as the amount invested, wages, and prices for imported energy are of significance for the computations involved. The process of long-range energy planning is nowhere near completion so the computation of an optimum structure of the energy industry is not yet possible. The two phases of the planning process – the calculation of the energy demand, and subsequently the calculation of the consumption of primary energy – must be constantly repeated (Figure B.5). This is indispensable for two reasons:

- The basic data of these two planning phases change, in particular due to the experience gained with long-range planning in other sectors of the national economy.

- The results obtained in long-range energy planning must be screened for their ability to be adapted to national economic planning.

In other words, the first computations by means of the production optimization mode, or similar computations from other methods, frequently give rise to investment or man-power requirements for the energy industry which cannot be satisfied by the national economy. There might also be an amount and a structure of energy demand which cannot be supplied at the proper time, e.g. if the power capacity required up to that time cannot be attained, or if a certain quantity of crude oil cannot be imported. The case may also arise in which the structure of the energy demand resulting from the first calculation would have such an adverse effect on the biosphere that it could not be realized if environmental controls are also sought.

The studies performed after the optimization calculation constitute an extremely significant stage of long-range planning for energy systems. Since a balance between the energy/economic requirements can rarely be reached immediately, it is necessary to eliminate any discrepancies. The solution may be to consider a higher efficiency relative to energy conversion with the aid of new or advanced systems and techniques, to consider the replacement of imported fuels with those from the industries, to provide for development of new or advanced techniques of energy use, to lower the pollutant emission, or finally, to change the national economic structure by not developing certain energy-intensive processes. This, at any rate, implies repeating the two phases in energy planning. Such an iteration process must be repeated until the degree of correspondence between requirement and potential can be considered adequate.

Some part of the feedback can be simulated by making use of mathematical models. For instance, the substitution optimization model can be linked with the production optimization model. Optimum distribution of fuel resources available only to a limited extent are then obtained not only in the field of energy use and conversion but also in the energy sector as a whole.

Special attention is paid to the relationship between the energy industry and environmental protection. Environmental control is not considered the necessary evil that places a great strain on the national economy. Measures for environmental protection are systematically included in the development of the national economy, as an effective safeguard of the social welfare. An example is the possibility of extensive reuse of waste products. The Ministry of Environmental Protection and Water Economy has outlined the main directives for environmental protection measures up to 1980. With these directives as a starting point, concrete concepts for districts of industrial conurbation are created on the basis of socialist legislation for environmental conservation. Such a program has been implemented by the County Council of the District of Leipzig.

In 1975, two-thirds of the investments in environmental protection were concentrated in districts of industrial conurbation which are assumed to be the most important areas for the energy industry. Their importance is shown by the fact that 19 percent of the particulate emissions in the GDR are from the power plants located in the districts of Halle and Cottbus. In 1975, 34 percent of the investments for environmental control were spent for air pollution control measures, 47 percent for water pollution control measures (a vital problem in the energy industry since the GDR has a lack of surface waters), 15 percent for the utilization and removal of trade refuse, and 4 percent for noise abatement measures. Altogether, environmental control in the GDR is planned in such a way that it will serve for the immediate improvement of the living conditions.

Summarizing, there has been some good experience in the methods applied to long-range energy planning in the GDR in recent years. The strategy for energy-industrial development derived from long-range planning is the starting point for working out the five-year plans. The good results obtained in achieving the target of these plans speak for the benefits of long-range planning. Here are some facts demonstrating the level of development in the GDR.

- The GDR is one of the countries in the world whose energy industries must be considered highly developed. It ranks third in Europe in the case of primary energy with about 44 Gcal/per capita, and ninth in Europe in electric power with about 4,000 kWh/per capita. The GDR is the largest producer of lignite in the world.
- Planning of energy intensiveness has been entirely successful. This is witnessed by the 4.5 percent average annual reduction in the intensity of supplied energy in recent years.
- The percentage of high-grade forms of supplied energy was corrected so that electric power, for instance, is about 12 percent of the total supply at the present.
- Policy has been consistently based on maximum utilization of primary energy, especially in the case of lignite. More than 90 percent of domestic imported energy comes from socialist countries (mainly from the Soviet Union). The fact that energy industries were not directly affected by the oil crisis demonstrates the success of such a policy.
- The energy technology is developed according to plan. Modern methods are applied and use is being made of modern equipment. The nuclear power stations, the 500 MW turbogenerators (developed by the Soviet Union) and the 60 m overburden conveyor gantry are examples.

In the planning of the GDR energy industry we will keep our course true to the target. We are confident that good results will be obtained by improving joint planning activities with other socialist countries within the Council of Mutual Economic Aid. This will receive further emphasis in our future activities.

II. RHONE-ALPES

Jean-Marie Martin and Dominique Finon – Institut Economique et Juridique de l'Energie (IEJE)

Two aspects of the French economic and political organization are of importance for an understanding of the energy and environmental decisions in the Rhone-Alpes region.

First, for historical reasons, the entire French decision system is extremely centralized. This is true both for the state decision making apparatus which is centralized in high-level administrative agencies (the ministries) geographically clustered in the capital, and also for the important firms whose power is also centralized within headquarters located in the capital. Government and corporate administrations (their overlapping will be discussed later) may be represented by bodies with greatly expanded heads and atrophied limbs that are reduced to executing orders coming from the top.* For a long time, the departments formed the framework

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* If any difficulty arises on a given occasion, the department or region refers to its central agency which indicates how the obstacle may be overcome. If this is not sufficient, the central agency sends a high official who settles the problem on the spot.

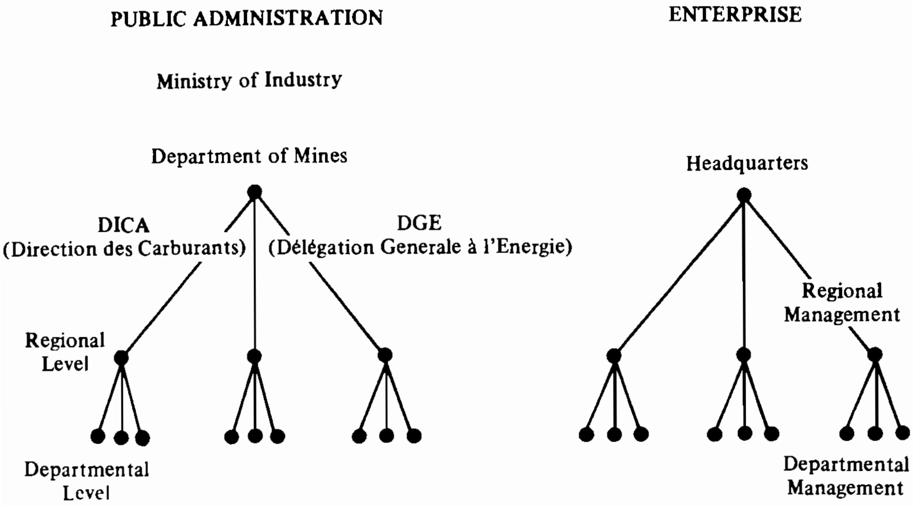

FIGURE B.6 Simplified decision structures of the French public administration and individual enterprise.

for executing orders. They were purposely small (about 90 in France) so that they could not compete with the central authority. Recently, a shift has occurred: Regions consisting of several departments (from 4 to 10, depending on the specific case), have been created but they have not yet acquired true autonomy.

Consider the two simplified decision structures in Figure B.6. In the realm of public administration and planning, monitoring and regulation are carried out only at the national level; in other words, they are uniform for the group of regions. The regional and departmental bodies collect information for the central agencies, promulgate the decisions of these agencies and supervise the application of the decisions.*

In the area of energy and environment, the central agencies do not have any unified model. They limit themselves to ruling on decisions made by the firms which, as will be clear later, produce good national models.

The second important feature of French institutions is the status of corporations in the energy sector. The structure of this sector (e.g., the relations between firms) differs from that of other sectors of economic activity. Most sectors usually consist of a greater or lesser number of private French firms. Corporations of this type have practically disappeared from the energy sector to the extent that there are only 2 types of firms:†

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* This structure is so resourceful that it is capable of shaping all innovations to its needs. A recent study has pointed out, for example, that contrary to all expectation, the generalization of information processing in French enterprises is favorable to centralization. See: Balle, Catherine. "The computer, a break in the reforms of structure of enterprises," *Le Monde*, September 18, 1975.

† The emergence of nuclear energy tends, however, to change this situation. Pechiney-Ugine-Kuhlman, one of the largest French firms, is now being aided in taking control of a part of the fuel cycle.

- branches of multinational firms which control about 50 percent of the French petroleum market
- public enterprises or mixed industry, either competing (CFP and ERAP in the oil branch)* or monopolistic (EDF, CDF, GDF, CEA, CNR) †

Branches of multinational firms have a variable degree of autonomy, according to the structure and the strategy of the firm upon which they depend. At any rate, these firms never make decisions on their own, since the stakes are of some importance (large investment in refining or in transport, for example).

In the eyes of such firms, a region is at most a subgroup of consumers whose characteristics (quantity, density, growth rate) it is advisable to consider in a model representing the conditions of development of future sales. The results of such a model can influence the policies of the firm, for instance, in the placing of investments.

Public enterprises or mixed industries enjoy a larger degree of power; however, this power is far from complete because the public status of such firms makes them subordinate to the state authority. The amount of subordination varies, however, according to the extent to which the enterprise is a monopoly (the guardianship of the state is less constraining for the firms like CFP and ERAP which compete with the branches of the multinational oil companies) and to the extent to which it can defray its investment expenses (EDF, which has become more than 50 percent self-financing, has acquired much more autonomy than CDF or GDF). No matter what their weight is in final decisions – especially those which concern new investments – all these firms resort to models in order to diminish the uncertainty in the evolution of their market, in the prices of their imported raw materials, and in the technologies which they adopt. But these models are conceived both by and for the central agencies. Regional specifications are only taken into consideration in the form of exogeneous data and constraints such as

- the probable evolution of the energy consumption
- the availability of sources of energy
- opportunities of sites and water cooling for the large power plants

Some comments should be made about the ties between the 2 decision-making structures. The national government is of paramount importance because it is a legacy of the history of a nation dominated by a struggle between the Centre (the monarchy) and the provinces (the feudal system). The structure of the firms closely approximates that of the central government for reasons easy to understand. Since the foreign oil firms first opened branches in France at the beginning of the century, they have tried to influence legislation which has not always been favorable to them; in order to do this, they have installed representatives as close as possible to the center of the national power. Later on, since the great wave of nationalization in 1945, rationalization has been synonymous with standardization and centralization. This was in reaction to the disintegration of the mechanism of production (especially electricity and gas), which resulted from undynamic and diffuse capitalism. The osmosis between government administration and energy firms has been made considerably easier and has been speeded up by another aspect of French

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* Compagnie Française des Petroles; Enterprise de Recherche et d'Applications Petrolières.
† Electricité de France; Charbonnages de France; Gaz de France; Commisariat à l'Energie Atomique; Compagnie Nationale du Rhône.

centralization, the uniform production of managers in the "*Grandes Ecoles*" of engineers also concentrated in the Paris region. Through a well-known and often-studied phenomenon, the same people go from the directorship of government agencies to that of public and sometimes private firms.

III. WISCONSIN

Stephen Born – Wisconsin State Planning Office; *Charles Cicchetti – Wisconsin Office of Emergency Energy Assistance*; and *Richard Cudahy – Wisconsin Public Service Commission*

Energy and environmental decision-making and planning in the United States is highly diffused; 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. At the Federal level, power and responsibility for energy/environmental policy matters, as for other public policy areas, is "balanced" between the executive and legislative branches of government. The judicial branch serves as an interpreter and arbiter of the process. Substantial authority for energy and environmental matters rests with the traditional cabinet agencies in the executive branch – the Departments of Interior, Commerce, and Agriculture. In recent years more and more power has been placed within a number of relatively independent agencies and other governmental bodies. These independent offices include the Energy Research and Development Administration (ERDA); Federal Energy Administration (FEA); Environmental Protection Agency (EPA); Federal Power Commission (FPC); National Science Foundation (NSF); Nuclear Regulatory Commission (NRC); and the Tennesee Valley Authority (TVA). In 1977 a cabinet-level office called the Department of Energy (DOE) was formed from a combination of the Energy Research and Development Administration (ERDA), the Federal Energy Administration (FEA), and a number of other smaller agencies. This listing is a partial one, and simply illustrates that there are many institutional factors that affect energy decisions and administer energy-related programs at the Federal level.

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 are Connecticut, California, and Kentucky. Most states, however, have a rather dispersed institutional framework for energy/environmental planning and decision-making. Wisconsin is fairly typical. State executive agencies are responsible for planning and administration of legislated programs at the state level. However, many state authorities and 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. To coordinate these functional planning efforts and to provide an independent policy analysis capability to the executive office, a comprehensive State Planning Office exists within the State Department of Administration. The following brief overview suggests the complexity of these arrangements.

The Department of Transportation (DOT) has the responsibility for all major energy consequences. At present, planning and operating programs are largely segregated by mode. It has not been organizationally or fiscally possible to examine transportation decisions from a multi-modal viewpoint, or to fully evaluate economic development or energy use "tradeoffs" associated with various modal choices.

State legislation is now pending that would reorganize DOT and its planning/decision-making functions into an integrated, genuinely multi-modal transportation department.

The Department of Natural Resources (DNR) is charged with planning for and management of the state's air, water, recreational, and biologic resources. Its environmental protection planning and management responsibilities exert great influence on a number of energy-related issues. The agency's air pollution control regulatory responsibility furnishes an excellent example.

For several years, even before passage of the Federal Clean Air Act in 1970, a national debate has been underway in the United States regarding air pollution and the issue of "nondegradation." The Supreme Court has upheld the position that state air quality plans must prevent significant deterioration of air quality. Much of the controversy has centered on the impact of such a policy on economic growth. States are charged with developing the requisite air quality implementation plans, and in Wisconsin DNR has primary responsibility.

In May 1975, three utilities submitted plans and specifications for the construction of Columbia II, a 527-MW power plant to be built in south-central Wisconsin at a location adjacent to its twin, Columbia I. Wisconsin's air pollution control regulations required DNR to review these plans for air quality implications. DNR found that although the proposed plant would not violate air quality standards and would meet federal emission requirements, it would cause significant degradation of air quality that would in effect preclude additional growth. The data showed that Columbia II would pollute to 97 percent of one SO_2 standard and to 68 percent of another standard. DNR determined that this was a significant degradation of air quality and halted construction of the power plant in June. A hearing in the affected area to assess the public attitude on permitting construction of the power plant was held in July. Over 1,000 people attended the hearing, but hearing testimony along with other letters, resolutions, and petitions submitted to the DNR reflected an almost even split between supporters and opponents of construction. Since the assessment of public attitude was inconclusive, DNR decided that construction of Columbia II could not be prohibited. Construction is proceeding under requirements that are to keep Columbia II's emissions at an absolute minimum. The Columbia II incident not only demonstrates the development implications of air quality regulations, but the intimate relationship between air quality and energy decisions and the powerful role of the state DNR in such matters.

The Public Service Commission (PSC) is a three-member quasi-judicial regulatory agency. Each member is appointed by the governor, and confirmed by the state senate for six-year terms. The commission regulates the rates and services of public utilities operating in the state which includes both privately-owned and municipally-owned electric utilities, natural gas distribution utilities, water and combined water-sewer utilities. With the exception of major construction projects, the commission does not regulate electric cooperatives. Also under commission jurisdiction are intrastate common and contract motor carriers and railroad operations.

The commission has the responsibility to set utility rates including the determination of a utility's revenue requirement and the structure of rates. Recently, the commission has been implementing peak-load pricing as the basis for designing electric utility rates. Under this principle, rates are set on the basis of the costs customers incur by using electricity at times of peak demands.

Under a recently enacted law, electric utilities and cooperatives every two years must submit to the commission ten-year advance plans covering major construction projects. The commission must then approve, modify or disapprove the plans.

Electric utilities and cooperatives must also receive commission certification to construct specific major facilities included within the advance plans.

In addition to these responsibilities, the commission must approve issuance of securities, certify depreciation rates used by utilities, establish uniform systems of accounts, approve affiliated transaction contracts and conduct audits and inspections of utilities.

The Department of Industry, Labor, and Human Relations (DIHLR) has many programs with energy implications. None is more visible or influences energy conservation more directly than the department's responsibilities for the administration and enforcement of state building codes. In January 1975, DIHLR promulgated building codes which, in addition to traditional public health, safety, and welfare considerations, included energy use standards for all new buildings. This standard was based on extensive technical review, which involved key faculty at the University of Wisconsin; the Wisconsin Energy Model had been used in the analyses related to standard setting. In June 1975, these rules were "sidetracked" by a legislative committee, which was under attack from housing industry interests and from masons, who contended that the energy conservation standard would cause them to lose their jobs.*

The Office of Emergency Energy Assistance (OEEA) was created to deal with fuel hardships which arose during the Arab oil embargo in late 1973.† The office is empowered by federal regulations to order the delivery of fuels to individuals and fuel dealers who are unable to meet their energy needs. The fuels delivered are withdrawn from the fuel set-aside for the state, a theoretical inventory of the various types of petroleum fuels held by those private petroleum firms bringing fuels into the State.‡ The office has certain other powers, under either state or federal law, including the power to obtain information on use and inventories of fuels. This information is then compiled for use in preventing or alleviating shortages which occur because of imperfections in the market mechanism as controlled by federal regulations. The energy office serves as advisor to the state legislature and the governor on energy matters and has worked on developing legislation which bears on energy use within the state. The energy office has also reacted to legislation proposed by others within the state and has used energy modeling to determine the effects of various legislative proposals. The energy office reacts to various actions proposed, or already in place, by other state and federal agencies and seeks to protect the interest of the citizens of the state, as affected by the actions of the other agencies. The energy office seeks to minimize the negative effects of any occurrence in the energy area upon the businesses, citizens, and workers within the state. It attempts, through public speeches, press releases and other attention-getting devices, to give the general public and businessmen the facts about the energy situation and what they can do to improve it.

The University of Wisconsin (UW) has the tripartite educational mission of research, teaching, and public service. Although best known for energy systems modeling activities, university energy researchers are involved in a wide range of

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* A new Wisconsin code went into effect in July 1978. See note at the end of section II.C. in Appendix C.

† In late 1976, OEEA was combined with the State Planning Office into a single "Office of State Planning and Energy."

‡ The products are allocated to the states by the Federal Energy Administration based on historical use before the Arab oil embargo. This was done so all states would share equally in any hardships.

studies – from basic solar energy research to techniques for monitoring the environmental impacts of power plant siting. Students are trained in interdisciplinary approaches for dealing with environmental and energy problems and later hold key agency positions within state government; state governmental problems have furnished worthwhile applied research areas for many students. The University Cooperative Extension Service has taken research and demonstrations results and brought them into the public forum through several public informational efforts. In short, there is a critical symbiosis between the university system and state government – a partnership that extends back through several decades. This cooperative spirit, pioneered in agriculture, but readily transferred to environmental and energy concerns, has been aptly named "the Wisconsin idea."

The Department of Administration (DOA) functions as the governor's agency within the state bureaucracy. The department is charged with preparation of the executive budget, which in recent years has become a major piece of policy legislation. DOA also houses the state's Federal/State Coordination Office and the Bureau of Facilities Management. The latter oversees all state buildings, and can initiate such procedures as life cycle costing in the planning of all state facilities. DOA also includes the State Planning Office, which is the state's comprehensive planning agency. This office is largely involved with physical, environmental, and economic planning.

The State Planning Office's programs are divided into three broad areas: state development policy planning; land use planning; and planning coordination (see Figure B.7). It has primary responsibilities in the areas of economic development, planning and coordination, land use planning, and coastal zone management, as well as in the process-oriented "planning coordination" area. In meeting its comprehensive planning and coordination responsibilities, the State Planning Office functions in several ways: (a) as a coordinator, liaison, or critical reviewer in working with interagency or intergovernmental groups or individual agencies; (b) as program developer and manager of new multifunctional, intergovernmental programs such as coastal zone management planning or state economic development planning; (c) as a policy analysis and research unit; (d) as a public involvement/ educational agent; and (e) as a provider of executive office services including legislative development and review, special projects or analysis, and limited budget issue involvement. As noted in Figure B.7, many of the planning office program areas and functions relate closely to energy and environmental concerns. One activity warrants special mention; close work between the university's Energy Systems and Policy Research Group and Planning Office staff has led to an analysis of the costs of alternative physical development patterns in terms of money, land consumption, and energy costs. The Wisconsin scenarios, described in Chapter 6, reflect some of the energy impacts described by this analysis.

One other aspect of Wisconsin's institutional setting as it pertains to energy and environment deserves special consideration. In 1972, Wisconsin passed the Wisconsin Environmental Policy Act (WEPA). The act, which is patterned after the National Environmental Policy Act of 1969 (NEPA), establishes a state policy to encourage harmony between human activity and the environment, promotes efforts to reduce damage to the environment, and stimulates understanding of important ecological systems. The act mandates a thorough analysis of environmental impact before any major state action is authorized. Agencies must consider alternative technologies and economic consequences of state-initiated projects; private actions regulated by state government are subject to the same procedures. The underlying premise of WEPA is that substantive policy decisions can be improved and a better balance

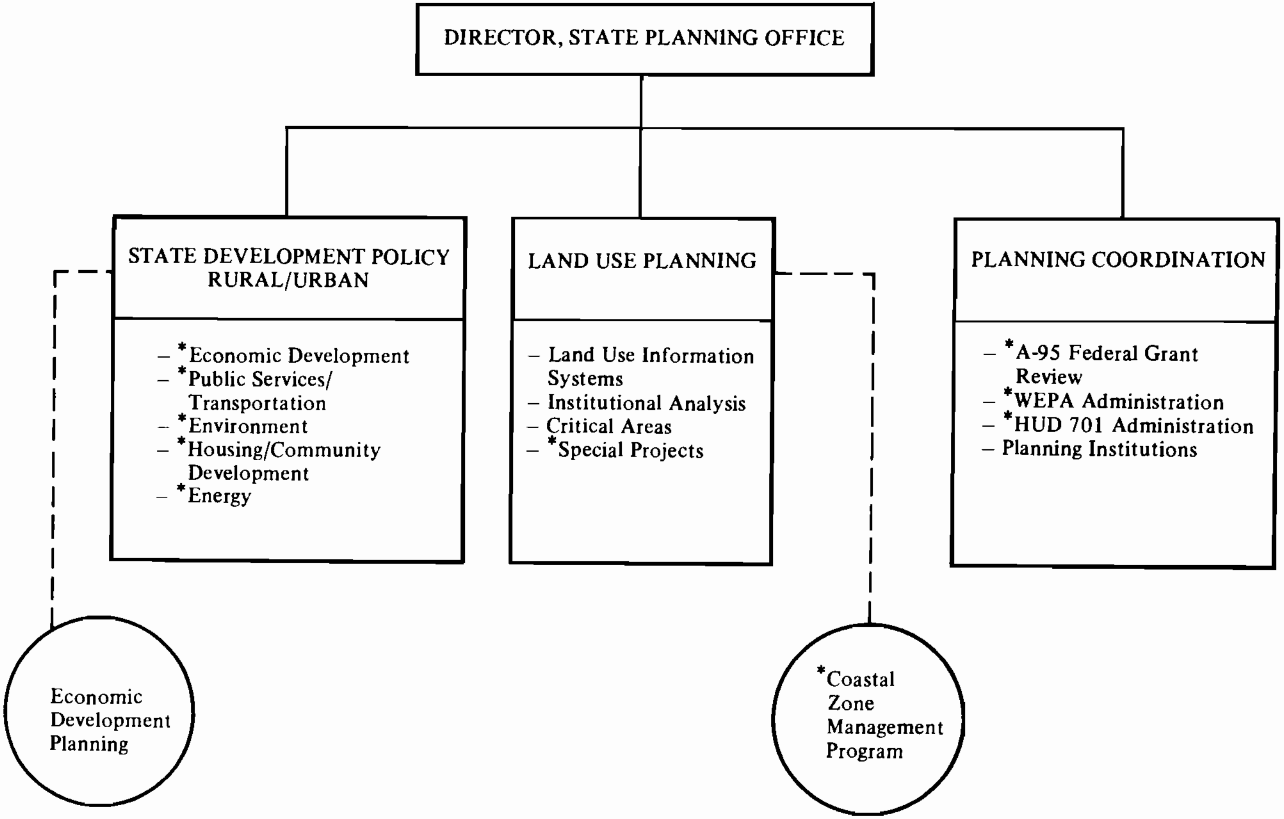

FIGURE B.7 Diagram of the State Planning Office programs in Wisconsin. An asterisk indicates energy-related functions.

will emerge between environmental and economic objectives if a broad range of environmental impacts, alternatives to the proposed action, and public comment are examined well before the final decisions are made.

Although the environmental impact statements and other documents are not binding on state governmental decision-making, WEPA (and NEPA) have had a far-reaching effect. Because of WEPA, environmental (including energy) considerations are now routinely a part of governmental decision-making, and the process is more accessible than ever before to citizens. Major energy related decisions – construction of a Great Lakes oil shipment terminal, construction of electric generating facilities and transmission lines, regulatory action related to utility rate changes, railroad line abandonments – have been subject to and delayed, modified, and even halted based on environmental questions raised by the Wisconsin Environmental Policy Act process. In fact, the environmental impact statement, and the associated review process, have become pervasive and extremely useful planning tools in energy decision making.

C Selected Management Practices

I. AIR QUALITY MANAGEMENT

Loretta Hervey and *Robin Dennis* – *IIASA*

I.A. INTRODUCTION

Air pollution is currently causing discomfort and disease in all industrialized nations, East and West. They have responded to this problem through a variety of economic, technical, and institutional approaches. The IIASA three-region study provided an opportunity to examine how three countries with highly diverse governmental and economic institutions have approached an environmental problem which is common to each. The previous sections of this chapter described this diversity. At one end of the scale is the United States, with decentralization of power, a diffuse decision-making structure, and a philosophy of free enterprise. In stark contrast is the GDR, with centralized decision-making, nationalized industry, and a tradition of comprehensive planning. France may be typified by a mixture of these elements – a long history of centralized government and nationalization of some energy enterprises.

This section provides a cross-national comparison of management in the three countries. Emphasis is on the national rather than regional level. During the course of the IIASA study, IIASA scientists analyzed parallel legal documents dealing with environmental protection in the three regions. They also obtained empirical values of pollution concentrations in the cities of each study area. This material provided a basis for a cross-national comparison of such factors as government roles in supervising industry, the chain of authority in the implementation of pollution legislation, pollution standards, and sanctions against polluters. An attempt was also made to assess each country's progress in executing its legislation, through examination of current concentrations of pollutants in the ambient air.

In the first part of this section, the evolution of pollution legislation is traced in France, the United States, and the GDR, with special attention given to emerging patterns of federal-regional responsibility in the environmental sphere. In the following part, the current structure of governmental bureaucracies which have been set up to implement environmental legislation are examined in each study area. Next, attention is focused upon the limits now in effect for pollutant concentrations in the ambient air[*] and for emissions[†] in France, the GDR, and the United States; here conceptual and definitional problems in comparisons of pollution "standards" are emphasized. Strategies for obtaining compliance to legislation, such as financial penalties, are summarized in the fourth section. Finally, environmental legislation is considered in the light of existing levels of pollution in the cities of each region. This section is based for the most part upon information provided in legal texts and not upon empirical studies.

I.B. HISTORICAL DIFFERENCES IN POLLUTION CONTROL LEGISLATION

I.B.1. France

Stationary Sources. Of the three countries under scrutiny, France has had most experience with direct government supervision of polluting industries. As early as 1810 Napoleon decreed that plants that emit offensive odors could not be built without permission. Under the 1917 "Law of Classed Establishments" the requirement for authorization was extended to dangerous as well as offensive plants.[‡] The final group of emittors to be brought under government control were combustion installations: in 1948 these units were ordered to conform to construction, installation, and output norms, and further to submit to periodic control visits. In 1964 they were included for the first time in the list of "Classed Establishments."[§]

The 1960s were marked by legal efforts to standardize pollution control measures and to extend government prerogatives. A general 1961 law ordered responsible officials to determine permissible levels of particulate, toxic, maloderous, and radioactive emissions. In 1963, uniform monetary fines were imposed on plants which failed to conform to emission restrictions, and departmental prefects were authorized to take emergency action against polluters in case of danger to public health. During this decade, prefects also acquired the power to create "zones of special protection" with stringent emission standards in heavily polluted metropolitan areas.[¶]

Recent pollution legislation in France has been mainly directed toward specific industries. For instance, in 1966 emission norms and other technical instructions were issued for the operation of thermal power plants. The following year formulas were published for calculating minimum chimney heights in new combustion installations; subsequently, emission limits for cement factories, iron-ore smelters, urban incinerators, cast-iron foundries, and steel works have appeared.[**]

French authorities have also attempted to decrease emissions more directly by limiting the sulfur content of fuels. A 1967 decree specified that the sulfur content of heavy fuel oil Number 1 and light fuel oil could not exceed 2 percent, while that of heavy fuel oil Number 2 was limited to 4 percent. In 1968 the sulfur content of

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[*] *Ambient air pollution concentrations* are defined as quantities (mass/unit volume or parts per million by volume) in the ambient air.

[†] *Emissions* are defined as quantities (weight or volume) of given pollutants discharged at their source, e.g. plant chimneys.

[‡] Jarrault, P., La Législation Française Relative à Prévention de la Pollution par les Sources Fixes (Centre Interprofessionel Technique d'Etudes de la Pollution Atmosphérique (CITEPA) Les Editions Européennes, "Thermique et Industrie," undated), p. 5.

[§] *Ibid.*, pp. 7, 25–30.

[¶] *Ibid.*, pp. 2–28.

[**] *Ibid.*, pp. 12–20.

domestic fuel oil was restricted to .7 percent, with progressive decreases to .3 percent forseen for the 1970s.*

Motor Vehicles. Legislation aimed at cutting down emissions from motor vehicles first appeared in the early 1960s in France. In 1963 a test of the opacity of smoke emissions was ordered for all new motor vehicles. The following year it was determined that the total quantity of unburned hydrocarbons could not exceed .15 percent of the fuel consumed during vehicle operation. Finally, a 1970 decree aligned French legislation with Regulation 15 of the Geneva Accord of 1958, as well as with the 1970 Directives of the Council of Ministers of the European Community.†

Ambient Air. The concept of "ambient air quality standards" has not been developed in French legislation.‡ The government has preferred to control pollution directly at the level of the emitting plant, rather than by setting general air quality standards and then giving plants or local authorities responsibility for ensuring that they are met. This seems to accord with France's traditionally highly centralized government and its history of government initiative in policing industrial emissions.

I.B.2. The United States

The history of environmental legislation in the United States attests to the federal government's very gradual assumption of responsibility for pollution control. In the 1955 Air Pollution Control Act a federal role was seen only in the funding of local anti-pollution programs and research. The 1963 Clean Air Act gave the Secretary of Health, Education, and Welfare (HEW) the authority to involve dangerous polluters in a conference – public hearing – court suit procedure; but this process proved so time-consuming that it only underscored the inability of the federal government to take action against polluters.§ Only after the passage of the 1967 Air Quality Act was the Secretary of HEW empowered to go directly to court to force a stop to dangerously high levels of pollution.

Ambient Air. The Air Quality Act also marked the federal government's first attempt to set nationwide air quality norms. The provisions of the act reveal the indirect tactics which legislators found it necessary to employ at this early stage: HEW was required to publish "air quality criteria" for dangerous pollutants; the states were then to develop "air quality standards" designed to meet the federal criteria, to produce plans for implementing and enforcing the standards, and, finally, to gain federal approval for these measures. If a state proved lax, HEW was permitted to intervene. However, not one state implementation plan was approved between 1967 and 1970, and HEW could not force compliance to nonexistent plans.¶

The failure of the 1967 act led U.S. legislators to restate its provisions in a much more detailed and stringent manner in the 1970 Clean Air Act Amendments. The pollution criteria of the earlier law (which had functioned simply as guidelines for the states' own standards) were replaced by national air quality standards, which

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[*] *Ibid.*, p. 32. Here the percentages of sulfur refer to the weight of the fuels, not the volume.

[†] Benarie, M., "Air Pollution Legislation and Governmental Controls of Air Quality in France" (Vert-le-Petit: Institut National de la Recherche Chimique Appliquée, 1975), Table 3.

[‡] The first step taken in this direction occurred in the early 1970s when ambient air "reference values" for SO_2 and particulate matter were promulgated for use in calculating required chimney heights.

[§] William D. Hurley, *Environmental Legislation* (Springfield, Illinois: Charles C Thomas Press, 1971), pp. 34–41.

[¶] *Ibid.*, pp. 43–50.

the states were required to adopt without modification. The pattern of interaction between federal and state governments which had characterized the 1967 act was carried over into the new law, for the states were ordered to develop plans for attaining and maintaining the national standards, and to submit them to the new Environmental Protection Agency (EPA) for approval. However, the amendments specified more exactly the content of the states' plans: they were to include land-use and transportation schemes, emergency plans for high-pollution occurrences, and outlines for statewide pollution surveillance systems. The states were to secure federal approval for their plans by May 31, 1975, but extensions have since been granted until the 1980s.*

Stationary Sources. The U.S. federal government has taken the initiative in controlling pollution from stationary sources much more slowly than its French counterpart. Until recently, U.S. legislators have preferred the more indirect approach of focusing their attention on ambient air quality and leaving point-source emission control to local authorities. This policy seems to reflect the country's overarching institutional structure: separation of federal and local power and government reluctance to interfere with private industry.

However, U.S. lawmakers did call for several federal emission standards for stationary sources in the 1970 amendments. Here the EPA was instructed to publish standards for rare but dangerous pollutants not likely to be covered by state implementation plans. In addition, the EPA was given the task of developing performance standards, including emission standards, for certain industrial plants. In the early 1970s standards were issued for such plants as new or reconstructed steam generators, sulfuric and nitric acid plants, cement plants, and iron and steel mills.†

Motor Vehicles. Perhaps because the issue of federal versus state jurisdiction is not as contested for mobile sources of pollution, the federal government has taken a direct approach toward curbing motor vehicle exhaust. When the need to regulate automobiles was recognized in the early 1960s, lawmakers skipped the stage of drafting guidelines ("criteria"); instead, in a 1965 act they directed the Secretary of HEW to set national emission standards for new foreign and domestic vehicles. By 1970, CO emissions from new cars were to be 71 percent lower than those from 1963 models, and hydrocarbon exhaust was similarly to be reduced by 82 percent. In the 1970 Clean Air Act Amendments, legislators took the radical step of calling for a nearly emission-free car engine within 6 years (later extended to 8).‡

I.B.3. The German Democratic Republic

Ambient Air. Because the GDR was founded in 1949, its legislators have had little time and many basic organizational problems to resolve, so environmental issues

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* U.S. Environmental Protection Agency, "A Progress Report: December 1970–June 1972" (Washington, D.C., November, 1972), pp. 1–2. Also, U.S. Environmental Protection Agency, "Progress in the Prevention and Control of Air Pollution in 1974" (Washington, D.C., 1975), pp. 61–69. See as well, Gladwin Hill, "Air Pollution Drive Lags, But Some Gains are Made." *The New York Times*, May 31, 1975, pp. 1, 15.

† U.S. Environmental Protection Agency, "A Progress Report: December 1970–June 1972," pp. 1–2. Also, U.S. Environmental Protection Agency, "Progress in the Prevention and Control of Air Pollution in 1974," pp. 33–35, 41–52.

‡ Hurley, *Environmental Legislation*, pp. 51–55. Also, James Naughton, "President Signs Bill to Cut Auto Fumes 90 percent by 1977." *The New York Times*, January 1, 1971, pp, 1, 11. See as well, U.S. Environmental Protection Agency, "Progress in the Prevention and Control of Air Pollution in 1974," pp. 5–12, 53–60.

had to wait for attention. The first attempt to regulate air pollution in the GDR was in a 1968 regulation, in which "threshold values" – levels of pollution above which damage to human health is believed to occur – were defined for ambient concentrations of 48 substances. Public officials were directed to consider these values when issuing siting permits, planning new investments, and reconstructing existing plants.*

The philosophy underlying the GDR's approach to environmental protection was first clearly expressed in the 1970 "Landeskulturgesetz." Environmental problems were incorporated into the planning process which characterizes GDR policymaking in general. As the law states, "the requirements of a socialist society are to develop productivity in a planned manner, so as to lead to an increase in the utility and productivity of natural resources and guarantee the maintenance and beautification of the natural environment."† The conviction that economic and conservationist goals can be coordinated through planning is the hallmark of GDR environmental legislation.

Stationary Sources. Underlying the GDR's plans is the assumption that industry and government can work together to control pollution. At the level of the national government, both ambient air quality and emission norms have been developed; 1973 legal directives set threshold values for ambient air concentrations of 113 pollutants, and provided as well formulas based on ambient air pollution levels and chimney heights for calculating permissible emissions. It is forseen that industry officials will use these prescriptions to ensure that emissions from plants do not cause ambient air quality norms to be violated.‡

Despite this delegation of responsibility, the central government bodies retain ultimate leverage over emitting plants. For instance, the chairman of the National Council of Ministers (*Vorsitzende des Ministerrates*) has the power to restrict industrial operations, or to order a change in fuels during dangerous occurrences of pollution. Punitive measures have also been spelled out for disciplining plants with chronically excessive emission levels.§

Motor Vehicles. The GDR's emphasis on cooperation between government and industry is also found in measures to control emissions from motor vehicles. A 1974 directive gave the federal Department of Exhaust Gas Inspection (Abgasprüfstelle der DDR) the task of setting emission threshold values for internal combustion engines and developing techniques for testing motor vehicles. At the same time the directive called for the creation of "Exhaust Gas Deputies" (Abgasbeuaftragte) in all plants connected with the importing, producing, or repairing of motor vehicles. Their task is to assure self-policing in plants by checking whether motor vehicles meet threshold emission values.

By 1974, norms had also been set for permissible idling time in moving traffic, carbon monoxide (CO) emissions (by weight of vehicle), and lead content of fuels.¶

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* *Gesetzblatt der DDR*, Part II, No. 80, July 25, 1968, "Anordnung zur Begrenzung und Ermittlung von Luftverunreiningungen (Immissionen)." pp. 640–642.

† *Gesetzblatt der DDR*, Part I, No. 12, May 28, 1970, "Gesetz über die planmässige Gestaltung der Sozialistischen Landeskultur in der Deutschen Demokratischen Republik – Landeskulturgesetz," p. 67.

‡ *Gesetzblatt der DDR*, Part I, No. 18, April 24, 1973, "Fünfte Durchführungsbestimmung zum Landeskulturgesetz – Reinhaltung der Luft." pp. 157–162.

§ *Ibid.*

¶ *Gesetzblatt der DDR*, Part I, No. 37, August 6, 1974, "Zweite Durchführungsbestimmung zur Fünften Durchführungsverordnung zum Landeskulturgesetz – Begrenzung, Überwachung, und Verminderung der Emissionen von Verbrennungsmotoren," pp. 353–356.

This overview of the evolution of environmental legislation in France, the United States, and the GDR has revealed contrasting styles of problem-solving. Governmental philosophy about reconciling economic and ecologic goals seems to be most clearly articulated in the legislation of the GDR. There the emphasis is on the planning of investments so as to avoid unhealthy concentrations of pollutants. The centralized decision-making system of the GDR has permitted the parallel development of both emission and ambient air quality norms at the national level, and the maintenance of these norms is assumed to be a cooperative venture of government and industry.

In France, the highly centralized government has laid most emphasis on the direct policing of industry by means of emission restrictions, rather than on the intermediate step of supervising ambient air quality.

In the United States, in contrast, the responsibility of the federal government has been confined to the setting of air quality standards (and emission standards for several types of stationary sources), while state authorities are charged with working out implementation plans for meeting the standards and policing industry. The division of power among national, state, and local authorities, as well as the restriction of government interference in private industry, has thus produced a more complex and diffuse approach toward pollution control than is found in the GDR and France.

I.C. IMPLEMENTATION OF LEGISLATION

Just as the approaches toward the setting of pollution norms in France, the GDR, and the United States seem to reflect the general institutional structure of each country, the chain of authority set up to implement environmental legislation follows a similar pattern.

For instance, the centralized management and planning characteristic of the GDR government as a whole is reproduced in agencies for environmental protection. At the national level, the "Council of Ministers" (*Ministerrat*) has responsibility for policymaking, planning, and central management of pollution control activities. The federal "Ministry of Health" (*Ministerium für Gesundheitswesen*) has been given the task of setting ambient air threshold values and developing a nationwide pollution monitoring system. Concomitantly, the "Ministries of Machine and Vehicle Construction and Transportation" (*Ministerium für Allgemeinen Maschinen-, Landmaschinen-, und Fahrzeugbau* and *Ministerium für Verkehrswesen*) must set emission threshold values for internal combustion engines. Finally, the Ministry for Environmental Protection and Water Management" (*Ministerium für Umweltschutz und Wasserwirtschaft*) is responsible for assuring the coordination of all pollution-abatement measures.

At the local level in the GDR, the distribution of tasks between "district councils" (*Räte der Bezirke*) and polluters accords with the national policy of cooperation between government and industry. Thus, emission threshold values for individual plants are set by the councils with the help of the plants themselves. If a plant finds it impossible to meet these limits, it must work with its local council to develop plans for lowering emissions. Representatives of government and industry also collaborate in planning "accommodation" measures to decrease the harmful effects of unavoidable pollution, and "compensation" measures in case of injuries to workers or damage to their living conditions.*

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* *Gesetzblatt der DDR*, "Füenfte Durchführungsverordnung zum Landeskulturgesetz – Reinhaltung der Luft," pp. 157–160.

As in the GDR, the strong central government of France has stressed the central coordination of pollution control activities. Since 1973, the "Directorate for the Prevention of Pollution and Nuisances" (*la Direction de la Prevention des Pollutions et des Nuisances*), within the "Ministry for the Protection of Nature and the Environment" (*Ministère de la Protection de la Nature et de l'Environnement*), has been responsible for preparing a national program for combatting pollution. The "minister of the environment" (*ministre de l'environnement*) is in charge of a corps of "environmental inspectors" and "regional environmental delegates" (*inspecteurs generaux de l'environnement* and *délégués regionaux à l'environnement*); he has as well ultimate responsibility for all environmental legislation, and must take action during episodes of exceptionally high pollution. Several other ministers at the national level are concerned with pollution problems, the "minister for industrial and scientific development" (*ministre du développement industriel et scientifique*), the "minister of public health" (*ministre de la santé publique et de la securité sociale*), and the "minister of the interior" (*ministre de l'interieur*).*

As far as actual regulation of noisome industries is concerned, the French government uses the following clearly articulated procedures. Before a potentially dangerous plant may begin operations, it must receive authorization from the "Bureau of Classed Establishments" (*Conseil Supérieur des Etablissements Classés*), a service under the jurisdiction of both the "Bureau of Mines" (*Service des Mines*) and the departmental prefect. If the plant is permitted to open, it must conform to precise technical prerequisites set forth as conditions of authorization. These include specification of fuels to be used, permissible emission rates, and monitoring procedures. The instructions result either from application of legal directives, which have been worked out by representatives of the industrial branches and the government, or (if no such directives exist for a particular type of plant) from the deliberations of the "Bureau of Classed Establishments." After granting an authorization, the inspectorate has the further responsibility of making periodic control visits, to assure that the technical prescriptions are being followed.†

In the United States the chain of authority in environmental affairs is based upon the traditional division of power between the national and state governments. This has led to complicated federal-state interactions, in which states must win federal approval for their pollution-control programs. On the federal level the EPA is responsible for funding and coordinating research on environmental problems, for trying to introduce conformity into pollution-abatement schemes across the country, for giving financial support to local programs, and for establishing ambient air quality standards and some emission standards. The administrator of the EPA also has recently acquired the authority to bring willful violators of pollution laws to court, and to order investigations of plants suspected of having illegally high emissions.‡

Wisconsin may be used to illustrate the role of state governments in pollution control in the United States. In response to the requirements of the 1967 Air Quality Act, the Wisconsin Department of Natural Resources (DNR) was given the task of establishing a comprehensive air pollution abatement program for the state. In 1970 it assumed responsibility for developing the "air quality implementation plan" called for by the Clean Air Act Amendments. This plan had to provide for

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* Jarrault, La Législation Française, pp. 45–46.

† *Ibid.*, pp. 9–20. See also Benarie, "Air Pollution Legislation and Governmental Controls of Air Quality in France," p. 2.

‡ Hurley, *Environmental Legislation*, pp. 34–50.

industrial emission standards strict enough to assure compliance with federal ambient air standards, as well as emergency plans for pollution crises, a statewide pollution surveillance system, and inspection of emitting plants. When the EPA rejected all state implementation plans in 1973,* the Southeastern Wisconsin Regional Planning Commission (SEWRPC) stepped in to work with the DNR. The two agencies are currently cooperating in developing a Regional Air Quality Maintenance Plan, which is based on an evaluation of SEWRPC's 1985 Land Use Plan and transportation projections. The Wisconsin Public Service Commission is yet another state agency involved in pollution control; it polices electric utilities by requiring them to submit every 2 years a 10-year plan for new construction. Before building is commenced, the commission must also carry out an environmental impact analysis.† Thus, in the United States, responsibility is not only distributed between federal and state government, it is further spread among a multitude of state agencies.

I.D. AMBIENT AIR QUALITY STANDARDS

Before making cross-national comparisons, it is important to consider that the concept of a standard may not be exactly equivalent in France, the GDR, and the United States. In fact, the word *standard* is only found in U.S. legislation; here a *primary ambient air standard* is defined as the "maximum level of a pollutant which should be permitted to occur in order to protect human life," and a *secondary ambient air standard* is "the maximum level of the pollutant which should be permitted to occur in order to protect animal and plant life and property from damage, and thereby protect the public welfare from any known or anticipated adverse effects of an air pollutant."‡ In the GDR, the term *ambient air "threshold value"* is used in place of *standard*. This term is defined as "the maximum concentration of a pollutant, which according to medical knowledge does not have a harmful effect on the human organism."§ Its denotation is thus quite similar to that of the U.S. primary ambient air standard. The term *reference value* is used in French legislation to indicate desirable limits for pollution concentrations in the ambient air. The sphere of applicability of such "reference values" is narrower than that of U.S. standards and GDR threshold values, for they are used mainly in calculating permissible chimney heights.¶

International differences may also be seen in the time periods for which a norm or standard applies. For instance, the U.S. air quality standard for carbon monoxide (CO) is given in the form of an 8-h average, while the corresponding GDR threshold value is a 24-h average. Though these may be converted to a common time unit, the original units might reflect different theories about the duration of pollution which is likely to affect health.

The current limits for concentrations of selected pollutants in the ambient air of the United States, the GDR, and France are presented in Table C.1. The figures

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* The rejections resulted from the states' failure to consider the problem of maintaining clean air standards, as population and motor vehicles increase.

† Section III in Appendix D describes energy/environment models in Wisconsin.

‡ Southeastern Wisconsin Regional Planning Commission, "Regional Air Quality Maintenance," p. 11.

§ *Gesetzblatt der DDR*, "Fünfte Durchführungsverordnung zum Landeskulturgesetz – Reinhaltung der Luft," p. 157.

¶ Jarrault, La Législation Française, p. 15. Also M. Benaire *et al.*, "Etude de la Pollution Atmosphérique de la Ville de Strasbourg du 1er Juin 1971 au 30 Juin 1972," (Vert-le-Petit: Institut National de la Recherche Chimique Appliquée, October 24, 1972), pp. 11–12.

TABLE C.1 Highest Concentrations of Pollutants Permitted in the Ambient Air of France, The United States, and the GDR ($\mu g/m^3$)

	France (24-h av)	United States	GDR(24-h av)
CO		10,000 (8-h av)[a] 40,000 (1-h av)	1,000
SO_2	250	365 (24-h av)[a]	150
NO_2		100 (annual av)	40
HC		160 (3-h av)[a]	
Particulates	150	260 (24-h av)[a] 75 (annual av)	
Dust			150
Soot			50

SOURCE: Benarie, M. "Air Pollution Legislation and Governmental Controls of Air Quality in France." Table I. *Gesetzblatt der DDR*, Part I, No. 18, 24 April 1973, "Erste Durchführungsverordnung zum Landeskulturgesetz – Reinhaltung der Luft." pp. 164–166. Code of Federal Regulations 40, part 50. Washington, D.C., July 1976.

[a] Concentration not to be exceeded more than once per year.

TABLE C.2 U.S. Emission Performance Standards for Fossil-Fuel-Fired Steam Generation Units with Heat Input of More than 250 Million Btu per Hour

Pollutant	Fuel	Maximum Emission per 10^6 Btu Heat Input (kg/2-h av)
SO_2	Liquid	.36
	Solid	.54
Particulates	All	.04
NO_2	Gaseous	.09
	Liquid	.13
	Solid	.31

SOURCE: Dunham, J.T., C. Rampacek, and T.A. Henri. "High-Sulfur Coal for Generating Electricity." *Science* 184 (4134): 346–351, Apr. 19, 1974. In 1979, these standards were being reviewed.

given for the United States are primary ambient air standards; secondary standards are either the same or more restrictive than the primary standards.

When considering these figures, it is tempting to ask which country has the strictest norms for air quality. It would appear that the GDR "threshold value" for SO_2, 150 $\mu g/m^3$, is more rigorous than the French "reference value" of 250 $\mu g/m^3$, and the U.S. "standard" of 365 $\mu g/m^3$. (All are 24-h averages). However, it is difficult to judge whether one country's limits are uniformly more rigorous than those of another, because comparable norms would not be found for each of the pollutants under study.

I.E. EMISSION STANDARDS AND NORMS

France, the GDR, and the United States also show differences in their approaches toward limiting emissions from stationary sources. A fundamental question is whether emission standards are set at the national level for all plants of a given type, or whether permissible emission levels are determined for each plant individually, on the basis of such factors as the existing level of pollution.

In the United States, the national emission standards that have recently been issued for new stationary power plants, certain types of chemical factories, and incinerators are applied uniformly to plants of a given type. An example of emission standards currently in effect in the United States may be found in Table C.2. In the GDR, in contrast, permissible emission levels are set on an individual basis. For this purpose, formulas have been issued for calculating permissible emissions at given stack heights and pollution conditions. In France, emission regulations are similarly tailored to plants individually. Technical instructions, including emission limits, are worked out by the "Inspectorate of Classed Establishments" for each new plant which receives authorization to begin operations. For some facilities, such as thermal power plants, cement works, iron and steel mills, and incinerators, maximum admissible pollution concentrations have been standardized in legal directives; but as Benarie has explained, "they are matched by the Inspectors to each individual plant (e.g., by way of dispersion and stack height calculations)."* Specific formulas for calculating required stack heights under given meteorological conditions and existing pollution levels have also been issued by French lawmakers. The following formula is one of the standard formulas used in France for calculating necessary stack heights for a given level of emissions from new combustion facilities:†

$$h = \sqrt{\frac{Aq}{C_m}\sqrt[3]{\frac{1}{R\Delta T}}}$$

where

h = stack height in meters
A = 340 for SO_2, 680 for particulate matter.
q = pollutant emission rate in kilograms per hour.
ΔT = temperature difference between the emitted gas and the ambient air (annual average of area) in °C.
R = gas rejection rate in cubic meters per hour.
C_m = air quality reference values (.25 mg/m^3 for SO_2, .15 mg/m^3 for particulate matter, minus the annual average SO_2 or particulate matter concentration).

A 1973 GDR legal text provides a table of values for "effective" increases in stack heights, discriminated according to the amount of gas emitted, the speed with which the gas is discharged, and its temperature. A second table indicates permissible emissions of SO_2 on the basis of "effective" chimney heights and the existing level of pollution. These values have been generated from a dispersion model.

In the GDR, emission limits for other pollutants are calculated according to the equation‡

$$e_z = S \cdot MIK_k$$

where

e_z = the permissible emission of a given gaseous pollutant in kilograms per hour.

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* Benarie, "Air Pollution Legislation," p. 2.

† Benarie, "Air Pollution Legislation," p. 3.

‡ *Gesetzblatt der DDR*, "Erste Durchführungsbestimmung zur Fünften Durchführungsverordnung zum Landeskulturgesetz – Reinhaltung der Luft" pp. 166–171.

TABLE C.3 French Motor Vehicle Emission Standards. (Allowable emissions during a 13-minute standardized test.)

Legal Weight of the Vehicle (kg)	CO (g)	Hydrocarbons (g)
Below 750	120	10.4
750–850	131	10.9
850–1,020	140	11.3
1,020–1,250	161	12.2
1,250–1,470	182	13.1
1,470–1,700	203	14.0
1,700–1,930	223	14.8
1,930–2,150	244	15.7
Above 2,150	264	16.6

SOURCE: Benarie, M. "Air Pollution Legislation and Government Controls of Air Quality in France." Table 3.

S = the "multiplication factor" for other gaseous pollutants.
MIK_k = short-time interval, ambient air concentration threshold value of a particular pollutant.

The "multiplication factor" is based upon the emission limits for SO_2 (which in turn depends upon the general level of pollution existing in a given area, as well as "effective" chimney heights).

These different approaches suggest an underlying divergence in the concept of emission limits. In the GDR and France, the relationship between emissions and ambient air quality has been worked out precisely: permissible levels of emissions vary with existing ambient air concentrations. If changes in the ambient air quality occur, for instance, because of the introduction of new industry, then emission limits can be modified. In contrast, the emission standards being developed in the United States are less flexible; it is just assumed that if industry complies with the standards, ambient air quality will be protected. Thus, while U.S. emission standards seem to be considered fixed quantities, France's maximum admissible concentrations and GDR emission threshold values are more adaptable; they may be revised to accord with new environmental conditions or even economic goals.

A more uniform approach has been taken toward limiting emissions from motor vehicles in the 3 countries under study. French motor vehicle emission norms comply with the stipulations of the Geneva Agreement of March 20, 1958; the quantity of pollutants collected in a 13-minute standardized test may not exceed the values presented in Table C.3. Nearly the same emission limits for carbon monoxide (CO) were to be used in production controls in the GDR in 1975. It was planned, however, that beginning in 1976 the norms for each weight of vehicle would become more stringent.*

In the United States, emission norms for light-weight passenger vehicles are expressed per vehicle mile rather than as the cumulative result of a testing period. According to the 1977 amendments to the Clean Air Act, CO emissions are to be limited to 3.4 g per vehicle mile. NO_x exhaust is to be cut to 0.1 g per vehicle

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* *Gesetzblatt der DDR*. "Zweite Durchführungsbestimmung zur Fünften Durchführungsverordnung zum Landeskulturgesetz," p. 355.

mile. Automobile manufacturers have managed to obtain a number of deferments for meetings these standards, however. The latest is until 1981.*

I.F. ENFORCEMENT STRATEGIES

The international differences noted in previous sections may also be seen in the area of enforcement. The types of sanctions applied to plants which disregard environmental legislation seem again to reflect the general institutional structures of the countries under study and the relations between government and industry which these engender.

For instance, the interest of the French government in controlling pollution in the plants is expressed in the relatively high financial penalties currently in effect for exceeding emission limits and hampering control checks. If a plant operator refuses an inspection, he may be imprisoned for up to 3 months and fined from 400 to 20,000 F ($80 to $4,000). Unsatisfactory findings during an initial inspection can lead to a fine of 400 to 2,000 F ($80 to $400), as well as an injunction to stop operations. An additional penalty of 100,000 F ($20,000) and 2 to 6 months in prison can be imposed on an operator who ignores such an order. The effectiveness of these control actions is suggested by the government claim that the percentage of plants found not to comply with emission regulations dropped from 20 in 1963 to 7 in 1969.† However, harder data on the frequency with which the fines are applied would be needed, in order to evaluate the stringency of French control strategies.

In contrast, the small fines levied against recalcitrant polluters in the GDR indicate that financial penalties are not an important part of this country's air pollution control strategy. Plants which do not adhere to pollution regulations during everyday operations or pollution emergencies could be required to pay 10 to 300 M ($5 to $150). Numerous infractions in an attempt to gain unfair economic advantage can result in a fine of 1,000 M ($500). "Dust and Exhaust Money" can also be exacted from an emitting plant, based upon the length of time that emission norms are exceeded and the pollutants involved. The imposition of this fine is meant to be more constructive than punitive, however, for it is thought to supply an economic stimulus for the installation of antipollution devices. GDR control strategies seem in general to focus more on planning future decreases in emissions, rather than on rigorously punishing current offenders.‡

In the United States, the complicated division of responsibility for pollution control between federal, state, and local government seems to have hindered the enforcement of environmental legislation in the past. The 1963 Clean Air Act empowered the administrator of the EPA to initiate an "abatement conference – court suit" procedure to stop health-endangering pollution, but this has proved inordinately time-consuming. (The procedure involves not only the EPA and the delinquent industry, but also state, regional, and local environmental agencies, a public hearings board, and judicial officials). The fact that the conference-hearing–court suit process was used only 10 times in 7 years attests to its impracticality.§ Only since the 1970 Clean Air Act Amendments have federal and state

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* *Environmental Quality: The Eighth Annual Report of the Council on Environmental Quality.* Washington, D.C., Dec., 1977, p. 22.

† Jarrault, La Législation Française, pp. 23, 28.

‡ *Gesetzblatt der DDR.* "Fünfte Durchführungsverordnung zum Landeskulturgesetz – Reinhaltung der Luft," pp. 161–162.

§ Hurley, *Environmental Legislation*, pp. 34–50, 58–59.

environmental agencies had the authority to make investigations of emitting plants and to initiate criminal proceedings. Willful violations can be punished with a $25,000 fine per day and a year's imprisonment. While such sanctions have rarely been applied, state and federal authorities seem to have been eager to take advantage of their right to investigate emitting plants. In the last 6 months of 1974, for instance, the EPA carried out 2,517 investigations with 234 enforcement procedures, and states made 81,160 investigations and 7,205 enforcement actions.*

I.G. EMPIRICAL FINDINGS

France, the GDR, and the United States are currently in the process of extending their networks of monitoring stations in order to collect more reliable and representative measurements of pollution concentrations.

In 1972 the French government developed a 5-year plan for expanding its network of monitoring devices to include all densely populated or highly industrialized areas, as well as for standardizing measurement procedures. The plan includes tying authorization of "Classed Establishments" to participation in monitoring activities. At the present time, available data are restricted to measurements of SO_2 and particulate matter concentrations in 18 French cities.†

In the GDR, environmental officials are also in the midst of developing and publishing standardized measurement procedures. In addition, plans have been drawn up for establishing ambient air concentration "registers" in populated areas, so that statistical data on background concentrations can be recorded. Currently, dust and SO_2 concentrations are being measured in 19 cities and towns of the GDR.‡

Until the late 1960s monitoring equipment was in operation in only 6 cities in Wisconsin, a typical midwestern state in the United States. When the Department of Natural Resources obtained authority to develop a statewide pollution control program in 1967, it immediately began to extend monitoring activities. There are currently stations in 29 cities, including 10 continuous monitoring sites. Particulate matter and SO_2 are the pollutants most often measured, but a small number of stations also monitor oxidants, hydrocarbons, COH, and CO. A centralized laboratory was opened in 1973 in order to facilitate quality control of analysis procedures.§

International comparisons of pollution concentrations must be undertaken very

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* Hill, "Air Pollution Drive Lags," *Times* pp. 1, 15.

† P. Jarrault, La Législation Française, p. 33; J. Syrota, "Les Données du Problème de la Pollution Atmosphérique," *Pollution Atmosphérique,* No. Special (July 1972) pp. 43–44; Centre Interprofessionel Technique d'Etudes de la Pollution Atmosphérique (CITEPA), "Statistiques françaises de la Pollution due à la Combustion," Study No. 40.; M. Benarie, "Etudes de la Pollution Atmosphérique de Mulhouse, Strasbourg, Rouen, et Vaudreine," (Vert-le-Petit: Institut National de la Recherche Chimique Appliquée, 1967–1973).

‡ Manfred Zier, "Einige Ergebnisse von Schwebestaubmessungen in unterschiedlich verstaubten Gebieten der DDR," In *Erfassung und Auswirkung von Luftverunreinigungen*, from the series, Technik und Umweltschutz (Leipzig: VEB Deutscher Verlag für Grundstoffindustrie, 1972), pp. 65–80; *Gesetzblatt der DDR*. "Erste Durchführungsverordnung zum Landeskulturgesetz," p. 162; Gerhard Mueller, "Das oekonomische Experiment zur Reinhaltung der Luft im Bezirk Halle," In *Technologie der Abwasserreinigung und Emissionskontrolle der Luft*, from the Series, Technik und Umweltschutz (Leipzig: VEB Deutscher Verlag für Grundstoffindustrie, 1973), pp. 111–129.

§ State of Wisconsin, Department of Natural Resources, "1973 Air Quality Data Report."

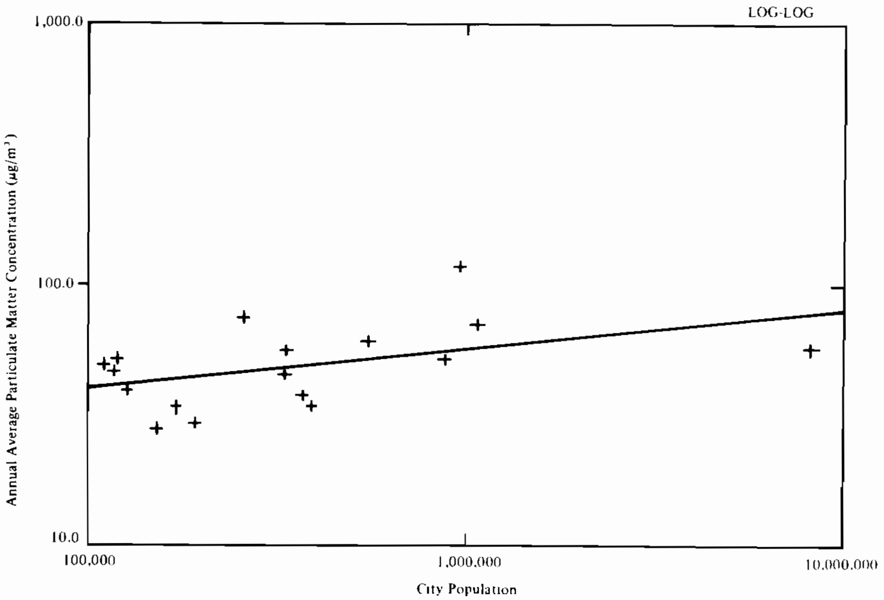

FIGURE C.1 Particulate matter concentrations (annual average) vs. city population for French cities (1967–1973).

cautiously, even if cities of similar size are considered. The mix of industries may differ between cities, and measurement techniques have not been standardized. Because of such uncontrolled factors, only tentative conclusions can be drawn from Figures C.1, C.2 and C.3.

It must first be noted that there is a marked positive relationship between annual average particulate matter concentrations and city size in each of the 3 countries under study. If particular points are taken from the graphs and compared, it appears that the GDR has the highest particulate matter concentration for a given city size, followed by France and Wisconsin. For instance, the city of Plauen in the GDR (population of 80,871) recorded an annual average particulate matter concentration of 70 $\mu g/m^3$ in 1970, while St. Etienne in France (metropolitan population of 110,897) registered an annual average particulate matter concentration of 61 $\mu g/m^3$ in 1972, and Beloit, Wisconsin (metropolitan population of 81,880) reported an annual average particulate matter concentration of 28 $\mu g/m^3$ in 1973. The findings may be misleading, however, because of the need to compare readings from different years and from cities with different types of industry.

It may be fairer to assess the success of air pollution control efforts by looking at changes over time in each country. Of the 17 French cities for which pollution concentrations could be obtained, 9 showed a consistent decrease in particulate matter, and 8 in SO_2, during the past decade. Readings in the remaining cities either stayed constant or showed wide fluctuations over time. A French observer has attributed the general improvement in France to a decrease in the sulfur content of

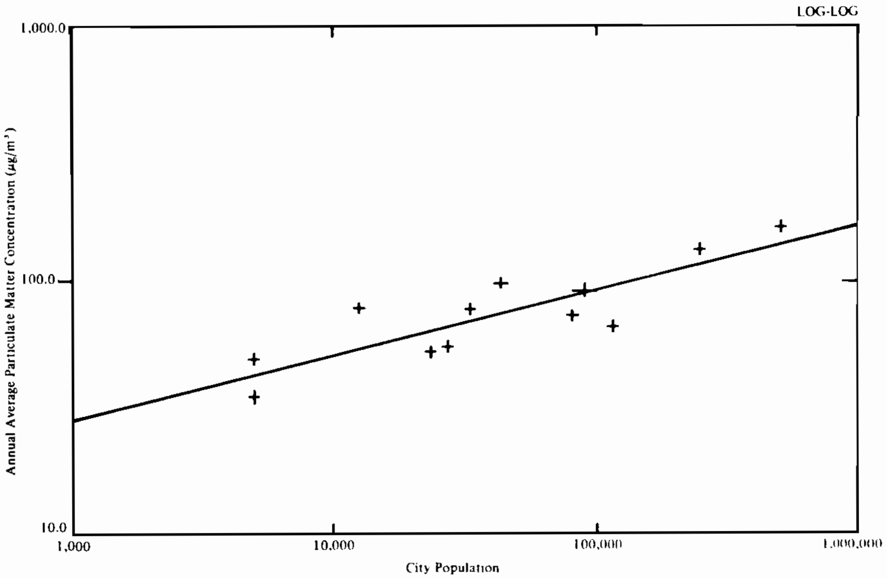

FIGURE C.2 Particulate matter concentrations (annual average) vs. city population for GDR cities (1965–1969).

fuel, to new regulations requiring taller stacks in emitting plants, and to the creation of zones of special protection.*

In GDR cities, pollution control efforts during the latter part of the 1960s seem to have been successful in holding pollution concentrations steady. None of the cities for which readings were available showed a decrease in pollution by 1970, but unfortunately, measurement results could not be obtained for subsequent years.

A survey of ambient air particulate matter concentrations in Wisconsin revealed a consistent decrease at each measurement station between 1971 and 1973. The EPA reported a 27-percent reduction in national levels of sulfur dioxide between 1970 and 1976, but less than half of the 313 air quality control areas in the United States are currently meeting Federal particulate standards.†

I.H. CONCLUSION

The question of how three countries with very different political structures have approached the same functional problem of controlling pollution is complex. This comparative analysis of environmental legislation has suggested that the institutional structure of each country has exerted an idiosyncratic influence on each component of strategies for combatting pollution. In France, a highly centralized government

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* M. Detrie, "Etude de l'Evolution de la Pollution due à la Combustion en France 1972–73–74."·*Pollution Atmosphérique*, No. 66, (April–June 1975), pp. 89–92.

† "The Delay in Meeting U.S. Clean Air Goals, *The New York Times*, Jan. 6, 1978, p. 18.

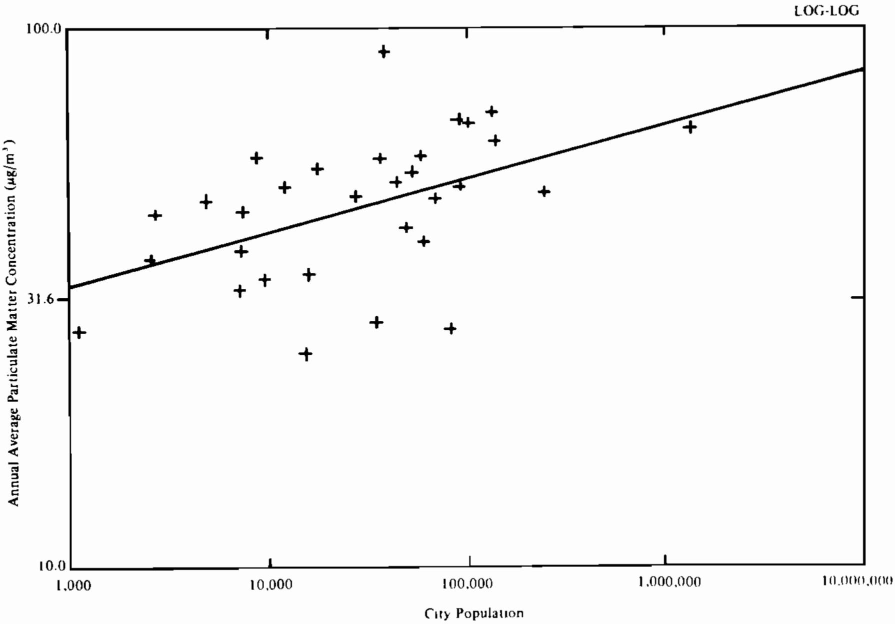

FIGURE C.3 Particulate matter concentrations (annual average) vs. city population for Wisconsin cities (1973).

can be shown from a long history of government initiative in the policing of industry, the centralized administration of pollution control activities, and the seemingly severe penalties for exceeding emission norms. The diffusion of power in the United States perhaps underlies the gradual involvement of the federal government in the area of pollution control, the delegation of responsibility for setting air quality standards to the federal government and for controlling emissions to state and local governments, the complicated procedure whereby federal approval must be gained for state pollution programs, and finally, the difficulty in implementing effective enforcement measures. The centralized decision-making and emphasis on cooperation characteristic of the GDR may be seen in its comprehensive planning of measures for decreasing pollution, the collaboration between government and industry representatives in setting emission norms, and the self-policing of plants.

Whether the strategies of one country are more effective than those of another in combating pollution cannot be determined at the present time. Final evaluation of pollution legislation will have to await the full implementation of all the laws currently "on the books." Most of the legislation in the three areas is so new that target dates for compliance have not yet been reached, or have been subject to deferments. For instance, technical instructions for combustion installations issued in 1975 in France called for the installation of pollution monitoring devices by 1978. The managers of plants built before 1976 were also given until 1978 to comply with emission norms.* For GDR briquette plants, 1976 was given as a deadline for meeting emission threshold values published in 1973.† In the United States, 16 states have won deferments until 1977 for the implementation of federally-approved abatement programs, and many power plants and steel mills are seeking deferments until the late 1980s for meeting emission standards.‡

II. ENERGY-RELATED BUILDING PRACTICES

One energy-related area that has come under closer scrutiny recently in each of the three regions, is standard-setting for energy use in buildings. Each region has developed minimum performance standards or recommendations for several types of structures. The standards are generally becoming more comprehensive and more strict as energy prices continue to climb and energy conservation measures become more desirable. Minimum performance standards for buildings help prevent needless energy wastage and encourage consideration of energy efficiency in building design.

The next three sections briefly describe the energy building codes and practices in the GDR, France, and Wisconsin. A comparison of particular standards in the regions is given in the final section.

II.A. THE GERMAN DEMOCRATIC REPUBLIC

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Energy alternatives in construction have been attracting more and more attention in recent years in the GDR as in other countries. Due to the growing trend towards lightweight buildings, consideration of thermal insulation in construction is surpassing static structural work in importance. The significance of thermal insulation in construction does not just result from the need to preserve existing buildings but above all from the intention to serve the people who use them. And, no less important, thermal insulation in construction is also a question of economy, especially where buildings are heated.

In the GDR, the National Standard TGL (Technische Güte- und Lieferbedingungen) 10 686, Sheets 1–6, dealing with "constructional-physical protective measures/thermal insulation" must be applied to all problems concerning thermal

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* *Journal Officiel de la République Française*, "Equipment et exploitation des installations thermiques en vue de reduire la pollution atmosphérique d'économiser l'energie." (July 31, 1975), pp. 7778–7781.

† Guenter Deysing, "Die Entwicklung der Volkswirtschaft im Bezirk Cottbus und die sich daraus ergebenden Aufgaben für die sozialistische Landeskultur." In *Luftverunreinigungen in bestimmter Gebiete und Technologische Verfahren zur Emissionsverminderung* in the Series, Technik und Umweltschutz (Leipzig: VEB Deutscher Verlag für Grundstoffindustrie, 1974), p. 15.

‡ Hill, "Air Pollution Drive Lags," *Times*, pp. 1, 15. Also, U.S. Environmental Protection Agency, "Progress in the Prevention and Control of Air Pollution in 1974," pp. 41–52.

insulation in construction. In recent years this standard has been supplemented and extended. As a result of this revision the new standard TGL 28 707, Sheets 1–10, dealing with "constructional thermal insulation" was binding in the GDR as of January 1, 1976. The principles governing this standard will be explained in this section.

Principal Requirements for Thermal Insulation in Construction. To protect against any moisture penetration, thermal insulation, along with heating, ventilating, and air conditioning systems, will have to meet the following fundamental requirements

- minimum hygienic conditions for rooms permanently used by people
- functional efficiency of the building
- preservation of buildings by prevention of any penetration of moisture and reduction of temperature-dependent stress in structural elements
- minimum expenditure on heating, ventilating, and air conditioning

Maximum efficiency must be the guiding principle when these requirements are met.

As an essential prerequisite for meeting these demands, the functional unity of a building and the technical equipment installed has to be ensured in view of the climate of the area of the site. For that reason the standard explicitly requires the design engineer in charge of heating, ventilating, and air conditioning installations to be drawn into planning and architectural activities at a very early date.

Thermal Resistivity of Structural Elements. Before special problems of thermal resistivity can be dealt with in detail, some standard specifications concerning the climate in the GDR need to be explained. The territory of the GDR has been divided into 3 regions of thermal resistivity. These regions have been defined on the basis of critical winter temperatures (outdoor air temperature established for the coldest 5-day period from 1901 to 1950). Winter temperatures calculated for regions 1, 2, and 3 were -15°C, -20°C, and -25°C. With regard to wind and rainfall, a site is characterized by the wind–rainfall index (WNI), expressed by the relation

$$WNI = \frac{Nv}{a}$$

where

N = mean annual rainfall in millimeters from 1901 to 1950
v = mean annual wind velocity in meters per second from 1961 to 1970
a = 1,000 mm · m/sec

The wind–rainfall indices in the 4 wind–rainfall regions specified for the GDR are less than 2.0; 2.0 to 2.6; 2.6 to 4.0; and greater than 4.0.

Calculation of the thermal resistivity required of any structural element is to be based on the consideration that inside wall temperatures must reliably meet constructional and hygienic requirements with regard to indoor temperatures. The site of the building has to be classified according to the relevant thermal-resistivity region and the wind-rainfall index taken into account. Building preservation proceeds from the need to prevent any generation of dew water. The dew-point temperature of the indoor air determines the minimum thermal resistivity to be established. The standard specifies admissible maximum values, which are mandatory, for the temperature difference between indoor temperature t_i and that of the inside surface of the structural element, Θ_i. Admissible maximum temperature differences for inhabited rooms with an indoor temperature of 20°C and a relative humidity of 60 percent, for example, are for

● outside walls	6.5°K
● outside walls of corner rooms	4.5°K
● partition walls in flats (with heating systems that can be controlled or shut off individually)	6.5°K
● roofing	3.5°K

An additional safety margin, which for example amounts to – 1.5°K in the case of outside walls, has to be considered for inhabited rooms subject to hygienic regulations. The minimum insulation values are calculated according to the equation

$$R = R_0 - (R_i + R_e)$$

where

R_i = the heat transfer resistance of the inside surface
R_e = the heat transfer resistance of the outside surface
R_0 is obtained from the relation

$$R_0 = R_i \frac{t_i - t_e}{t_i - \Theta_i}$$

t_e = the temperature to be used in calculations for the thermal-resistivity region involved.

The units of R are square meters – degrees Kelvin per Watt ($m^2 \cdot {}^\circ K/W$).

If R_e is assumed to be constant for all buildings in direct contact with outdoor air in winter ($0.04\ m^2 \cdot {}^\circ K/W$, or, in terms of α, the heat transfer coefficient, $\alpha_e = 25\ W/m^2 \cdot {}^\circ K$), R_i will be between 0.07 and $0.17\ m^2 \cdot {}^\circ K/W$ (or, in terms of α, $\alpha_i = 6$ to $14\ W/m^2 \cdot {}^\circ K$), depending on the kind of ventilation (gravity or forced-draught).

The standard gives all parameters needed to establish minimum thermal resistivity for any particular application. For easier handling in everyday use, the standard directly specifies the minimum thermal resistivity values for the most important structural elements related to the thermal-resisitivity regions, e.g. for the outside walls of inhabited rooms ($t_i = 20°C$; relative humidity = 60 percent):

- in thermal-resistivity region 1 – $0.50\ m^2 \cdot {}^\circ K/W$
- in thermal-resistivity region 2 – $0.60\ m^2 \cdot {}^\circ K/W$
- in thermal-resistivity region 3 – $0.70\ m^2 \cdot {}^\circ K/W$

The standard not only recommends reference values for thermal resistivity; because of unsteady temperature influences in summer conditions it also specifies minimum values for the heat capacity of exterior structural elements. The criterion applied is the temperature amplitude attenuation, which is defined as the quotient of the daily outdoor air temperature amplitude and the reduced temperature amplitude for the inside surface of the structural element. A temperature amplitude attenuation of 10 is, for example, required for outside walls with an arbitrary share of glass elements and without direct exposure to the sun.

Economical Thermal Insulation. The requirements and reference values discussed so far are mandatory for the designing of buildings in the GDR. In addition, the standard contains recommendations which should be used to assess thermal insulation efficiency of structural elements in heated buildings. It is assumed that the expenditure on installation and operation of a heating system depends on the expenditure on thermal insulation. (The heating requirements of buildings needed for heating system design, are calculated in the GDR according to National Standard TGL 112-0319,* dealing with heat requirements of buildings.) There is an obvious need to design both building and heating system so that total expenditure is kept at a minimum. The expenditure index G serves as the criterion for efficiency calculation.

$$G = J_B f_B + j_B + J_H f_H + j_H$$

where

J = investment costs in Marks per square meter (M/m^2).
f = capital charge factor in inverse years ($1/yr$).
j = operating expenses in Marks per square meter per year ($M/m^2/yr$).
index B = structural element.
index H = heating system.
The units of G are Marks per square meter per year ($M/m^2/yr$).

Optimum thermal resistance, i.e. optimum insulating layer thickness of any structural element involved, can be established on the basis of G. In cases where the optimum resistance is lower than the minimum values prescribed by the standard, the minimum values of the standard must be applied.

Summary. Thermal insulation in construction, especially the thermal resistivity of structural elements, has attracted much attention in the GDR. National Standard TGL 28 706, dealing with constructional thermal insulation, which was binding as of January 1, 1976, represents up-to-date national and international knowledge and experience in this field. Requirements and reference values will not only contribute to ensuring and maintaining functional efficiency of buildings but will above all serve the people who use them. Joint consideration of building standards and expenditures with the aim of reaching an optimum balance is an essential factor in reducing the demands made on the resources of any national economy. It is especially this point that future activities in the GDR will be concerned with in dealing with thermal insulation in construction.

II.B. FRANCE

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France has to face very different climate conditions from north to south and from east to west. There is a hot, Mediterranean climate in the south; a wet oceanic climate in the middle west and north; and a continental climate in the east and in the mountains. Therefore, 3 climate areas (A, B, and C) are distinguished in the building standards as shown in Table C.4. The degree-days and "basic minimum

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* This standard is being revised.

TABLE C.4 Climate Designations of the French Departments According to Legislation for Low-Rent Housing

	Over 500 m	200–500 m	Under 200 m		Over 500 m	200–500 m	Under 200 m
Ain	A	A	B	Lot	A	B	B
Aisne		A	A	Lot-et-Garonne		B	B
Allier	A	B	B	Lozere	A	B	
Alpes(-de-Haute Provence)	A	B	B	Maine-et-Loire			B
Alpes (Hautes)	A	A		Manche		B	B
Alpes-Maritimes	A	B	C	Marne		A	A
Ardeche	A	B	B	Marne (Haute)		A	A
Ardennes		A	A	Mayenne		B	B
Ariege	A	B		Meurthe-et-Moselle	A	A	A
Aube		A	A	Meuse		A	A
Aude	A	B	C	Morbihan		B	B
Aveyron	A	B		Moselle	A	A	A
Belfort (Territoire de)	A	A		Nievre	A	B	B
Bouches-du-Rhone	A	B	C	Nord			B
Calvados		B	B	Oise	B	B	B
Cantal	A	A		Orne	B	B	B
Charente		B	B	Paris (Ville-de-)			B
Charente-Maritime			C	Pas-de-Calais			B
Cher		B	B	Puy-de-Dome	A	A	
Correze	A	B	B	Pyrenees (Atlantiques)	A	B	C
Corse	A	B	C	Pyrenees (Hautes)	A	B	B
Cote-d'Or	A	A	A	Pyrenees (Orientales)	A	B	C
Cotes-du-Nord		B	B	Rhin (Bas)	A	A	A
Creuse	A	B		Rhin (Haut)	A	A	A
Dordogne		B	B	Rhone	A	B	B
Doubs	A	A	A	Saone (Haute)	A	A	A
Drome	A	B	B	Saone-et-Loire	A	B	B
Essonne		B	B	Sarthe		B	B
Eure		B	B	Savoie	A	A	
Eure-et-Loir			B	Savoie (Haute)	A	A	

Finistere	B	B	B	Seine-Saint-Denis			B
Gard	A	B	C	Seine-Maritime		B	B
Garonne (Haute)	A	B	B	Seine-et-Marne			B
Gers		B	B	Sevres (Deux)			B
Gironde			C	Somme		B	B
Hauts-de-Seine			B	Tarn	A	B	B
Herault	A	B	C	Tarn-et-Garonne		B	B
Ille-et-Vilaine			B	Val-de-Marne			B
Indre		B	B	Val-d'Oise			B
Indre-et-Loire		B	B	Var	A	B	C
Isere	A	B	B	Vaucluse	A	B	C
Jura	A	A		Vendee		C	C
Landes			C	Vienne		B	B
Loire	A	B	B	Vienne (Haute)	A	B	B
Loire (Haute)	A	A		Vosges	A	A	
Loire-Atlantique			C	Yonne		B	B
Loiret				Yvelines			B
Loir-et-Cher			B				

SOURCE: Association technique des industries du gaz en France, "Chauffage au gaz des locaux d'habitation et service d'eau chaude associée." Collection des techniques gazières. *Ed. Société du journal des usines à gaz*, 1975.

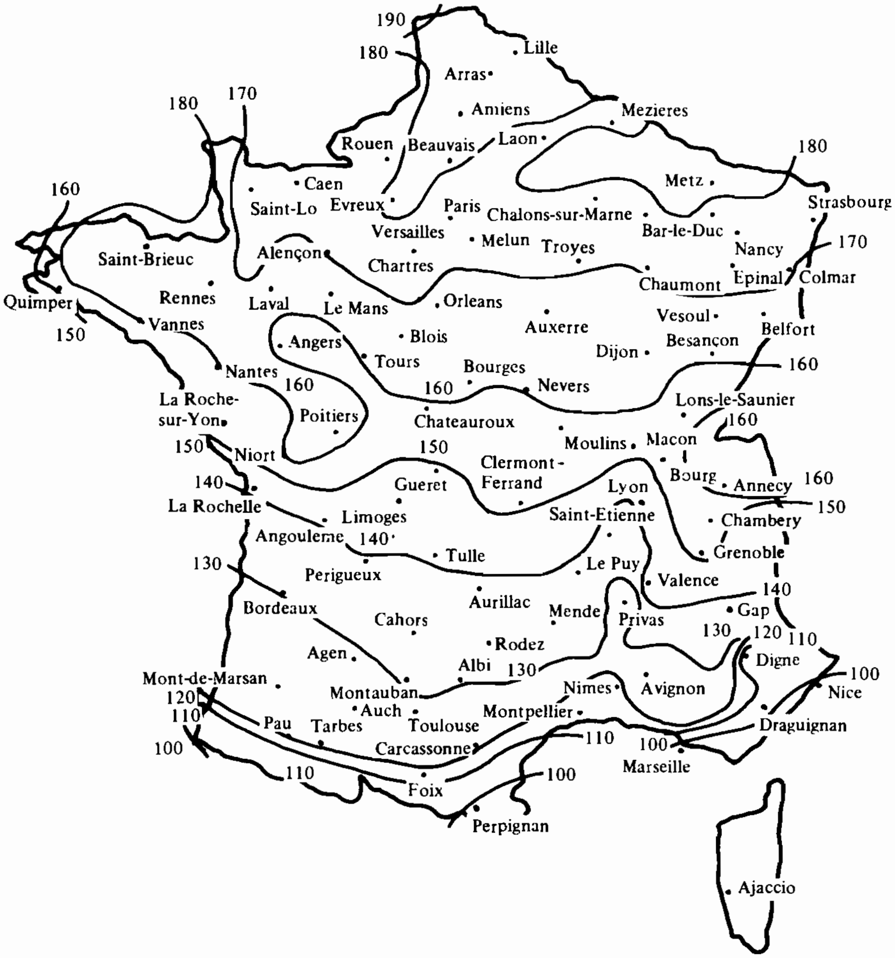

FIGURE C.4 Length of the heating season for all parts of France.

external temperature" also differ widely among regions in France. The degree-days for 83 meteorological points aggregated into 14 groups are given in Table C.5 and the "basic minimum external temperature" for all the departments are listed in Table C.6.

The lowest number of Celsius degree-days observed in France is 1,300 and the highest is 3,300; the lowest basic temperature is − 14°C and the highest − 2°C. In most parts of France (area *B*) 2,450 degree-days are considered to be a reasonable average value.

The length of the heating season for each part of France is drawn on the map

TABLE C.5 Degree-days for 83 Meteorological Points

		October								April			May		
	Altitude (m)	1–10	11–20	21–31	Nov.	Dec.	Jan.	Feb.	Mar.	1–10	11–20	21–30	1–10	11–20	Total from Oct. 1 to May 20
Group I															
Dunkerque	9	51	65	87	321	422	434	387	375	102	92	82	73	64	2555
Boulogne-sur-Mer	73	49	63	85	315	425	431	387	369	102	92	82	73	64	2537
Abbeville	57	57	71	94	342	446	453	396	357	100	89	78	67	57	2707
Lille	55	60	74	98	357	465	463	407	369	101	90	79	68	57	2693
Saint-Quentin	98	60	75	100	266	477	481	413	366	101	89	77	65	54	2724
Group II															
Reims	94	59	74	87	363	474	484	407	357	96	84	72	60	48	2665
Romilly	77	59	73	85	354	471	474	404	350	94	82	70	58	46	2620
Auxerre	207	53	68	94	348	462	465	399	325	86	75	64	52	41	2532
Chateau-Chinon	598	62	77	98	369	505	515	452	372	102	92	82	71	61	2858
Langres	464	65	81	100	696	530	543	460	384	103	91	79	67	55	2954
Saint-Dizier	139	41	75	90	343	530	545	448	405	103	75	53	60	57	2825
Group III															
Metz	189	62	78	104	384	518	518	441	378	97	84	71	58	45	2838
Nancy	203	65	80	105	381	508	518	438	381	100	87	74	63	49	2854
Strasbourg	151	60	77	104	387	524	527	441	372	93	90	67	54	41	2827
Mulhouse	267	59	75	101	378	521	533	446	475	98	85	72	59	46	2948
Group IV															
Belfort	422	62	79	107	296	533	549	460	378	101	88	75	62	49	2939
Luxeuil	272	64	80	107	390	521	536	452	394	106	93	80	67	54	2944
Besancon	311	55	71	97	366	502	505	424	353	95	82	69	57	44	2719
Dijon	220	53	70	97	369	499	508	415	341	89	77	65	52	40	2675
Mont-Saint-Vincent	603	65	80	106	384	524	533	457	372	102	92	82	71	61	2935
Macon	216	51	67	93	354	487	493	407	325	89	77	65	52	40	2600
Amberieu	253	50	66	91	348	493	499	413	341	89	77	65	53	41	2626
Lyon	196	44	60	85	333	474	484	399	322	84	72	60	47	35	2499
Group V															
Grenoble (Eybens)	223	47	64	90	348	502	505	413	329	89	76	63	50	38	2614
Challes-les-Eaux	291	52	70	98	378	524	533	441	363	98	80	68	55	43	2797
Bourg-Saint-Maurice	865	62	81	111	417	533	595	485	409	105	93	81	68	56	3096
Lus-la-Croix-Haute	1037	81	96	123	426	580	586	513	468	127	115	103	91	80	3339
Embrun	870	52	71	100	387	539	533	443	369	99	87	75	63	52	2870
Group VI															
Millau	409	37	43	77	309	434	443	373	325	87	76	65	53	42	2374
Gourdon	205	32	48	71	288	412	412	340	270	72	62	52	42	31	2132
Le Puy-en-Velay	714	62	77	103	375	511	521	441	391	103	96	84	72	61	2905
Saint-Etienne-Boutheon	399	52	68	93	351	471	487	393	353	96	85	74	62	51	2636
Clermont-Ferrand	329	48	53	87	333	455	462	393	332	89	78	67	56	46	2509
Vichy	430	46	62	86	333	456	465	393	332	89	78	67	56	45	2509
Limoges	282	53	67	89	327	450	446	385	338	93	83	73	63	53	2520

TABLE C.5 – Continued

	Altitude (m)	October 1–10	October 11–20	October 21–31	Nov.	Dec.	Jan.	Feb.	Mar.	April 1–10	April 11–20	April 21–30	May 1–10	May 11–20	Total from Oct. 1 to May 20
Group VII															
Chateauroux	160	45	60	84	324	437	443	376	319	85	74	63	52	41	2403
Bourges	157	47	62	86	330	449	449	382	325	87	76	65	53	42	2453
Nevers	176	55	69	93	342	459	434	393	341	94	82	70	58	46	2536
Romorantin	80	59	65	90	345	443	440	373	329	88	77	66	56	46	2467
Tours	96	31	50	77	324	431	428	365	316	85	74	63	52	42	2338
Orleans-Bricy	125	52	67	91	342	456	456	387	338	91	80	69	57	46	2532
Group VIII															
Chartres	155	54	69	94	351	459	459	393	347	94	83	72	61	50	2586
Paris-Orly	89	52	66	91	345	453	353	387	335	88	77	66	54	43	2510
Paris-Montsouris	78	48	63	87	333	440	440	376	319	84	72	60	48	36	2406
Paris-Le-Bourget	52	50	65	89	336	443	446	382	332	88	76	64	52	41	2464
Beauvais	101	60	74	98	360	462	468	404	366	100	89	78	66	55	2680
Group IX															
Rouen	68	55	70	94	343	443	449	387	347	98	86	75	64	53	2569
Cap-de-la-Heve	101	45	59	81	306	397	406	365	338	98	87	76	66	56	2380
Caen	66	53	66	87	318	412	415	365	344	100	89	78	67	57	2451
Alencon	140	60	74	98	354	446	453	387	347	99	98	77	66	56	2605
Cherbourg-Chant	8	41	52	69	255	339	350	323	316	91	83	75	67	58	2118
Group X															
Dinard	65	44	57	78	291	375	381	337	322	94	84	74	65	55	2257
Ile de Brehat	25	35	46	64	243	319	335	309	304	90	82	74	66	58	2025
Ile d'Ouessant	27	39	47	61	219	285	307	281	282	85	78	71	65	58	1878
Brest-Guipavas	98	36	50	71	276	353	357	329	310	95	87	79	72	65	2180
Lorient (Lann-Bihoue)	42	46	57	75	270	372	363	329	307	87	78	69	60	50	2163
Rostrenen	262	54	65	84	300	403	403	362	357	101	92	83	75	66	2445
Rennes	35	46	60	82	306	397	397	345	313	89	79	69	59	50	2292
Group XI															
Le Mans	52	50	64	87	324	434	428	371	332	90	79	68	56	45	2428
Angers	54	46	60	72	312	419	409	354	313	86	75	64	54	44	2308
Nantes	26	40	54	75	291	397	391	343	298	82	72	62	52	42	2199
Ile d'Yeu-Saint-Sauveur	32	22	39	56	324	326	332	301	279	77	67	57	48	38	1877
La Rochelle	7	31	45	67	273	378	332	329	285	79	68	57	46	35	2025
Poitiers	118	45	60	83	318	425	425	365	316	87	76	65	54	44	2363
Cognac[a]	30	31	53	57	265	411	442	327	301	77	65	45	41	42	2157
Angouleme[b]	83	42	46	64	288	419	366	374	335	98	76	47	50	58	2263
Group XII															
Bordeaux	47	29	44	66	276	384	378	320	270	74	64	54	44	34	2037
Cazaux	24	26	40	61	255	357	357	309	263	70	61	52	43	33	1927
Agen	61	28	44	67	282	397	403	326	273	72	62	52	41	31	2078
Mont-de-Marsan	59	31	46	68	276	391	384	320	270	70	60	50	40	30	2036

Biarritz (Aerodrome)	29	19	27	43	192	291	295	264	229	66	58	40	42	34	1610
Pau	189	31	45	65	270	381	381	320	270	75	65	57	48	33	2048
Saint-Girons	411	30	47	71	297	423	428	351	295	85	75	65	55	45	2222
Toulouse-Blagnac	151	23	40	63	276	400	403	331	273	74	63	52	41	31	2070
Group XIII															
Carcassonne	123	19	35	57	252	369	384	315	263	69	58	47	37	25	1930
Perpignan	43	20	16	44	183	291	310	247	208	49	39	29	19	9	1464
Montpellier	5	17	31	50	222	353	372	303	257	66	55	44	33	22	1825
Nimes	52	15	28	49	234	357	369	298	242	60	49	38	27	16	1782
Group XIV															
Montelimar	73	28	44	67	282	415	425	343	276	72	60	48	36	25	2121
Orange	53	21	37	60	264	391	397	323	260	66	54	42	30	19	1964
Marignane	3	16	26	47	225	350	372	306	248	64	52	40	8	16	1790
Toulon	28	23	11	28	159	260	283	245	211	55	45	34	23	13	1356
Saint-Raphael	2	20	20	37	183	295	322	270	236	62	51	40	29	18	1583
Nice	5	21	12	30	171	279	301	250	220	58	47	36	25	15	1465
Bastia	10	22	12	29	165	273	295	247	229	63	52	41	30	20	1478
Ajaccio (Campo del Oro)	4	21	15	33	171	273	293	255	236	66	56	46	35	25	1531

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[a] Town added 1961–62 – averages of 4 yr (1960–64) are given as reference.
[b] Town added 1961–62 – averages of 3 yr (1961–64) are given as reference.

TABLE C.6 Average Minimum Outside Temperatures of French Departments

	Temp. (°C)		Temp. (°C)		Temp. (°C)		Temp. (°C)
Ain	−8	Dordogne	−5	Loiret	−7	Haute-Saone	−10
Aisne	−7	Doubs	−10	Lot	−6	Saone-et-Loire	−8
Allier	−8	Drome	−6	Lot-et-Garonne	−5	Sarthe	−7
Alpes (Basses)	−9	Eure	−7	Lozere	−6	Savoie	−10
Alpes (Hautes)	−9	Eure-et-Loir	−7	Maine-et-Loire	−7	Haute-Savoie	−12
Alpes-Maritimes		Finistere	−4	Manche	−4	Seine[a]	−7
Inland	−9	Gard	−5	Marne	−10	Seine-Maritime	−7
Coast	−2	Haute-Garonne	−5	Haute-Marne	−10	Seine-et-Marne	−7
Ardeche	−6	Gers	−5	Mayenne	−7	Seine-et-Oise[a]	−7
Ardennes	−11	Gironde		Meurthe-et-Moselle	−11	Deux-Sevres	−7
Ariege	−5	Inland	−5	Meuse	−11	Somme	−9
Aube	−10	Coast	−4	Morbihan	−4	Tarn	−5
Aude	−5	Herault	−5	Moselle	−11	Tarn-et-Garonne	−5
Aveyron	−6	Ille-et-Vilaine	−5	Nievre	−7	Var	
Bouches-du-Rhone	−5	Indre	−7	Nord	−9	Inland	−5
Calvados	−5	Indre-et-Loire	−7	Oise	−7	Coast	−2
Cantal	−8	Isere	−10	Orne	−7	Vaucluse	−6
Charente	−5	Jura	−10	Pas-de-Calais	−9	Vendee	
Charente-Maritime		Landes		Puy-de-Dome	−8	Inland	−5
Inland	−5	Inland	−5	Pyrenees-Atlantiques		Coast	−4
Coast	−4	Coast	−4	Inland	−5	Vienne	−7
Cher	−7	Loir-et-Cher	−7	Coast	−4	Haute-Vienne	−8
Correze	−6	Loire	−8	Hautes-Pyrenees	−5	Vosges	−11
Corse	−8	Haute-Loire	−5	Pyrenees-Orientales	−4	Yonne	−8
Cote-d'Or	−4	Loire-Atlantique		Bas-Rhin	−14		
Cotes-du-Nord	−2	Inland	−5	Haut-Rhin	−14		
Creuse	−8	Coast	−4	Rhone	−8		

SOURCE: Association technique des industries du gaz en France "Chauffage au gaz des locaux d'habitation et service d'eau chaude associée," Collection des techniques gazières. *Ed. Societé du journal des usines à gaz,* 1975.

[a] In 1968, Seine and Seine-et-Oise were divided into seven departments: Essonne, Hauts-de-Seine, Seine-St.-Denis, Val-de-Marne, Val-d'Oise, Ville-de-Paris, and Yvelines.

TABLE C.7 Summary of Insulation Recommendations for Winter Nonelectric Heating made by Centre Scientifique et Technique du Batiment[a]

	Insulation Coefficient G (kcal/m^3 · h · °C)						
	Apartments				Individual Houses		
Winter	Current Housing	Corner Housing	1st Floor or Upper Floor Housing	1st Floor or Upper Floor Housing/Corner	Single Unit House	Duplex or Housing at End of Row	Row Housing at End of Row
Climate zone A	0.95	1.2	1.3	1.55	1.9	1.7	1.5
	(0.7)	(0.8)	(0.9)	(1)	(1.1)	(1)	(0.9)
Climate zone B	1.1	1.35	1.6	1.8	2.2	2.0	1.8
	(0.75)	(0.85)	(1)	(1.1)	(1.25)	(1.15)	(1.05)
Climate zone C	1.2	1.5	1.75	2.0	2.4	2.2	2.0
	(0.8)	(0.9)	(1.1)	(1.2)	(1.4)	(1.3)	(1.2)

TABLE C.7 – Continued

	Coefficient k of Opaque Partitions (kcal/m^2 · h · ° C)												
	Roof		Walls					Floors					
Winter	Roof	Floor in Individual Attic		Outside Walls of Apt.	Corner Apts.	Individual Walls	Individual Walls Against Garage	In Open Area	On Foundation Enclosure, Non/Weakly Ventilated	On Foundation Enclosure, Poorly Ventilated	On Foundation Enclosure, Well Aired	On the Ground	On Individual Cellar
Climate zone A	0.8	0.9	> 600 kg/m^2	1.5	1.5	1.5	1.5	0.7	Insulation on Periphery	1.5	1.0	Insulation on Periphery	1.0
			451–600	1.4	1.4	1.4							
			351–450	1.3	1.3	1.3							
			251–350	1.2	1.2	1.2							
			151–250	1.1	1.1	1.1							
			< 150	1.0	1.0	1.0							
Climate zone B	1.0	1.2	> 600 kg/m^2	1.7	1.5	1.5	1.6	0.8	Insulation on Periphery	2.0	1.2	Insulation on Periphery	1.2
			451–600	1.6	1.4	1.4							
			351–450	1.5	1.3	1.3							
			251–350	1.4	1.2	1.2							
			151–250	1.2	1.1	1.1							
			< 150	1.0	1.0	1.0							
Climate zone C	1.2	1.5	< 600 kg/m^2	1.9	1.7	1.7	1.7	0.9			1.4		1.4
			451–600	1.8	1.6	1.6							
			351–450	1.7	1.5	1.5							
			251–350	1.5	1.4	1.4							
			151–250	1.3	1.2	1.2							
			< 150	1.0	1.0	1.0							

SOURCE: Association technique des industries du gaz en France, "Chauffage au gaz des locaux d'habitation et service d'eau chaude associée." Collection des techniques gazières. *Ed. Société du journal des usines à gaz,* 1975.

[a] The numbers in parentheses correspond to the extreme values of electric heating.

TABLE C.8 Energy Use in Residential Buildings (1972)

	Per Unit Volume	Per Unit Floor Area
Fuel consumption	112×10^6 cal/m^3	280×10^6 cal/m^2
Electricity consumption	9.2 kWh/m^3	23 kWh/m^2
Total energy consumption	140 kWh/m^3	350 kWh/m^2

shown in Figure C.4. The length of the heating season varies from 190 days in the north to 100 days in the south.

Criteria for Current Building Practices. Until the decree of April 10, 1974, concerning insulation standards, there was no uniformity in building practices. The only guidelines are those of the CSTB (*Centre Scientifique et Technique du Batiment*) for low-rent buildings (Table C.7). Typical insulation of the different kinds of buildings can be represented by the following ranges of the parameter G with the unit kilocalories per cubic meter per hour per degree Celsius (kcal/m^3/h/°C):

● small building, concrete, very cheap, bad insulation		G = 1.7–2.5
● small single-family house, traditional, 90 m^2 (e.g. in Paris suburb)		G = 1.4–2.2
● average traditional buildings (before 1940)	house	G = 1.3–2.1
	apartment	G = 1.1–1.7
● very big buildings		G = 0.9–1.4

The average volume of the house or the apartments depends on the age of the buildings:

● buildings before 1949	house	V = 180 m^3
	apartment	V = 150 m^3
● 1949–1961	house	V = 190 m^3
	apartment	V = 170 m^3
● 1961–1970	house	V = 205 m^3
	apartment	V = 185 m^3
● 1970–1975	house	V = 250 m^3
	apartment	V = 190 m^3

Actual Energy Uses. In 1972, the total volume of all the heated residential buildings was 2.88×10^9 m^3; the energy consumption for heating, cooking, and air conditioning was 322.8 Gth* of fuel and 14.6 TWh; the electricity consumption of lighting, mechanical use, etc., was 120 TWh. The actual energy use in the residential buildings for the year 1972 can be seen in Table C.8.

Total consumption by use is approximately:

● heating	285 kWh/m^2
● cooking	20 kWh/m^2
● hot water	35 kWh/m^2
● specific electricity uses (lighting and machinery)	10 kWh/m^2

Building Codes. It would be too long and too difficult to present a complete history of building code development. Two recent decrees seem to be important.

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* 1 Gth = 10^{15} cal.

TABLE C.9 The Seven Classes of Housing Defined by the 1974 Building Decree

	Type[a]	Value of Ratio[b] k	Habitable Space
I	Independent	Indifferent	$V < 150\ m^3$
II	Independent	Indifferent	$V \geqslant 150\ m^3$
	Nonindependent	$k > 1.75$	$V < 150\ m^3$
III	Independent	Indifferent	$V \geqslant 300\ m^3$
	Nonindependent	$k > 1.75$	$V \geqslant 150\ m^3$
IV	Nonindependent	$1.25 < k \leqslant 1.75$	Indifferent
V	Nonindependent	$0.75 < k \leqslant 1.25$	Indifferent
VI	Nonindependent	$0.25 \leqslant k \leqslant 0.75$	Indifferent
VII	Nonindependent	$k \leqslant 0.25$	Indifferent

[a] A room is independent if (1) it is not connected to any other dwelling, (2) the connected dwelling is not heated, or (3) the connected dwelling is partitioned into rooms of less than 15 m^2.

[b] k is the ratio of the surface of the horizontal partitions, the sloping horizontal parts touching the outside walls, the floor of the ventilation enclosure, or a nonheated room, to the habitable surface.

- Decree 69-596 of June 14, 1969, which gave the general rules for the construction of buildings for housing
- Decree 74-306 of April 10, 1974, which modified the prior decree with regard to heating.

The purpose of the first decree is to make uniform the standards of construction in order to guarantee the quality of the buildings for the users of those buildings. The purpose of the second decree was to save energy in buildings (it was during the oil shortage). Apart from these decrees there is a code made by the CSTB which is fundamental from the architect's point of view but which is not a law.

The decree of April 10, 1974, was made by the government (the prime minister) in order to minimize energy expenditures. It called for a constant temperature of 18°C in residential buildings. It deals with two kinds of measures: one concerned with insulation standards, and another concerned with the regulation of heating systems.

This decree distinguishes 7 kinds of residential buildings (Table C.9), 3 climate areas, and 2 steps in the practical application of the decree. For each kind of building, each climate area and each step, it gives a minimum-allowable insulation standard G, which is in units of kilocalories per cubic meter per hour per degree Celsius (kcal/m^3/h/°C). See Table C.10.

Expected Effects of Decrees. The effects of this decree on the energy consumption will appear increasingly in the next years. The energy consumption for heating will be reduced by 40 or 50 percent for the residential buildings constructed after July 1, 1975. In the year 1985, between one-fourth and one-third of the residential buildings will have been built with the new standards. Therefore, the energy consumption in 1985 will be about 10 to 15 percent lower than the consumption that could be expected without insulation standards. In 2000, 50 to 60 percent of the residential buildings will be built with the new standards, and energy consumption for heating will be 25 to 30 percent lower than the expected consumption without standards.

In France, the most important impact on the economy is the reduction of imports of oil and natural gas and thereby the reduction of "the payment in

TABLE C.10 Minimum Permissible Insulation Standards by Housing Class as Set by the 1974 Building Decree (value of *G* in Kcal/m^3 · h · °C)

	Date Application Made for Permission to Build					
	May 1, 1974			July 1, 1975		
Housing Class	Climate Zone A	Climate Zone B	Climate Zone C	Climate Zone A	Climate Zone B	Climate Zone C
I	1.98	2.28	2.49	1.38	1.50	1.72
II	1.85	2.15	2.37	1.25	1.38	1.63
III	1.72	1.98	2.19	1.12	1.25	1.50
IV	1.55	1.75	1.98	1.03	1.16	1.38
V	1.38	1.59	1.75	0.95	1.03	1.25
VI	1.20	1.42	1.55	0.82	0.90	1.08
VII	1.08	1.25	1.38	0.73	0.82	0.95

dollars." In the year 1985, 5 to 7 Mtep* will be saved each year, which represents about \$400–\$600 million†, and in 2000, 15 to 20 Mtep will be saved each year.

Another effect of the decrees that is also very important is the decrease of air pollution of SO_2, NO_x, and CO. Burning one Mtep of heating oil gives about 14,000 metric tons of SO_2 in France; each Mtep of fuel, gas, or oil burned in a furnace gives 2,600 metric tons of NO_x (assumed to be NO_2) and 5,800 metric tons of CO.

II.C. WISCONSIN

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The designs and construction techniques used in buildings in Wisconsin have evolved in response to many factors. These include the functions for which the building is intended, the budget available to the builder, the style of the architectural firm selected, and the construction materials and labor force available. It has only been recently that energy requirements for space heating and air conditioning have assumed some importance in the design of buildings. The energy used for these purposes results from the interaction between building design and the regional weather patterns.

Wisconsin has a climate with a relatively long cold winter and a relatively short, mild summer. The heating season is approximately 180 days (6 months) long, with monthly average winter temperature of about 20°F (−7°C). The design winter temperature in southern Wisconsin is −10°F (−23°C), and is the average air temperature that is exceeded less than 22 h each year. Wisconsin has approximately 4,500 Celsius heating degree-days,‡ which is the sum (over the days in the heating season) of the number of degrees that the air temperature is less than 18°C (65°F). This value is a measure of the heating requirements for buildings in different regions. In summer, the design temperature is 33°C (92°F). Cooling conditions, in which the air temperature is about 26°C (80°F) occur for 500 h (20 days) during the average summer.

Prior to the recent concern over energy, buildings were designed to meet the objectives described above. Heating and cooling system requirements were usually determined after the design was firm, and equipment selection was then made. The space conditioning requirements were determined following the established engineering procedures described in the handbook of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE).

Buildings in Wisconsin reflect this lack of concern over energy use. It is difficult to accurately ascertain their total energy use, since design calculations are only for the "worst" case operating conditions, and also may not reflect changes in building operation or control.

In order to provide some information on energy use in buildings, we have conducted a survey of commercial buildings in Madison, Wisconsin. These data, in addition to the building characteristics and function, consist of the monthly utility records for the natural gas and electricity consumed over the last 4 yr. The buildings range in gross floor area from 1,000 to 50,000 ft^2 (100 to 5,000 m^2) and in height

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* Megatons of petroleum equivalent (Mtep) $\cong 11 \times 10^{15}$ cal.

† If there is no electric heating during this period of time.

‡ Fahrenheit heating degree-days can be obtained by multiplying Celsius degree-days by 9/5.

from 1 to 8 stories. The types included are hospitals, schools, office buildings, retail buildings, hotels, and food stores. Natural gas is used almost exclusively in these buildings for space and water heating, and electrical use is predominantly for lighting, air conditioning, and office equipment.

The results of this survey are summarized in Table C.11. These results show that building function is the major determinant of use. There is no influence of building size on energy use. The energy use for space and water heating varies by about a factor of 3 over all buildings, while electrical use varies up to a factor of 80. The average total energy use for space and water heating is about 3 times that for electricity. The dollar costs associated with the average energy uses are about \$0.3 and \$0.4/ft^2/yr for natural gas and electricity. These low energy costs indicate the difficulty of motivating conservation measures solely by economic considerations.

Wisconsin Energy Code for Commercial and Industrial Buildings. Since 1914, the state of Wisconsin has had a building code that specifies construction requirements for most commercial and industrial buildings. The provisions of this code are enforced by the Department of Industry, Labor, and Human Relations (DILHR). Enforcement is achieved by approval of the building plans by DILHR prior to construction of the building. Until 1974, the code was primarily concerned with requirements for structural integrity, safety, and health in individual buildings. It was not concerned with energy measures for the state as a whole.

In December 1973, a committee of experts was appointed from the public at large to develop an energy conservation code which would become law upon approval by the legislature after public hearings, and upon adoption by DILHR commissioners. The Energy Conservation Committee first developed a set of emergency rules which were permanently adopted in June 1974. These rules lowered the inside design temperatures and the design ventilation requirements per person, and allowed ventilation rates to be based on the actual occupancy of a building rather than its maximum capacity. A second set of rules developed by the committee became law in January 1975. These rules raised the winter outdoor design temperatures in the state, specified maximum infiltration rates, and specified the maximum heat loss through the building's exterior surface. This latter provision was quite controversial, and was finally suspended in June 1975. The suspended rule underwent review by another appointed committee, and the maximum heat-loss rule became part of the Wisconsin Administrative Code as of December 1976.

The main effect of the majority of the provisions of the code is to allow architects and engineers to lower energy uses where feasible. As such, these provisions do not apply to all buildings, and may not apply even to a portion of a building. Thermostat turndowns and ventilation reductions are applicable to existing buildings, while the design specifications apply only to new buildings. The resulting energy use changes are difficult to determine; however, it is felt that there will be measurable savings.

The thermal performance specification sets an allowable maximum energy loss through the building exterior surface. This maximum allowable heat flow through the envelope area (walls, windows, doors, and roof) is specified to be 13 Btu/h-ft$_e^2$ (130 kJ/h-m^2).* The nature of this rule allows an estimate of energy savings both for specific buildings and for the state as a whole. The energy changes depend on resulting changes in building construction techniques and on the continued pattern of construction of commercial buildings. Both of these effects are difficult to assess.

The result of a selected survey of building plans made early in 1974 is shown in

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* ft$_e^2$ = the number of square feet of envelope.

TABLE C.11 Energy Use in Buildings in Madison, Wisconsin

Space and Water Heating (10^5 Btu/ft$^2 \cdot$ yr = 10^4 kJ/m$^2 \cdot$ yr)	Number of Buildings	Building Type
3–4	2	Hospitals
2–3	1	Hotel
1.5–2	4	College, hotels
1–1.5	8	Offices, retail stores, schools
0.75–1	7	Offices, retail stores, schools
0.5–0.75	1	Medical clinic
Average = 1.5×10^5 Btu/ft^2/yr		
Electrical Use (kWh/ft$^2 \cdot$ yr)	Number of Buildings	Building Type
80–90	1	Food store
30–40	2	Office
20–30	4	Offices, retail stores
15–20	7	Hospital, offices, retail stores
10–15	4	Hospital, offices, retail stores
5–10	8	Office, school, retail stores
3–5	2	School
1–3	3	Church, school
Average = 15.5 kWh/ft^2/yr		

TABLE C.12 Designed Space Heating Energy Use in Commercial Buildings in Wisconsin

Envelope Heat Loss (Btu/h · ft$_e^2$)	Number of Buildings (1974)	Number of Buildings (1975)
20–30	10	79
15–20	4	
13–15	7	19
10–13	7	59
5–10	1	34

Average envelope loss in 1974: 17 Btu/h · ft$_e^2$; in 1975: 15.2 Btu/h · ft$_e^2$.

Table C.12. This survey showed that buildings are currently designed for an envelope heat loss of about 17 Btu/h-ft^2. A larger survey made in the summer of 1975 after the rule had been suspended is also shown in Table C.12. This shows an average envelope heat loss of 15.2 Btu/h-ft^2. Clearly, there has been increasing concern over energy use, mainly through awareness of energy price and availability. The rule, if in force, would have served to change the design of about one-half of all buildings constructed. The remainder would have met the design requirements without enforcement.

Energy projections for the state were made to evaluate the effect of the code. In the absence of the code, it was estimated that buildings would have an average envelope heat loss of 16 Btu/h-ft$_e^2$, while with the code the value would be 13 Btu/h-ft$_e^2$. For both cases it was assumed that floor area would increase in proportion to the projected population increase. The energy savings in the year 2000 resulting from the code are estimated to be approximately 0.7×10^{12} Btu/yr, or about 4 percent of the expected total heat loss through the walls. This is approximately 0.4 percent of the energy use in the commercial sector. In terms of energy, this represents a saving of approximately 7 million ft^3 of natural gas, enough to heat roughly 2,000 homes in the year 2000. Thus, while the savings are a small percentage of the total energy use, the effect on given users may be significant.

Evaluation of the direct economic impact of the thermal performance specification was controversial. It was recognized that additional costs would be involved in constructing buildings, and that these might be on the order of 3–5 percent of the total building cost. Even though the cost of the added insulation could be recovered in a few years, it forced a significant increase in first cost, which, in the current economic situation, is seen to be a deterrent to construction.

Secondary economic effects were anticipated by the glass and masonry industries. The performance specifications discourage installation of glass over large areas, and lead to increases in the cost of masonry walls by requiring added insulation. The specific economic impacts are difficult to evaluate, but in view of the current construction industry slowdown, any adverse effects were felt to be intolerable.

Summary. The construction techniques used in Wisconsin buildings have evolved with time in response to energy price and availability. The engineering and architectural professions have recognized these increased costs, and have, in general, designed buildings accordingly. Energy codes serve as a ceiling for those building owners who can afford to disregard energy prices. The savings in energy use through building codes is a small proportion of the total energy use. However, energy savings may still have a significant effect on those users who would otherwise be unable to obtain fuels. The scope of energy codes, the political processes required for their implementation, and the economic considerations all serve to make codes a controversial mechanism for energy conservation.*

II.D. SUMMARY AND COMPARISON

The three preceding sections demonstrate the increasing concern for energy efficient building practices in each of the three regions. Standards or recommendations concerning energy losses from various types of buildings exist in each region. These standards typically represent minimum performance as determined by the standard-setters; the standards are not determined from minimization of total costs, including factors such as fuel, insulation, and interest costs.

Close examination of the three preceding sections reveals that comparisons of the standards of the regions is difficult because the bases for standard-setting in the three regions are different. For example:

- GDR – standards set for the minimum thermal resistivity for several types of surfaces (e.g. outside walls, outside walls of corner rooms, and roofs) for three climate zones.
- France – standards set for maximum heat loss per unit time, temperature difference, and volume for several types of residential buildings for three climate zones.
- Wisconsin – standards set for maximum heat loss per unit time and area (excluding infiltration and ventilation) through total building envelopes (walls, windows, doors, and roof).

In spite of these basic differences between the regions in philosophy of standard-setting, an attempt was made to compare the standards for the outside walls of buildings. As shown in row 1 of Table C.13, each of the regions is divided into several climate zones. It is noteworthy that the ranges in minimum design temperatures (row 2 of Table C.13) and the ranges in heating degree-days (row 3) used in the regions have little overlap; that is, Wisconsin has the coldest climate with minimum design temperatures of -23 to -32°C, the GDR is next coldest with -15 to -25°C, and France is the warmest with -2 to -14°C. These temperature and degree-day data indicate that, if energy costs, insulation costs, and other costs were the same in all regions, larger expenditures would be justified for energy conservation in Wisconsin than for a similar building in the GDR or France. However, energy prices, material costs, and other economic factors are not the same in all three regions. Therefore, the economic optimum for insulation would be different for similar buildings in each of the regions even if the climates were identical. Such economic differences can be expected to affect standard-setting although the standards are not intended to be economic optima.

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* Following considerable additional discussions, a new Wisconsin code defining energy standards for all new public and commercial buildings (including residential buildings with more than two units) took effect in July 1978. It specifies maximum allowable heat flow through the envelope area according to the number of stories, e.g. 12 Btu/h/ft^2 for 1- or 2-story buildings; 13 Btu/h/ft^2 for 3-or 4-story buildings, and still larger values for higher buildings. This code also institutes, for the first time in Wisconsin, energy equipment design performance standards, e.g., combustion efficiencies. In the residential sector, a new code was put into effect in December 1978 for construction of new 1- and 2-family dwellings; it includes thermal transmittance standards. See J.S. Buehring, "Energy Conservation and Fuel Strategies in the Residential and Commercial/Service Sectors," in W.K. Foell (ed.), *Proceedings of the 1978 Conference on Alternative Energy Futures for Wisconsin* (Madison: University of Wisconsin – Madison, 1978).

TABLE C.13 Selected Data For Energy Standards or Design Recommendations For Buildings

	GDR	France	Wisconsin	
1. Number of temperature zones used for building codes	3	3	4	
2. Range in minimum design temperatures used over those zones	°C − 15 to − 25 °F + 5 to − 13	− 2 to − 14 + 28 to + 7	− 23 to − 32 − 10 to − 25	
3. Range in heating degree days	°C °F Not Available	1,300 to 3,300 2,300 to 5,900	3,900 to 5,100 7,000 to 9,200	
4. Description of conditions for the standard	Outside walls of inhabited rooms with temperature of 20°C and relative humidity of 60 percent; includes ventilating	Outside wall of apartment with nonelectric heating in low-rent buildings[a]	Current Standard Heat loss (excluding infiltration and ventilation) through total building envelope (walls, windows, doors, and roof). Indoor temp. of 19.4°C. Applies to commercial buildings and apartment buildings with 4 or more units.	ASHRAE Standard 90-75 (not currently used but may be modified for use in Wisconsin) Minimum thermal performance for new buildings. Indoor temp. of 22°C. Applies to outside walls under Wisconsin climate conditions.

TABLE C.13 – Continued

	GDR	France	Wisconsin			
5. Published standard or recommendation converted to common units.	Standard for minimum resistivity 0.50 m² • °K/W for warmest zone 0.70 m² • °K/W for coldest zone	Recommendation for maximum conductance related to wall characteristics: 1.2–2.2 W/m² • °K for warmest zone 1.2–1.7 W/m² • °K for coldest zone[a]	Standard for maximum heat loss: 41 W/m² (13 Btu/h • ft²)	Standard for maximum conductance (W/m² • °K):		
				Detached one- or two-family units	Other residential buildings 3 stories or less	All other buildings over 3 stories
			warmest zone	1.1	1.5	1.8
			coldest zone	0.97	1.2	1.6
6. Rough estimates of allowable heat loss for outside wall of two-story apartment building (W/m² • °K)						
warmest zone	2.0	1.2–2.2[a]	1.3[b]	1.5		
coldest zone	1.4	1.2–1.7[a]	1.1[b]	1.2		

SOURCES: (1) The three previous sections, prepared by engineers from each of the regions, and (2) American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 90-75.

NOTE: To convert W/m² • °K to Btu/h • ft² • °F, multiply by 0.176.

[a] The maximum allowable heat loss per unit time, temperature difference, and volume was reduced by 30 to 40 percent on July 1, 1975. The standards used in this table were obtained from the Rhone-Alpes section and correspond to the May 1974 insulation standards. Thus, the values shown here for France are higher than current values.

[b] To estimate the maximum heat loss for an apartment building outer wall meeting the Wisconsin standard, the following assumptions were used: indoor temperature of 67 °F, two-story apartment building, story height of 10 ft, four apartments per building, 900 ft² per apartment, and roof conductance (Btu/h • ft² • °F) of 0.04 in the coldest zone and 0.05 in the warmest zone.

A description of the conditions for the standards for outside walls of buildings are listed in row 4 of Table C.13. The actual standards or recommendations are listed in row 5. Two different standards are listed under the Wisconsin column. The first is the current standard being used by the Department of Industry, Labor, and Human Relations. The second is the standard recommended by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). The ASHRAE standards or a modified set of standards similar in structure to them may be used in Wisconsin in the future.

Out of the many possibilities for comparison between the regions, the allowable heat loss through an outside wall of a two-storey building was arbitrarily selected in row 6. The assumptions and qualifications listed in the table should be carefully noted. Since there are so many differences in assumptions and techniques, the similarity of the overall results exhibited in row 6 is surprising. In each of the regions, less heat loss is allowed (more insulation is required) in the colder zone than in the warmer zone. The allowable heat losses appear to have some relationship to the climate data. These standards can be expected to change from time to time, as energy costs continue to climb and closer scrutiny is given to energy practices in construction. As indicated in a footnote to Table C.13, the French standards have already become more strict than those shown in the table.

III. ENERGY-RELATED PRICING PRACTICES

The following sections on energy prices and pricing policy in France, the German Democratic Republic, and the United States, reveal many differences in institutions, policy goals, and political constraints. Despite these obvious differences, what are revealing are the common themes that develop in each of the next three sections.

The most notable is that in each region, price levels were found to be at inappropriate levels, with the common realization that prices needed to be adjusted on a continuing basis to meet the needs of the changing resource, economic, social, and political situation. Another common theme was the recognition of the high capital costs involved in supplying energy and the need to guarantee the fiscal soundness of the energy supply sector, whether private or public, so that it can compete in the financial markets. A related theme was the commonly recognized principle of marginal or incremental cost pricing which was seen as a necessary condition to achieve economic efficiency. In each of the countries, however, this principle was qualified in application by the reality of numerous constraints and trade-offs. Finally, each region is shown to be highly sensitive to and influenced by changes in the international energy markets.

Any comparison of pricing in the three countries also requires recognition of the differences in the three regions. In both France and the GDR, the regulatory authorities are national and centralized. The United States has both national and state regulatory control. In addition, different regulatory bodies have responsibility for the various energy types. It is perhaps this characteristic combined with the private ownership of the energy supply industry in the United States which has led to the split between principle and policy. In the GDR and France, the principles and policy are more closely related although clearly not the same for the two regions.

In the GDR, the consumer is protected by fixed prices in energy and industry bears the brunt of the price increases. France exhibits the opposite tendency – the competitive position of industry is protected with lower energy prices than for the domestic sector. In the United States, a clear pattern emerges only in the form of the consistency with which various interests jockey for position. To reiterate a previous point, however, none of these pricing arrangements were found to be satisfactory and in each nation, change in prices and pricing policy is continuing.

III.A. THE GERMAN DEMOCRATIC REPUBLIC

L. Jordan – Institut für Energetik

In the German Democratic Republic, price control is operated and supervised by the designated public authorities. These authorities have to enforce and supervise the application of the principles of state-controlled price policy, which has been defined and decided by the government under the direction of the Socialist Unity Party (SED), the leading political party. Central controlling power has been delegated to a Price Board headed by a minister, who is directly responsible to the Council of Ministers for the implementation of the state-controlled price policy.

One of the most important principles which is never ignored by the party executives and the government is the stability of consumer goods retail prices and of charges for services to the population. The Council of Ministers has decided on a policy published in the Official Gazette of the GDR, committing all public authorities and economic executive bodies within their fields of activities to invariable observance of this socioeconomic principle. Supervision is conducted by the public authorities themselves with price supervising committees set up by the Supervisory Bureaus attached to the public authorities at all levels.

Other general principles of the price policy pursued in the GDR concern

- Serious consideration and efficient planning of necessary price variances
- Centralized decision-making concerning steps to alter prices on the basis of cost calculation, in terms of the productive sector of the national economy and in terms of the consequences for the consumer (central price concept)
- Close approximation of prices to the estimated value of the socially necessary expenditure of labor for products and services
- Economic stimulation applied to supplying and consuming enterprises, with the aim of encouraging objectives of national economic importance (e.g., establishing a predefined energy demand structure or efficient use of energy), with the price acting as an economic incentive
- The binding character of any newly-fixed price for all producers and consumers of products and services

The price policy pursued after World War II and also after the GDR was set up in 1949 is based on the principle of maintaining the prices (frozen prices) that were valid in 1944 and after, and exceptions have been made only in individual cases where alterations were reasonable (but not in the energy supply industry). At the end of the 1950s and early in the 1960s, economic and organizational developments in the GDR made it necessary to evaluate the material asset, i.e. capital goods and current funds, and the results of material production in new terms. The gap between cost and prices has become so wide in the past 15 to 20 yr that the prices obtained for primary industry products has in many cases not even covered costs. This experience at last led to the preparation and step-by-step execution of an industrial price reform (IPR) for the national economy of the GDR. The first stage of the IPR, which already included the energy supply industry, started April 1, 1964. It resulted in an increase in energy prices of, on the average, 60 to 80 percent. Thus, the objective of IPR, to establish the principle of economic efficiency (recovering of costs and generation of profits) in individual enterprises and corporations, was achieved.

The very name of the IPR indicates that only the prices to industrial producers were altered. Prices of consumer goods to be paid by the public remained constant. In this way the socio-economic principle of price control was defined and consistently applied in close cooperation with the other general principles stated above.

In the course of further economic progress in the GDR, there has been increasing awareness that the financial means required to renew and indefinitely extend the productive fund, i.e. capital goods and current funds, would in the future have to be provided by the enterprises and corporations themselves; responsibility would rest with the individual management. This arrangement, which is still fully valid, was defined as the principle of self-generation of the financial means needed for extended production. It increases the scope of individual responsibility born by the directors of enterprises and corporations, and economic executive bodies for organizing and financing the reproduction process as far as the departments they head are concerned. In the energy supply industry, this problem is of particular importance for price fixing in view of the very high funding requirements involved in energy production or generation and supply.

Any enforcement of the principle stated above, concerning self-generation of the financial means needed for extended reproduction, requires, however, that the share of profits contained in the price has to be calculated in consideration of the productive funds already advanced. For the energy supply industry this arrangement actually results in relatively low fund-related profitability rates as compared with the average calculated for all other industries within the national economy. The profitability rates related to cost-pricing, however, are substantially above the national economic average. This situation is due to the ratio of fund expenditure to cost-price, which in turn can be related to the high funding requirements that mark the energy supply industry.

On the basis of the knowledge discussed above, energy supply prices were calculated in the years from 1968 to 1970 for the 1971–75 five-year plan period. These energy supply prices were calculated and fixed according to the general principles governing state-controlled price policy and price setting, previously explained, with the following additional guidelines relating to energy supply price policy:

- Very close approximation of energy supply prices to the socially necessary expenditure of labor for energy supplies
- Approximate calculation of the socially necessary expenditure of labor from the average cost in the industry and the previously centrally fixed average fund profitability rate, as related to the entire national economy
- Consideration of necessary cost-price deviation in view of actual conditions in the 1971–75 five-year plan period (e.g., relative price for fuel oil and city gas)
- Avoidance of subsequent price alternations in the energy-intensive industries within the national economy in the 1971–75 five-year plan period
- Prevention of any price rises affecting the population, religious communities, and other consumers; reduced price increases for agricultural enterprises (increase up to the industrial price level planned for December 31, 1970, according to IPR)

- Freezing the new energy supply prices for the first time ever, for a period of at least 5 yr (up to December 31, 1975).

The energy supply prices worked out according to these guidelines were declared binding for the 1971–75 five-year plan period by the Council of Ministers. Changes in the price levels of energy were associated with some changes in rate schedules. This did not result, however, in any breakthrough with respect to the required simplification of the rate system (above all for electric energy) which has been sought for years. The prices and rate schedules were substantially altered in proportion to the price level that had developed for the energy supply involved. Supply types were maintained with the only changes concerned with the relation between price levels of various substitutable energy supplies.

On the basis of price analyses drawn up for the years 1972 and 1973 and of investigation into the effectiveness of the energy prices, which are taken from 1975 for the 1976–1980 period, an "energy supply price concept for the 1976–1980 period" was worked out. The expenditue and price calculations carried through led to further substantial alteration in energy supply prices beginning January 1, 1976. These price alterations were approved in March 1975 by the GDR Council of Ministers.

When the new energy prices were calculated, the following special principles were applied to energy supply price determination:

- The socially necessary expenditure of labor for the supply of energy, calculated for the year 1985 with the aid of the reproduction model of the GDR energy supply industry, served as the basis or starting point for all price calculations.
- In addition, the development trends of foreign trade expenditure for the import of energy in the next 10 yr were taken into account.
- Necessary value-price deviations, which result from the application of the particular energy form and from the ratio of value to utility (e.g. in the case of city gas) should be considered.
- No price alterations should affect the population, religious communities, agriculture (to some extent), and other consumers specified in the price regulations.
- There should be payment of product-related subsidies out of the public budget for energy suppliers who supply consumers allowed to pay low prices and for energy suppliers whose industrial sales price has been specified so that it is below the socially necessary expenditure of labor (e.g. in case of brown coal and coke).
- Calculated energy prices should for the first time be oriented towards long-term applicability, i.e., over a period of about 10 yr.

This energy price alteration has been connected with a rearrangement of price lists and rate structure. These prices and rate structures are expected to be more intelligible and easier to apply.

III.B. FRANCE

Daniel Blain – Délégation Générale à l'Energie, Ministère de l'Industrie

In France, the production, transportation, and distribution of gas, electricity, and coal are primarily supplied by public firms. In addition, the state also possesses regulatory control of the petroleum industry. Within this general context, the prices of energy can be considered as being administered; their determination is subject to economic fluctuations, financial factors, and international constraints. The past development of energy prices allows us to discern a number of principles which are applied in the setting of energy prices.

Principles for Setting Energy Prices

In an economy operating at the optimum, the prices of goods are equal to marginal costs. From a dynamic perspective, one must consider the marginal costs of medium-range development. Under marginal cost pricing, whatever the market situation, monopoly or more or less perfect competition, the choice of firms and consumers are properly directed and waste is avoided. For more than a decade, this principle has served as a guideline for the general orientation of energy price setting. For example, during the years from 1960 to 1970, energy prices decreased, in constant prices, due to the decrease in the price of imported energy and increases in productivity. Moreover, the structure of prices for a given energy commodity for different uses is similar to the structure of the development costs. The best example of this is price setting for residential, service, and industrial uses of electricity.

The problem of administering prices is made more complex when constraints or economic objectives are taken into account. These constraints lead to modification of the structure and the level of some prices. Thus the policies of regulation may lead, during periods of increasing inflation, to postponement of certain price increases. The goal of ensuring the competitive position of French industry justifies the desire to adjust energy prices for large industrial consumers to the price level found in other countries. Finally, the consideration of external costs such as those relating to employment, the environment, or security of supply, may justify the price difference found between the production level and the consumer level; these differences are effected by means of taxes or subsidies.

Administrative Procedures Employed for Setting Energy Prices

The firms in the energy sector are placed under the dual guardianship of the Ministry of Economy and Finances which officially publishes energy prices – the tariffs for public gas and electricity utilities, and the maximum price (scale price) for coal and petroleum industries. From the level of prices previously set, firms can request a rate change for reasons such as variations in the price of imported energy, increases in production costs related to the increase of the general level of prices and salaries, or due to difficulties in financing new investments. The firm's request is examined by the public authorities who establish new prices taking into account the particular situation of the firm and the general economic climate. The price adjustments are established by agreement between the firms and the regulating authorities. The final decision results in a compromise between the general principle of marginal cost and the realities of economic fluctuations or permanent constraints. Thus, during a period of inflation the increase of administered prices tends to lag behind that of the general level of prices and results in a later recovery of costs.

Increase of Energy Prices Since the End of 1973

At the end of 1973, the price of crude petroleum tripled from 90 F/ton to 270 F/ton.* This increase justified an increase in the price of refined petroleum

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* A franc is approximately equal to 20 cents.

products of 198 F/ton. The price setting of petroleum products is complex because they are linked products obtained by refining. For a given crude petroleum price, the price of each product will be within a broad range which is determined by the technical costs of conversion by cracking. When considering these costs on a short-term basis, these technical costs do not play a role because new conversion facilities cannot be rapidly added.

The increases in price decided upon at the end of 1973 and at the beginning of 1974 were determined by the global energy prices and policy, and by international constraints. During such periods of inflation and instability in foreign trade, it seemed desirable to minimize the financial pressure on industry in order to preserve competition, and instead to put the larger price increase on fuels purchased for private (household) use. Thus there was a rise of 125 F/ton for residual fuel oil, 160 F/ton for gas and oil, and 400 F/ton for motor fuels. Such a price increase structure was made possible by the fact that the other European countries adopted a similar policy. In fact, significant price divergences between various countries would have resulted in grave perturbations in the exchange of refined products.

The rise in petroleum product prices had two consequences: on the one hand they perceptibly increased the production costs for large users, and in particular for central power stations, and on the other hand they created distortions in the combustion fuel market and encouraged the consumer to switch to gas or coal since the prices of these two fuels had not changed. This orientation was certainly desirable for medium-range planning but could not be immediately realized for lack of availability of gas and coal.

The setting of energy prices at the beginning of 1974 took into account the technical and economic constraints peculiar to the energy sector and also general economic constraints, particularly the inflation problem. Thus the first electricity, gas and coal price increases were lower than they theoretically could have been. The increases in electricity prices were below the increase in production costs and the rate increases were larger for the residential sector than for the industrial sector. Similarly, the increases in price of industrial and residential gas were below those for residual fuel oil and residential fuel oil.

During the latter part of 1974 and 1975, new increases in energy prices were instituted which made the prices for diverse energy commodities more consistent. It should be noted that at the time of new increases in the price of raw petroleum, there was an increase in the price of heavy and residential fuel but not of motor fuels. Similarly, new increases in the price of electricity and gas caused the industrial rates rather than the residential ones to increase.

With the rate of inflation remaining rather high, the increases in energy prices are decided upon with great caution, especially because the public is particularly sensitive to any increases. However, the increase in imported petroleum prices which appears permanent has led the government to adopt a new energy supply strategy based on energy conservation, the development of nuclear energy, the increase in natural gas consumption, and petroleum research in France.

This strategy requires an important investment effort which creates financial problems for the energy companies. Price levels should be sufficient to provide access under favorable conditions to national and international financial markets. It is through the conciliation of the various constraints and medium-range development objectives and through price increases from time to time that the decision-makers will be able to adapt the energy market to the situation created by rapid price increases of petroleum.

III.C. THE UNITED STATES

Charles Cicchetti – Wisconsin Office of Emergency Energy Assistance

There are many characteristics one may assign to the manner in which energy prices are established in the United States. But two of them are decidedly inappropriate; they are neither established in a freely competitive manner, nor, in a consistent one. In addition, the explosion in world oil prices in 1973 greatly changed the energy pricing practices in the United States. The manner in which energy prices are established and affected by government policy in the U.S. will be discussed. There will be a discussion of pre-embargo oil prices, current oil price policy, natural gas pricing, electricity pricing, other primary energy sources, and current prospects for change.*

Pre-Embargo Oil Pricing

Despite the fact that some of the staunchest advocates of free enterprise capital economics in the United States are members of the oil industry, that sector is the most protected and favorably regulated major industry. Many people in the world have discovered the meaning of the words *oil cartel* since 1973. However, consumers in the United States have always had to confront the realities of a cartel for oil. The form of this cartel has often changed, but its effects of controlling prices and quantities has been quite real. The current OPEC-dominated (Organization of Petroleum Exporting Countries) cartel is different, due to its foreign origin, but the concepts of restricting supply to keep prices high and competition slight are normal for the U.S. oil industry.

The history of the U.S. oil cartel can be outlined as follows.

- John D. Rockefeller gained control of a large part of the refinery capacity in the United States, but was forced to break up his empire by the U.S. government.
- The governments of producing states in the early part of this century enacted conservation laws. Each state set production levels that controlled supply and helped keep the prices of crude oil, taxes to the state treasury, and oil producers' profits high.
- When the economic depression of the early 1930s hit the U.S. economy, demand for crude oil dropped sharply. Producing states and oil companies started to drop their oil prices to compete for this reduced demand. President Franklin D. Roosevelt developed and promoted legislation that formed an Interstate Oil Compact Commission. This act required the producing states to coordinate their production restrictions, and made it illegal for any state to sell oil that exceeded the agreed-upon amount. The federal government of the United States established, acting with the state governments, the quantity of oil that would be produced in the United States.
- After World War II the United States was no longer self-sufficient in crude oil production. The vast reserves in the Middle East provided an alternative source of

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* This paper, presented at the initial workshop (November 1975) of the research project, placed considerable emphasis on policies and debates current at that time. Many of these policies and conditions have changed since then. However, the editor and research team members feel that this paper nevertheless provides one important perspective on energy-related pricing practices at a crucial time, and therefore chose to leave this paper in its original form.

reserves at very low cost. In order to protect domestic oil producers, a voluntary import quota program was established by President Eisenhower in the early 1950s. When the voluntary program failed, President Dwight D. Eisenhower established a mandatory oil import quota program which he claimed was for national security purposes. This program also established that imports be set at a fixed percentage of domestic production, and once again supply was controlled by the federal government of the United States. Since domestic production was fixed by state and federal government, and the basis for imports was the level of domestic production, this meant that the entire supply of crude oil to the United States was controlled and prices kept high.

- From the late 1950s until the spring of 1973 import quotas and domestic production were fixed by the United States in order to keep out cheap foreign imports and to keep the U.S. domestic oil producers protected from that source of competition. This meant that the United States paid twice as much for crude oil consumption as it would have paid had imports been allowed to freely enter the United States. It also meant, as some critics of the program have indicated, that the national energy policy of the United States was "to drain America first."

By the end of 1971 and early 1972 it was clear that domestic oil production in the United States was leveling off. At the same time, demand for petroleum products continued to increase at a brisk pace. This put pressure on President Richard Nixon to increase the oil imports that were allowed to enter the United States. He did this on a temporary emergency basis. This meant that the U.S. oil industry was encouraged to lobby for favorable legislation in Washington D.C. rather than search for oil in the oil production regions of the United States. It also meant that U.S. refinery capacity was built outside of the United States because of the enormous capital investment and the uncertainty about continued imports of crude oil caused by their temporary nature.

- During this same period the oil petroleum exporting countries were showing an ability to increase the posted price that was used for the purposes of calculating tax responsibilities of the major oil companies that were producing in the OPEC nations. During this period the amount of tax that was being paid per barrel was permitted to be credited against the U.S. corporate income tax obligations of these same companies for the United States portion of their business. This meant that multinational oil companies were willing partners in the OPEC price increases prior to the embargo. The taxes could be paid out of U.S. tax obligations, and, at the same time price increases attributed to posted price increases were permitted to be passed on to consumers in the United States.
- By the spring of 1973, President Nixon, under pressure from major oil companies who were unable to get sufficient crude oil for their refineries to meet the demands of their customers, ended the Mandatory Oil Import Quota Program. This meant that for the first time large quantities of nonquantity-controlled products and crude oil would be permitted to flow into the U.S. economy. At that point, the U.S. price of crude oil was about $4.25 per barrel, while the imported price of that same crude oil was only about $2.00 to $2.50 per barrel.

The 1973 Oil Embargo and Current Oil Pricing in the United States

Just prior to the announcement of the OPEC embargo in 1973, a slight decrease in the cost of crude oil in the United States was perceived. But, before consumers could gain the benefit, war broke out in the Middle East. Along with that war came the political and economic realization of the strength that the producing countries possessed with respect to world oil pricing. The price of foreign oil increased by more than 500 percent in less than 6 months. In addition, the quantity of oil that was available for consumers was curtailed.

In the United States it was initially believed that the embargo would matter very little because only a small part of the U.S. imports, which were then less than 30 percent of daily consumption, were coming from OPEC nations that were involved in the embargo of 1973. A miscalculation had been made, however, for the oil refineries that were built outside of the United States to meet the U.S. needs during the latter part of the mandatory Oil Import Quota Program were cut off from supplies and therefore could not supply the U.S. market. This increased the size of the U.S. shortage far beyond what had been expected. In addition, domestic oil prices were allowed to increase a minimum of 25 percent over the pre-embargo level. This fact, plus a decision which allowed any new U.S. oil production to be priced at the OPEC level, resulted in enormous profit increases for U.S. oil companies.

During the shortage the United States formed the Federal Energy Administration. A two-tier pricing system of crude oil was established in the United States. It also established an allocation system in order to have all the states share the petroleum shortage equitably. This was done for petroleum products as well as for crude oil. Although the embargo has ended and the petroleum shortage is less important because a slight surplus of petroleum products exists in the United States today, programs established in 1973 to deal with the shortage have still been retained. Two of these programs are being debated continuously by the executive and legislative branches of government. Both affect the pricing of crude oil, and therefore, the pricing of petroleum products.

- The crude oil allocation program requires some refineries in the United States that have supplies of low-priced, $5.25 per barrel, oil to share this oil with other refineries who have to import crude oil or purchase new domestic oil at prices of more than $13.00 per barrel. Under this program, a refinery is sometimes forced to give up the cheaper oil to a competitor and then to repurchase crude oil at more than $13.00 a barrel to replace the cheaper oil that it was forced to sell.
- The crude oil entitlement program reinforces the crude oil allocation program. Under this program, oil companies, which after the allocation of crude oil among refineries, find that they are importing or using more domestic new oil at a higher price than the average refineries in the United States, are entitled to receive a payment of approximately $7.00 per barrel from those oil companies that have refineries that use a greater proportion than the national average of low-priced old domestic oil.

Both programs, during the current period of relative oil surplus, result in economic incentives that encourage a greater importation of foreign oil and a reduction in the production of "old" domestic oil. (One check on the system is that if a U.S. oil company begins production of domestic oil, it is allowed to convert one barrel of old oil for each barrel of new oil produced and thus receive a price of $13.00 per barrel instead of $5.25 per barrel. This incentive is not sufficient to stop the growth in oil imports to the United States.)

In the 2 years since the oil embargo, U.S. oil consumption has been reduced about 6 percent. However, imports, which were about 26 percent in 1973, are around 40 percent of U.S. needs today. This means that the economic incentives encourage oil companies to import oil rather than produce domestic oil, which is in violation of the objective to make the United States independent of foreign sources of oil. While there is widespread support to reduce imports of foreign oil in the United States, President Ford has been unable to convince the Congress that the 2 programs which are encouraging greater imports should be ended.

The way President Ford proposed to end these programs was to make all domestic oil companies winners, and this is the reason for the conflict. He would do this by letting all U.S. prices rise to the price level set by the OPEC nations. Under such a plan, the higher profits dispersed among U.S. oil companies would have been large enough that the companies would have all gained. The opposition to the President has come from the Congress, which opposes such a dramatic price increase, claiming that it would encourage greater inflation and threaten the economic recovery that has just begun to be observed in the United States. President Ford and the Congress are at a stalemate, and as a result, there are rising prices and greater dependence upon foreign oil. Neither side appears to be gaining from this standoff. It is hoped that enough political forces can be brought together to end incentive programs that encourage greater imports and at the same time to establish a single U.S. price, which will not have an adverse effect upon the economic recovery that is underway.

Natural Gas Pricing in the United States

The development of natural gas pricing regulation in the United States was quite different from the policy of regulating oil prices in the United States. First, the price of natural gas paid by consumers is regulated at the state level. Consumption is regulated by Public Service Commissions in most of the fifty states. Each commission determines the cost of supplying natural gas to customers by distribution utilities and the cost is marked up to provide a return to the owners of the utilities. This is the basis for charging consumers of natural gas for the volume taken.

Distribution companies purchase natural gas from interstate pipelines. The owners of the pipelines buy the gas from producers of the natural gas, who sometimes own the pipelines themselves. The pipelines are in turn regulated on a cost-of-service basis, similar to the utilities that distribute the gas, by the Federal Power Commission. For the past 15 years the Federal Power Commission has regulated the price that pipeline owners can pay for the gas they purchase from the producers of the natural gas. The regulatory powers of the Federal Power Commission are not uniform nationwide, however. They are not in the business of regulating the price of natural gas that is consumed in the state in which it has been produced. For many years this price in the intrastate market was below the price of natural gas sold in more distant interstate markets. In the last few years, however, the price difference has reversed. This means that gas in a producing state might be sold in that state for as much as \$2.00/1,000 ft^3, while that same gas, if sold thousands of miles away, might only be purchased for resale at about \$.50/1,000 ft^3. This two-tier pricing has, over time, led to a situation where gas is available for intrastate demands but is no longer available to meet a growing interstate market. The most serious energy problem in the United States today is that the natural gas that had been assigned to the interstate market is presently being curtailed, as contracts to supply this gas are routinely abandoned by the pipeline owners with the approval of the Federal Power Commission.

Policy that would eliminate the two-tier pricing system is in order but there is national debate in the United States over how and at what level this new price should be set. President Ford is more inclined to set all gas prices at close to \$2.00/1,000 ft^3, thus making all gas companies, and all gas producing states, winners.

The Congress, on the other hand, is more concerned with the effect on inflation and consumers of total deregulation and seems more inclined to set a price closer to the current interstate price of \$.50/1,000 ft^3. It is hoped that rational thinking will again take hold, but it is doubtful that this will happen until the problem surrounding the natural gas shortage become more obvious to the voters of the United States. In addition to that general concern, a second concern is that natural gas policy reform will take place in a crisis situation and rational thinking will be difficult, if not possible under such circumstances.*

Electricity Pricing

Electricity price regulation in the United States is primarily a function of state regulatory commissions. These are the same commissions that regulate the price of natural gas in the consuming states. The Federal Power Commission plays a role in regulating the price that one electricity-producing utility can charge another when electricity is exchanged by those utilities. Most electric utilities in the United States are investor-owned utilities. State regulation of electricity pricing follows the same procedures as natural gas price regulation at the state level. The basic approach is to estimate the cost of producing electricity and then an adjustment is made to recover a fair return for the investors who own the utility. This procedure establishes the level of revenue that can be collected by the utility from its customers.

Most gas and electric utilities in the United States have practiced some form of volume discount pricing to encourage greater energy use for several decades. In the last few years this practice of volume discount pricing has come under serious challenge by consumer intervenors in regulatory proceedings. In recent times, the price of electricity and natural gas has increased due to inflation, higher capital costs, and higher operating costs related to the oil embargo of 1973. Load management and time-of-day pricing of electricity are both being considered in the United States and Wisconsin is taking a leading role.

Not all electric utilities in the United States are investor-owned. Some are owned by the cities in which the electricity and natural gas is distributed. Some are owned by cooperatives in the rural portions of the United States. Many of these do not generate their own electricity but purchase it directly from federal generating authorities. Often such public production and distribution of electricity is more heavily located in those portions of the United States in which hydroelectric power is a significant part of the electricity supply.

Coal and Uranium

Both coal and uranium are not directly regulated from a price standpoint in the United States. However, both are primarily used to produce electricity which is directly regulated at the consumer level. In addition, the price of both coal and uranium moves in concert with the price of oil and natural gas. This has meant that the effects of the Arab oil embargo of 1973 on coal and uranium prices in the United States have been quite dramatic.

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* The Natural Gas Policy Act, which became law in November 1978, greatly changes U.S. gas pricing policy. It extends federal price control to the interstate market for the first time. It will also allow steady rises in the price ceiling for natural gas. New natural gas will be decontrolled in 1985. – ED.

Postscript

The United States is the most energy intensive society in the world. After reviewing in a critical way the weaknesses of American energy pricing policy this fact might surprise some. Upon further reflection, it might be concluded that the weakness of American energy pricing policy may be a partial cause of the greater energy intensiveness of the American society. American policymakers must try to learn how societies in which energy has been far more scarce, have developed sensible, comprehensive rational energy pricing policies. Efforts are being made to learn from the experiences of other countries. It is hoped that other countries, which look with envy at the high level of U.S. per capita income, will not try to imitate these foolish pricing practices, only to see the United States institute different and more rational practices.

D Models for Management of Energy/Environment Systems

INTRODUCTION*

A model is always a simplified representation of reality which reflects the status and the interest of the modeler (or of the person in charge of the modeling). Thus, one finds purely cognitive (descriptive) models, meant to improve one's knowledge of reality (physical, social, cultural), as well as decision (prescriptive) models which help a person or an institution make the best possible decision. Even in the same sphere of decision-making, the final decision varies according to the status, the functions, the temporal horizon, and point of view of the decision maker.

In dealing with energy matters, for example, one usually distinguishes between (1) the corporate models which help in choosing a sales strategy or a long-term investment strategy in a given market (coal, oil, natural gas, electricity), and (2) the public planning models of a governmental authority which identify the difficulties that could arise if the firm's strategies prove incompatible with the plans of the government.

From one nation to another (the United States, the German Democratic Republic, France), the structure of economic decision making (in other words, the totality of relations which connect centers of power) varies. One state may limit itself to indirect monitoring of the activity of firms, whereas another state actually determines the objectives to which the firms must adapt their programs. In this case, the scope of interaction between firms and the state can correspond to the boundaries of the studied region; in another case it can greatly exceed these boundaries.

These few considerations imply that no evaluation of a model can be made (except an evaluation of its internal coherence) without referring to the *objectives* and the *resources* of the authority in charge of the model. With reference to a given region (the state of Wisconsin, the GDR, or Rhone-Alpes), the relevancy of a decision model increases as a function of the self-governing capability of the region.

The IIASA comparative study provided an opportunity to appraise and compare

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* The Introduction is taken in part from Martin and Finon.[20]

energy system models in three regions with greatly different socioeconomic characteristics and institutional structures. This comparison was valuable to each region not only in assessing its potential use of models from other regions, but as an indication of how models are tied to the policy objectives and characteristics of a region. Although each region employs a large variety of models, only the major *system-wide* descriptive and planning models were appraised. Sectoral and operations models were excluded as were site-specific models for locating and designing energy facilities. A review article is available in which a great number of energy models are cataloged and summarized, including additional models in the three countries.[2]

The following section presents descriptions and appraisals of the system models. Each of the three collaborating institutions described its own set of energy/environment models; and each appraised the models of the other two groups from the perspective of its own system and methodological requirements for planning and policy analysis. For example, the Wisconsin group identified the types of information it desires and examined whether the French models treat these areas adequately. It must be emphasized that the groups had limited descriptions of the models that they appraised. The appraisals are not detailed and there was no opportunity for misunderstandings and inaccurate interpretations to be corrected. Nevertheless, the participants felt that the procedure was a valuable one and contributed to finding new directions for each of the collaborating research groups.

I. THE GERMAN DEMOCRATIC REPUBLIC

I.A. DESCRIPTION OF THE MODELS

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The energy sector of each country is one of the national economic subsystems which have a direct and considerable influence on the growth rate of the national economy and the increase of the national income. Therefore, it is a permanent objective to continually provide a rational basis for the provision of society with a demand-determined supply of energy. A tool for the proper achievement of this goal is the application of mathematical/economic models for optimization of the energy sector with consideration of national economic constraints. It is in the interest of society to include the largest possible system in the optimization models. According to the current level of our understanding, that kind of objective can be achieved only with mathematical/economic model systems which consider all essential economic, technological, and technical parameters, and to a limited degree, also political/economic influences.

I.A.1. Previous Developments in the Application of Mathematical/Economic Models for Long-Term Planning

In the GDR, mathematical/economic models for mid- and long-term planning have been applied with success in the energy sector for many years. From this experience, it has been recognized that the optimization of economically important subprocesses can actually only be achieved through the minimization of costs in the entire national economy. However, in the use of mathematical/economic models, only limited possibilities exist to characterize the total national economy in the necessary depth and quality. Therefore, an energy sector submodel was developed, taking into account the crucial national economic constraints. The energy sector was not built up as an administrative/technical unit. It includes all essential processes of energy supply and conversion, energy transport, and the industrial and nonindustrial energy uses, as well as the total import and export of energy over a long time period.

In the initial stage of the application of the models it was not possible to include the energy sector comprehensively in one model. Splitting energy use into industrial and nonindustrial processes could not be achieved. Included in a central model, however, in one relatively complete aggregation (but sufficient for central national planning and decisions) were all essential facilities of primary petroleum processing, heat and electrical energy production, coal mining and coal processing, the production of city gas and the preparation of natural gas, as well as the importing of solid, liquid, and gaseous fuels. As an economic objective function, the minimization of social costs was used. The model brought together the following aspects:

- The development of demand as a function of time
- The sequence of investments
- The time-dependent occurrences of investment and plant expenses
- The variable load-factor of the plants in successive periods of time
- The economic necessity for prematurely closing down existing plants
- The change in the technical/economic indices as a function of time
- The development of technology in successive time periods and the constant modernization of equipment according to the latest technological innovations
- The economic/dynamic view of the selection of plants considering the mutual influence of plants available at different time periods; i.e., the influence of earlier plants on those built at a later time, and vice versa
- An appropriately concise presentation and grouping of the primary energy production and energy conversion plants as well as the primary energy resources of the country
- The interdependency between the plants of the energy sector
- Necessary economic restrictions

The time period considered extended 15 years from the end of the current 5-year plan and was divided into multi-year sections of unequal length. As soon as this model had been found reliable in practice, models for the individual branches of the energy sector (e.g., coal mining, the gas sector, the electricity and heat sectors, and primary natural oil processing), were developed according to the same principle. A separate model was built to optimize that part of the energy demand in which a substitution of fuels is possible and which is important enough for an optimization. These models were used independently of each other for optimization of single branches. Although the results of the submodels gave deeper insights into the structure of the single branches, it was not possible to combine them in order to obtain balanced results representing the optimal solution for the energy sector as a whole. Therefore, a system of models was developed for linking the already existing models, thus making them a tool for analyzing the whole energy sector.

I.A.2. Construction and Application of the Central Mathematical/Economic Model System of the Energy Sector

For the construction of a model system, it is assumed that the combination of the advantages of all the branch models leads to a super model, which in practice cannot be managed. A method which would allow coordination of the submodels of the branches is therefore searched for. A central coupling model system is being developed that, in its entirety as well as inside each single model, complies with the same demands as the central model of the energy sector. The basic assumption for the harmony of these single results is the uniformity of all submodels with respect to the type of model used, to the objective criterion including its concrete form of application, to the time period under consideration and its subdivision, as well as to the structure of the nomenclatures. In addition to this, it was decided to give increasing importance to the regional aspect. With this goal in mind, the construction of models of the complex regional energy supply for regional units of the country is necessitated. In these models all quantities that can be influenced on a regional basis are optimized. Results for subregions had to be obtained as soon as possible, with the personnel and experience available.

Therefore the construction of the model system was planned to be done in two stages. The first stage contains (1) the modification of the individual branch models and the energy demand optimization model in such a way that they could be coupled, and (2) the creation of an appropriate coupling algorithm and the testing of this model system in the practical planning activity. In the second stage it is planned to elaborate step by step, complex regional models for political units of the country and selected cities and areas of industrial agglomeration, and seek to prove this by check calculations for selected cases. It was agreed that the step-wise designing of the single regional models already begins during the construction of the first stage and should be continued after completion. Currently, the primary stage appears in the first phase of its practical application, whereas for the second stage, a large part of the regional models still has to be worked out.

The first stage of the central model system consists of four main parts (Figure D.1). They are:

1. The central optimization model, which contains the entire energy sector in aggregated form
2. The demand optimization model, which encompasses the substitution and optimization part of the energy demand
3. The optimization part of the energy sector subsystems, energy production, and energy conversion
4. The coordination model for the direct coupling of the production optimization models of the various subsystems of the energy sector and of the demand optimization model, taking into consideration essential restrictions with respect to the total energy sector

The following strategy is used: In the first step, the energy demand of all economic sectors is calculated with the help of the demand optimization model and other research methods. The results of these calculations are produced in such a way that they can be, without contradiction, immediately introduced into the central optimization model as an essential part of the model. On this basis, the optimal energy supply and plant structure is determined by means of the central optimization model. Both models, when considered as a unit, represent an extended central optimization model. It is possible to reverse the order so that the central

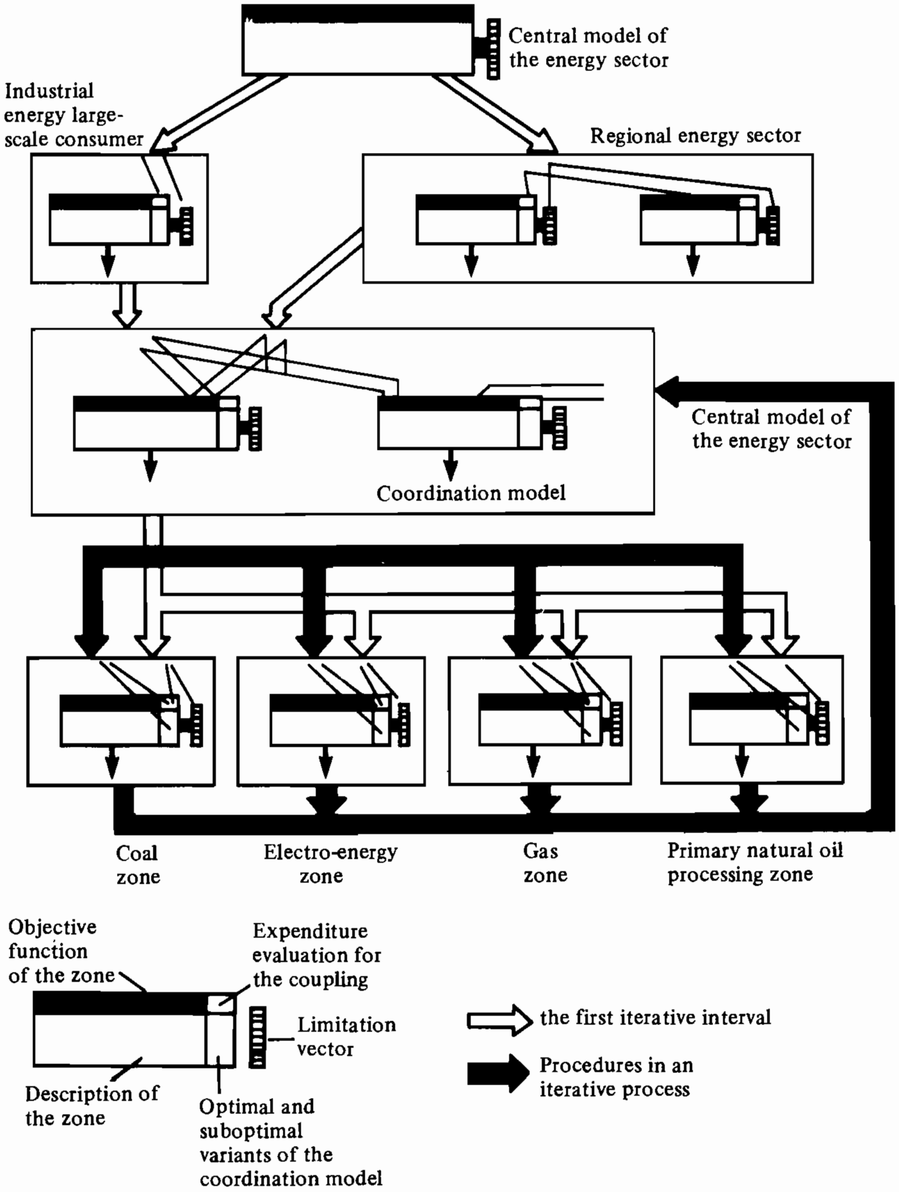

FIGURE D.1 A schematic diagram of the central mathematical/economic model system of the GDR energy sector.

optimization model is first evaluated in order to define realistic constraints for the demand optimization model. In this connection, one cannot say that the first step is the most important.

The first suggestions for the planning of the individual subsystems of the energy sector are deduced from the results of the optimization, and they are presented in the form of indices; each individual subsystem can then start with the optimization within the given limits. The results of these independent optimization calculations then flow into the central coordination model.

I.A.3. Coupling Algorithm for the Coordination of Submodels

Because of the large amount of labor and time that must be spent for the coordination of the submodels, it is necessary to carry out all formal calculation work for the balancing of the individual results and the selection of the optimal structure for the energy sector with the help of a suitable algorithm. Such a coupling algorithm must fulfill the following five basic conditions:

1. It must consistently represent the relevant conditions of the planning system in use and the general interdependency of all energy-producing and energy-consuming sectors.
2. It must be highly practical; in other words, the costs of labor and calculation time must remain within reasonable limits.
3. All variants appearing as intermediate or final solutions must, in principle, be technically and economically feasible.
4. The coupling algorithm must allow a variable application of the single models. This means it must be possible to use each single model either independently or as an integrated part of the model system, without further adjustments.
5. The coupling algorithm must allow for the active cooperation of the planning experts.

A series of "decomposition processes" for the solution of large systems is known from the theory of linear optimization. Their mathematical validity has been proved. Their practical use (applicability), however, is small, particularly with regard to the above five basic conditions. For this reason, a coupling algorithm for the practical control of the model system of the energy sector has been developed in the GDR. As previously noted, a preliminary balancing resulted from using the central optimization model to get data for the energy supply capacities. In this context, all necessary restrictions on the economy must be considered, e.g., import facilities, investing capacities, and the labor market. Considering these limits, possible ranges of energy use are determined both for the regions and for large industrial consumers, and the costs for providing the amount of energy desired are calculated. These structures serve as limits for the application of regional models within the energy sector and for a demand model of the large industrial consumers, and simultaneously prevent the appearance of unrealistic energy demand structures, either in the regions, or from the large consumers.

Using these models, primary optimized energy demand structures and primary energy supply input concepts are obtained within the established bounds. These structures, however, still need to be checked with the sectors of energy extraction. For this purpose the calculated energy demand structures are inserted into the central optimization model:

$$Z = \sum_{j,k,t} c_{jkt}x_{jkt} + \sum_{i,t} c_{it}i_{it} + \sum_{\mu} Z^B_{\mu}p_{\mu} + \sum_{\kappa,\tau} Z^B_{\kappa\tau}p_{\kappa\tau} \rightarrow \text{Min}$$

$$\begin{aligned}
\sum_{j,k} a_{ijkt}x_{jkt} + i_{it} + \sum_{\mu} b_{it\mu}p_{\mu} + \sum_{\kappa,\tau} b_{it\kappa\tau}p_{\kappa\tau} &\geqslant \hat{b}_{it} \\
x_{jkt} &\lesseqgtr X_{jkt} \\
i_{it} &\lesseqgtr I_{it} \\
\sum_{\mu} p_{\mu} &= 1 \\
\sum_{\kappa,\tau} p_{\kappa\tau} &= 1 \text{ (for each } \tau)
\end{aligned}$$

where

Z = value of the objective function (total cost).
c_{jkt} = specific social costs of the energy conversion plant j of the subsystem k in a year t.
c_{it} = specific social costs for the import of energy in a year t.
a_{ijkt} = specific coefficient of either the extraction or the input of the energy form i in the plant j of the subsystem k in a year t.
x_{jkt} = quantity processed in the energy conversion plant j of the subsystem k in a year t.
i_{it} = amount of energy supply i imported in a year t.
Z^B_{μ} and $Z^B_{\kappa\tau}$ = total social costs of the variant μ, which was calculated in the demand optimization model for the large industrial consumers, and of the variant κ, which was obtained in the model of the region τ, respectively.
$b_{it\mu}$ and $b_{it\kappa\tau}$ = demand for energy form i in a year t for the variant μ (large industrial consumers) and the variant κ of the region τ, respectively.
$\hat{b}_{it}$ = energy demand which is not optimized.
$p_{\mu}, p_{\kappa\tau}$ = weight factors ($0 \leqslant p \leqslant 1$).
x_{jkt} and I_{it} = limitation for the capacity of the conversion plants and the energy import, respectively.

To avoid double counting in handling both energy production and energy conversion and use at the same time, a given variant of energy demand must be associated only with the costs resulting from the direct use of the various energy forms. When costs for the energy production are used in the calculations, they must be eliminated from the total cost of the variants.

The calculations of this model provide an initial balanced and optimized energy supply and plant structure. However, since the central optimization model works with highly aggregated indices, it has to be checked with the various sectors of energy supply represented by detailed models. These models contain reference data deduced from the central model for the amount of energy to be produced by a given sector as well as for the costs associated with the energy input. In addition to this it is necessary to calculate for each sector some other variants of energy supply that take into account the given economic restrictions, i.e. upper and lower bounds of capacities that can or have to be used are centrally determined. Within these limits, however, full freedom of choice is given. In this manner, several variants of energy supply structures are created so that coordination with the energy demand structures of the fuel consumers is needed. For that purpose another central model is applied. As opposed to the models which have been described earlier, it consists of vectors describing the output and input of the various forms of energy in the individual sectors. The model, called the "*coordination model,*" has the following form:

$$Z = \sum_{\mu} Z_{\mu}^{B} p_{\mu} + \sum_{k,\lambda} Z_{k\lambda}^{E} \rho_{k\lambda} + \sum_{\kappa,\tau} Z_{\kappa\tau}^{B} p_{\kappa\tau} + \sum_{i,t} c_{it} i_{it} \rightarrow \text{Min}$$

$$\sum_{\mu} b_{it\mu} p_{\mu} + \sum_{k,\lambda} f_{ikt\lambda} \rho_{k\lambda} + \sum_{\kappa,\tau} b_{it\kappa\tau} p_{\kappa\tau} + i_{it} \geqslant \hat{b}_{it}$$

$$\sum_{\mu} q_{st\mu} p_{\mu} + \sum_{k,\lambda} q_{kst\lambda} \rho_{k\lambda} + \sum_{\kappa,\tau} q_{st\kappa\tau} p_{\kappa\tau} \lesseqqgtr Q_{st}$$

$$\sum_{\mu} p_{\mu} = 1$$

$$\sum_{\lambda} \rho_{k\lambda} \leqslant 1 \text{ (for every } k\text{)}$$

$$\sum_{\kappa} p_{\kappa\tau} = 1 \text{ (for every } \tau\text{)}$$

$$i_{it} \lesseqqgtr I_{it}$$

where

$Z_{\mu}^{B}, Z_{\kappa\tau}^{B}, Z_{k\lambda}^{E}$ = total social costs for the variants calculated in the optimization models of the subsystems k ($Z_{k\lambda}^{E}$), of the regions τ ($Z_{\kappa\tau}^{B}$), and in the demand optimization model for large-scale industrial consumers (Z_{μ}^{B}) respectively.

$b_{it\mu}; b_{it\kappa\tau}$ = demand for supply of energy form i in a year t for the variants calculated in the demand optimization model.

$f_{ikt\lambda}$ = variant λ of either the output or the input of the energy form i in a year t through the subsystem k.

$q_{st\mu}, q_{skt\lambda}, q_{st\kappa\tau}$ = extent to which our individual subsystem or region is restricted by the restraint s in year t with respect to the total energy sector or the economy as a whole.

Q_{st} = limit for the restrictions.

p, ρ = weight factors ($0 \leqslant p, \rho \leqslant 1$),

c_{it} = specific social costs for the import of energy.

i_{it} = energy import.

In order to avoid double counting, those cost elements that are accounted for in other sectors have to be eliminated from the cost factor associated with a variant of a given sector. For each sector, the solution of this vector model is balanced and optimized with respect to the total energy sector. The optimal variant may be a vector already calculated by our individual branch model or a combination of two or more of them. If such a "mixed variant" occurs, its technical and economic feasibility must be checked by planning experts.

Because of the high level of aggregation in the coordination model, a renewed application of the submodels of the sectors may be necessary in order to get a more concrete and precise idea of the optimal variant of the central model. Complete submodels are used for this purpose. In order to avoid double calculations, one just has to remove the cost factors for the use of energy provided by other sectors. The limits for an individual model are composed of all variants of energy production and use which already have been calculated for the sector represented by the model. Here the optimal variants determined by the coordination model are also included. Contrary to the conventional practice of linear optimization models, these vectors are incorporated into the decision part of the optimization model. Factors that express the importance of a given variant for the optimum of the entire energy sector are estimated and used to weight the variables. The optimal variant obtained in the coordination process is the most effective with respect to the entire system, when subjected to the conditions that must hold at this stage of the calculations. Therefore, it takes the value zero in the submodels. The use of the other variants results in a deviation from the optimum. The value assigned to a suboptimal variant in the submodels therefore is its deviation from the optimal variant. The "reduced costs" which are obtained by the linear optimization as a dual solution, can be applied as values of the deviation.

$$Z_k = \sum_{j,l,t} c_{jklt} x_{jklt} + 0 \cdot \psi_k^* + \sum_{\lambda} r_{k\lambda} \psi_{k\lambda} \to \text{Min}$$

$$\sum_{j,t} a_{iklt} x_{jklt} + f^*_{ikt} \psi^*_k + \sum_{\lambda} f_{iklt} \psi_{k\lambda} \geqslant 0$$

$$x_{jklt} \lesseqgtr X_{jklt}$$

$$\psi^*_k + \sum_{\lambda} \psi_{k\lambda} = 1$$

where

c_{jklt} = specific social costs of the energy conversion plant l of the plant category j, of the subsystem k in a year t.
a_{ijklt} = specific coefficient of the outputs or the input of the energy form i in a year t of a certain plant and of category j in a subsystem k.
X_{jklt} = quantity processed by the plant l in a year t.
$f^*_{ikt}, f_{ikt\lambda}$ = supply and demand of the energy source i in a year t by the subsystem k; * denotes the optimal variant of the coordination model; λ denotes the suboptimal variable of the coordination model, $f^*_{ikt} \in f_{ikt\lambda}$.
$r_{k\lambda}$ = "reduced costs" of the coordination model for the variant λ of the subsystem k.
$\psi^*_k, \psi_{k\lambda}$ = weight factors.

This technique allows the selection of that structure of a sector which is more effective than the optimal structure chosen by the central model. This is indeed the case when the cost decrease in a specific sector compensates for the cost increase with respect to the entire system that arises from the application of a suboptimal variant.

A second advantage of this technique is that in cases where the optimal variant has been identified by the central model and cannot be realized technologically or economically in its formally calculated structure, there are always alternatives available, along with an indication of their excess economic costs relative to the cost of the optimal variant.

If in one or more individual sectors the process of optimization results in an improved structure of the output of and the demand for energy, the process of iterative approximation has to be combined with a renewed application of the coordination model. The optimal structure of the entire system is found when the results of the optimization for the individual branches are in agreement with the result of the coordination model. The process may be stopped when the deviation between the structure of the entire system and the structures of the individual branches is below a given tolerance parameter.

In practical applications, the number of iterative steps is low. In the calculations performed so far, the number of iterations was between 3 and 4. The fast convergence is due to the structure of the algorithm as well as to the careful balancing before the application of the model system.

I.A.4. Application and Problems of the Model System

The description of the parts of the model system developed so far, and of the yet incomplete areas, have demonstrated that a stepwise procedure has to be followed, not only in developing such tools for preparing decisions, but also in their application. This is important from several viewpoints. No given tool used in the process of planning can automatically be generalized to make a practical algorithm, even if it is highly practical and flexible in itself. This sounds contradictory, but it is certainly true with respect to the application of the models. It takes several years of practical experience for those who run the models as well as for those who have to interpret the results, i.e. the decision makers in the government and the authorities leading the individual branches, to find the right way of dealing with mathematical/economic calculation procedures of this kind. And even this statement is valid only if the right, applicable level of aggregation has been found. The main problem is the correct interpretation of the results of the models. One must be able to extract from the results the essential features of the real world, taking into consideration the various aggregations that have been made to obtain the results and to use them for finding the right decision.

The application of models and model systems should by no means be understood in such a way that, with the help of these modern tools, final plans can be produced by computers. Only by creative processing of the results by experts, can plans and other decision fundamentals be elaborated. These are, however, in every aspect superior to plans calculated in the conventional way, due to the higher degree of balance and optimality as well as to the governing role of the "objective function" which guarantees that subjective elements are eliminated in the planning process. Quite often, teams of scientists or operations research groups are commissioned not only for the construction and application of the models, but also for the definition of the objective function and the interpretation of the results. This is only for the first steps. Efficient decision making is only accomplished when there is close cooperation between decision makers and modelers, and when there is a mutual understanding of the necessarily different ways of viewing the given problems. By merging the two viewpoints the new quality is created which is necessary in getting away from either the complete rejection or the glorification of the new technique; and ways can then be found for its effective use.

The fact that a model system is available does not necessarily mean that one should refrain from the use of its submodels. On the contrary, an effective use of a model is only achieved when it is adapted for the solving of specific problems. Depending on the type of problem and its complexity, either the entire system, a subsystem, or an earlier version may be appropriate in finding a solution. Too much use of a model prevents, rather than promotes, successful utilization, since the optimization itself has to be done in an optimal way. Although the human role seems to be decreasing with increasing rationalisation of work preparation and calculation stage of the evaluation process (which can only be done with use of a computer), still, the creative capacity of humans increases through the possibility of people–machine–people dialogue. This is the case if people understand and shape this process such that they analyze, evaluate, and give directions at various intermediate stages, in other words, in a creative controlling manner. This is possible, but only when one has extensive experience. The simple and efficient coupling algorithm that has been developed in the GDR is especially suitable for this purpose. It provides a tool for controlling collaboration of all branches of the energy sector, which is based on the principle of democratic centralism, and for utilizing extensively the advantages of such collaboration. Previous experience shows that the coupling algorithm is suitable for coupling systems with quite different structures, if the models are adjusted in a consistent manner. From a mathematical–methodological point of view, we believe that it is possible to incorporate the energy sectors of several countries into one model system. The main difficulty in doing this lies in the fact that the economic conditions differ significantly in the individual countries. With the progress of economic integration of socialist countries, increasingly favorable conditions for such coupling will appear inside the Council for Mutual Economic Assistance (CMEA). There is still enough time available for the construction and use of such a hierarchial model system, since the availability of optimization models for the energy sector in the interested countries is a necessary condition. In future work on balancing and optimizing the energy sector, the problem of differing economic conditions should not be overlooked.

I.B. APPRAISAL OF THE GDR MODELS BY RHONE-ALPES

Dominique Finon and *Jean-Marie Martin – Institut Economique et Juridique de l'Energie (IEJE)*

The German Democratic Republic has a socialist economy with centralized planning. The models have, on these grounds, an explicit role in helping to determine the objectives of different branches of production and the standards of household consumption, within the framework of constraints imposed by political factors. Programming tools which permit the optimization of a function under constraints appear to be used; they especially formalize the energy system – one of the areas appropriate for the application of such tools. The future of the economy in a country like the GDR may certainly be more easily controlled and thus is more predictable than the future of market economies, for the parameters for the operation of the entire economy are in the hands of a single decision-making body. The normative approaches correspond explicitly to the objective function of the planning and political bodies; for this reason these approaches have a relevance that is lacking in the market economies. The absence of a market also makes the utilization of planning necessary. Therefore the use of formalized methods of linear programming is of considerable help.

It is thus no coincidence that a great number of optimization models exist in the GDR. They have been applied to the energy sphere both at the level of the sector as a whole and at the level of its component parts; one may find models for the oil, gas, coal, and electricity branches. For electricity there is also a model for the siting of nuclear equipment and a model for the short-term management of electric power plants. For coal there is a simulation model pertaining to the rail transport of lignite and so forth. In the realm of consumption there are two models: an optimization model of energy substitutions for major energy consumers in the industrial branch; and a regional optimization model for the providing of energy to the residential and service sectors by means of hot water for heating.

At a higher level one finds an optimization model for the sector as a whole, as well as a model for centralized coordination. The models developed at the Institut für Energetik in Leipzig (consumption and global models) are interrelated in such a manner that their results are consistent.[1] It is not certain, however, whether the research on branch models conducted at other institutions (Berlin, Vetschan, Schwedt, and so on) has been coordinated with the work at Leipzig, i.e. whether the structure and results of the more specific models are consistent with those of the more general models. It is certain, a priori, that the linear programming utilized in all the models assures a certain unity and homogeneity of conception, especially since most have the same objective function (minimization of costs discounted over a long period of time). But different methods of decentralized planning, inspired by methods of decomposition in linear programming (Dantzig-Wolfes's algorithm of decomposition, for example) also exist. They have been used already (in Hungary, for example), and permit one to ensure that programs situated at different levels of decision-making are consistent (for example, the Kornai-Liptak method).

Available reports and descriptions do not specify the exact relations between different institutions and ministries; they also do not specify the exact role of these models in the development of energy plans in the GDR. It would be interesting to know if the models are operational and sufficiently viable to assist planners at the present time in determining the future objectives of energy production, as well as the evolution of production plants and the consumption of energy. More particularly, it would be interesting to have some precise data on the ease of using the models, on the complexity of the information systems utilized, and on their sensitivity to the modification of parameters.

In any case, the GDR seems to have one of the most extensive experiences with energy modeling in the world, at least with optimization models. This type of experience is perhaps not generalizable to countries with market economies, at least not to those in which national planning is undeveloped (the United States, and the FRG, for example). However, it is possible to imagine the use of models in France, Italy, or England, where planning methods (seeking to minimize the costs to the society as a whole) are inspired by neoclassical theory. It is true that major difficulties impede the use of such models in energy sectors in which most enterprises are private – their opposition to all planning is absolute. At the very most, they confront government objectives that conflict with their own, and eventually get them modified so all the objectives are in harmony. France provides us with proof of this, for there the outcome of a plan has become more and more removed from objectives defined five years earlier – in proportion to the increasing power of the international oil oligarchy.

Thus, from an institutional point of view, public agencies may have difficulties in using such models. A further consideration is that the use of several of the models leads to problems of data collection, which should not be underestimated. In particular, the optimization model for substitutions of different forms of energy developed by the Institut für Energetik* would necessitate a survey of all production plants in the sectors under consideration, in order to enumerate existing equipment and to determine the method of utilizing energy. Such a survey also necessitates very precise information to which it is difficult to obtain access.

This type of model may be utilized in market economies, however, to determine the structure of production and consumption of energy which would be most efficient for the society. This does not signify that the market and state regulation would permit the attainment of ideal results. Moreover, the models may be utilized for more forecasting purposes, by using the coherence of the normative approach to explore possible energy futures. In particular, this type of model may aid in studying the future of new technological processes or new sources of energy (hydrogen, solar energy, geothermal energy, the heat pump) in order to guide investment in research and development.†

It is interesting to see the very great similarity between the ENERGIE model of the Institut Economique et Juridique de l'Energie (IEJE) and the models of the Leipzig Institute,‡ although the former is less perfectly formalized than the latter. The philosophies of the two studies are identical at the level of the analytical approach to the production and consumption systems and at the level of the modeling technique used (linear programming, minimization of cost discounted over a long period, and so on).

It should be made clear that all possibilities for this type of tool have not been used in the GDR; indeed, such models permit the consideration of environmental impacts, and possibly the associated damages, in the form of social costs or of constraints on the limitation of environmental disturbances. (Only the model which deals with the siting of nuclear power plants in the GDR considers this aspect). This might be explained by the fact that concern for the preservation of the environment seems to be, for the present, less frequently expressed in socialist countries than in market economies. In regard to other political objectives, one assumes quotas on the import of fuel produced by the Council for Mutual Economic Assistance (CMEA) and other countries, as well as production goals of other economic sectors which determine energy demand (goals based on the general plan). This method of taking into account political objectives of governments in energy matters may not be directly applied to market economies because of institutional differences.

In conclusion, from a formal point of view the GDR models may be utilized in

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* Study cited in J.P. Charpentier, p. 61.[2]

† This prospective type of model necessitates a time horizon of 25–30 years. It is difficult to transpose this distant horizon to socialist economics, for there the majority of exogenous parameters depend on public decision-making bodies, which impose their own 15-year horizon. The less rigid market economies have greater uncertainty associated with them that permits more flexibility in the choice of a time horizon.

‡ This may be explained by the fact that the GDR models are (or should be) inserted more or less directly into the planning process.

western economies without much adaptation, if the needed data exist. If they are utilized for planning purposes, they cannot help but raise certain problems between private firms and public agencies. Their main use could be in exploring futures because they give much coherence to energy planning. On the other hand it would be interesting to analyze the reasons why so few methods other than optimization are utilized in the GDR.

I.C. APPRAISAL OF THE GDR MODELS BY WISCONSIN

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It is important to note that the GDR efforts can be described as primarily aimed at long-term planning activities with emphasis on the energy/economy (as opposed to the energy/environment) relationship. As such, they combine demand projections, technological development estimations, and investment planning in a system that allows for analysis of alternative growth strategies. Although it would appear that there are energy-related environmental modeling activities going on in various institutions and planning organizations in the GDR (including the Leipzig Institut für Energetik), these models have not been integrated into the central energy planning models of the GDR. Consequently it is quite difficult to determine the manner in which environmental consequences and strategies enter the modeling and planning process.

The complexity of the energy/economic modeling requirements is demonstrated by the size of the GDR modeling activity and the need to use a decomposition routine for solution. Although this presents no insurmountable computational barrier in Wisconsin, it does create a somewhat more complex modeling problem in a system where centralized planning activities are the exception rather than the rule. This stems from the fact that with decentralized decision making, even if an optimal (whatever that is) plan could be structured, it would be difficult to accomplish implementation. Further, it would probably be nearly impossible to achieve the participant–model–participant–model interchange necessary to solve such a large model in a society where decision-making responsibility is fragmented to the extent it is in Wisconsin. Also, it is difficult to conceive of a univariate objective function similar to the cost minimization objective employed by the GDR which would be appropriate for such a model applied to the Wisconsin socioeconomic system. Given the mobility of many major sectors of the Wisconsin economy and the fact that Wisconsin's systems are a subset of the broader energy/environment system of the United States, a considerably more complex objective function would undoubtedly be required in an optimization routine similar to that utilized in the GDR. It would also appear difficult to construct objective functions which would include in a comprehensive manner the environmental considerations which strongly influence Wisconsin energy planning through the process of public hearings and procedures.

However, in spite of these limitations, the GDR activities provide substantial benefits for energy/environment modeling in Wisconsin. This stems from the high degree of integration involved in the modeling activities. The GDR has advanced far in examining and modeling the significant interrelationships between the various sectors of an economy. This integrated analysis provides a clearer picture of the trade-offs across the total energy sector and, hence, a more complete and accurate statement of the alternatives available to the decision makers.

The GDR experiences in these areas as reflected by their modeling approach provide much needed insights for the modeling activities of Wisconsin. The need for integration is strong, irrespective of whether one can employ an optimization procedure for systemwide decision making or must limit the modeling activities to analyzing the impacts of the behavior of various participants in the system. Also, even if a centralized modeling activity such as that employed by the GDR cannot be used as the primary decision tool, it does provide a means for both analyzing the degree of efficiency associated with projected activity patterns of participants in a socioeconomic system and for assisting in the development of policies aimed at providing signals for those participants which will lead to activities which are consistent with maximization of social welfare.

In addition to the very broad issue of the transference of the GDR modeling methodologies, it is possible to examine specific aspects of those models and activities as they relate to the question of adaption to the requirements of a Wisconsin energy/environment modeling system. In the area of demand analysis, it is difficult to visualize how the GDR system of developing a plan for future economic activity could be adapted to a market-oriented system such as exists in Wisconsin. Not only does such planning fail to account for the basis of consumption decisions in a market economy, but more importantly, its deterministic structure also introduces a serious inability to analyze the sensitivity of policy decisions to the stochastic realities of the system. This shortcoming, while serious in a planned economy, would be very deleterious for planning in a market economy where variation from the expected is the rule, and analysis of the impact of such variation on policy alternatives often provides the basis for selection of one course of action over others.

The shortcomings of the GDR demand projection techniques notwithstanding, their efforts in this area related to conversion of final product demands to energy requirements through the use of technical process coefficients appear to hold interesting possibilities for use in energy demand projection efforts in Wisconsin. That is, once a set of final demands for Wisconsin's industry has been estimated, the GDR activities in developing process energy-intensity coefficients should prove useful for converting those demands to energy requirements. This conversion is extremely important in a state like Wisconsin where energy requirements will undoubtedly play an increasingly important role in determining the future structure of the industrial sector.

Another area where the GDR activities might prove useful for energy modeling in Wisconsin is in utility investment planning. Both the individual electric utilities and the Public Service Commission in Wisconsin need an integrated planning approach in order to optimize the additions of new generating, transmission, and distribution facilities. The linking of industry with the entire energy sector in the GDR model provides a means of approaching this integation. If in addition it proved feasible to include regional environmental constraints explicitly in that type of model, the approach would be of considerable interest to Wisconsin energy modelers and planners.

II. FRANCE

II.A. DESCRIPTION OF THE MODELS

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As has been stressed in section II of Appendix B, economic and, in particular, energy activities in the Rhone-Alpes region do not constitute a self-contained economic system, since the institutional and economic structure of France is very centralized. Moreover, there are no energy models adapted particularly to the Rhone-Alpes region. The majority of the models which do exist represent French activities in a centralized manner. Therefore, national rather than regional models will be the focus of this section.

II.A.1. Models of Decision Making

The majority of these models are very specific and are relevant to operational research or the simple administration of enterprises.

The Oil Branch Models[2] At the branch level, various oil companies have elaborated:[3]

- models which optimize the administration and the operation of a refinery, taking into account its technical characteristics, the quality of oil supplied to the refinery, and the production program imposed by company headquarters, and also taking into account the company's market in the area of the refinery. In order to do this, the variable expenses (the buying of crude oil, utilities, and various products) are minimized as given objectives of production; the specific characteristics of products are also taken into account, with the assistance of programming techniques.
- models of transport and distribution which minimize the transport expenses, as well as models of the availability of different oil products taking into account the siting of refineries, of departmental storage places, and of main areas of consumption. These models are most often regional and also use programming or variational algorithms.

Much more general and global models exist, which attempt to optimize the strategy of oil companies by planning their investments in exploration, refining, and distribution, and by optimizing their strategy of acquiring markets (fuels, light products, and so on). Again, it is necessary to remember that half of the French oil market is controlled by multinational firms whose investment policy depends on the strategy of all the other multinational firms. Strategic models do not exist at the national level in these branches.

The Gas Branch Models Except for the models that optimize the management of a gas pipeline, taking into account the possible growth of different regional markets and the availability of gas (national resources, import contracts), and the models for the management of reservoirs with underground storage in order to handle peak demand, few models for gas have been developed in France by Gas de France.

However it should be mentioned that different methodologies have been utilized in place of formal models, either to analyze the competitiveness of gas, or to help in choosing investments.

To analyze competitiveness, the markets for gas have been studied case by case by considering the different domains where it is usable and/or used;* one determines an equivalent price for gas from the price of a competing fuel, taking into account the profit of utilization, costs of equipment, and costs to gas users. To help in the choice of investment, Gas de France studies the profit of investment projects; with the help of a criterion, it determines from a multitude of profitable operations (in other words, those for which the rate of profit is more than the rate imposed by public power) those which produce the best forecasted financial result.[4] It is in effect necessary to cut down on less profitable projects because investment credits granted by public authorities are limited.

The Electricity Branch Models This branch has been an object of particular attention on the part of the modelers: the first linear programming models used in France were developed in 1954 by Electricité de France (EDF) for the purpose of choosing electrical investments. Since this time, the company's researchers are making progress in utilizing new computational techniques (nonlinear programming, dynamic programming, the theory of optimal control, and so on). We would like to point out that very specific models exist such as those for optimizing the nuclear fuel cycles,[5,6] for optimizing the network of electricity transport, and for maximizing the reliability of this network.[7] But it is appropriate to dwell upon more general models, in particular on models for demand forecasting and for choosing between electricity investments.

The models for forecasting electricity demand used by EDF are relatively simple and based upon extrapolation of past trends, using statistical relations of the simple or multiple regression type.[8] These relations (generally logarithmic) are used to calculate the quantities of electrical energy at the global level (or at the level of highly aggregated sectors such as the residential, service, or industrial sector) at time t:†

$$\log C_t = a + b \cdot t$$

or the models relate quantities of electrical energy to economic activities as represented by an operational economic index of the gross national product (Product National Brut or PNB) or industrial value added (Valeur Ajoutée Industrielle or VAI):

$$\log C_t = a + b \log PIB_t.$$

Forecasters at EDF have concluded that these models provide the best results and that all efforts to associate electricity consumption with other variables (such as the relative price of capital, of labor, or of fuels as compared with electricity in industry, or such as income and/or the number of households in the residential and commercial sector) prove to be unsatisfactory.[9] It is necessary to point out that this econometric approach assumes that the consumption of electricity is inelastic with respect to price, and that the market for electricity has developed in a relatively autonomous manner in a specific domain. The new commercial strategy of EDF and the great increase in the price of petroleum products, however, makes compartmentalization of markets impossible for different types of energy and makes these

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* Some specific domains are tubular boilers, different types of drying, and the baking of clay.

† Aggregation may be according to low and high voltage consumption.

methods more subject to criticism. At the present time it is necessary to supplement econometric forecasts with the commercial objectives of a firm; further the forecasts must be supplemented by various scenarios for the future. One could never completely discard methods of extrapolation, but beyond a horizon of five years, such projections should be used with much caution.

In addition, a short- to medium-term forecasting model of the daily load curve is used to define the output power according to the hour, the day, the week, and the month, by extrapolating various coefficients which characterize important parameters.[10]

Let us now consider the models for the choice of electricity investments. An extensive bibliography exists on this subject.[11, 12, 13] These models minimize in the long run (1975–2000) the actualized costs of electricity production over a long period of time, in accordance with given production objectives. These objectives are determined by projections of total electricity demand that are worked out (1) with the aid of the econometric models discussed above, and (2) by a representation of this demand by means of weekly load curves. The different types of equipment for electricity production, incuding hydroelectric equipment, are explicitly taken into account and are characterized both by their capacity and by the services they are supposed to render (in other words, their functioning during the different hours of the load curve, taking into account their availability). The risks associated with hydropower and hourly electricity consumption are taken into account with the help of probabilities established from past samples; these permit one to take into consideration possible failures of the production system.

The actual model* uses the theory of optimal control. The objective function of minimization is a function of cost composed of three terms (investment, operating cost, and cost of failure†). The control variables are the quantities of equipment to be installed year by year, and the constraints express an obligation to satisfy future demand as well as the forced (or limited) development of certain types of equipment. The algorithm has two parts: first, the control variables are determined and then the optimal management for equipment of given power is defined. The program allows one to obtain an optimal equipment plan at the national level, the duration of the economic life of equipment, the probability of failure, the marginal costs of production of a kilowatt-hour (according to the hour, day, and month) and values in use. The marginal costs which have thus been determined serve to establish electricity tariffs. In order to do this, one adds to them the marginal costs of transport and distribution calculated elsewhere and a "toll" which permits the EDF to attain a budget equilibrium and even to possess an appreciable self-financing capacity.[15, 16] The values of use determined by the model aid in the comparison of individual hydroelectric projects with reference equipment (for conventional thermal or nuclear energy) serving the same purpose in order to study their profitability.‡

These models of investment choices are particularly complex because the system of French electricity production is a mixed hydropower–conventional thermal (or nuclear) energy system.§ This necessitates a rather detailed representation of the management of hydropower equipment (water flows, locks, reservoirs, pumps)

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* Called the "new national model of investment."[14]

† The cost of power failure is a nonlinear function increasing in relation to the duration and the amplitude of the power failure.

‡ This decentralized procedure is called the "Blue Note."[17]

§ The models use nonlinear programming.

during different hours of the year, taking into account the daily, weekly, or seasonal carry-overs which are available. In the model now in use, a submodel simulates the management of the electrical capacity in such a manner that the diagram of the weekly (or monthly) load of the conventional thermal capacity is as flat as possible. It is necessary to stress that among the evolving models of investment choices only the model "Investments 85" constructed in 1965 was disaggregated into five regions; the Rhone-Alpes region, together with the Mediterranean–Cote d'Azur region, constituted the southwest region of this model. The southwest region was linked with other regions by variables describing interregional exchanges. The objective was not to specify transport equipment, but rather to try to outline a preliminary scheme for the localization of production equipment, taking into consideration the location of hydropower resources and consumers.

It is necessary to point out that these investment models only deal with private costs and, in no case social costs such as the degradation of the environment arising from atmospheric or water pollution, or from land use. In other words, not a single environmental constraint has explicitly been taken into account. From a practical point of view, for example, these models have never explicitly integrated the choice of siting for electricity installations since almost all the models have not been modified for individual regions.* In France, where there are only a few rivers whose flow is sufficient to safely support the installation of numerous sources of thermal pollution, the problem of cooling prevails over transport expenditures when choosing the siting of central thermal installations.

Consideration of environmental impacts, however, has not been excluded from the concerns of EDF. These include harmful effects of radioactivity, noise, and oscillations of electrical or radioelectric origin, and other harmful effects causing changes in the air, water, and ground. Ecological problems have been evaluated with reference to a group of factors from fields as varied as physics, medicine, biology, or psychology. Some of the elements are purely qualitative or subjective and have been taken into account because of judgments or explicit or implicit choices made by alert citizens who are presumed to express the attitudes and the aspirations of the community. The evaluation of the relative importance of ecological problems posed by different production installations has been calculated using a single unit by means of "ecological points." Seven types of ecological problems have been catalogued for reference plants, e.g. 600 MW units in conventional thermal plants. Then, for a given type of ecological problem, the present value of impacts brought about by different techniques has been calculated. Finally using a comparison between the different types of impacts with the help of a preference function,† the total value of impacts of different installations has been calculated in terms of "ecological points." Consequently, one can evaluate the ecological gain of each action undertaken to reduce harmful effects to the environment. With this technique, one can also obtain an implicit evaluation in monetary terms of an "ecological point," an evaluation which will, however, remain more or less inexact. There is no room to dwell further upon this approach to environmental problems which, in fact, is not directly related to the EDF's models of investment choices.

At the sectoral level, no comprehensive decision model exists which is designed

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* The regionalization included in the model "Investments 85" was not fine enough to permit this problem to be taken into consideration.

† This function of preference expresses the level of concern attached to each category of harmful effects and is based on subjective considerations (acceptable levels of change in the natural environment, quality of the atmosphere, and so forth).

to influence the decisions of public authorities or of organs close to those. This applies, too, to the regional energy system. Previously, a method of energy planning did exist and it was used within the framework of the IV French Plan (1961–65) and V French Plan (1966–70). The method included an informal model which permitted one to determine how France could be supplied with energy at the lowest cost, taking into account the objective of having a reliable supply. But this method was abandoned in 1970 at the time of the conception of the V Plan, for the public authorities no longer had command over the energy system.

There is also a simulation model for the financing of the energy sector which permits one to forecast from 1970 to 1985 (or 1990) the medium- and long-term consequences of changes in energy policy (tariffs, taxes, investments, regulation)* for the financing, employment, and annual investment needs, and the budgets of enterprises in the energy sector.

The Cognitive Models Very few efforts have been made in France to study the French energy system with the help of models in order to better understand the system and to explore its future effectiveness. One may take note, for example, of the scenario method; it permits one to reduce the complexity of the system studied through the selection of the most important factors, and to trace different scenarios for the development of nuclear energy up to the year 2000.

At the Institut Economique et Juridique de l'Energie (IEJE) Grenoble, an optimization model for the energy sector has been developed without any ties to the public authorities.[18, 19] It does not, in other words, serve directly to help the sectoral decision makers. Its goal is to test the reaction of the French energy system to modification of its political and economic environment in, for example, the

- Price of oil
- Cost of nuclear facilities
- Development of certain technologies
- Policy of preserving the environment
- Policy of making the supply of energy secure or of limiting oil dependency

The model uses linear programming to reduce all the quantified costs of investment and utilization to satisfy energy demand; at the same time the model considers utilization expenses over the period 1975–2020. The activities in the energy sphere are approached in a centralized manner; France is considered as a whole.

The system is described by means of a network in which the nodes represent economic operations (extraction, import, processing, transformation, transport, consumption) defined as all energy-related activities in the French territory. It integrates the consumption of energy with possibilities for choosing between the different forms of end-use energy. In its current version, only SO_2 emissions have been taken into consideration from among all negative influences on the environment, but the method of formalization could easily be extended to other types of environmental impact.

The model chooses between the different processes for producing different types of energy on the basis of minimizing the cost while satisfying demand and conforming to various political constraints (limitation of dependence on oil, possible acceleration of the nuclear program, limitation of the levels of emissions, and so on). The variables of the model are, in other words, the flows through the pathways of

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* FINER's model constructed by D. Blain at the Ministry of Economics and Finances, No. 1972.

the figure during different years (variables of exploitation) and the equipment capacities to be created in the future (equipment variables). The different parts of the model are then composed of a subsystem of consumption and a subsystem of production.

The Subsystem of Consumption Demand is partly endogenous to the model. In addition to the sector's own consumption, the consumption to be satisfied is disaggregated into three groups of consumers (industry, transport, domestic furnaces), nine types of final energy (coke, coal, gas, electricity, motor fuels for the transport systems, napthalene for chemistry, domestic fuel oil, fuel oil with a high sulfur content, and heavy fuel oil with a low sulfur content). One also distiguishes between two types of use, substitutable use and unsubstitutable use. Substitutable use is characteristic of heating where there is competition between different forms of energy. One considers various domains in which the characteristics of the competition between types of energies are different (use of steam and ovens in industry, heating of individual homes, and collective heating in the residential sector).

Suppose c is a group of consumers and

ϕ = a form of final energy.
$x^1(\phi, c)$ = the flows of this form ϕ directed towards unsubstitutable use.
$x^{11}(\phi, c)$ = flows directed towards thermal use.
$r(\phi, c)$ = the profit from utilizing ϕ in the equipment of the consumer.
$D(\phi, c)$ = the specific energy needs of the consumer.
U_c = the consumers' need for useful thermal energy.
$T(\phi, c)$ = the initial capacity of the energy-using equipment of the consumer for thermal purposes.
$X(\phi, c)$ = the capacity created between the starting date and the date under consideration.

Constraints on satisfying the energy demand are:

$$\text{specific needs:}\quad x^1(\phi, c) > D(\phi, c) \text{ for all } \phi$$

$$\text{substitutable needs:}\quad \sum_{\phi} r(\phi, c) \cdot x^{11}(\phi, c) \geqslant U_c$$

$$\text{capacity constraints:}\quad x^{11}(\phi, c) \leqslant T(\phi, c) + X(\phi, c)$$

The objective function of this subsystem is a part of the objective function of the total system and includes the cost of the equipment utilized and the expense of purchasing energy. We should stress the fact that the model integrates possibilities of choice between energy types at the level of final consumption, parallel to the concentrated decisions of the energy production system. The representation of substitution between energy types has nothing to do with price elasticities of consumption, the use of which is critical in every long-term model.

The Subsystem of Production The model connects different subsystems of production (coal, gas, electricity, and oil). One can show with the network the interdependencies between operations and the ways of managing the equipment installations, e.g. the contribution of electrical equipment to the various hourly positions of the load curve, taking into consideration the different types of crude oil and different degrees of distillation. In the new version used at the present time, the model integrates low enthalpy geothermal and solar energy for the heating of buildings and the recovery of the heat from power plants.

Optimization permits choices to be made among

- Energy forms in the different competing domains
- Processes having different capital requirements
- Types of energy to be imported and types of energy which should be locally produced
- Various degrees of pollution production and the consumption process*

It is thus possible for the years 1975–2020 to obtain calculations of (taking into account the values of the different parameters):

- The balance of primary energy
- The national or disaggregated balance of final energy consumption
- The supply of equipment for production and consumption
- The activity of the various plants
- The increase of investments necessary for the adaptation of the energy capacity
- The needs for currency necessary for import of fuels
- The total expenses from year to year (whether realized or not)
- The emission of pollutants considered in the model

This type of model, which by no means replaces the decision makers, would permit an analysis of the rigidity of the energy structure, the competition between energy types in the various domains where competition exists, and possibly their margin of operation. This is the ideal tool for obtaining some idea of the future of an energy type or new technology (for instance, solar energy, geothermal energy, hydrogen, or recovery of heat from power plants) 15–25 years from now.† In the

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* The limitation of emissions is developed at the national level in France. Such a procedure may seem unreasonable especially if only a single impact is considered. However, at the national level, one can fix thresholds of emissions or of waste materials which may not be exceeded, and which would be defined in such a way that the harmful effects observed by individuals would be at an acceptable level in the most polluted geographical sectors. See on this subject, D. Finon, "Evaluation of the Costs of an Environment Protection Policy on the French Energy System" in *Energy and Environment* (Paris: Organization for Economic Cooperation and Development (OECD), 1974, pp. 239–273).

† Others have a much more normative concept of this type of tool and would like to use it to calculate the optimal distribution of the various energies and to deduce optimal prices and tariffs (with the help of dual variables) which allow the guiding of the consumers' choice in the best way for the society. We prefer to give a more exploratory function to this type of tool.

The model in its new version is actually used in a very pragmatic manner in the energy sector of nine countries of the European Economic Community (EEC), with the help of a network general enough to be applied to each. The goal is to calculate at the same time the annual needs for investments and currency until 1985 and to trace various energy futures up to 2000–2020, taking into account the values of the parameters. One foresees the further study of the compatibility of the local optimum with the national optimum of the nine sectors that are integrated.

future the model will be reviewed to study specifically these new energies and techniques; it will also be improved at the level of the consumers by a disaggregation that is more driven by the type of use and other factors.*

This type of model can be (and will be even more so in an improved version) a good instrument for analyzing the three fundamental elements of the energy policy:

- the energy economy
- the development of national resources
- the choice of the sources of import

with the aid of various criteria: the lowest cost for the community (taking into account the financing problems), the least economic dependency on other countries, the reliability of supplies, and finally, the limit of ecological consequences.†

In summary, no specific models exist in the Rhone-Alpes region, but there are models covering all the French activities in one branch or one sector. This is mainly due to the institutional and economic centralization of France.

Among the existing models, the most numerous are decision models covering one branch and, for a particular branch, those using well-specified methods. They utilize, in general, optimization techniques. At the national sector level, the only formalized model that exists is without a real tie with the centers of public or private decision making.

II.B. APPRAISAL OF THE FRENCH MODELS BY THE GDR

Peter Hedrich and *Dietmar Ufer – Institut für Energetik*

France is a country that is setting the pace on the international level in the field of mathematical/economic model application for the optimization of long-range planning of large-scale energy systems. The activities performed by Electricité de France in this field provide good examples.

It can be said that the trend of activities by the "base," i.e. in the individual branches of the energy industry, has followed EDF's lead, and resulted in advances on problems of the development of the structure of systems and energy suppliers, economy and financing, and to some extent of environmental control. Significant arrangements with the consumers have also been established.‡ A model or model system covering the overall energy industry of the country was not developed for planning purposes by France because of the existing social conditions, and the diverging interests of the individual enterprises and monopolistic groups on both the national and international level. Even the individual branches, such as those of

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* In connection with the research developed at the Institut Economique et Juridique de l'Energie by B. Chateau and B. Lapillonne on a prospective basis (by systems analysis of the energy demand in the year 2000), this demand was studied from an analytical point of view in the consumer's sector, taking into account present and future technologies.

† The reduction of the foreign dependency, by the development of national resources and the energy economy has strong limits resulting from the criterion of cost minimization.

‡ The great variety of models for the operational control are not dealt with here.

electric power generation, do not apply nationwide models due to the fact that there was no undertaking of a completely monopolistic character.*

The awareness of these circumstances apparently gave rise to the objective of developing a model system of the energy industries all over the country, a system that permits long-range forecasting of strategic character in

- Application of energy supplies and their selection
- Scientific and technological development and required research and development assignments
- Environmental protection and ecology
- Safeguarding of the energy supply
- Potentials and limits of energy imports

With perfect knowledge of the interdependence of production, conversion, and consumption, the energy application processes could be applied with discrimination in the industrial and nonindustrial activities, and in households. Thus, a key step was taken. If the results obtained from these models are to serve for immediate decision making, it is absolutely necessary to take the obvious measures in the field of economic planning and to see to the situation regarding ownership, both of which have been neglected. The model in its existing form is appropriate to study the effects on the modified strategic elements and the environment, in the sense of business gaming. We are in strong agreement with the fundamental French attitude that statements of importance about regions can be made only incidentally to general consideration about the energy industry.

II.B.1. Model Characteristics

The model serves for planning the structural variables of the energy system in the entire country; it does not carry out technological calculations. It also forecasts the determining quantities of demand and, within the framework of energy technology and national economy, the most convenient technological processes for the energy forms that can be interchanged. Thus, the limits of the system are fixed in response to the actual requirements. The model system is capable of making suggestions for strategic statements about the exploitation of national energy resources, about the most convenient structure and operation mode of the energy conversion equipment, and about the import of energy supplies. The modeled groups of statements are assessed under the present conditions for the activities within the next 5 to 10 years. They appear to satisfy the principal needs with the exception of the analysis of

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* The development in the GDR took place in the reverse direction. In the first half of the 1960s the theoretical bases were being worked out. The starting base was the overall model of the energy industry with its sectors of coal, gas, electric power, oil, and public district heating, as well as imports and exports. In 1967 the National Planning Board adopted this model for application in long-range national planning; the model was also adopted by the Ministry for Coal and Energy. There was a step-by-step development of:

- Submodels in the relevant branches and sectors of energy consumption and supply
- An adequate coupling algorithm
- Regional models for the decisions appropriate to the Bezirks.

These models were adopted into the planning practice. The setting up of regional models will be finished in the near future.

environmental impacts and the possible gaining in importance of the regions. Significant extensions of the model could be achieved, however, if the problems about uncertainty of the input information could be solved.*

The main arrangement of the overall model, submodels of subsystems including the energy application activities, and regional models, matches in its fundamental setup the overall conception tried out during the previous 5 years in the GDR. The substance of the economic criterion, namely, minimum cost for the overall system, is the only adequate criterion in the economic realm; however, its consequences were not elucidated in detail.

The time span through the year 2020 has within it a period that can be accurately modeled. From our point of view and practice, however, we must call into question the application of a conclusive and deterministic model for such a long time span. For such computations, the farthest horizon should be the year 1995, or 2000 at most. This in particular applies to the reliability of the economic input, and the case of multivariant computations. Complex optimization could be omitted for the period from 2000 to 2020. The complexity calculations, however, must still be considered significant for the period 2000–2020. This point is discussed further in section III.B. with respect to the Wisconsin model.

The main characteristics of the French models include real temporal complexity of periods of several years, bringing of the initial condition up to date, grouping of variables according to capacity and employment to capacity, and prevention of multiple assessment. Dealing with the plants available at the start of the period under review, and utilization of mean values for the transport expenditure and environment factors are relatively effective and suitable, from our experience. Certain doubts, at least theoretical ones, arise with regard to the cost trends over the periods of several years. Concentration of investment cost on one item is not advisable in our opinion. The exponential simulation of operating cost can be traced back to the experience gained with monosystems in which such cost can be fully applied. The direct complexity in the matrix block, however, requires linear increase as far as the proportionality between the forms of energy is concerned. Nonproportional economic trends should be represented by their direct causes.

The model could be improved by taking depreciation into consideration. The provision for the comparison of the plants existing at the end of the period under review appeared to be lacking. The constraints applied and the political–economic formulations of questions regarding the resource restrictions and utilization of national resources, appear to match the GDR experiences. The data structures – both inputs and outputs – satisfy the requirements, but some problems arise when making provision for and interpreting the output data. From the standpoint of economic calculation and importance to the energy system, it requires utilization of all accessible national and possibly international scientific capabilities. The model apparently utilizes standard programs for the analysis of results, i.e. sensitivity analyses. Of special interest would have been a description of the programs for efficient command of such models in the preparatory and analysis phases.

We wish to emphasize once again our opinion that any overestimating of the models should be avoided. They must be considered only an aid in making decisions.

In spite of the differences in detail, when approaching the problem in accordance with the method applied, the French model has many similarities to the overall energy models used for years in the GDR. Accordingly, the two tools used offer the potential of a real exchange of experience fostered by IIASA. However, we would

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* Significant work was and is being done in this field in the Soviet Union.

like to underline once again the doubts mentioned above with regard to the barriers and limits of such a procedure with respect to the socio-economic facts. The overall method of solution and its use within the limits of the Common Market, in our opinion, only give way to mere academic reflections if they are not used in national economic decision making.

The bibliography quoted in the French publications used in drafting this analysis,[18, 19, 20] show that the research groups at the University of Grenoble were not fully aware of the level reached in socialist countries. The sources, including those concerning the GDR, are outdated and in no way report fully the level reached. In particular, the publications by the Soviet Union and the GDR, including work by other socialist countries that have applied similar methods, would certainly have been a rich source of knowledge and suggestions.

II.C. APPRAISAL OF THE FRENCH MODELS BY WISCONSIN

Wesley K. Foell – Energy Research Center, University of Wisconsin – Madison; and *James Pappas – University of Wisconsin – Madison*

Although there is considerable centralization in energy planning in France, the private sector plays a significant role and, hence, the energy modeling activities there are somewhat more directly akin to those in Wisconsin than in the GDR. From the French activities it seems that there are several areas in which Wisconsin can benefit from transference of methodologies. The broadest of these is the programming model developed at the Institut Economique et Juridique de l'Energie in Grenoble (IEJE). This procedure holds promise for analyzing not only alternative state energy policies but perhaps more importantly the impact of various proposed national energy policies on the state. Its integrative structure would allow its use for evaluating the energy/environment impact of alternative development futures for Wisconsin and the optimization of the total energy system, subject to constraints on availability of particular primary energy fuels. Thus, it could be a potentially important tool for analyzing the future structure of Wisconsin's energy industries. In this area, such an approach could provide important inputs to both private sector decision makers and state policy planners.

One of the severe limitations in applying the above model to regional problems in Wisconsin is linked to the manner in which environmental constraints are imposed in the model. As the model now stands, environmental constraints are expressed in the form of total emissions of SO_2 or other pollutants. In practice in Wisconsin, the constraints on energy system development that arise through environmental considerations take the form of a multiplicity of impact factors, far more complex than can be expressed through emissions alone. To use an optimization model of the above type to include environmental considerations in a significant way would require modification of the constraints and perhaps the statement of the objective function. However, after pointing out this difficulty, it does not seem at all unreasonable to consider the possibility of moving in the direction of these extensions of the French energy model, that is, building into it the description and consideration of more detailed regional environmental constraints and costs. The creation of such a tool would have considerable benefit for Wisconsin energy modelers.

Given the history of a long and extensive effort in modeling of the French electric energy system, it is perhaps not surprising that this area provides some of the greatest potential for model transference. Although the French use of trend projection methods of long-run electricity demand estimation suffer serious shortcomings in times of major structural changes in energy supply/consumption patterns, the work on short-run demand analysis is exceedingly important for load management purposes. Given not only increasing total demand but also an even more rapid growth in peak demand due to summer cooling requirements, improving the load characteristics of demand is one of the major problems facing the Wisconsin electric utility system. This can be accomplished only by means of analysis of that load composition. The French have progressed far in this analysis, not only in modeling the load characteristics of electricity demand, but also in costing the supply of electricity over the load structure. This costing makes possible further French contribution in the area of electricity pricing. Here the French have proved to be leaders in experimenting with various price strategies aimed at improving the system efficiency through load adjustment.

Although the French investment model for the electricity industry is sound and would be useful as an alternative to the corporate planning models currently employed in Wisconsin, its lack of specific environmental analysis means that substantial modification would be necessary. Nonetheless, its potential for systemwide analysis is substantial, and it might prove a useful methodology for use by the Wisconsin Public Service Commission to evaluate the cost impacts of alternative link requirements between the various electric utility companies serving areas of Wisconsin. As in the GDR, experiences with the greater integration of the French electric system provide a potential for improving on the efficiency of future capacity expansion in the Wisconsin electric utility industry.

Finally there are the oil and gas models of France. Both models hold limited promise for transference to Wisconsin due to the very limited nature of activities of these industries in Wisconsin. There are no oil or gas reserves in the state and only one refinery. Further, distribution of natural gas is not expanding due to projected supply shortfalls in the future. Hence, only the models of transport and distribution of petroleum products appear to have direct applicability for Wisconsin modeling activities.

III. WISCONSIN

III.A. DESCRIPTION OF THE MODEL

James Pappas – University of Wisconsin – Madison

Energy system modeling in Wisconsin is comprised of a variety of efforts in both the public and private sectors, aimed at an analysis of problems associated with energy supply, demand, and environmental impact. The fragmentation of these efforts is extreme, with many parallel modeling activities being carried on simultaneously.

The nature of both Wisconsin's energy system and the modeling activities associated with that system developed largely from the social, economic, environmental, and political structure of the state.[21,22] Wisconsin is richly endowed with both natural and human resources. It does not, however, have any significant energy resources. Historically, agriculture, resource extraction and processing, and tourism or recreational activities have played major roles in the state's economy. An intensive, broad-based industrial sector has developed in the southeastern portion of the state and it is here that the vast majority of the state's populace now reside.

Wisconsin's energy system evolved in response to the energy requirements generated by this pattern of economic growth and development. This evolution occurred largely through the interaction of suppliers and consumers in a private market setting with virtually no integrated planning and relatively limited direct government intervention. This historical pattern of a limited government role in Wisconsin's energy system development stems from many factors. The virtual lack of energy resources in the state, however, is undoubtedly a major factor, particularly when coupled with a national policy aimed at making energy readily available in the private sector markets at relatively low prices. In short, the energy sector has historically been neither a major component of Wisconsin's gross state product nor a major constraint on the state's economic development. It has not, therefore, been an area of major concern to the state government.

Because of the primary reliance on private sector development of the Wisconsin energy system, and the relatively limited government concern related to this sector, the resultant disaggregation in energy analysis and planning makes it impossible to describe a unique, well-integrated energy modeling system for the state. Instead, one finds a variety of parallel modeling activities being carried on not only by the suppliers (and major consumers) of various energy resources in the private sector, but also by numerous state agencies. There has been a recent realization of the importance of energy to the state's economic well being on the part of the state's political leaders. Because of this disaggregation, the various modeling approaches being used in both the private and public sectors will be outlined, as well as the institutional mechanisms through which linkages occur.

While energy modeling in Wisconsin encompasses the entire range of activities associated with analyzing the state's energy system – from long-range forecasting and planning to operational management – most individual efforts are rather narrow in scope. That is, they focus on either a specific energy source, or on a particular energy policy problem. An exception to this generalization is the work of the Energy Systems and Policy Research Group (ESPRG) at the University of Wisconsin. This multidisciplinary research activity has resulted in the development of a computerized dynamic simulation model of Wisconsin's energy system. The WISconsin Regional Energy Model (WISE) combines an engineering and economic approach to model the state's energy system within a multidimensional framework that describes energy demand, conversion, transport, and uses explicitly accounting for technological, economic, and environmental interactions. It consists of a collection of submodels that combine in simple mathematical terms data and information about energy flows in Wisconsin to describe or simulate the energy system and its relationship to other characteristics of the state, e.g. demographic, economic, and environmental. A simulation structure was chosen for several reasons. First, simulation is a convenient method of integrating the variety of analytical techniques likely to be employed in a multidisciplinary effort of this type. Second, a simulation structure provides a great deal of flexibility in both the modeling process and application of the model to systems analysis. For example, it enables one to modify selected components of the system without the necessity of reworking the entire model, and to focus attention on specific areas of the energy system as well as on the system as a whole. Finally, the simulation structure lends itself to the scenario generating approach that is extremely useful in the analysis of major policy issues and alternatives. That is, simulation facilitates the application of the model to questions of the "what if" type.

Rather than dwell on the specific structure of the WISE model (which is examined in detail in other ESPRG publications*), and also in Chapter 3 of this volume, we shall limit our discussion to an overview of its capabilities and use. The WISE model is designed primarily for intermediate to long-range planning analysis. The typical horizon employed is the year 2000. Among other applications, WISE has been used to: (1) forecast energy demands by energy source and user classification, (2) estimate the additions required to the electricity generating, transmission, and distribution facilities in the state and evaluate the financing requirements, total system costs, and environmental impacts of alternative generating systems (i.e. nuclear versus fossil fueled) designed to meet the additional requirements, (3) examine environmental impacts associated with alternative future energy use patterns, and (4) analyze the role that conservation can play in determining the state's energy future. From these applications, it should be apparent that the WISE model is capable of both forecasting energy/environment futures for the state and analyzing the impacts of alternative policy decisions relating to both public and private sector activities in the energy area.

It is important to note that the development and actual employment of the WISE model rests almost exclusively with the ESPRG at the University of Wisconsin, a research team not formally or institutionally linked to Wisconsin's energy system planning and operational decision making. Lacking a direct tie to the decision-making bodies in the state, the use of the WISE model for input into energy policy analysis has rested on its ability to provide timely and easily comprehended responses to important energy policy issues as they arise. This response capability has been designed into the WISE model through the use of the simulation structure and an interactive control language which provides users with convenient access to both the models and data systems, and allows for intervention in simulated energy futures in order to test both the consequences of policy changes and the sensitivity of these futures to various assumptions employed in the analysis. It is further enhanced by the formal and informal working relationships that have been established by the ESPRG with several administrative and regulatory departments of the state of Wisconsin. The result is that while the ESPRG cannot be considered to be among the energy system policymaking bodies in Wisconsin, it does play an important role as a provider of technical expertise in policy analysis and, as will become clear from the material which follows, it has had a significant effect on the development of an analytical approach to policy analysis within several of the Wisconsin state agencies which have major decision-making responsibility in the energy/environment areas.

The description of other energy modeling activities in the state will be on the basis of model types and use. Because of the virtual inseparability of energy use and economic activity, virtually all modeling activities incorporate a general economic forecast for the state. These forecasts are prepared in both the public and private

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* A detailed survey of the structure and use of the WISE model and a comprehensive list of publications describing it are contained in W.K. Foell, J.W. Mitchell, and J.L. Pappas, The WISconsin Regional Energy Model: A Systems Approach to Regional Energy Analysis, Institute for Environmental Studies Report No. 56 (Madison: University of Wisconsin – Madison, Sept. 1975).

sectors using a variety of methodologies, ranging from simple trend projections to complex econometric and input/output models. Within the state agencies, independent forecasts are prepared by the Department of Industry and Labor and Human Relations, the Department of Revenue, and by faculty at the University of Wisconsin. Although these forecasts are prepared for a variety of different uses and are not often reconciled, there is a high correlation between the various projections. This undoubtedly stems in large part from the fact that Wisconsin's economy is inextricably tied to the entire U.S. economy and all state forecasts are inherently based on the same projections of national economic activity levels.

Population size and characteristics provide another basic input into all energy modeling activities. In Wisconsin, this factor is modeled in detail by the Office of the State Demographer. This model considers age, sex, and county, and includes considerations of migration, fertility, and mortality. Detailed population projections are provided to the twenty-first century. Energy demand forecasts in Wisconsin (other than those prepared by the ESPRG) have typically been on a single energy source basis. Until very recently, virtually all of this work was done in the private sector and on a firm by firm basis. Thus, for example, individual electric utilities could be expected to project demand by major user categories within their respective service areas. Typically these projections entailed extrapolation of historical trends adjusted for any major structural change in user composition which the utility was aware of (e.g. the planned expansion of a major industrial customer or the location of a major new industrial facility in the firm's service area). Such projections were used as input for investment planning and seldom extended beyond a five-to-seven–year period. Ten-year projections were in the *very* long run and went well beyond the relevant planning period. These simple demand models served quite well over an extended period due to the regularity which characterized the development and growth of not only electricity but also the entire energy system in Wisconsin until the beginning of this decade.

As a result of the disruptions which have characterized the entire energy system since 1970, the electric utilities are no longer able to rely on historical trends for planning purposes. This has been accentuated by a necessary lengthening of the planning horizon for individual firms, brought about in part by the longer construction period associated with the use of nuclear technology and in part by the more active role in the planning process taken by government agencies and representatives of special interest groups in the public (e.g. environmentalists and conservationists). This change in demand forecasting requirements was both sudden and substantial, catching many electric utilities generally unprepared to respond adequately in the development of needed forecasting methodologies. It led to a contract between the major electric utilities in Wisconsin and the Stanford Research Institute, a large private consulting firm, for an in-depth analysis and forecast of energy demands in Wisconsin through the year 2000.[23]

The nature of demand modeling in the other energy industries closely parallels that in the electric utility sector. Gas utilities and suppliers of coal, fuel oil, and gasoline have all tended to use historical data on customer use, population and income growth, and market penetration to develop projections of future demand. For many cases, the state of Wisconsin is not the relevant market area and, hence, no "Wisconsin" projection is forthcoming. This is particularly true for the coal and petroleum sectors where the primary suppliers tend to operate in a national or international market and for whom the Wisconsin market is an extremely small part, so small, in fact, that it is often treated as some fixed percentage of the national market – usually around two percent. In the case of those natural gas transmission and distribution companies whose primary market area is Wisconsin, their lack of direct ties to the production of natural gas, coupled with a situation where the demand for their product far exceeds any foreseeable supply, limits the benefits from detailed demand analysis and forecasting. Such modeling has therefore had limited development.

Recently the state has moved into the arena of energy demand forecasting on several fronts. These activities began when the Public Service Commission (PSC) aggregated the forecasts of individual electric utilities to develop a clearer picture of the projected generation, transmission, and distribution system in the state. They have relied to this point on the projections provided by the utilities and by ESPRG at the university,[24,28] while working on the development of an "in house" capability for demand estimation.

The other state agency currently involved in energy demand analysis and projection is the Office of Emergency Energy Assistance (OEEA). This newly formed agency is charged with responsibility for assisting in the allocation of energy resources when the market mechanism fails because of a major imbalance between supply and demand (i.e. when price is not allowed to play its role) and to assist in the development of an energy policy for the state. The OEEA is involved primarily with short-term energy issues and thus has not developed the capability for intermediate to long-range energy forecasting but relies instead on the ESPRG work and other externally generated projections in those instances where required. It has, however, developed an extensive set of computerized energy consumption data bases and retrieval software for analyzing that data. These data include a monthly allocation of all petroleum projects coming into the state, which shows for every distributor of petroleum products where he obtains his supplies and to whom the products are sold. These data are used to keep track of the origin of Wisconsin's petroleum supplies and to analyze the short-run impacts of a disruption in that supply. Similar data are collected for both coal and natural gas flows in Wisconsin. An additional data file listing the primary fuel requirements, alternative fuel capabilities including storage and switching time, and daily use rates has been prepared for all low-priority natural gas customers in the state. These data are being used by the OEEA to analyze the impacts of a natural gas curtailment and the alternative allocation schemes that have been proposed for the remaining gas.

Investment planning activities in Wisconsin closely parallel those in the demand area. The vast majority of such efforts are carried on by the individual firms operating in the state. A variety of corporate planning models are utilized in these efforts. These models typically project the time pattern of finance requirements based on forecasts of future system capacity needs and estimates of the technologically available means of satisfying those needs. These corporate planning models are usually detailed engineering/economic models of either a simulation or mathematical programming nature. Where a linear programming approach is used, constrained cost minimization over the planning horizon is the typical objective. Although the electricity generating capacity submodel (GENCAP) in WISE is somewhat less detailed than most corporate planning models, it is representative of the simulation structure employed.

Probably the only energy firms where corporate planning models explicitly model in detail a Wisconsin component are the electric and natural gas utilities serving the state. Electric utilities, for example, use extensive models to convert projected consumer demand into capacity requirements using load curve analysis. These forecasts of capacity requirements are in turn used to analyze the economic impacts of alternative generation and distribution systems and from this, detailed projections of capital investment and financing requirements are obtained. These models have typically employed a five- to seven-year planning horizon in the past but recent events have lengthened it to ten to twelve years.

Although the major coal and petroleum suppliers all utilize such corporate planning models, in most cases the Wisconsin component is small relative to their total activities – involving perhaps no investment where sales are channeled through independent distributors – and, hence, is either combined with surrounding states for a regional analysis or not disaggregated at all from the national model. In those situations where a Wisconsin component is analyzed it invariably relates to distribution facilities which typically are relatively low-cost components with short planning horizons and, hence, are not major components in the model.

The only state agency that carries on any investment planning analysis in the energy system is the PSC and its effort is limited primarily to the electricity industry. The PSC approach is essentially equivalent to a corporate planning model in which system costing is the primary objective. The model structure is similar to GENCAP but with more detail concerning load flows by user class. It is used to evaluate the investment plans of individual electric utilities and for analysis of alternative rate structures. This effort has been done on a company by company basis and only recently has work begun on a systemwide effort patterned after the work of ESPRG.

A final area where energy-related modeling is taking place in Wisconsin relates to environmental impact. Here the effort is more completely integrated into state planning activities due to the need to ensure compliance with both state and national environmental standards. In this effort the Department of Natural Resources (DNR) has responsibility for both developing standards to ensure compliance with the codes and for monitoring emissions in the state. In this effort, they are working closely with several other state agencies as well as developing their own models for some specific analysis. They are for example working closely with the PSC in the development of impact statements for future electric utility generating plants and transmission systems. Here the methodology is similar to that employed in the ESPRG Environmental Impact Model but with greater emphasis on its specific relationships. Similar work is being carried on by the utility firms in the state as part of the licensing for new plants.

DNR is also working on broader models of air and water quality. One of these efforts involves monitoring by DNR of primary fuel use by each of the major energy-using facilities in the state. Emission data are then constructed from the fuel use survey and a physical diffusion model develops ambient concentration levels for various pollutants. These data then provide the basis for establishing pollution abatement requirements for the facilities.

The above methodology is also being employed for long-range environmental quality analysis and planning for southeastern Wisconsin, the most heavily industiralized and populated section of the state.[25] Here an economic planning model provides specific industrial and transportation energy use projections through the year 2000. These fuel-use figures are converted to emissions factors which are then combined with projections of area sources of pollution (e.g. residential housing and commercial areas) to develop estimates of air quality. A scenario-generating capability allows the impact of alternative development plans and pollution abatement standards to be analyzed.

To summarize, energy/environmental planning in Wisconsin is highly fragmented and, hence, there is relatively little centralized effort in this area. Even in the case of the energy utilities (i.e., electric and natural gas distributors) where the state has long played a major role in regulating activities, the individual firms are the primary decision makers and as such have historically done virtually all of the planning. Recently the PSC and DNR have taken a more active role in these planning activities due primarily to (1) mandates laid down in both Federal and state environmental protection legislation,[26,27] (2) concerns about the risks inherent in nuclear generation of electricity, and (3) major structural changes in the energy supply/demand relationship which indicate a long-term supply shortfall unless significant modifications in energy use patterns are forthcoming. Other state agencies (particularly OEEA and the Department of Planning) are also moving rapidly to develop the data systems and modeling techniques necessary to introduce energy relationships into state policy analysis more explicitly. The efforts are being assisted by the work of ESPRG and other research groups at the University of Wisconsin.

III.B. APPRAISAL OF THE WISCONSIN MODEL BY THE GDR

Peter Hedrich and *Dietmar Ufer – Institut für Energetik*

In the state of Wisconsin there has been a great number of initiatives taken to assess future trends in the energy industry and their consequences for other spheres of economic and social activities. The majority of these initiatives concern investigations by private enterprises engaged, for example, in supplying electricity, which need the resulting data and other evidence to pursue a policy that results in maximum profits. A policy stressing maximum profits leads to one-sided development directed only towards fields that are of interest to the enterprise concerned. Other aspects, e.g. supplies to the state or even the United States as a whole, and energy suppliers other than those involved in the specific business transactions, scarcely attract due attention in these circumstances. Since, in addition, public institutions are interested in energy demand developments, energy supplies, and the relevant problems of environmental protection, there may be uncoordinated parallel work.

The initiative taken by the Energy System and Policy Research Group (ESPRG) of the University of Wisconsin, which is making efforts to systematize all the Wisconsin activities in this field, therefore marks great progress. A comprehensive system of models is intended to serve investigations into the energy supply industry and environmental protection, not from the point of view taken by just one enterprise or any other isolated group of interested parties, but within the scope of the entire state. It must be regarded as a good development that the research group plans to cooperate with the public authorities and present calculations that are of practical significance. The confinements of these efforts become apparent, however, if it is or would be necessary to apply the knowledge gained against the resistance put up by certain groups representing vested interests (such as energy supply enterprises, landlords, and the automobile industry). The power of public authorities to influence private enterprises can safely be regarded as quite limited. Much valuable knowledge that might be of use to people can therefore not be put into effect.

The model is therefore not suited for immediate preparations of decisions to be taken by the energy supply industry or at government level but is rather intended to serve studies dealing with the consequences for the energy supply industry and the environment of various economic, technological, demographic, and other developments and strategies. This situation is apparent from the fact that the results of investigations using the model are not expressed in quantities that are clearly specified in terms of place and time, but mainly represent variants, trends and statements of the "if–then" type.

It is also necessary to state that the work done by the University of Wisconsin is concerned only with overcoming the uncoordinated state of energy supply planning in one state. There has not been any attempt made so far to work out a system dealing with the planning of energy supplies and environment protection covering the whole of the United States on the basis of the same principles. It is also not apparent that a territorial energy supply strategy is to or can be established for the United States with the aid of the Wisconsin model.

The contrast with energy supply planning in the GDR results from the different arrangements of production in the GDR and the United States. As a part of socialist economy, the GDR energy supply industry is under central management. Planning proceeds in the interests of society as a whole, with the planning process being organized in the way of a pyramid, reaching from the industrial plants with their staff up to the Ministry of Coal and Energy Supplies and top-level government (reflecting the principle of democratic centralism). All industries, and indeed the entire social progress, are subject to planning in socialist society, without consideration whether one branch or another may or may not temporally attract special attention for reasons of overall trade policy or current events (remember the so-called oil crisis!). The results of scientific work done to develop the energy supply industry are taken into account when the GDR National Economic Plan is being drawn up. That plan, which is actually worked out with the cooperation of the working people in the factories and fields is in the end given legal status. Its specifications are put into effect at all public authority and industrial management levels.

The Wisconsin model serves to forecast developments over a period of up to 30 years. In calculating the inputs, it primarily uses trend computing. It may be possible to extend the period covered by a forecast by one or two decades. In any case, it has to be considered, however, that in reality the developing processes usually do not proceed in a continuous mode but may include discontinuities at one time or other. The model takes this condition into consideration by defining and computing qualitatively different model approaches (scenarios).

In the GDR, pure trend computing is used in a limited way only (in minor subsectors for tally calculations) in the course of planning activities covering two or three decades. The methods applied in the Wisconsin model are of interest to us, however, for forecasts reaching beyond the year 2000.

The Wisconsin model is a variant (descriptive) model. It is not intended for or capable of optimization. In view of the widely varying conditions of ownership characterizing the energy supply industry in Wisconsin, this limitation is realistic and theoretically correct. Any optimizing criterion agreeing with the interest of the entire population of the state would not be recognized by the private enterprises, which are driven by their urge for maximum profits.

The model system worked out by the University of Wisconsin does not comprise energy supply and environmental protection but, rather, the entire economy including substantial spheres of social developments. This arrangement is necessary because additional data concerning, for example, developments in industry, agriculture, and other branches outside the actual energy supply industry, are not made available by other institutions. In the end, therefore, the Wisconsin model covers all economic activities in the state in terms of developments to be expected, in order to be able to provide statements concerning the energy supply industry and environmental protection. If other branches of the economy, for example agriculture or transportation, were to start such investigations, this situation might lead to ineffective repetition of work.

In contrast to Wisconsin conditions, energy supply planning in the GDR is part of national economic planning as a whole. The inputs needed for energy supply planning from other industries (concerning, for example, the production of cement or rolled steel) are calculated by these industries in the course of their own planning. The feedback from energy supply planning to the other industries operates within the entire national economic planning process.

For determining the ultimate energy demands, the Wisconsin model uses almost exclusively (above all for industrial activities) economic quantities to characterize volume and growth of production. This procedure is handicapped because certain structural alterations, which may be significant for the energy supply industry, are not recognized and therefore not considered. A disaggregation of the industry into 20 branches cannot make up for this deficiency.

The method of useful energy supply planning by consideration of energy-intensive products and their specific energy consumption indices, which in the GDR has been practiced for a long time, permits changes in national economic structure to be taken into account in energy supply planning. Planning with genuine natural physical indices is, in addition, well suited to cover any interdependencies in industry and other fields. Interdependence schemes based on economic quantities only, as prepared in Wisconsin, can in contrast be expected to provide much less accurate evidence.

Available information on the Wisconsin model does not show how the interaction between the substitutable energy supplies in the various branches of the energy supply industry is taken into account and planned. Planned energy supply substitution according to a defined or still-to-be defined strategy is not at all foreseen for the industrial consumption of energy. As a result, there is an impression that every individual energy supplier is dealt with in a more or less isolated manner within the model system, with the electricity supply industry clearly enjoying a prominent position. The latter situation is probably due to the power stations being the only major energy conversion plants in Wisconsin.

From the point of view of the GDR, it appears as a drawback that the Wisconsin model does not provide for the computing of comprehensive energy supply balances, balances dealing with individual energy supply according to available resources and the uses that are made of these supplies, and comprehensive primary energy balances.

The structure of the Wisconsin model and the way in which the submodels are coordinated are very efficient. Similarly to the central model system applied to the GDR energy supply industry, the arrangements allow calculations with the submodels as well as calculations involving the coordinated model as a whole. Output of results, in some cases with graphs, is quite suitable for nonexpert staff.

The Wisconsin model comprises submodels investigating the consequences on the environment of activities by the energy supply industry. These investigations are very valuable since they may be the starting point for activities to limit, or avoid damage to the environment by all branches of the energy supply industry. Coordination, in terms of a model, of activities by the energy supply industry and environmental control, which has not been practiced yet in the GDR, offers great possibilities to investigate the interaction between the two.

The Wisconsin model has been worked out in social conditions that differ from those in the GDR, and the objective is therefore different, too. The procedures and methods applied are, however, of interest for the GDR. Their application seems to be suitable for cases that do not permit application of optimizing models that are in use in the GDR. Even with such distant planning horizons, however, a more or less comprehensive energy supplier balance, with consideration of the interdependencies of the suppliers, should be worked out. The procedures applied for environmental control planning and its coordination with energy supply planning are also of interest to the GDR for planning periods covering 10 to 20 years and appear to be applicable in their present form.*

III.C. APPRAISAL OF THE WISCONSIN MODEL BY RHONE-ALPES

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This analysis will only take into consideration the WISE model of the University of Wisconsin because few specific details are available about other models.† The WISE model has been developed in a very pragmatic way, with the intention to provide clarification to decision makers and even to provide the public with a better understanding of the consequences of different energy choices in terms of environmental impacts. The model permits a very disaggregated presentation of energy production and consumption activities, because its developers have a detailed understanding of various consumption and production processes; the method permits one to calculate quite precisely the different undesirable effects resulting from each type of activity. This type of model is not meant to be a tool for planning, but rather a tool for forecasting energy consumption, the evolution of production, and environmental consequences – taking into account many possible starting points. Optimization methods simulate one energy policy, e.g. to seek the least social cost under the constraints of limiting dependence on oil or reducing harmful effects. The method utilized in the WISE models, however, permits one to test many different policies. It is, for example, possible to measure the impact of an energy conservation policy that imposes insulation standards for housing or that improves the load factor in cars; these parameters are exogenous to the WISE model since the standard of optimal insulation may have been an outcome of an optimization model.

The WISE model appears to be a neutral model representing the energy system of Wisconsin, defined in terms of the totality of the activities associated with the production and consumption of energy. It would be applicable to all energy systems in the world, considered from this point of view, except that it has been conceived for a system which is strongly dependent on the outside world for its supply of primary fuels. The application of this model, in this sense, should pose more problems for the GDR than for the Rhone-Alpes region (or for France) to the degree that the essential energy needs in the GDR are satisfied by locally-mined coal.

The logic of the approach under discussion necessitates a very elaborate disaggregation of various subsystems in order to arrive at the fundamental determinants of demand. For example, at the level of space heating in the residential and service sectors, it requires information about the climate, insulation, outside surface area of housing, type of housing, the number of housing units, and so on. Thus, one of the difficulties in applying this type of model lies in obtaining the tremendous amount of data needed for the assignment of values to the parameters, as well as in

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* The review of the Wisconsin energy model was based on: W.K. Foell, The Wisconsin Energy Model: A Tool for Regional Energy Policy Analysis, Institute for Environmental Studies Report No. 35 (Madison, University of Wisconsin – Madison, Nov. 1974); and J.L. Pappas, "Draft Outline for the Description of the Energy System Modeling Activities in Wisconsin," (unpublished).

† As described in Chapter 6, it appears that these models are almost identical to the branch models utilized in France by Electricité de France (EDF) as well as by the oil companies.

defining the values of the coefficient in relationships between two variables. For instance, in the industrial subsystem it is necessary to know the coefficient of energy intensity corresponding to energy consumption per unit of value added.

It is difficult to avoid certain inconsistencies when using such disaggregated methods. Thus, to return to the industrial subsystem, it is necessary to extrapolate from the available data in order to obtain the coefficients of energy intensity for future consumption of energy; this presupposes that the techniques will remain fixed over long periods of time. Moreover, it is necessary to know the economic activities of different branches during the next 20 or 30 years and this requires a certain level of estimation. This is perhaps easier in the case of end-use energy in the domestic, service, and transportation sectors. The data must be evaluated rather arbitrarily, and much is dependent on the subjectivity of the modeler and his experience in the field of modeling.

Moreover, since it is not possible to formalize everything with the same finesse, certain areas are less well formalized than others; this produces distortions in the accuracy of the results and increases the error in the findings obtained by aggregation of the partial results. Thus the representation of freight transport in the state of Wisconsin would appear very crude, in view of the precision of the representation of the urban and intraurban passenger transport. In the same manner, in the industrial and domestic sector, the possibility of replacing fuels by electricity through the substitution of heating methods or industrial processes has been neglected.* It is sometimes more interesting to remain at a certain level of aggregation of economic phenomena when this permits one to obtain information more easily or when this permits one to profit from errors' canceling each other in the different components of an aggregate.†

In any case, the simulation technique under discussion here is very useful, in view of the flexibility it has in permitting one to construct a global model, domain by domain, to modify or improve a given point in the representation, and to develop more precisely the formalization of certain other points. Moreover, it is ideal for coupling with the scenario method, which permits a consistent definition of parameters.

In conclusion, one may perhaps criticize a certain unevenness in the exactness of representation of the various parts of the model, the necessity to control a large number of parameters, and to investigate an enormous mass of data. The model remains an extremely pragmatic tool directly useful in aiding the decision makers to measure the consequences of their present and future choices; moreover, its careful design permits much flexibility.

The model, however, is better conceived to study the environmental impacts and the regulations concerning pollution rather than to study the development of the overall energy system. It is nonspecific and can be easily applied to all energy systems which present the same conditions of fuel dependency as the state of Wisconsin. However, this nonspecificity is connected with a concept of systems as a group of activities without a purpose and without capacity for self-reproduction (in which the total would be the sum of the parts). It is perhaps here that one sees the methodological limits of this approach in providing long-term forecasts; a system

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* It is possible that from the point of view of environmental impacts, certain simplifications of representation may be justified. But they cannot be justified if, at the same time, one seeks a precise forecast of the consumption of energy.

† For example, the evolution of the consumption of electricity in households is a logistic curve corresponding to the penetration of the various secondary domestic appliances.

has its own dynamics and its own logic which must be brought to light in order to model it and to try to represent its modes of evolving. The WISE model assumes a system without its own internal dynamics, for it presents a multitude of exogenous parameters whose level is more or less arbitrarily determined. Here, more is at stake than a theoretical and abstract observation, for this important external factor could be a cause for questioning the significance of the model's results.

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E Evaluation and Choice of Energy/Environment Alternatives

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I. INTRODUCTION

Chapters 4, 5, and 6 have provided alternative pictures of energy and environmental futures in the German Democratic Republic, Rhone-Alpes, and Wisconsin. The scenario-writing process through which these futures were studied is purely *descriptive* in nature, that is, it only provides a description of some of the characteristics of the system as it moves through a series of states. However, the process does not tell us *what path* to take from one state to another, given a particular *objective* or *goal* which we wish to achieve in the system. It does not provide a formal approach to the *evaluation of alternatives*. What path should be followed if, for example, conventional costs for energy facilities are to be minimized? If environmental impact is to be minimized? If subregional economic equity is to be preserved? We denote procedures for choosing such paths, i.e. alternatives, as *prescriptive* techniques. Some of the system models described in Appendix D could be classified as prescriptive in nature. For example the ENERGIE model originating in Grenoble could be used to choose energy supply strategies which would lead to minimum discounted energy system costs (including capital and operating costs).

No formal objectives or objective functions have been defined for the scenarios – other than the statement of an overall policy rationale or framework within which the evolution of the system could be described. Furthermore, the scenario descriptions in Chapters 4, 5, and 6 provide little guidance for embedding the energy/environment information into a *decision process*.

This chapter describes one of the approaches used by the IIASA research group in the evaluation of energy/environment alternatives. It uses the framework of multiattribute decision analysis. As will be seen from the following sections, the approach was chosen in part because of the belief that it also contributed greatly to the *communication* process, another essential ingredient of energy/environment management. The approach is not presented here as a solution to the evaluation problem. The lack of an appropriate formal approach for incorporating uncertainty into policy evaluation and for dealing explicitly with the unknown remains a critical issue for resource system analysts and managers.

II. THE DIFFICULTIES OF ENERGY/ENVIRONMENT MANAGEMENT

In the context of this book, the energy/environment system of a region includes its socioeconomic, technological, and ecological characteristics. The difficulties of managing this system can in part be explained by the following characteristics.

The Interdependencies of Economic, Technological, and Ecological Characteristics of a Region. These interdependencies are not only extremely difficult to quantify, but they imply that conflicting objectives need to be considered within the management process. A well-known example is the current controversy about whether high rates of economic growth are compatible with a high-quality environment. Another example on a regional level is whether specific environmental protection measures are compatible with local economic growth and maintenance of jobs.

Difficulties in Identifying Costs and Benefits and in Associating Them with Specific Societal Groups. Accounting in a quantitative way for impacts on air quality, aesthetics, and resource supply is very difficult, especially over time. In addition, the costs and the benefits are not always bestowed upon individuals or groups in an equitable manner.

Uncertainties – Changes Over Time. There are uncertainties about the benefits and costs of any particular management policy. Even if there exists a good understanding of the system interdependencies today, they may change drastically over time in a manner that we do not understand or may not even expect. Some of the environmental effects have very long-term delays making them difficult to estimate with present information.

Difficulties in Communicating This Complex Material. Even if the above information is precisely known, it is difficult to communicate to individuals and institutions that must make decisions on the management problem or implement strategies. The problem of communicating quantitative and technical information to people who are not specialists is even more difficult. As the complexity of our technologically oriented society increases, this problem is increasing in importance.

Multiple Decision Makers Within Overlapping Institutional Frameworks, e.g. Multiple Levels of Government. Because the energy/environment system cuts across so many parts of society, institutional structures that have evolved are complex. This results in a multiplicity, and sometimes unidentified array, of policymakers who are deeply involved in the management problem.

There has been considerable interest in formal methodologies to cope with the above problems and to combine environmental impacts into a single figure of merit for evaluation of alternative courses of action.[1,2,3,4] Others have suggested utility assessments for risk analysis[5] and for evaluation of alternative power plant sites.[6,7,8] This chapter suggests and illustrates multiattribute decision analysis as an appropriate approach for formally addressing some of the above complexities in managing energy/environment systems. The approach is introduced in the next section; the remainder of the chapter is devoted primarily to illustrating the approach for examining alternative electricity supply strategies in the state of Wisconsin.

III. MULTIATTRIBUTE DECISION ANALYSIS

As described in Chapters 4–7, a simulation model has been used to examine the environmental consequences of the alternative energy scenarios for the German

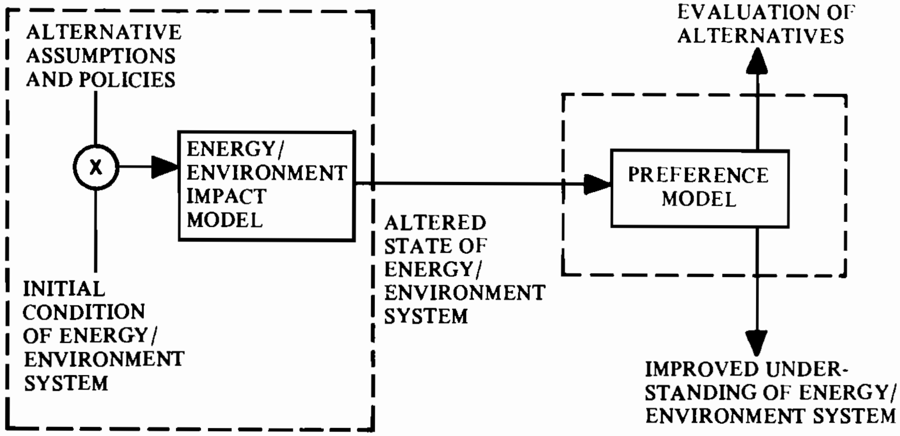

FIGURE E.1. Relationship between the impact model and the preference model.

Democratic Republic, Rhone-Alpes, and Wisconsin. The environmental impact models* used for that purpose are meant to be as objective as possible, i.e., an attempt was made to minimize subjective or value-judgment content. However, in a strict sense this was not possible since no model can be more than a reflection of the model-builder's view of a simplified image of reality. It is hoped that the model provides the best description that he can produce.

Because of the earlier-mentioned complexity of energy/environment systems, it is extremely difficult to utilize this model *directly* for evaluating specific policies. With this in mind, we suggest that it may be useful to introduce a preference model into the process. The use of a preference model, coupled with the impact model, can provide a convenient framework to *help* a decision maker evaluate alternatives in terms of the degree to which each of a set of objectives is met.

The relationship between the energy/environment "Impact Model" and the "Preference Model" is illustrated in Figure E.1. The outputs of the Impact Model are impact levels of the attributes, i.e., the degree to which an attribute alters the state of the system. For instance, the policy of introducing nuclear power facilities may result in a certain level of radioactive waste, of power generated, of water used, of land occupied, and of death. The impact model might give point estimates of such levels or present the information in a probabilistic fashion. Then the decision maker is supposed to consider the possible states and select a policy from the alternatives.

To effectively process all the information in one's mind is a very difficult task. From the characteristics of the problem outlined in the last section, three of the major complexities leading to this difficulty are:

- The uncertainties about the impact of any alternative, especially considering the time frame involved

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* The models are summarized in Chapter 3 of this volume. More detailed descriptions can be found in the references listed there.

- The multiple objective nature of the problem and the necessity to make value tradeoffs between various levels of attributes
- The differences between the preference structures of the individual members of the decision-making unit and the lack of systematic procedures for articulating and resolving these differences

Two general approaches for addressing these issues are an informal qualitative one and a formal quantitative one.* In the former approach, one processes the pros and cons of each alternative in his own mind and discusses his thinking with other concerned members of the decision-making body. Eventually a decision will result from agreement or compromise. The formal approach attempts to quantify each decision-maker's preference structure and couple this with the implications of the impact model. The individual preference models allow one to explore the areas of agreement and disagreement between decision makers. The process itself is important in addressing the third complexity mentioned above. The formal approach will be the focus of the following pages.

The result of quantifying one's preferences is a model of these preferences called a utility function. When multiple objectives are involved, a measure of effectiveness, or attribute, is needed to indicate the degree to which each objective is met. Hence we have the terminology, multiattribute utility function. This multiattribute utility function is nothing more than an objective function (to be maximized) with one special property: in cases involving uncertainty, the expected utility calculated for an alternative is an appropriate measure of the desirablity of that alternative. Thus, if one accepts a set of reasonable axioms postulated by von Neumann and Morgenstern,[10] one should choose the alternative leading to the highest expected utility.

For discussion purposes, it is convenient to divide decision analysis into four steps: structuring the problem, identifying the impacts, quantifying the preferences, and evaluating the alternatives. The next four sections of this chapter respectively cover these steps.

IV. THE PROBLEM: THE CHOICE OF ALTERNATIVE ELECTRICITY SUPPLY STRATEGIES

Each of the three regions provides a wealth of examples of the complexity of this management problem. One problem that arises in all three regions and which is becoming increasingly important and visible for a broad spectrum of decision makers and the public is the evaluation of alternative electricity supply strategies.

In Wisconsin, much of the discussion of this question has focused on the relative advantages and disadvantages of nuclear and coal electricity-supply systems; the environmental impacts of the two systems have been the major topics. More recently, the question of the desirability of continued growth of electricity supply has been brought into the discussion. In the eyes of a significant fraction of the Wisconsin community, the societal choice of levels of energy use is a major component of environmental management. It is one of the most complex aspects of the problem.[11]

In Rhone-Alpes, the question is of a similar nature although the specific

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* Whether a group chooses the formal or informal process is itself a decision. Some of the advantages and disadvantages of each of these approaches are suggested by Keeney and Raiffa.[9]

TABLE E.1 Six Alternative Policies for Wisconsin Electrical Generation from 1970 to 2000

Policy 1	• Electrical generation increases at average annual growth rate of 4.7%. • Almost all new plants fueled with coal. • SO_2 emissions controlled by using stack gas removal systems and low-sulfur coal. • 99% particulate control.
Policy 2	• Electrical generation – same as Policy 1. • Almost all new plants are fueled with coal. • No SO_2 stack gas removal systems and same amount of low-sulfur coal as Policy 1. • 89% particulate control.
Policy 3	• Electrical generation – same as Policy 1. • Almost all new plants use nuclear fuel. • Emission controls for SO_2 and particulates – same as Policy 1.
Policy 4	• Electrical generation – same as Policy 1. • After 1975, all coal is low-sulfur from distant mines in western states. • 50% of new plants after 1982 use coal and 50% use nuclear fuel. • After 1975, all coal and uranium is obtained from surface mines. • Emission controls for SO_2 and particulates – same as Policy 1.
Policy 5	• Electrical generation increases at an average annual growth rate of 2.8%. • Almost all new plants are fueled with coal. • Emission controls for SO_2 and particulates – same as Policy 1.
Policy 6	• Electrical generation – same as Policy 5. • Almost all new plants use nuclear fuel. • Emission controls for SO_2 and particulates – same as Policy 1.

alternative strategies differ slightly in form from those in Wisconsin. Furthermore, the choices are generally made at the national level. The current strategy favored by the government is the increasing penetration of electricity use in the energy market, with a major fraction of the electricity supplied by nuclear power. The current plan of Electricité de France is to have in the Rhone-Alpes area an installed capacity of approximately 6,000 MWe by 1980, and possible continued expansion thereafter. However, an energy study by the Institut Économique et Juridique de l'Energie in Grenoble provided a vivid picture of an alternative plan that involved significant energy conservation and increased emphasis on nonelectrical forms of energy.[12] Although the discussion and analysis of environmental impacts of alternative systems were initially not as intensive as those in Wisconsin, they are now receiving increased attention in both public and government circles.

In the GDR, the electricity generation technology has been almost exclusively based upon lignite fuel. Although the economic and environmental tradeoffs have been considered in the selection of energy strategies, the available options seem to have been relatively narrow in scope. However, when viewed farther into the future, for example, over the next 50 years, there appears to be a range of alternatives available. As in the other two regions, altering the nature and magnitude of energy demand would seem possible by influencing the economic infrastructure. Similarly, over time it appears feasible for the GDR to choose from a spectrum of supply technologies, including electricity (via nuclear energy) or a range of nonelectrical strategies, for example, district heating.

It is therefore possible to discuss a similar subset of electricity supply strategies within each of the three regions. Because more extensive environmental analysis had been performed for Wisconsin, it has been chosen as a case to illustrate the application of decision analysis to evaluate alternatives. However as will be discussed at the end of this chapter, the approach appears to be appropriate for application in the other regions as well.

IV.A. THE ALTERNATIVES FOR ELECTRICITY SUPPLY IN WISCONSIN

The policies which we will examine for electricity supply in Wisconsin will be defined by two decision variables:

- The fuels used to supply the electricity
- The degree of conservation of electricity, i.e. the limiting of demand

More specifically, the six policies evaluated are briefly described in Table E.1. The average annual growth rates of approximately five and three percent were selected from several alternative electricity generation scenarios presented in a previous publication.[11] The other characteristics of the policies in Table E.1 have been arbitrarily selected simply as illustrations. These policies by no means completely span the alternatives facing Wisconsin. For example, one issue not addressed in these six policies is the impact of alternative power plant cooling systems.

IV.B. THE OBJECTIVES AND ATTRIBUTES

In our analysis, we will focus on aspects such as the environment, human health and safety, and nuclear safeguards, rather than economic considerations. The latter have received considerably more attention historically, and we feel the features of decision analysis are better illustrated with the former.

After considerable discussion with individuals in policymaking roles in Wisconsin, a set of objectives for examining alternatives was outlined.[13] The process of specifying objectives requires some value judgments – deciding which objectives are important enough to include. For each of these, an attribute is specified to indicate the degree to which that objective is met. This resulted in the 11 attributes in Table E2. The units and ranges of possible impacts for the 6 alternatives evaluated are included in the table. These attributes are an aggregation of the numerous impact categories provided by the impact model described in the next section. Since the selection of attributes also depends on preferences and value judgment, another set of attributes may be more appropriate for a particular individual. For example, some people may feel that since occupational risks are presumably taken voluntarily, occupational fatalities should be considered separately from public fatalities. The first attribute in Table E.2 is the sum of all quantified health and accident fatalities, both occupational and public. In the overall process, there should be an iterative interaction between the utility assessment and the specification of the aggregated attributes.

TABLE E.2 Attributes for Initial Application of Multiattribute Decision Analysis to the Wisconsin Electrical Energy System

	Measure	Worst value	Best value
$X_1 \equiv$ total quantified fatalities	deaths	700	100
$X_2 \equiv$ permanent land use	acres	2,000	1
$X_3 \equiv$ temporary land use	acres	200,000	10,000
$X_4 \equiv$ water evaporated	10^{12} gal	1.5	0.5
$X_5 \equiv SO_2$ pollution	10^6 tons	80	5
$X_6 \equiv$ particulate pollution	10^6 tons	10	0.2
$X_7 \equiv$ thermal energy needed	10^{12} kWh(t)	6	3
$X_8 \equiv$ radioactive waste	metric tons	200	1
$X_9 \equiv$ nuclear safeguards	tons of plutonium produced	50	1
$X_{10} \equiv$ health effects of chronic air pollution exposure	tons of lead	2,000	1
$X_{11} \equiv$ electricity generated	10^{12} kWh(e)	0.5	3

V. THE ELECTRICITY IMPACT MODEL

The generalized framework of the composite environmental impact model in Figure E.1 is elaborated upon in Figure E.2. The assumptions that specify a policy, namely a specified regional electricity demand and supply mix over a period of time, are provided as input to the Electricity Impact Model (EIM),[13,14] which was summarized in section IV.D.3. of Chapter 3. As described there, the primary input to the EIM is a set of assumptions about (1) quantity and sources of electrical generation as a function of time,* and (2) important parameters (e.g., technological relationships, accident rates), possibly time-dependent, that affect impacts. The primary output is an array of "quantified" environmental impacts associated with the power generating facilities as well as the supporting fuel industries. These systemwide impacts, which are aggregated into the 11 attributes $X_1, X_2, \ldots, X_{11}$, occur as a direct result of the electricity generation; a significant portion of the impacts may be imposed outside the region where the electricity is generated. For example, uranium is mined in the western part of the United States to fuel nuclear reactors located in Wisconsin.

It is difficult to display in a general fashion the ways in which electricity use results in impacts, but Figure E.3 shows the pathways for a large number of effects. Pathway 1 includes impacts such as air pollution from coal-fired plants, radioactive releases from the nuclear reactor, chemical releases from the power plant, and waste heat. The direct effects of electrical generation shown as Pathway 2 are effects at the power plant such as land and water use. Pathway 3 accounts for occupational health risk, such as uranium miners' exposure to radiation. Pollution from nuclear fuel reprocessing plants is represented by Pathway 4. Occupational accident risk at the power plant itself is shown as Pathway 5. Pathway 6 represents the usual economic costs and the unquantified impacts associated with electrical generation. To compare future alternatives, the decision maker must combine these quantified impacts with the unquantified impacts, conventional costs, and other factors that affect his decision process.

The calculation of quantified impacts from a particular energy system in a particular year is based upon impact factors that relate impacts to a unit of electricity generation for a reference plant in the specified year. The impact factor can be varied as a function of time to simulate changes in technology or regulation. There are numerous impact factors associated with each energy system in the EIM; an example is cases of black lung disability from underground bituminous coal mining per kWh of generation from coal plants.

Since all impacts cannot be quantified, the output of the EIM cannot be considered a complete set of impact information. Environmental impacts can be divided into quantified impacts (those included in the EIM) and unquantified impacts, i.e., all other environmental concerns not included in the EIM. Some impacts are unquantified because: (1) they have just been recognized as potentially important and therefore have not been investigated; (2) they are not even recognized as impacts; or (3) quantification is based almost entirely on value judgment. However, merely specifying and defining the impacts to be calculated requires some value judgments. Two examples of recognized unquantified impacts that are not included in the EIM are: the potential long-term global climatic effects of continued CO_2 release from fossil fuel combustion[15] and the potential long-term risks

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* This information can be provided by other models, such as other submodels of the WISconsin Regional Energy Model.

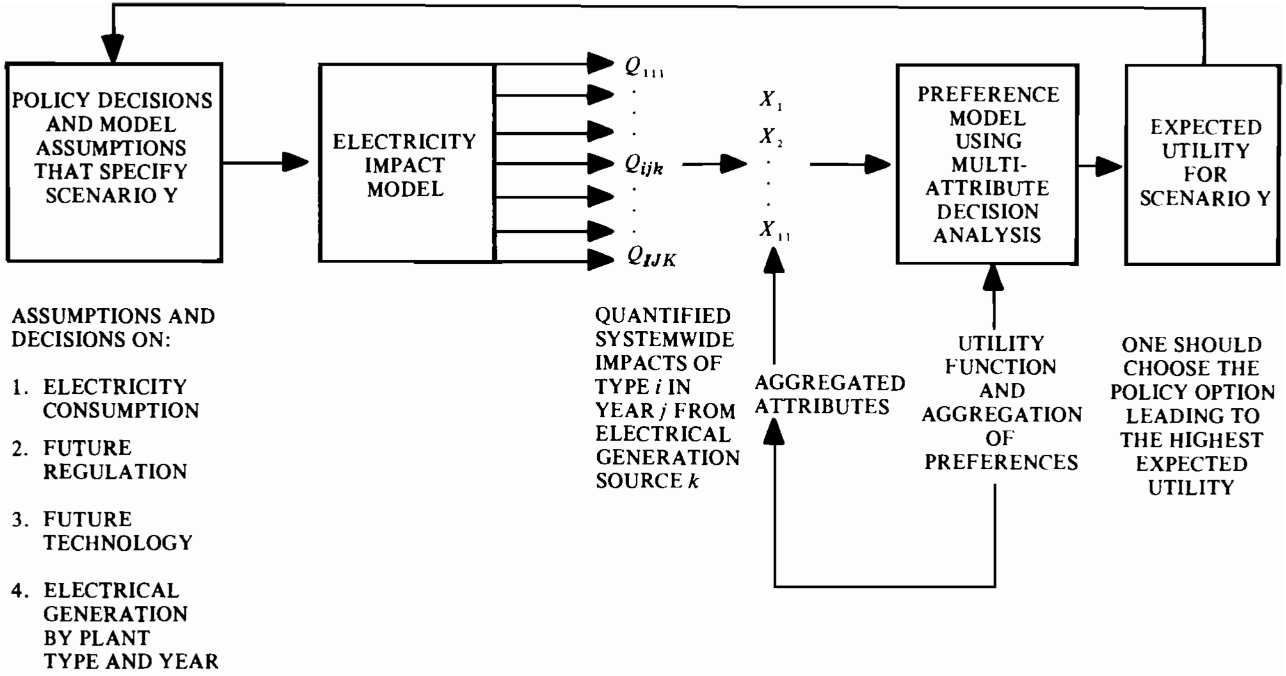

FIGURE E.2 Composite environmental impact model.

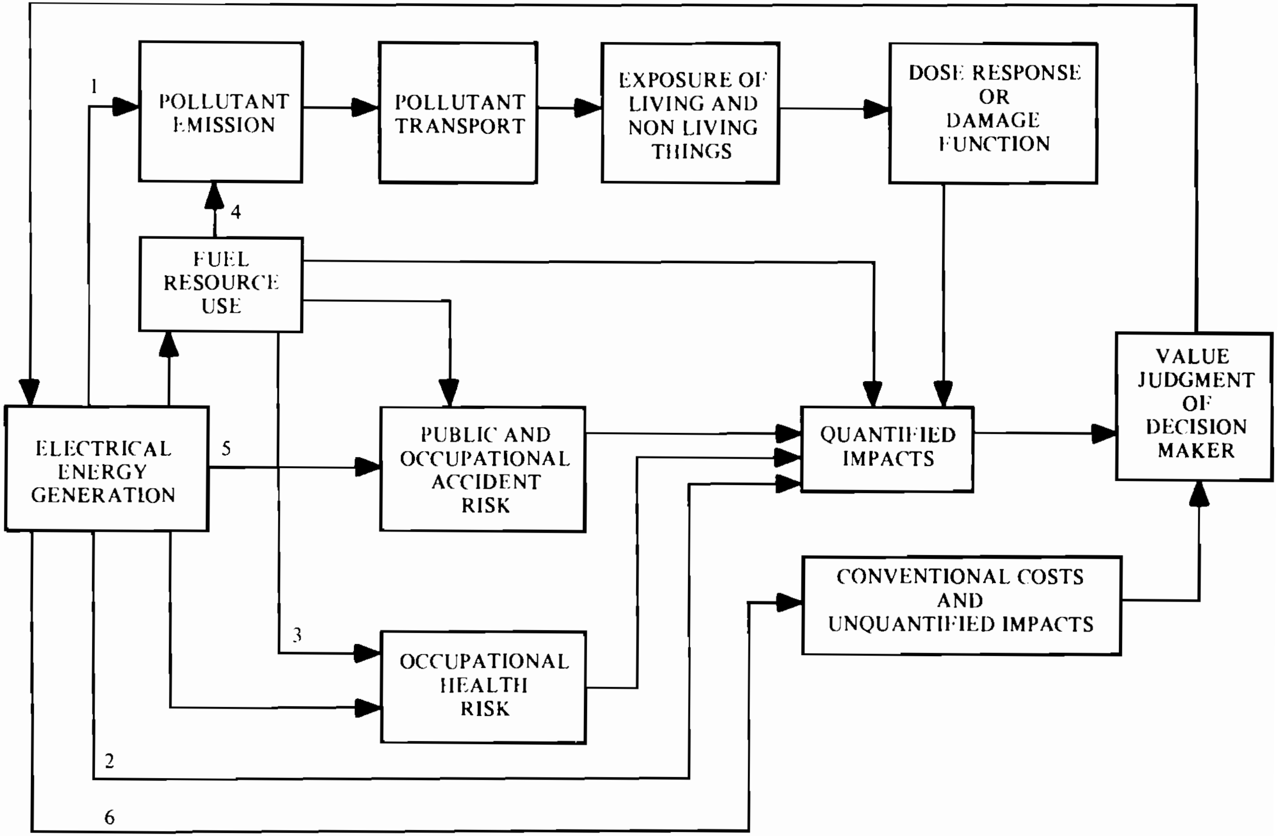

FIGURE E.3 Electrical energy impact pathways.

associated with radioactive waste.[16,17] Such potential impacts are difficult to quantify in conventional terms, but concerns over such recognized unquantified impacts can be included in multiattribute decision analysis by defining an appropriate proxy attribute. For instance, the amount of CO_2 released could be a proxy variable for its long-term climatic effects.

Since there is uncertainty associated with each impact factor in the EIM, the levels of impacts determined by the model could be expressed in terms of a probability distribution. With the present EIM, most of the impacts estimated do not have explicit probability distributions associated with them because, in general, the available data do not warrant the increased effort required to incorporate probability distributions in the model.

VI. THE PREFERENCE MODEL

Once all of the impacts of each alternative are specified as clearly as possible, it is still a very difficult task to identify the best policy. This is primarily due to the complexities of the problem outlined in section II. In this section, we introduce multiattribute utility as an approach for addressing these complexities in a systematic and rational manner. First, we will briefly review multiattribute utility theory, next suggest a procedure to render it operational, and finally discuss its implementation in conjunction with our electricity supply strategy problem.

Let us introduce some terminology in the context of our problem. We will define x_i to be a specific level of attribute X_i. For example, since X_1 is measured in number of deaths, then $x_1 = 230$ means a consequence of 230 deaths. The problem is to find a utility function $u(x) = u(x_1, \ldots, x_{11})$ over the 11 attributes $X_1, \ldots, X_{11}$.

If we have assessed u, we can say x is preferred to x' if $u(x)$ is greater than $u(x')$. More importantly, if any of the quantified impacts were expressed in terms of probability distributions, the decision analysis framework presented in this section would still be useful. In such a case, the probability distributions and utility functions would be integrated to provide expected utility. If the total impact of an alternative was quantified by probability density function $p(x)$ over consequences $x \equiv (x_1, \ldots, x_{11})$, then the expected utility $E(u)$ for that alternative is given by

$$E(u) = \int u(x)p(x)\,\mathrm{d}x$$

integrated over all possible consequences. The ability to handle preferences under uncertainty is one of the strengths of utility theory. This quantification of probabilities and utilities greatly facilitates the use of sensitivity analyses.

VI.A. MULTIATTRIBUTE UTILITY THEORY

The main results of multiattribute utility theory concern representation theorems stating conditions under which a utility function can be expressed in a specific simple functional form. If such a form is appropriate for an analysis, it is then generally much easier to proceed with the assessments necessary to specify the utility function.

The basic notions used in deriving representation theorems are the concepts of preferential independence and utility independence. Let us state these concepts in terms of our problem and then state the representation theorem used in structuring preferences in the next section.

- *Preferential Independence*: The pair $\{X_1, X_2\}$ is preferentially independent of $\{X_3, \ldots, X_{11}\}$ if one's preference order for x_1, x_2 combinations in $(x_1, \ldots, x_{11})$, given $x_3, \ldots, x_{11}$ are held fixed, does not depend on the levels at which they are fixed.

This assumption is equivalent to saying the value tradeoffs between fatalities and permanent land use levels do not depend on radioactive waste, energy generated, and so on. It implies for instance, that the indifference curves over X_1 and X_2 levels do not depend on $X_3, \ldots, X_{11}$.

- *Utility Independence*: Attribute X_1 is utility independent of $\{X_2, \ldots, X_{11}\}$ if one's preference order for lotteries* on X_1, with $x_2, \ldots, x_{11}$ held fixed, does not depend on the levels at which it is fixed.

This assumption is equivalent to saying that decisions concerning alternatives which have different impacts on fatalities only (and which have the same impacts in terms of SO_2 pollution, radioactive waste, energy generated, and so on) can be made by considering these impacts on fatalities only and that these decisions will be the same regardless of the fixed levels of SO_2 pollution, radioactive waste, energy generated, and so on.

Using such independence notions, a multiattribute utility function can be split into parts. The following is an illustration of one such decomposition.

- *Theorem*: Given $\{X_1, \ldots, X_{11}\}$, if $\{X_1, X_i\}$, $i = 2, \ldots, 11$, is preferentially independent of the other attributes and if X_1 is utility independent of $\{X_2, \ldots, X_{11}\}$, then either

$$u(x_1, \ldots, x_{11}) = \sum_{i=1}^{11} k_i u_i(x_i), \text{ if } \sum k_i = 1 \tag{1}$$

or

$$1 + ku(x_1, \ldots, x_{11}) = \prod_{i=1}^{11} [1 + kk_i u_i(x_i)], \text{ if } \sum k_i \neq 1 \tag{2}$$

where u and u_i, $i = 1, \ldots, 11$, are utility functions scaled from 0 to 1, the k_i are scaling constants with $0 < k_i < 1$, and $k > -1$ is the nonzero solution to $1 + k = \prod_{i=1}^{11} (1 + kk_i)$ if (2) holds.

Equation (1) is the additive utility function and (2) is the multiplicative utility function. More details about these, including suggestions for assessment, are found in Keeney and Raiffa.[18] The important point is that provided the appropriate assumptions hold, the 11 attribute utility function can be assessed by assessing 11 one-attribute utility functions, u_i, plus 11 scaling constants, k_i. Such a decomposition makes assessment of u a much simpler task.

* A lottery is defined by indicating all possible consequences which may occur and their associated probabilities. Lotteries on X_1 are lotteries involving uncertainties about the level of X_1 only.

VI.B. ASSESSING A UTILITY FUNCTION

The actual assessment process requires personal interaction with the decision maker, since his utility function is (and should be) a formalization of his subjective preferences. The utility function allows us to combine, in a logically consistent manner, the contribution of fatalities, SO_2 pollution, radioactive waste, electrical energy generated, and so on, into one index of desirability (namely, utility) for each possible state $(x_1, \ldots, x_{11})$. To capture the decision-maker's preferences requires that he explicitly address two types of issues:

1. The relative desirability of different degrees of achievement of a particular objective.
2. The relative desirability of some specified achievement of one objective versus another specified degree of achievement of a second objective

Addressing the first issue allows us to determine the u_i's in Eqs. (1) and (2), whereas information about the second issue is needed to specify the k_i's. Let us illustrate the types of questions used to obtain a utility function.

A question illustrating the first issue might be presented to the decision maker as follows:

"Suppose you must choose between two alternatives. It seems to you that their impacts in terms of all the attributes except energy generated are about the same. Alternative A, which is the status quo option, has very little uncertainty and will result in 1.5×10^{12} kWh(e) over the next 30 years. On the other hand, alternative B is innovative and has a large degree of uncertainty. Best estimates and experiments indicate that with alternative B, there is about a 50-50 chance of 1.1 or 2.1×10^{12} kWh(e) in the same period. If you have complete responsibility for the decision, which alternative would you choose?"

It is easy to see that B leads to an average of 1.6×10^{12} kWh(e), but because of the risks involved, the sure 1.5 may be preferred. A question addressing the second issue is as follows:

"Two competing policies C and D will result in identical consequences in terms of all attributes except fatalities and electricity generated. Policy C will give you 2.0×10^{12} kWh(e) but result in 500 fatalities over the next 30 years. Policy D leads to only 1.4×10^{12} kWh(e) but the associated deaths are 250. If the responsibility is yours, which of the two policies would you select?"

Collectively, responses to questions like those above directly address the uncertainty and multiple objective complexities raised earlier in this paper. One would naturally expect that if different individuals of a decision making unit went through such a line of questioning, they would respond differently. This would result in different utility functions. By examining these utility functions, it may be possible to get a clear indication of the substance and degree of disagreement. This is a first step toward resolving the differences.

VI.C. ASSESSMENTS

Utility assessments were completed for all 11 attributes for 2 individuals familiar with Wisconsin energy planning.* In section VIII, we also will briefly describe some related results involving the assessment of the preferences of some policy makers. Here we only briefly review some of the details of the assessment. A thorough review of one assessment is found in Keeney.[19]

The assessment procedure was divided into five steps:

1. Familiarizing the "decision maker" with the concepts of utility theory
2. Verifying preferential independence and utility independence assumptions
3. Assessing single-attribute utility functions
4. Assessing the scaling constants
5. Checking for consistency

The familiarization process is basically an explanation for the person whose preferences are being assessed by the person doing the assessing. The purpose is to agree on terminology and motivate the interest in the problem.

The preferential independence conditions were verified by examining indifference curves in 2 dimensions (i.e., with 2 attributes allowed to vary) with all other attribute levels fixed. The basic question was whether these indifference curves depended on the fixed levels of the other attributes. For all pairs we checked – 10 pairs for each individual – there were no dependencies; this indicates each pair of attributes was preferentially independent of the other nine.

Similarly, by assessing a utility function for 1 attribute conditioned on the other 10 being held at fixed levels, one can examine the dependency on those fixed levels. Again we found no dependencies; therefore, each attribute was utility independent of the others. This implied the utility function, in each of the two cases, would necessarily be of the form of Eq. (1) or Eq. (2).

To be consistent with either Eq. (1) or Eq. (2), the utility function u_i over attribute X_i is set equal to 0 at the least desirable level of X_i in the range. The shape of the function is determined by asking questions of type 1 discussed in the previous section. The results for Individuals *A* and *B* are given in Figure E.4 for 6 of the attributes. The shapes of the curves indicate that for tons of plutonium and electricity generation, Individual *B* preferred the midpoint of the range to a lottery that resulted in a 50-percent chance of the least desirable level and a 50-percent chance of the most desirable level. Individual *A* had different preferences for plutonium levels; he preferred the "best–worst" lottery over a certain 25.5 tons of plutonium.

Individual *A* felt that the most preferred level of electrical generation was approximately 1.5×10^{12} kWh(e) and that the least desirable level in the range was 0.5×10^{12} kWh(e). Therefore, his utility function for that attribute reaches 1.0 at 1.5×10^{12} kWh(e) and is less than 1.0 at the highest value of electricity generation. Several of the utility functions, including those in Figure E.4 for fatalities, were linear; in that case the individual was indifferent between the midpoint and a 50-50 lottery involving the extreme levels of the attribute.

Questioning on the utility function shape for the plutonium attribute revealed why the 2 individuals had such different preferences for that attribute. Individual

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* These individuals frequently were consulted by persons having responsibilities for evaluating and selecting energy policy in Wisconsin; they had no direct decision responsibilities. Thus, the assessments here are meant to be illustrative; the results were not to be directly used in prescribing policy.

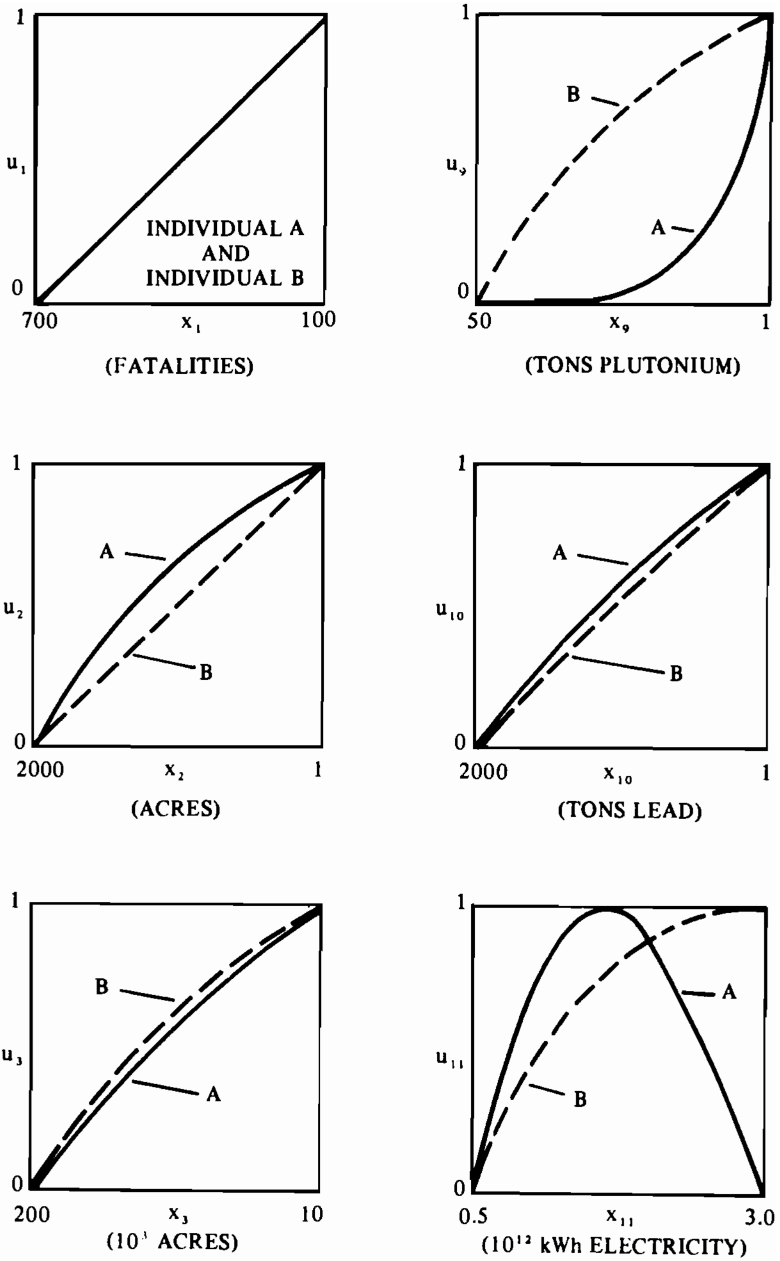

FIGURE E.4 Selected single-attribute utility functions for two individuals.

TABLE E.3 Utility Function Scaling Constants

	Individual A	Individual B
X_1 ≡ total quantified fatalities	0.354	0.267
X_2 ≡ permanent land use	.004	.018
X_3 ≡ temporary land use	.033	.021
X_4 ≡ water evaporated	.083	.016
X_5 ≡ SO_2 pollution	.008	.060
X_6 ≡ particulate pollution	.008	.008
X_7 ≡ thermal energy needed	.017	.011
X_8 ≡ radioactive waste	.132	.057
X_9 ≡ nuclear safeguards	.177	.152
X_{10} ≡ health effects of chronic air pollution exposure	.118	.339
X_{11} ≡ electricity generated	.066	.051
Sum	1.0	1.0

A felt that once plutonium production is greater than a certain minimal level, the opportunity for undesirable events, such as theft, diversion, and terrorist attacks, will certainly exist because of increased problems of accountability, storage, and transportation. Furthermore, he felt that if plutonium production were very large, the likelihood of these undesirable events would only slightly increase. Therefore, Individual *A* had the "risk-prone" utility function shape for plutonium; he was willing to accept a 50-percent chance of the highest level (50 tons in this case) of plutonium production in order to obtain a 50-percent chance for the lowest level (1 ton), rather than taking a certain 25.5 (the average of 50 and 1) tons of production. On the other hand, Individual *B* felt that, over the indicated range, each additional ton of plutonium is more likely to result in these undesirable effects. Stated another way, he felt that the problems associated with accountability, storage, and transportation for 50 tons of plutonium were more than twice as difficult than for 25 tons of plutonium. Therefore his utility declines at an increasing rate for each additional ton of plutonium produced.

The scaling constants for the utility functions are shown in Table E.3. For both individuals, the sum of the k_i's is one, indicating the additive utility function (1) is appropriate. The values of the k_i depend strongly on the ranges of the attributes shown in Table E.2. If the range of one of the attributes were changed, *all* k_i would change. Comparison of the k_i's for an individual indicates the relative importance of each attribute for the specified ranges.

Both utility functions were subjected to internal consistency checks. When inconsistencies were identified, their respective implications were discussed with the appropriate individual, and he was asked to reconcile these by changing some of his assessments leading to the inconsistency. To help choose which assessments to change, we presented data indicating different manners in which the assessments could be altered to achieve consistency. Each of the preference assessments utilized here – which should be considered preliminary assessments – required approximately 1 day of assessment time. Such an effort often leads to important insights and an improved understanding of the problem. It also identifies gaps in knowledge (e.g. the health impact of lead emissions) relevant to preference assessments. To investigate these gaps may require significant efforts by researchers (e.g., the medical profession). With such information available, it would be possible to responsibly

TABLE E.4 Attribute Levels and Expected Utilities for Six Electrical Energy Policies in Wisconsin from 1970 to 2000

	Reference case[a]	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5	Policy 6
$X_1 \equiv$ fatalities (deaths)	100	380	380	240	680	280	210
$X_2 \equiv$ permanent land use (acres)	1	420	420	1,100	770	380	730
$X_3 \equiv$ temporary land use (acres)	10,000	140,000	137,000	85,000	43,000	99,000	71,000
$X_4 \equiv$ water evaporated (10^{12} gal)	0.5	0.72	0.71	0.84	0.79	0.55	0.61
$X_5 \equiv SO_2$ pollution (10^6 tons)	5.0	12	23	8.0	8.6	9.5	7.4
$X_6 \equiv$ particulate pollution (10^6 tons)	0.2	0.69	6.2	0.40	0.56	0.51	0.37
$X_7 \equiv$ energy needed (10^{12} kWh(t))	3.0	4.9	4.9	5.2	5.3	3.8	3.9
$X_8 \equiv$ radioactive waste (metric tons fission products)	1.0	61	61	160	110	54	105
$X_9 \equiv$ nuclear safeguards (tons fissile plutonium)	1.0	11	11	30	21	10	19
$X_{10} \equiv$ chronic health effects (tons lead emitted)	1.0	124	1,110	71	100	92	66
$X_{11} \equiv$ electricity generated							
(10^{12} kWh(e) nuclear)		0.36	0.36	0.99	0.68	0.33	0.64
(10^{12} kWh(e) coal)		1.37	1.37	0.74	1.05	0.99	0.68
(10^{12} kWh(e) coal + nuclear)	3.0	1.73	1.73	1.73	1.73	1.32	1.32
Expected Utilities							
Individual *A*	0.938	0.620	0.569	0.589	0.383	0.711	0.680
Individual *B*	1.0	0.789	0.624	0.785	0.631	0.846	0.849

[a] Attributes set at extreme values.

assess the utility function of a key "energy decision maker" with 1 to 3 days of his time.

VII. APPLICATION OF UTILITY FUNCTIONS TO EXAMINE POLICIES

The scaling factors in Table E.3 and the $u_i(x_i)$ completely specify the multiattribute utility function, $u(x_1, \ldots, x_{11})$. These two preliminary utility functions were used to evaluate expected utilities associated with the several energy policies (see Table E.1) concerning electrical generation in Wisconsin over the period 1970 through 2000. The impacts of each policy, characterized by levels of the attributes,* and the expected utilities for both individuals are listed in Table E.4. The reference case in the first column is listed simply for orientation. This case uses the "most desirable levels," that is, the lowest impacts and highest electrical generation, and results in an expected utility of 1.0 for Individual *B*. Since Individual *A* preferred a lower level of electricity generation to the maximum 3.0 (Figure E.4), his expected utility was not 1.0 for the reference case.

The implications of the remaining 6 policies in Table E.4 are output from the EIM. The attribute levels shown are the cumulative effects of electrical generation from 1970 through 2000; no time-discounting or measurement of preferences that depend on the timing of the impacts have been used in this illustrative application. The basic differences between the policies have been highlighted in Table E.1. The first four policies have identical electrical generation with different supply mixes and pollution control, while the last two policies have lower electrical generation with different supply mixes.

If it is assumed that the individuals expressed their true preferences and that they behave in a logically consistent manner, the expected utilities can be used to indicate their overall preferences. Under these conditions, Table E.4 shows that both individuals should prefer the low electricity policies over the first four policies. This is primarily because increasing electrical generation, without changing the supply mix, results in higher levels of impacts. The decrease in utility associated with higher levels of impacts must be more than offset by increased utility associated with the increased level of electrical generation if cases with higher electrical generation are to have higher expected utilities. For these particular policies, Individual *A* has approximately the same utility for the lower level of electrical generation as for the higher level (Figure E.4) and therefore has no increase in utility to balance the decrease associated with increased levels of impacts. Individual *B* does have some increase in utility associated with the increased level of electrical generation but for these policies the increase was not sufficient to compensate for the decrease in utility associated with increased levels of impacts.

No strong preferences are evident for policy 1 over policy 3 or for policy 5 over policy 6. Thus, if the purpose of the assessment were to indicate whether a mostly coal or mostly nuclear energy future is preferred by the decision maker, further analysis would be necessary. If these techniques were applied to a real policy study,

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* Of course, the impacts of energy policies are not known with the certainty indicated in the table. With more effort, the present deterministic EIM could be used as a basis for a probabilistic simulation model to characterize policies by probability distributions over levels of the attributes. One would combine these probability distributions with the utility functions to calculate expected utilities for evaluating the policies.

TABLE E.5 Ranges of the Four Attributes Used in Utility Assessments

	Units	Range
$X_1 \equiv$ Total quantified fatalities	Deaths	100–700
$X_2 \equiv SO_2$ pollution	10^6 tons	5–80
$X_3 \equiv$ Radioactive waste	Metric tons	0–200
$X_4 \equiv$ Electricity generated	10^{12} kWh(e)	0.5–3.0

the attribute list would be expanded to include other impacts and to include conventional costs.

The utilities in Table E.4 can also be directly used if uncertainty is incorporated into the models. For example, if Individual A had a choice between an alternative 1: Impacts of policy 3 for sure, and an alternative 2: A 50-percent chance of the impacts of policy 4 and a 50-percent chance of the impacts of policy 5, he should prefer alternative 1, since his expected utility for this is 0.589 and for alternative 2 it is only $0.5(0.383 + 0.711) = 0.547$. This expected utility feature is one of the main reasons for using multiattribute utility for analyzing problems where uncertainties are important. In this example, the uncertainties could be associated with the levels of impacts or the ability to carry out the policies.

VIII. INITIAL UTILITY ASSESSMENTS OF POLICYMAKERS IN THE THREE REGIONS

The detailed utility assessments discussed in section VI of this chapter quantified the preferences of energy/environment specialists from Wisconsin, but not actual policymakers. Those assessments are in themselves important – both the process and the results – but they do not indicate whether policymakers would be willing to investigate the usefulness of multiattribute utility to help them examine some very complex questions. To examine this question, preliminary utility assessments were completed for 5 individuals from the GDR, Rhone-Alpes, and Wisconsin. The group included a mixture of policymakers and energy/environment specialists. The resulting utility functions were used to evaluate a subset of the alternative electricity supply policies discussed in the previous section (Table E.1).

To further simplify the task (because of time limitations) only 4 of the 11 attributes in Table 2 were used. The 4 attributes and their ranges are given in Table E.5. Collectively these 4 attributes covered a variety of value-tradeoff issues embodied in the energy planning and evaluation processes. The non-Wisconsin individuals were made aware of current trends in Wisconsin electricity use so that they could understand the ranges of that attribute. The preliminary assessments presented here required 2 to 3 hours from each of the individuals whose utility function was measured.

The scaling constants for the resulting utility functions are shown in Table E.6. Three of the individuals' overall utility functions turned out to be multiplicative and the other two additive. Total quantified fatalities had either the largest or second largest k_i in all 5 cases. Electricity generation ranked first in importance for the only individual who did not have k_1 larger than the other k_i.

These 5 preliminary utility functions were used to evaluate expected utilities associated with several policies for electrical generation in Wisconsin over the period 1970 through 2000. The levels of the 4 attributes and the expected utilities

TABLE E.6 Utility Function Scaling Constants for Five Individuals

	Fatalities (k_1)	SO$_2$ (k_2)	Radioactive Waste (k_3)	Electricity Generated (k_4)	Multiplicative Scaling Constant (k) (Eq. 2)
A	0.30	0.05	0.015	0.030	13.8
B	0.60	0.016	0.14	0.10	0.8
C	0.33	0.275	0.0	0.55	— 0.4
D	0.65	0.02	0.24	0.09	[a]
E	0.61	0.14	0.14	0.11	[a]

[a] These individuals had additive utility functions (Eq. 1).

TABLE E.7 Expected Utilities for Five Individuals for Four Policies

		Reference Case: Attributes at Extreme Levels	Policy 1: Mostly Coal, Good Pollution Control	Policy 2: Mostly Nuclear Energy	Policy 3: Low-Sulfur Coal from Distant Mines and Some Nuclear Energy	Policy 4: Mostly Coal with Less Electricity
Total quantified fatalities		100	380	240	680	280
SO_2 pollution (10^6 tons)		5.0	12	8.0	8.6	9.5
Radioactive waste (metric tons)		0.0	61	160	110	54
Electricity generated (10^{12} kWh(e))		3.0	1.7	1.7	1.7	1.3
Expected utility for individual	A	1.00	0.53	0.66	0.14	0.65
	B	1.00	0.56	0.63	0.14	0.65
	C	1.00	0.76	0.83	0.64	0.41
	D	0.92	0.62	0.66	0.24	0.73
	E	1.00	0.65	0.72	0.31	0.74

for each of the individuals are listed in Table E.7. The reference case – attributes at extreme levels – is listed simply for orientation; it uses the "most desirable levels," that is, the lowest impacts and highest electrical generation, and results in an expected utility of 1.0.

The implications of the remaining 4 policies in Table E.7 are output from the EIM. Policy 1 has most of the generation at coal-fired plants with relatively good pollution control. Nuclear power contributed only about 20 percent of the cumulative generation from 1970 through 2000. Policy 2 has the same electricity generation as policy 1, and nearly 60 percent is from nuclear sources. Policy 3 has about 40 percent of the generation from nuclear sources and the remainder from coal-fired plants that use low-sulfur coal obtained from surface mines that are more than 2,000 kilometers from the power plants. Policy 4 has about 25 percent less electrical generation, and coal-fired plants produce about 75 percent of the total generation.

Table E.7 shows that all 5 individuals should prefer one or more of the other policies to policy 3. This is primarily the result of the large number of fatalities expected for policy 3 and the relatively high scaling factor each of the individuals place on fatalities (Table E.6).

Individual *C* indicated a strong preference to achieve a certain level of electrical generation, and therefore he had higher expected utilities from policies 1, 2, and 3 than from policy 4, which had a lower level of electricity generation. Individuals *A*, *B*, and *E* would view policy 2 (higher generation mainly from nuclear sources) and policy 4 (lower generation and less nuclear power penetration) almost the same.

It is clear that if this technique were applied to a detailed policy over a longer time of study, considerably more analysis would be necessary and the attribute list would be expanded to include other impacts and conventional costs. However, this experience with individuals from the 3 regions indicated that at least some policymakers were willing to think hard about their preferences and quantify them in a manner that could aid the analysis of policy choices that they faced.

IX. BENEFITS OF THE ASSESSMENT PROCESS

In the previous two sections it was shown how a utility function can assist one in evaluating policy. The *process* of assessing the utility function has many benefits in itself. The process can be a substantial aid in identifying important issues and sensitizing individuals to them, generating and evaluating alternatives, isolating and resolving conflicts of judgment and preference between members of the decision-making team, communication between several decision makers, and, in this particular application, identifying improvements needed in the impact model.

IX.A. COMMUNICATION

The assessment of preferences forces individuals to be more precise in deciding why they feel certain levels of attributes are important. Clearly policymakers must face such issues regularly. However, because of the complexities that cloud their choices, the value trade-offs involved are sometimes a bit hazy. The assessment formalization helps to make the trade-offs more explicit. With a better understanding of one's own values, it should be much easier to communicate them to others. The communication then serves as a catalyst to identify parts of the problem which were previously overlooked. As an example, the initial reaction to a trade-off involving human fatalities and other impacts is often discomfort, as one must effectively place a value on human life (or a reduction in someone's lifetime). The viewpoint eventually reached is that such tradeoffs are practical questions that must be addressed for rational decisions.

IX.B. IDENTIFYING IMPORTANT ISSUES

When one assesses preferences, it is often the case that the respondent says something like "I can't answer that definitely, because it depends on . . . ." This sometimes indicates important structural relationships not in the model. For instance, a decision maker may say that trade-offs between fatalities and energy generated depends on who is dying, how, and when. If this is important in making the decision, then obviously the decision maker should have the information when the decision is made. In trying to informally analyze the entire problem, such issues are sometimes overlooked.

As mentioned earlier, some people feel that occupational risks are partially compensated by salary premiums and therefore occupational health and safety should be considered separately from health and safety of the general public, who expose themselves to the risks involuntarily. In addition, some people feel that an illness that disables or gradually leads to death is worse than a fatality caused by an accident. The timing of the impacts must also be addressed. Radiation health impacts may not appear for many years after the exposure due to the electrical generation, while uranium mining fatalities occur some years before the generation occurs. The generation itself may be taking place over a period of years. Thus, in the limit, one can imagine separate impact categories for occupational health impact in time period 1, occupational accident impact in time period 1, public health impact in time period 1, and so forth. The process of aggregating or disaggregating these impact categories is part of the preference assessment.

IX.C. ISOLATING AND RESOLVING CONFLICT

Roughly speaking, the scaling factors in Eqs. (1) and (2) in section VI.A. designated by k_i indicate the importance of the respective attributes of the possible concerns. If these are different for different individuals, it may be possible to go behind the answers and get at the reasons for the differences. For example, one might find that an individual who originally assessed a rather large k_5 (associated with SO_2 pollution) relative to k_1 (associated with fatalities) had knowledge about very large detrimental impacts of SO_2 of which other individuals were not aware. Upon reflection, some individuals may then change their preferences to reduce the conflict.

The assessment process, a period of reflection, and discussions with other people resulted in some changes in scaling factors and single-attribute utility functions for at least one of the individuals involved in this study.[19] The statements concerning one's preferences that are required during assessment are sometimes difficult to provide, especially when one must associate for the first time some unquantified effects with a proxy variable. After such an experience, individuals may be more likely to discuss their judgments about particular attributes which they have weighted differently from other individuals.

IX.D. IMPROVEMENTS IN IMPACT MODELS

All of the above three advantages of the formalism of preference models have desirable effects for the development of the impact model. It helps to focus on what impacts should be modeled, on structural relationships and interdependencies to indicate how to model these impacts, and on data necessary for a responsible modeling effort. The modelers are made aware of additional areas of concern and what proxy variables are appropriate for impacts that are difficult to quantify in conventional terms.

IX.E. GENERATING ALTERNATIVES

Because of different preferences, we may find that a particular "best" overall alternative is rated very good for most of the members of the decision group, but rather low for a few. From detailed examination, it might be clear that the difference is caused by attribute X_3, for example. Then by focusing thought on alternatives which might improve attribute X_3, the group may find an alternative much better for those who disliked the original alternative and only slightly worse for those who liked it. Conceivably, one might even find a new alternative better for everyone. Because of the complexity in the problem, it is sometimes possible to generate such "dominant" alternatives.

X. POTENTIAL IMPLEMENTATION OF THE METHODOLOGY

This chapter has described a methodology for using decision analysis in conjunction with environmental impact analysis of energy systems. In addition to the methodology presented, an example was presented for the evaluation of several energy/environment policies in the state of Wisconsin. It was shown how a utility function can assist one in evaluating alternative policies, and that, in addition, the *process* of assessing the utility function also has many benefits in itself. This section suggests some possible mechanisms and benefits of applications of this methodology in the three regions studied in the IIASA research program.

Because each of the three regions has a very different set of energy/environment models as well as greatly differing institutional structures for decision- and policymaking, the use of decision analysis would differ in each case. It might be more applicable to policy issues in a given region than in others. However, in view of the many person-years of scientific effort that have been devoted to constructing energy/environment models in each of the countries, it does not seem at all unreasonable to consider devoting a modest amount of time to the construction of preference models for use with impact models. A relatively small amount of effort may have a significant effect. Some alternative approaches to the application of the methodology are outlined below for each of the three regions.

X.A. WISCONSIN

Energy/environment decision and policymakers in Wisconsin operate within a relatively decentralized structure, that is, the decision making is diffuse (see Appendix B, section III). As a consequence, the information and technical expertise is also distributed broadly throughout a number of agencies and offices. The methodology described in this chapter could be used to conduct formal assessments of decision- and policymakers at various levels of government to provide them with a better understanding of the trade-offs between the many complex issues. Clearly, in this case the method would not be used to provide a recipe for overall formal decision making but rather as a tool to improve communication, clarify some of the more complex issues, help generate alternatives, and to help individual decision-making units in the system.

A second use of the methodology would be the assessment of the scientific and technical staff of Wisconsin energy and environment commissions to aid them in structuring their research priorities. One of the major objectives of this application is the identification of gaps in knowledge and in methodology. In Wisconsin, the approach might be of value to the Public Service Commission, the Department of Natural Resources, the Department of Transportation, the State Planning Office, and perhaps others.

A less conventional and as yet untested use of this methodology would be as a means of interaction with public interest groups for the purpose of clarifying their understanding of and positions on energy/environment issues. For example, in Wisconsin the Environmental Defense Fund, the Sierra Club, and the League of Women Voters might be appropriate clients for this method. It would help not only to clarify the issues and perhaps raise the level of the discussions, but it might also help these public interest groups to arrive at their positions on a specific issue. Clearly, this use is not without its problems; it is understandable that a user of such an approach must be convinced that it will provide him with additional information with which to make his decisions and with which he can better achieve his objectives.

X.B. RHONE-ALPES

Each of the applications for Wisconsin is also of potential use in the Rhone-Alpes, but because the region is far less self-governing than Wisconsin the applications of the methodology would be different. Use of the methodology as an aid in laying out research priorities might be appropriate for helping French national agencies to understand the regional aspects of their policies and to establish their research priorities related to regional questions. Electricité de France is planning a major expansion of nuclear power for the Rhone-Alpes region. The use of an impact model in conjunction with a preference model could help to clarify the issues as perceived by local groups in that region. From another perspective, we found interest on the part of local agencies in using this approach as a discussion tool. During the IIASA workshop, Management of Energy/Environment Systems, in November 1975, various local French participants expressed interest in further experimentation with the method.

X.C. THE GERMAN DEMOCRATIC REPUBLIC

Each of the above approaches could also be applied in one way or another in the GDR. However, because there is much greater use of formal government planning in the GDR, less emphasis would probably be given to its use in interaction with local and public groups. It seems admirably suited for use in efforts to obtain appropriate objective functions for formal optimization models in the energy and environment sectors. One major problem associated with the use of formal optimization procedures is defining suitable objective functions and constraints. Clearly, these objective functions and constraints should take into account a multitude of costs, benefits, system attributes, and the like; decision analysis could help considerably to determine the ways in which these should be combined within a formal optimization procedure. Research is currently underway at IIASA and the University of Wisconsin to develop a formalism for incorporating decision analysis into formal optimization procedures for energy/environment system planning.

XI. FINAL COMMENTS

The above suggestions are only indicative of possible uses of decision analysis as a tool for embedding impact models into an institutional framework for policy design and analysis. Such an approach would require in each of the three regions the development of some knowledge of decision analysis and utility theory. Admittedly, the use of the technique is as much an art as a science. However, the same could be said about building an impact model from an infinite array of possible environmental impacts.

In ending this discussion, we must add the obvious caveat. Even though a preference model combined with an impact model can be used to evaluate alternatives, the answers and implications for action are all conditional on the model's being a complete representation of the real world. This is clearly never the case. The composite model can serve as an aid to decision makers but it cannot and should not replace them or their judgment in making decisions.

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