THE WISCONSIN–IIASA SET OF ENERGY/ENVIRONMENT (WISE) MODELS FOR REGIONAL PLANNING AND MANAGEMENT: An Overview

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FOREWORD

In January 1975 IIASA undertook a research program designed to integrate regional energy and environmental management from a systems perspective. The primary objectives of the program were (1) to describe and analyze patterns of regional energy use and to examine the relationship between energy use and 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 methods for energy/environment management and policy design; and (4) to examine energy strategies for specific regions. The IIASA research program represented an extension of work initiated at the University of Wisconsin–Madison.

The term 'regional,' as it is used in this research, is not restricted to national, subnational, or multinational areas. It refers to a geographical region, appropriately bounded to enable analysis of *energy and environmental systems* – either from a physical, socioeconomic, or administrative perspective, or from all three. A regional rather than global perspective has been employed because many of the significant social and environmental consequences of energy systems are best analyzed within the context of a specific region. This research was undertaken within IIASA's Resources and Environment Area. It complements IIASA's Energy Systems Program, which focuses primarily on global aspects of energy.

Thus far, four regional case studies have been carried out within the research framework. The first study originated at the University of Wisconsin–Madison, in the form of a policy-oriented study of energy systems in the state of Wisconsin, USA. This work was then extended within a comparative framework to include the German Democratic Republic, the Rhône-Alpes region of France, and Wisconsin. Subsequently, the research group undertook a two-year study of the energy/environment system in Austria. Most recently, the research team at the University of Wisconsin–Madison has begun to apply the case study approach to developing regions, through collaborative programs in Mexico and the Asia–Pacific area.

The research is directed toward both methods and policy analysis, in an effort to bridge the gap between practitioners and clients of applied systems analysis. The case studies have been conducted in close cooperation with research institutions in each of the study regions. The flow of models, data, and personnel between IIASA and the collaborating institutions has broadened the methodological foundations of the effort. The participation of decision makers and policy analysts from each of the regions has also ensured that the results of the work are evaluated in real-world contexts.

In the process of describing and disseminating the results of this research, IIASA has become aware of the breadth of interests of our audience. Some individuals are concerned with mathematical formulations, computer software, and data requirements, while others wish to see only the policy implications of the results. For this reason, we have structured our reporting to meet the needs of four types of audiences:

(1) Policy makers and decision makers;
(2) Energy/environment managers, planners, and technical advisors;
(3) Modelers and analysts;
(4) Computer systems specialists and programmers.

This report is addressed primarily to Groups (2) and (3). It presents the conceptual and quantitative framework of the case studies, as well as an overview of the individual models developed to assess sectoral energy demand, supply, and environmental impacts. The overview focuses on model objectives, basic assumptions, data requirements, outputs, and sample results. Bibliographies are provided for the sources of more detailed information on the models. The overall objective of this report is to enable an energy analyst or modeler to assess the applicability of these approaches for his own purposes and to decide upon the next step in adapting them for a specific application.

The Appendix to the introductory chapter provides a bibliography of publications related to the models described in this report. Two books provide a comprehensive description of the research project: Foell, W.K., ed. *Management of Energy/Environment Systems: Methods and Case Studies.* Chichester: John Wiley & Sons, 1979; and Foell, W.K. and L. Hervey, eds. *National Perspectives on Management of Energy/Environment Systems.* Chichester: John Wiley & Sons, forthcoming. The first book presents the methods and results of the comparative case studies of the German Democratic Republic, the Rhône-Alpes region, and Wisconsin. The second book provides an overview of energy/environment planning and management practices in 12 IIASA National Member Countries, with special focus on the institutional framework of policy analysis.

JANUSZ KINDLER
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ACKNOWLEDGMENTS

The development of the methods described in this report has resulted from the contribution of many individuals at IIASA and within the network of collaborating institutions. We have attempted to credit these contributions through literature references and citations associated with the individual models.

Although this report represents a true collective effort, the following individuals wrote sections of the report (and in many cases, were instrumental in developing the models):

Chapter 1	W. Foell and M. Hanson
Section 2.2	A. Hölzl and M. Hanson
Section 2.3	J. Richter and A. Hölzl
Section 3.2	E. Pönitz
Section 3.3	A. Hölzl
Section 3.4	M. Hanson
Section 4.2	L. Hervey
Section 4.3	J. Peerenboom
Section 5.2	W. Buehring, R. Dennis, W. Foell, L. Hervey
Section 5.3	R. Dennis
Section 5.4	R. Dennis, K. Ito
Section 5.5	W. Buehring, R. Dennis
Section 5.6	H. Stehfest
Chapter 6	W. Buehring, W. Foell, R. Keeney
Chapter 7	J. Buehring and A. Toifelhardt

A special note of thanks is given to Elizabeth Ampt, Helen Maidment, and Judy Ray for their competent, dedicated, and cheerful assistance throughout the research effort. Their contributions were invaluable in aiding communication and coordination within the network of institutions and individuals involved in the studies.

CONTENTS

SUMMARY

This report presents an overview of the analytical framework and quantitative models used in the IIASA case studies on Regional Energy/Environment Management and Planning. Its purpose is to summarize the structure of the models, to provide a complete listing of the sources of more detailed model and data descriptions, and to indicate how the models are integrated to provide a foundation for regional energy/environment policy analysis. Within this context the term 'region' denotes geographic or administrative units, ranging from small countries such as Austria to subnational regions such as the state of Wisconsin in the USA. The audience for the report includes managers, planners, technical advisors, and modelers.

As shown in Figure S-1, the set of models used in the research project encompasses socioeconomic links to the energy system; energy demand in the residential, industrial, commercial/service, agricultural, and transportation sectors; the energy supply sector; environmental impacts associated with the energy system; and policy makers' preferences. The arrows in Figure S-1 show the flow of information between the models. The dashed arrows indicate feedbacks that in most cases are taken into account by the model user rather than by formal mathematical links.

This report gives a brief description of the purpose and general structure of each model, data requirements, examples of input and output, and model limitations. As a whole, the models integrate information about energy flows in a region to simulate the energy system and its relationship to other regional variables, e.g., demographic and economic trends and the environment.

Socioeconomic Models. The approaches used to trace the possible evolution of regional socioeconomic structures are dependent on data availability. Demographic projections are generally available from regional planning offices, and these provide a basis for estimating population growth, household size, housing types, and the size and density of cities – key inputs to the energy demand models. Similarly, the evolution of economic activity can often be estimated on the basis of existing regional forecasts and models. The socioeconomic models used in the Austrian Case Study – the *Population Allocation Model* and the *AUSTRIA II Input–Output Model* – are described in detail in this report. They provide examples of the techniques developed both to project population trends and the activity of the intermediate sectors of the economy and to link these variables to sectoral energy demand models.

Energy Demand Models. Simulation models are used to examine possible development paths of energy demand in the residential, commercial/service, industrial, agricultural, and transportation sectors. They may be described as technological process models, with socioeconomic variables used as exogenous inputs. Energy consumption is analyzed by fuel types, and when possible, by physical process.

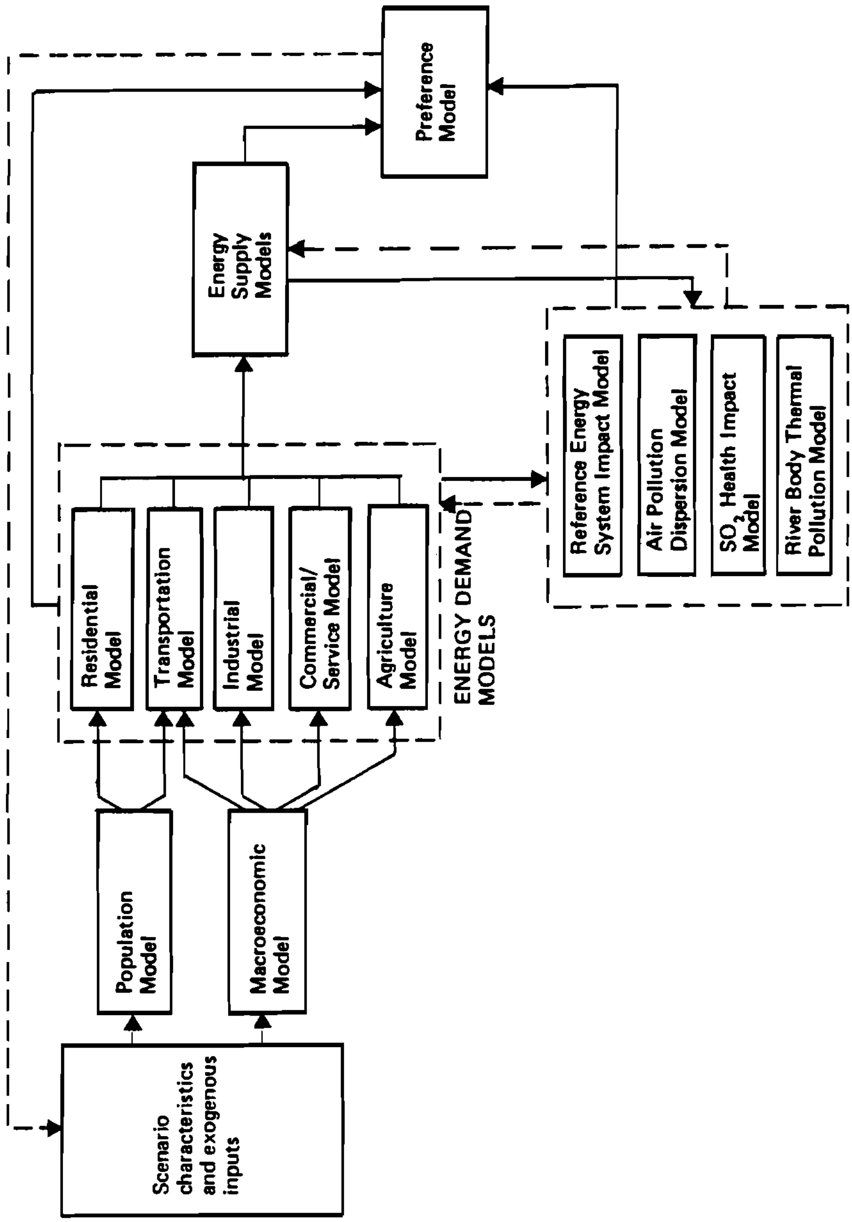

FIGURE S-1 An overview of the set of models developed for the case studies on regional energy/environment planning and management.

The model for the *residential sector* focuses on the household. Energy consumption is analyzed in terms of base appliances (space and water heating, as well as central air conditioning, if applicable) and secondary appliances (such as refrigerators, stoves, and televisions). The model simulates the number, type, and quality of housing units, their heating source, the number of base and secondary appliances, and the energy use of these appliances. The model may be used to examine the impact of proposed policy measures – such as new building codes, improved levels of insulation, and fuel shifts – on the annual energy demand of the residential sector.

The model developed for the *commercial/service, industrial, and agricultural sectors* focuses on the level of economic activity by subsector and the energy intensity per unit of activity. The end-use energy demand calculations are based on value added, the total energy input per unit of value added, and the fuel mix. Because the model relies entirely on exogenous data, it is important to evaluate the plausibility of assumptions about the future activity levels and the energy use patterns of each sector. In the case studies several different sources were used to derive these assumptions. In the Austrian study, described at greatest length in this report, simulation runs were made with an input–output model, with a high level of sectoral disaggregation, driven by assumptions about the activity of trading partners.

In the *transportation sector*, personal travel and freight are treated separately. The procedure for projecting personal travel energy use involves estimating the number of person-kilometers traveled, by mode, using variables such as fuel price, city size, and population density. This quantity is then converted to vehicle-kilometers, on the basis of information on patterns of usage. With information on the technological characteristics of the stock of vehicles, the model then calculates energy consumed for a given number of vehicle-kilometers. The procedure for projecting the freight transport component involves relating ton-kilometers, by mode, to industrial, commercial/service, and agricultural activity.

The Energy Supply Sector. Two approaches have been used to study energy supply questions in the case studies. First, a descriptive energy demand/supply balance approach was employed to calculate the amounts of primary energy by source required to meet end-use demand. This entails accounting for transportation, refining, conversion, and distribution losses, as well as plant thermal efficiencies in the electricity and district heat sectors. Second, a version of the Brookhaven Energy System Optimization Model (BESOM), a formal resource optimization model, was used to a limited extent (only in the Austrian Case Study) to examine interfuel competition and resource supply strategies.

Environmental Models. The *Reference Energy System Impact Model* is designed to calculate quantified environmental impacts associated with the energy supply chain – from extraction of primary energy to delivery of energy to the point of end-use. The impacts are computed on an aggregate level for a given region, without consideration of specific plants or supply networks at the local level. In the model "impact factors," derived from the available scientific literature, are related to units of energy. Only impacts that can be analyzed quantitatively are included in the model, such as land use, water pollution, air pollution, and impacts on human health resulting from accidents and exposure to noxious agents.

The *Air Pollution Dispersion Model* is a local system model that calculates the urban exposure to air pollutants produced by fuel combustion at the point of end-use. A simple "smeared concentration approximation" method is used in the model to describe air pollution dispersion and to calculate spatially-averaged annual ground-level concentrations of pollutants.

The *SO_2 Health Impact Model* calculates the human health impact associated with a given level of exposure to SO_2 air pollution. The model provides an estimate of excess morbidity and premature mortality in certain groups of at-risk populations. This damage function model can be used with both local system models or a reference system model.

Finally, the *River Body Thermal Pollution Model* is used to examine environmental impacts of waste heat released from electric power plants, i.e., temperature increases in bodies of water and water evaporation.

A Preference Model for Appraisal of Energy/Environment Systems. A preference model based on multi-attribute utility theory is used in the case studies to help decision makers evaluate alternative energy/environment strategies. The model takes into consideration the uncertainties of any given strategy, the multiple objective nature of energy/environment problems, and the differences among the preference structures of the individual members of decision-making groups. An application of this technique to the evaluation of electricity generation strategies in the state of Wisconsin is presented in this report.

Software and Hardware. The final chapter describes some of the software and hardware used to integrate and control the set of energy/environment system models.

1 INTRODUCTION

The models and quantitative methods developed as a part of the IIASA research project on Regional Energy/Environment Management are summarized in this report. These methods and their applications in several regional case studies have been individually documented at much greater length in companion reports, books, and articles. These are listed in the Appendix at the conclusion of this chapter. This report is intended as a guide for researchers who want to ascertain relatively quickly (1) the essential structure or methodology of the models used in the project, (2) the sources of more detailed model and data descriptions, and (3) the manner in which the models were integrated to provide a basis for regional energy/environment policy analysis.

This report is not intended for the individual who wants policy-oriented descriptions of energy/environment options, consequences, trade-offs, and recommendations. These are provided in other reports documenting the case studies. Neither is the report intended for the researcher who wants program-level details, such as complete equation specification and data enumeration for models. However, this report does provide the sources for this information.

Experience has convinced us of the need for the level of documentation contained in this report. Policy makers, on the one hand, often need more than a brief report describing final options and staff recommendations. Their recourse should not be programmer-level documents. Researchers, on the other hand, should be spared the need to plow through mountains of material to obtain information on their colleagues' work. If the methods described here seem appropriate for a researcher's task, he can use this overview to give direction to his subsequent work.

Finally, systems analysts often fill roles that are somewhere between 'policy maker' and 'pure researcher.' For them it is the insights derived from systems analysis and modeling that are most important. In this report we have attempted to make some of these insights available without reproducing our entire effort.

We believe that the value of the work described here lies not in the originality or sophistication of the individual methods and models, but rather in the *process and framework that integrate them* to describe the overall energy/environment system of a region. Their application in case studies for a variety of regions has provided an opportunity to examine their usefulness under different conditions and constraints of data availability. Applying the models under severe time restraints has also been beneficial in at least one sense: we have learned to be brutally pragmatic in adapting or modifying existing methods and data to the problem at hand.

The following chapters contain descriptions of the set of models and methods used in the case studies of regional energy/environmental management. Components of the models are described with the help of flow diagrams. Basic assumptions and constraints, selected mathematical formulations, data sources, and sample results are also presented for each model. The report should enable a *systems analyst* to determine the potential applicability of the models and to decide upon the next step in implementing them.

The research program as a whole is based on the assumption that in most regions and countries of the world, a need exists for the development and application of methods to study regional energy/environment systems and to investigate the impacts of alternative energy policies. "Regional" in this context does not signify simply a federal state or a specific geographical region, but rather refers to a system bounded so that one can speak of an energy/environment system from a common physical, socioeconomic, and/or administrative viewpoint. The environmental component of the so-called "energy/environment system" is limited in general to those impacts directly related to the supply and consumption of energy; it does not include the large number of impacts that are not directly linked to energy.

Four main regional case studies have been carried out within the framework described here. The work originated at the University of Wisconsin with a policy-oriented study of energy systems in the state of Wisconsin, USA (Buehring *et al.* 1974, Foell *et al.* 1974). It was extended within a comparative framework to include the German Democratic Republic, Rhône-Alpes (France), and Wisconsin (Foell 1979). The most recent study has been of Austria (Foell *et al.* 1979). Research on selected methods and policy issues is continuing for these regions. The approach is also being extended to additional regions and countries, including Mexico and the Asia–Pacific region (Energy Systems and Policy Research Program and Instituto Tecnologico y de Estudios Superiores de Monterrey 1980).

1.1 BACKGROUND OF THE MODELS

The development of the family of models was based on a philosophy of continuous evolution and refinement and on an insistence upon the maintenance of flexibility. This strategy is an outgrowth of our perception that the energy problem is changing rapidly in this period of great uncertainty. A viable research approach must thus stress flexibility and permit innovation. We have conceived of our research as a continuing process moving through four sequential phases of modeling:

(1) Model conception;
(2) Model development and testing;
(3) Implementation and use of the models in policy formation and decision making;
(4) Feedback leading to refinement of the models and further conceptualization.

The overall family of models can best be described as a set of models that combine data and information about energy flows in a region to describe or simulate the energy system and the relationship of this system to other regional attributes, e.g., demography, the economy, and the environment. An overall simulation framework has proved convenient for integrating the diverse analytical techniques employed in the course of various case studies.

The "system of models" has four major components:

(1) Socioeconomic Activity Models;
(2) End-use Energy Demand Models;
(3) Energy Conversion and Supply Models;
(4) Environmental Impact Models.

The detailed structure of these components has evolved in response to the specific policy issues examined in the case studies and applications of the models.

In general, the issues addressed were relevant to mid- and long-term planning and policy analysis covering a time period of 5–50 years into the future. Strategic rather than tactical issues were chosen for analysis, as shown in the following examples:

(1) What are the energy and environmental implications of policies that encourage alternative urban forms and land-use patterns? What are the consequences of policies that favor changes in present transport system trends?

(2) What impact will various energy conservation policies have on future energy requirements and possible demand/supply imbalances for a region? What additional electrical generating facilities will be needed under different economic growth policies?

(3) What environmental control and pollution abatement strategies should be employed to achieve specific environmental goals, e.g., a given level of air quality?

The spectrum of policy issues addressed in the case studies will be described in more detail in the following chapters, in connection with specific models.

1.2 USE OF THE MODELS WITHIN A SCENARIO FRAMEWORK

As described above, each of the models is associated with a component of the energy system. The models can be used individually to analyze specific issues, or they can be integrated within a so-called scenario framework to examine overall future energy paths of a region (Foell 1976a). Scenarios are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes, critical points in time, or crucial decisions.

Broadly described, scenario building is a detailed investigation of possible future conditions and the consequences of alternative assumptions about them. This set of future conditions 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. Important policy issues can be examined through 'sensitivity studies,' in which only one or a few parameters are varied and the resulting new scenarios are compared.

In order to specify a policy set or framework within which a scenario was built, we have developed a means for expressing a scenario in terms of a limited number of characteristics. Table 1 gives an overview of these characteristics for the four scenarios analyzed in the Austrian Case Study (Foell *et al.* 1979). As shown in Column 1 of Table 1, we relate those characteristics to four scenario properties: socioeconomic structure, lifestyle, technology, and environment. Within the framework of these four categories, a large number of assumptions about future events and/or policies and strategies can be built into the scenarios.

The information in Row 1 of Table 1 shows that some of the specified characteristics were common to all Austrian scenarios, e.g., population growth. In contrast, the technical efficiency of energy use (Row 7) varied significantly among scenarios. Considerable

TABLE 1 Overview of the scenarios examined in the Austrian Case Study.

Summary characteristics		Scenario S1 (Base Case)	Scenario S2 (High Case)	Scenario S3 (Low Case)	Scenario S4 (Conservation Case)
Socioeconomic structure	Population	Average Austrian growth rate of 0.22%/yr			
	Human settlements	Migration important: rural to urban; Vienna declining; western cities grow more rapidly			
	Economy	Medium growth rate 1970–1985: 3.30%/yr 1985–2015: 1.76%/yr	High growth rate 1970–1985: 3.43%/yr 1985–2015: 2.73%/yr	Low growth rate 1970–1985: 3.23%/yr 1985–2015: 1.21%/yr	Same as S3
Lifestyle	Personal consumption	Current trends in personal consumption	Higher consumption than in S1	Lower consumption than in S1	Lower consumption than in S1
	Transportation	Car ownership 300 vehicles/1,000 population	Car ownership 400 vehicles/1,000 population	Car ownership 250 vehicles/1,000 population	Same as S1
	Housing	Bigger new homes ($0.8\ m^2/yr$) Emphasis on electrical appliances and convenient fuels	New home size increases faster than in S1 High emphasis on electrical appliances and convenient fuels	New home size increases more slowly than in S1 Less emphasis on electrical appliances and convenient fuels	Same as S3
Technology	Industry	Overall decrease in energy intensiveness through significant penetration of energy conserving technology	General increase in energy intensiveness	Same as S1	Significant decrease in energy intensiveness through vigorous development and implementation of energy conserving technology

	Transportation	Car efficiency 8.9 liter/100 km	Car efficiency 12.3 liter/100 km	Car efficiency 8.9 liter/100 km	Car efficiency 7.0 liter/100 km
	Housing	1971 insulation standard	Same as S1	By 2000 new homes 40% better than 1971 insulation standard	By 2000 new homes 55% better than 1971 insulation standard
	Energy supply	Decreased emphasis on coal			
		Electricity demand grows more rapidly than total end-use energy demand			
		Medium nuclear growth	High nuclear growth	Low nuclear growth	No nuclear growth
		Adequate oil and gas supply	Adequate oil and gas supply	Adequate oil and gas supply	Constrained oil supply
Environment	Environmental regulations	Proposed SO_2 oil desulfurization regulations by 1981 plus US emission limits of SO_2, all sources, by 2000			
		0.50 of US emission limits on SO_2, point sources, by 2015	0.42 of US emission limits on SO_2, point sources, by 2015	0.71 of US emission limits on SO_2, point sources, by 2015	Same as S3
		1.18 of US emission limits on particulates, industry point sources, by 2015	1.0 of US emission limits on particulates, industry point sources, by 2015	1.60 of US emission limits on particulates, industry point sources, by 2015	Same as S3
		US emission limits of particulates, electric power plants, by 2015			

attention must be devoted to internal consistency among the specified characteristics, although one can never ensure complete consistency.

The framework summarized in Column 1 of Table 1 gives the exogenous functions, boundary conditions, and constraints for the family of models and data bases used to calculate the details of the alternative energy/environment futures. Characteristics such as those given in Table 1 provided the major inputs to the models described in this report. Some of the models have direct links to several of the characteristics in the table. For example, inputs to the personal transportation model (Section 3.4) are directly specified by several of the characteristics in Table 1, including human settlement patterns, transportation lifestyle (car ownership), technical efficiency of cars, and car emission standards.

Figure 1 summarizes the three-step analytical process that linked issues, scenarios, and models in the case studies.

As shown, this process involves:

(1) Identification and choice of the *issues*;
(2) Definition of *scenarios* within the framework described above;
(3) Use of models to build and evaluate the alternative futures.

1.3 OVERALL STRUCTURE OF THE FAMILY OF MODELS

The models used in the case studies describe four major energy/environment system components. The general flow of information between these components is depicted in a highly simplified manner in Figure 2. The flow may be summarized as follows (the numbers in parentheses correspond to the flows shown in Figure 2):

(A) Regional socioeconomic information (e.g., population settlement patterns, economic activity, etc.) is provided exogenously (1) and/or by models (2).

(B) The socioeconomic information serves as input (3) to energy demand models (4), which are structured according to economic sector (e.g., industrial, commercial/service, or residential sectors) or by technological process (e.g., heating, cooling, lighting, etc.). In general, the outputs of the energy demand models are in the form of annual demands, generally specified by fuel and, in the case of transportation, annual emission.

(C) The outputs of the energy demand models form the inputs (5) to energy supply models, which are used in turn to calculate primary energy requirements, required conversion and transport facilities, supply system costs, and so forth. In most of the analyses conducted in the case studies, supply was directly matched to demand or related to demand within a framework of constraints. An exception was the use of a formal resource allocation model based on minimization of a cost function in the Austrian Case Study.

(D) 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 are used to

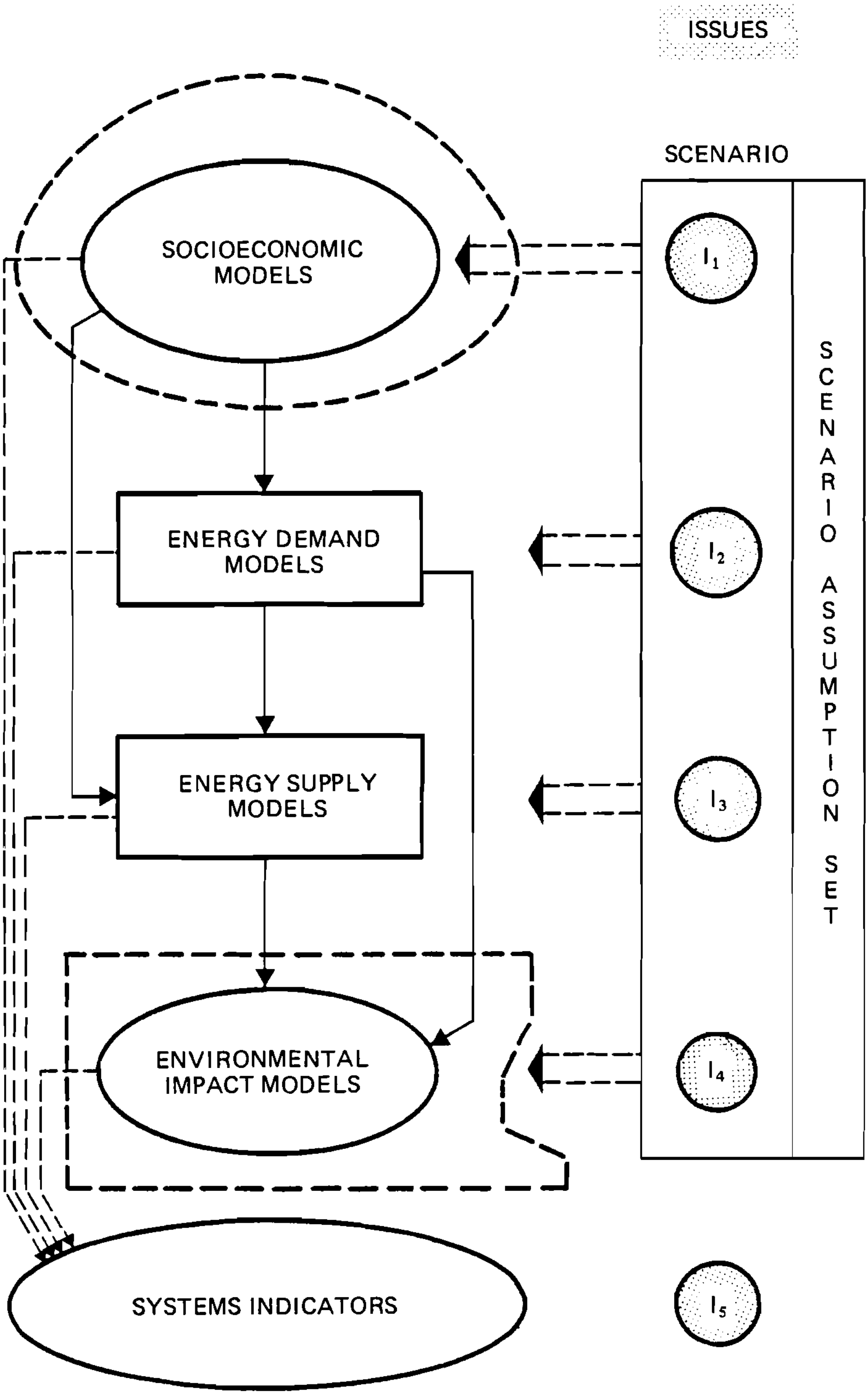

FIGURE 1 Schematic representation of the relationship among issues, scenarios, and models.

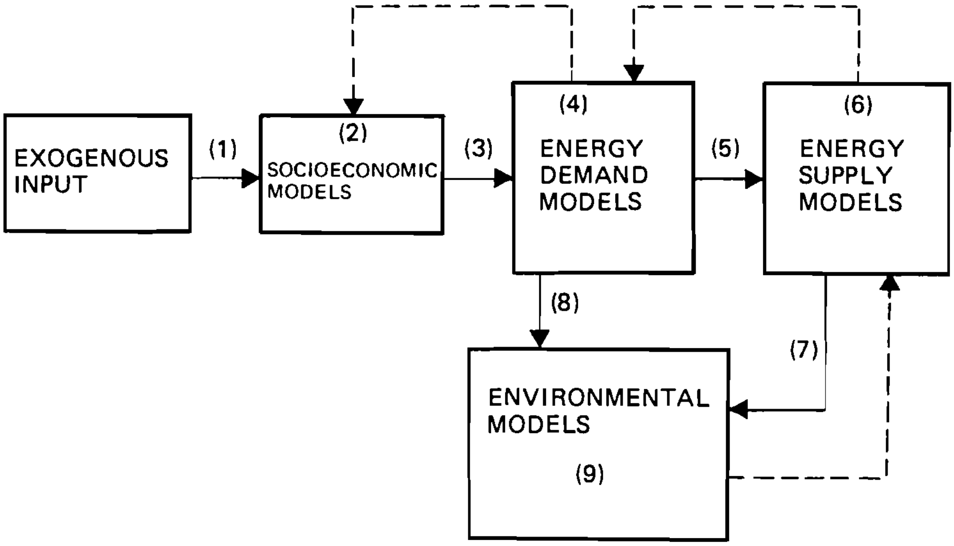

FIGURE 2 Simplified diagram of the overall information flow among model components.

calculate a broad spectrum of impacts, including human health and safety impacts, on a systemwide and subregional basis.

There are additional flows of information between the major components, as indicated by the dashed lines in Figure 2. In general, although not in all cases, the dashed flows (feedbacks) are implemented by intervention of the model user and not by formal mathematical links.

1.4 ORGANIZATION OF THE REPORT

This report is organized in accordance with the major system components shown in Figure 2. Chapter 2 outlines the overall approach used to specify socioeconomic inputs to the energy system and describes two specific models – a population allocation model and the AUSTRIA II Input–Output Model.

Chapter 3 begins with an introduction to the energy demand models; descriptions of the sectoral models follow, covering the residential, industrial, commercial/service, agriculture and transportation sectors.

Chapter 4 discusses the energy supply sector. There two approaches used to analyze regional energy supply are presented. The first is a straightforward demand/supply balance approach based upon the construction of a reference energy system. The second makes use of a formal resource allocation model to examine interfuel competition and resource supply strategies.

Chapter 5 focuses on environmental analysis. Overviews of a Reference Energy System Impact Model, an Air Pollution Dispersion Model, an SO_2 Health Impact Model, and a River Body Thermal Pollution Model are provided in this chapter.

Chapter 6 describes the use of a "preference model" for the incorporation of subjectivity and uncertainty into the evaluation of alternative energy/environment strategies. It presents an application of this technique to the evaluation of electricity generation strategies in Wisconsin. Finally, Chapter 7 describes some of the software and hardware used to integrate and run the family of energy/environment system models.

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APPENDIX
Principal Documentation for the Studies on Regional Energy/Environment Management

General Background Papers:

Foell, W.K., J.L. Pappas, and J.W. Mitchell (1974) The WISconsin Regional Energy Model: A Systems Approach to Regional Energy Analysis. Report No. 56. University of Wisconsin–Madison: Institute for Environmental Studies.

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

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2 SOCIOECONOMIC MODELS

2.1 INTRODUCTION

A starting point for the analysis of the future development of regional energy/environment systems is a description of the economic and demographic characteristics of a given region. Energy flows and associated emissions are dependent on such variables as social and economic factors, demographic characteristics, and the industrial and commercial composition of the region.

In the case studies of the German Democratic Republic (GDR), the Rhône-Alpes region of France, Wisconsin, and Austria, a set of socioeconomic activity models was used to analyze the possible evolution of the socioeconomic structure during the next 40–50 years. The availability of data and operational models determined which particular set of socioeconomic models was used in a given region. However, the models provided comparable demographic and economic information for input to the energy demand, energy supply, and environmental impact models.

Demographic models. In each of the regions aggregate demographic projections were obtained from models in operation at regional planning offices. If necessary, additional models were developed by the IIASA team to study population trends on a less aggregated, sub-regional basis. The demographic data provided by these models included the spatial location, size, and population density of cities – information necessary for estimating travel behavior and for calculating human health impacts of energy-related emissions; the size of households and housing types – information needed for estimating energy consumption by the residential sector and for assessing the feasibility of district and solar heating; and automobile ownership levels – a causal factor in personal travel and thus a critical input to the transportation model.

The demographic models revealed some diverse trends in the four regions. Overall population growth rates varied from approximately zero in the GDR and quite low in Austria to 1.0 percent per year or higher in Wisconsin and Rhône-Alpes. Other trends, such as increasing automobile ownership levels and growing urban dispersal, were common to all the regions.

Economic activity models. Value added was used to represent economic activity in all regions except the GDR, where net material product was used as an indicator. Intermediate economic activity was disaggregated into three categories, i.e., industrial, service/commercial, and agricultural activity. The definitions of these categories differed slightly by region; in general, the industrial category includes all manufacturing and handcraft industry, and the service/commercial sector includes retail and wholesale trade and services.

In each of the regions the industrial and service/commercial categories have been disaggregated into well-defined components, similar to those in the two-digit SIC (Standard Industrial Classification) system used in the USA. This allows policy analysis to penetrate to the industry, and in some cases even to the process, level.

Although it is difficult and controversial, forecasting the output of the industrial, service/commercial, and agricultural sectors for the study period is key to the analysis. The forecasting methods applied in each of the regions reflected in part the availability of models and existing forecasts. The methods ranged from the use of an input-output model, with economic growth tied to growth rates of principal trading partners, in the case of Austria, to the use of official plans in conjunction with optimization models in the GDR. In the case studies of the Rhône-Alpes region and Wisconsin, the analysis was heavily based on the extrapolation of sectoral trends, often related to national economic trends. Specific investment plans of large firms in the regions also played an important role in the forecasting activity. The analyses of industrial, service/commercial, and agricultural output over time were done in constant units of currency to remove the effects of inflation.

The values specified for socioeconomic variables within the regions must be consistent with the values of corresponding variables outside the region, e.g., at the national or global level. The strategies used to assure this consistency differed by region; a formal mathematical link was used in the Austrian study, while comparisons with national trends were made in Wisconsin.

The socioeconomic information provided by the demographic and economic models are key inputs for the energy demand, energy supply, and environmental impact models. The careful and explicit elaboration of scenarios is the unifying component that relates these models and permits policy analysis in a simulation or "what if" context. The following two sections of this chapter present a description of population models and regional economic models used in the case studies. Although the discussion focuses specifically on Austria, the general application of these models and the transformation of their outputs into a form compatible with the requirements of the energy demand, energy supply, and environmental impact models are representative of the other case studies.

2.2 THE POPULATION ALLOCATION MODEL

2.2.1 Purpose

Demographic change during the study period was a driving function in the residential, transportation, and health impact models used in the regional energy/environment case studies. These models require input data on the total population and/or the total number of households in the regions during the study period. The data must be provided in certain spatial and functional categories; however, the degree of detail varies by region, depending on the availability of information. The general approach used in all the studies was first to obtain aggregate demographic projections from regional planning offices and then to build a model for allocating the projected population to smaller spatial and functional units.

The procedure developed for the Austrian Case Study will be used in this section to illustrate this approach to making demographic projections. In the Austrian study the results of selected simulation runs made by the Oesterreichisches Institut fuer Raumplanung (OeIR) were used as primary input data. Similar procedures were applied in the other case studies.

2.2.2 Requirements and Structure of the Allocation Model

The structure of a population allocation model depends on the information available on the future evolution of a given region's population and on the requirements of the models for which it must supply input data. Figure 3 indicates the sources of baseline demographic statistics and projections for the Austrian Case Study, the level of disaggregation required, and the role of demographic information in the scenario-building process.

For the residential model (see Section 3.2) information is needed on the total number of homes and the number of incremental homes, broken down by political region (Bundesland) and by city size. More detailed demographic data are required by the transportation model (see Section 3.4) to account for the relationship between community type and travel behavior and to calculate emission concentrations within each urban center. Detailed population distribution data is also needed for the health impact model (see Section 5) because both emission concentrations (from factories, residential buildings, and motor vehicles) and the number of persons exposed to them depend on population densities.

2.2.3 Components of the Population Allocation Model

In the Austrian Case Study, data with a high level of spatial disaggregation were available for the population allocation model. This permitted simulation of migration behavior between very small regional units called political districts (politische Bezirke).* However, analysis at the district level is not necessary for most purposes; larger units such as provinces (Bundeslaender) are usually adequate. Data at this level of regional detail, disaggregated into urban and rural categories, adequately capture the most important interregional variations in climate conditions, prevailing housing structures, and fuel consumption patterns. Factors that affect energy consumption – such as average family size, type and size of homes, equipment of homes, mode and frequency of travel, and exposure to air pollution – are significantly different in urban and rural areas.

Demographic data on the level of the "functional" region suit the requirements of the transportation model and the health impact model. Functional regions consist of one urban center where regional industrial and commercial activities are concentrated, a surrounding area from which a large fraction of the working population commutes into the urban center, and an outer ring with little commuting. In the Austrian study, if the outer ring of a functional region did not fall into a single province, it was subdivided in order to allow for an aggregation of the results by province. An analysis by K. Sherill (1976) was used to define functional regions in Austria.

Projection of the total population. Results from the regional age- and sex-specific population model developed by A. Rogers and F. Willekens (1976, 1977) at IIASA and applied to Austria by the OeIR were used in the Austrian Case Study. The OeIR simulation runs provided population projections for 9 provinces and 94 political districts for the years 1981 and 1991 (Sauberer *et al.* 1976). Baseline population data were available

*Austria is divided for administrative purposes into 97 political districts.

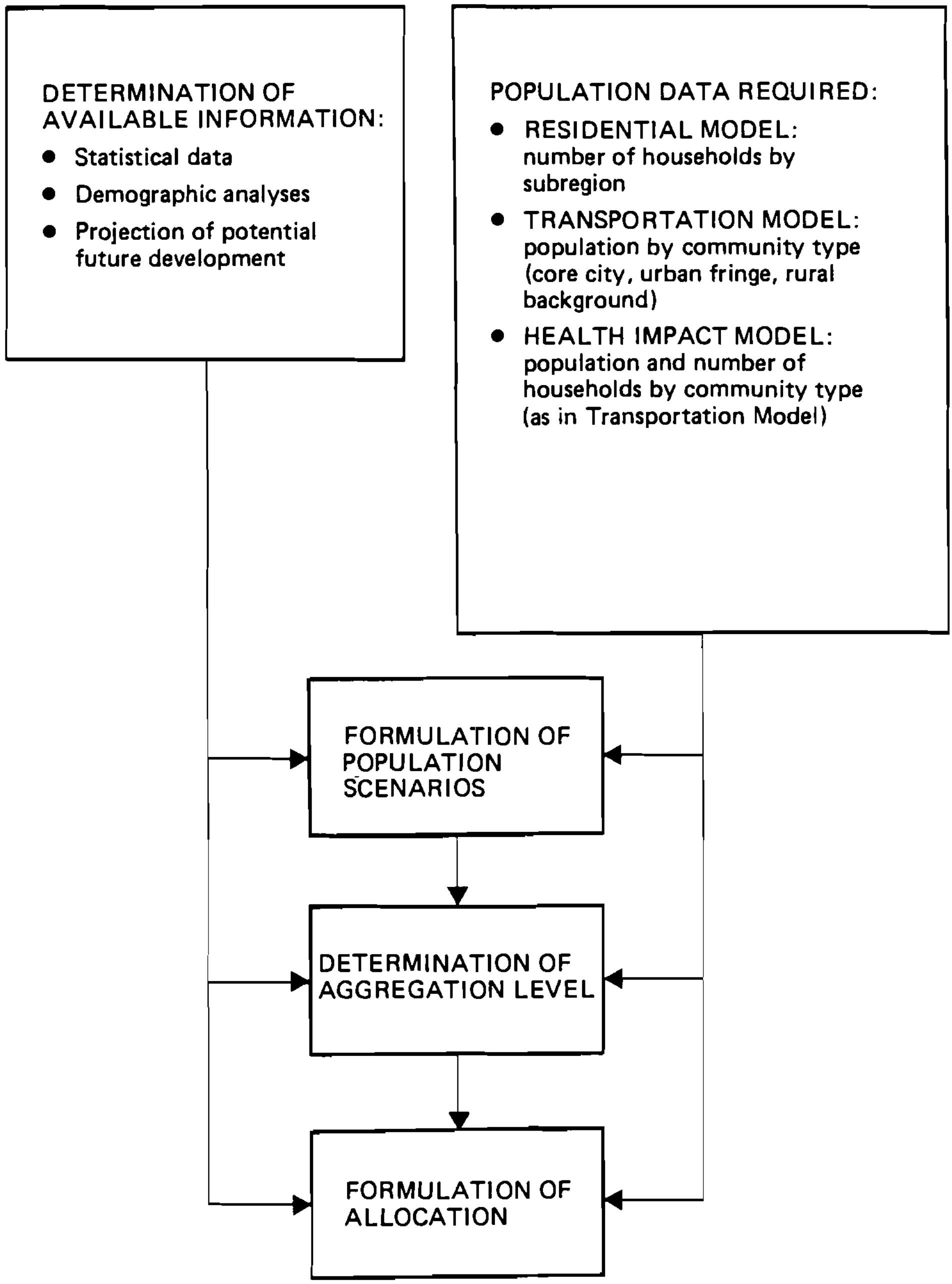

FIGURE 3 Information flow through the population allocation model used in the Austrian Case Study. Sources of statistical data included publications of the Oesterreichisches Statistisches Zentralamt (1972, 1974, 1975); sources of demographic analyses included the Geschaeftsstelle der Oesterreichischen Raumordnungskonferenz (1975) and Sherrill (1976); Sauberer *et al.* (1976) provided demographic projections.

from the Austrian Population Census of March 12, 1971 (Oesterreichisches Statistisches Zentralamt 1974). Annual population projections were derived by interpolation between the years 1971, 1981, and 1991, and by extrapolation for later years.

Projection of the urban–rural population distribution. In the Austrian Case Study a decision rule was developed to reflect the assumption that urban areas in Austria would grow while the rural areas would decline. If population projections for a certain district showed an increase, the incremental population was assigned to the urban areas (main city and secondary cities) in proportion to their size. If projections for a district showed a decline, the loss was assumed to occur in the rural areas first. Only if the loss was larger than the entire rural population were decreases in population assumed to occur in urban categories in proportion to their size.

Projection of the number of households. Projections of the total number of households in each district were based on 1971 values and on the assumption that the average number of persons per household would decline at the same rate in each district. At the district level household size was assumed to be the same in both urban and rural areas. The error introduced by this assumption was small because the largest cities represented a single district, with no rural component. For the provinces and for Austria as a whole, the difference between the average household size in rural and urban areas was captured reasonably well, as can be seen in the summary demographic output data presented in Table 2 and Table 3.

2.2.4 Input and Output

Two variants were selected from the population projections provided by the OeIR for examination in the Austrian Case Study. In OeIR Variant 2.1, mortality was calculated on the basis of age-specific (five-year age groups) fertility rates for each political district, using the average rates recorded for the years 1971–1973. Death rates were calculated on the basis of 1970–1972 statistics on life expectancy. Migration rates were taken from a study of internal migration between 1966 and 1971, carried out in conjunction with the 1971 Census. It was assumed in this Variant that during the time frame of the projection the age- and sex-specific migration for each district would not differ from the 1971 rates.* In Variant 2.1, the projected population of Austria increases from 7.46×10^6 people in 1971 to 8.26×10^6 people in 2015. The projections of population by province and average household size by province for this "Growth Case" are showin in Table 2.

In OeIR Variant 4.3, population projections were also based on fertility rates observed between 1971 and 1973, but during the time frame of the projection the rates were assumed to decrease, to account for the drop in fertility observed after 1973. The same assumptions were applied to all districts. The projections of population by province and average household size by province used for this "Decline Case" are shown in Table 3.

The two OeIR simulations, which differ mainly with respect to assumed fertility rates, demonstrate the sensitivity of the projections to these parameters. By 1990 the

*International migration is not accounted for directly in the OeIR projections. It is assumed that a compensatory migration balance exists between individual political districts and foreign countries.

TABLE 2.a Population projections for Austria 1971–2015, decline case. These projections are based on data supplied by the Oesterreichisches Institut fuer Raumplanung (Variant 2.1).

Region	Total population (10^3)			Average change/ yr (%)	Rural population (%)			Average change/ yr (%)
	1971	1990	2015		1971	1990	2015	
Burgenland	272	247	212	–0.56	65	61	54	–0.42
Carinthia	525	526	518	0.30	42	40	36	–0.35
Lower Austria	1,414	1,308	1,164	–0.44	56	52	47	–0.40
Upper Austria	1,223	1,266	1,335	0.20	46	44	41	–0.26
Salzburg	402	456	526	0.61	43	38	33	–0.60
Styria	1,192	1,170	1,133	–0.12	47	45	42	–0.26
Tyrol	541	613	718	0.65	53	47	40	–0.64
Vorarlberg	271	321	387	0.81	42	36	30	–0.76
Vienna	1,615	1,440	1,248	–0.58	0	0	0	
Austria	7,456	7,347	7,241	–0.07	39	37	34	–0.31

TABLE 2.b Average household size in Austria 1971–2015, decline case. These projections are based on data supplied by the Oesterreichisches Institut fuer Raumplanung (Variant 2.1).

Region	No. of persons per household			Average change/ yr (%)	No. of persons per household in rural areas			Average change/ yr (%)
	1971	1990	2015		1971	1990	2015	
Burgenland	3.43	3.43	3.03	–0.28	3.52	3.26	3.03	–0.34
Carinthia	3.09	2.94	2.72	–0.29	3.91	3.71	3.50	–0.25
Lower Austria	2.86	2.71	2.53	–0.28	3.16	2.99	2.78	–0.29
Upper Austria	2.95	2.65	2.62	–0.27	3.55	3.36	3.11	–0.30
Salzburg	2.92	2.82	2.65	–0.22	3.64	3.42	3.17	–0.31
Styria	3.02	2.86	2.67	–0.28	3.62	3.45	3.22	–0.27
Tyrol	3.11	2.97	2.82	–0.22	3.75	3.57	3.32	–0.28
Vorarlberg	3.39	3.22	2.99	–0.28	3.48	3.29	3.03	–0.31
Vienna	2.20	2.07	1.92	–0.31	–	–	–	–
Austria	2.66	2.56	2.43	–0.21	3.49	3.26	3.10	–0.27

total population projection associated with the "low fertility" variant is already 4% lower than that in the variant with higher fertility. By 2015 population in the low variant has reached only 7.24×10^6 people, 13% below that in the high variant.

2.2.5 Concluding Observations

After a region has been chosen and the main issues have been defined, a first step in mid- to long-term energy/environment analysis is the study of demographic trends. We have found that suitable demographic projections are frequently available from regional planning

TABLE 3.a Population projections for Austria 1971–2015, growth case. These projections are based on data supplied by the Oesterreichisches Institut fuer Raumplanung (Variant 4.3).

Region	Population (10^3) 1971	1990	2015	Average change/ yr (%)	Rural population (%) 1971	1990	2015	Average change/ yr (%)
Burgenland	272	260	250	–0.19	65	63	61	–0.14
Carinthia	526	551	605	0.32	42	39	34	–0.48
Lower Austria	1,414	1,388	1,398	–0.03	56	52	47	–0.40
Upper Austria	1,223	1,327	1,541	0.53	46	42	37	–0.49
Salzburg	402	475	601	0.92	43	36	29	–0.89
Styria	1,192	1,223	1,297	0.19	47	45	41	–0.31
Tyrol	541	636	817	0.94	53	45	35	–0.94
Vorarlberg	271	335	449	1.15	42	34	26	–1.08
Vienna	1,615	1,467	1,302	–0.49	0	0	0	
Austria	7,456	7,662	8,260	0.23	39	36	33	–0.38

TABLE 3.b Average household size in Austria 1971–2015, growth case. These projections are based on data supplied by the Oesterreichisches Institut fuer Raumplanung (Variant 4.3).

Region	No. of persons per household 1971	1990	2015	Average change/ yr (%)	No. of persons per household in rural areas 1971	1990	2015	Average change/ yr (%)
Burgenland	3.43	3.34	3.06	–0.26	3.52	3.26	3.04	–0.33
Carinthia	3.09	2.93	2.76	–0.26	3.91	3.75	3.45	–0.28
Lower Austria	2.86	2.71	3.53	–0.28	3.16	2.99	2.79	–0.28
Upper Austria	2.95	2.81	2.65	–0.24	3.55	3.37	3.12	–0.29
Salzburg	2.92	2.84	2.67	–0.20	3.64	3.42	3.17	–0.31
Styria	3.02	2.87	2.68	–0.27	3.62	3.43	3.19	–0.29
Tyrol	3.11	2.99	2.84	–0.21	3.75	3.57	3.32	–0.28
Vorarlberg	3.39	3.19	2.98	–0.29	3.48	3.29	3.03	–0.31
Vienna	2.20	2.07	1.92	–0.31	–	–	–	–
Austria	2.66	2.58	2.47	–0.17	3.49	3.31	3.08	–0.28

offices. Utilization of existing projections is advantageous for conserving research resources and making the study consistent with other socioeconomic research based on the same projections. In some instances, modification of existing projections is necessary to obtain input needed for the demand, supply, and environmental impact models or to provide alternative projections for policy study purposes (for instance for studying the impact of alternative land use patterns).

Since there is no formal feedback between the population projections and the other models it is important to assure that assumptions underlying other models do not contradict demographic assumptions. It is clear that economic development and environmental conditions have an influence on migration, death rates, and birth rates.

2.3 THE AUSTRIA II INPUT–OUTPUT MODEL AND ITS APPLICATION TO ENERGY DEMAND MODELING

2.3.1 Purpose of the Model

The evolution of energy demand, energy supply, and environmental conditions in a region is closely linked to the evolution of the region's economy. Detailed economic development alternatives were described in each of the four regional case studies. The Austrian Case Study provides one example of the type of economic analysis used in the IIASA project.

In the Austrian Case Study the AUSTRIA II Input–Output Model was used to simulate the effects of given scenario assumptions on the Austrian economy. Assumptions about the economic development of Austria's trading partners, the evolution of the components of final demand, and the evolution of inputs in the intermediate sectors of the economy, especially the evolution of energy inputs, were quantified and used as scenario input data in the AUSTRIA II Model. This input constituted an addition to or replacement for exogenous input data normally included in the model. The projections of economic activity produced by the AUSTRIA II Model were then used as input for the energy demand models. In the AUSTRIA II Model, energy demand by fuel type in the intermediate sectors is directly linked to the value added by economic sector.

In order to evaluate the general capabilities of the AUSTRIA II Model and its suitability for the special application of deriving energy demand projections, it is necessary to describe the objectives, the basic features, and the institutional background of the model.

The AUSTRIA II Model was built to calculate the future demand for various goods and services produced in Austria. This objective is met through the preparation of input–output tables at constant prices for each year of the projection period. Nearly all the aggregates of national accounts are made available as a by-product of this procedure.

The model concentrates only on the medium-term aspects of economic development. (In general, projections are made for a period of up to 15 years.) The model permits one to simulate the effect of various economic development scenarios with respect to Austria's trading partners, competitiveness of Austrian products in world markets, and technological changes.

These goals follow from the institutional background of the model; the model was developed in the Statistical Division of the Bundeskammer der gewerblichen Wirtschaft (Economic Chamber), a nongovernmental institution under public law in Vienna that represents the interests of business in the field of economic policy. A major task of the Economic Chamber is to provide methodological advice and general data to its members. Austria's economy is characterized by a high proportion of medium-size enterprises with no in-house research departments and few resources for marketing research. For this reason the results of the AUSTRIA II Model and other input–output information play a key role in the marketing research program at the national level.

2.3.2 General Model Description

AUSTRIA II is an iteratively-solved, demand-oriented input–output model. It is based on an input–output table of the Austrian economy for the year 1970 (Richter and Teufelsbauer 1973a), which in turn was derived from an input–output table for 1964 (Oesterreichisches Statistisches Zentralamt 1973), the last officially available input–output table for Austria. Figure 4 shows the input–output concept used in the AUSTRIA II Model , as well as an overview of the model structure.

2.3.3 Initial Definition of Terms

Before the workings of the model can be considered in detail, it is necessary to provide the reader with initial definitions and a description of the major components of the model. Detailed explanations (in German) of the concepts underlying the model are provided by the Oesterreichisches Statistisches Zentralamt (1973) and Richter and Teufelsbauer (1973a, 1973b). Only the most important terms and model features will be explained here.

The model distinguishes between two categories of total demand, namely, intermediate demand and final demand. Intermediate demand can be defined as the demand for goods and services by companies for production pruposes, excluding investments that are recorded as a final demand category. AUSTRIA II differentiates 31 producing (or intermediate) sectors. Table 4 gives a definition of these sectors in terms of the Austrian classification of economic activities established in 1968 [Betriebssystematik 1968, as set forth by the Oesterreichisches Statistisches Zentralamt (1976)]. The intermediate demand of these sectors in a given year is calculated from final demand projections and a table of projected input–output coefficients, which describe the interdependencies of the intermediate sectors.

Final demand consists of domestic final demand and exports. Domestic final demand may be broken down into six categories: private consumption, public consumption, investment in machinery and equipment, investment in construction, inventory changes, and, according to the "domestic concept," expenditures made by foreign tourists in Austria. Because of the important role of foreign trade in Austria's economic activity, much emphasis is given to a rather detailed treatment of this sector.

2.3.4 Major Components of the Model

Private Consumption

The final demand category includes expenditures made by domestic private households, disaggregated by supply sector. The purchase of real estate and the purchase or construction of buildings is not included. Since the input–output table is based on domestic activity, the private consumption category also excludes expenditures on consumer goods by Austrians in foreign countries. In contrast to the system of national accounts, valuation is at producer prices, not at consumer prices. Trade margins contained in private consumption are recorded as private consumption of services supplied by the trade sector. The sales of the other supply sectors contain no trade margins.

Because private consumption is a driving force in the economy, this category is considered in some detail in the AUSTRIA II Model. A number of consumption functions are estimated to analyze the dependence of the demand for certain goods and services on personal disposable income. All functions are estimated at constant 1970 consumer prices.

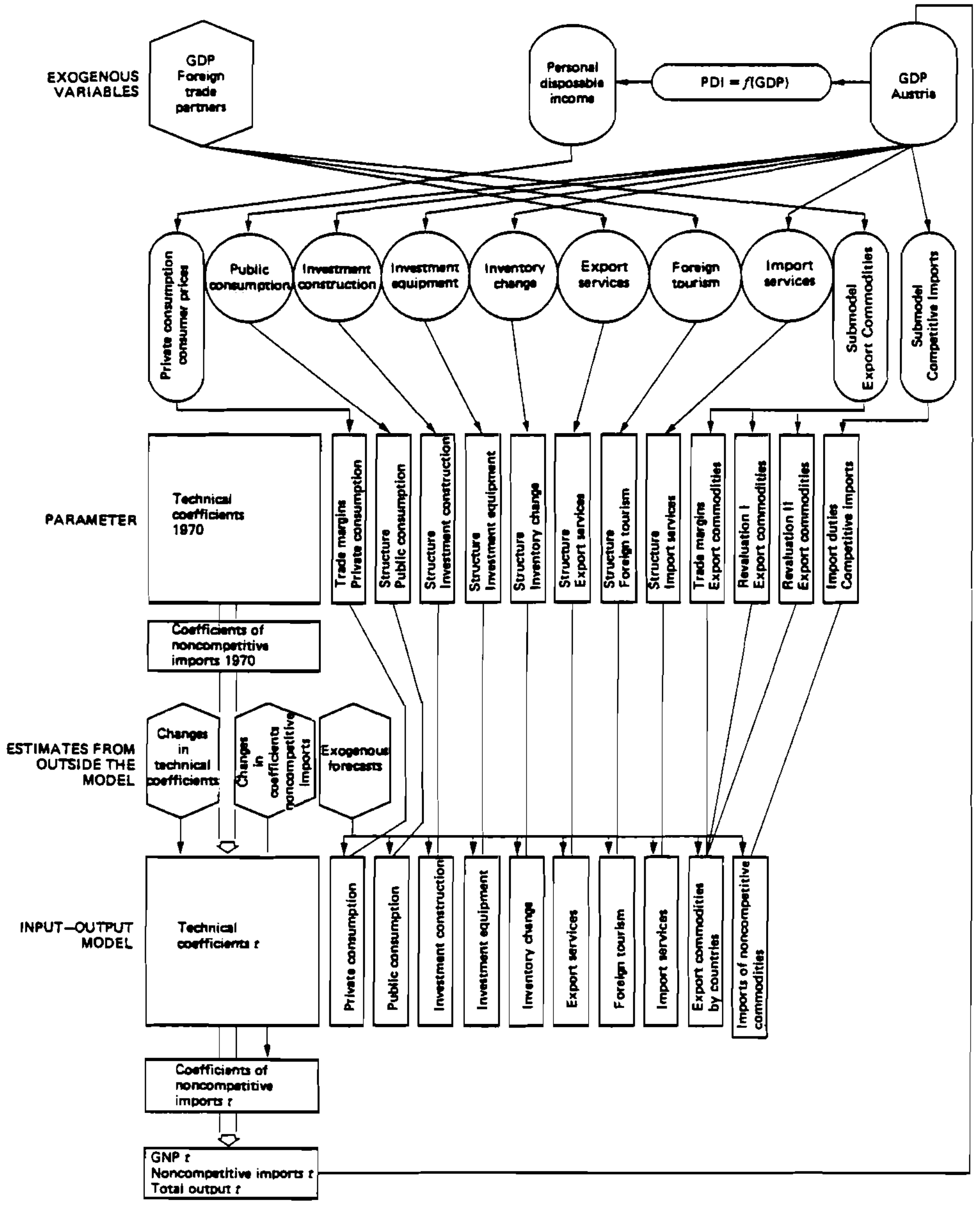

FIGURE 4 The structure of the AUSTRIA II Model.

TABLE 4 Definition of the intermediate sectors of the AUSTRIA II Model.

	Austrian classification of economic activities (Betriebssystematik) 1968		
AUSTRIA II sectors	2-digit	Minus	Plus
(1) Agriculture and forestry	01,02		
(2) Mining	21,22,24–26	262,268	4722
(3) Petroleum and natural gas	23,46	462	
(4) Stone, clay, cement	27,47	4722	262
(5) Glass	48		
(6) Food	31,32	328	
(7) Tobacco			328
(8) Textiles	33		
(9) Clothes	34	3432	382
(10) Leather	35,36		3432
(11) Chemicals	44,45		268,462
(12) Iron and steel	51	512,513	
(13) Machinery	52,54,55	521	581,582
(14) Casting			513
(15) Nonferrous metals			512
(16) Iron and metal products	53,59		521
(17) Electrical machinery and equipment	56,57		
(18) Vehicle construction and repair	58	581,582	
(19) Saw mills			371
(20) Wood products			
(21) Pulp, paper, plywood			411
(22) Paper products, printing, publishing	41–43	411	
(23) Construction industry	61–63		
(24) Electricity, gas, and water	11–14		
(25) Trade and leasing	71–76		
(26) Transportation and communication	81–85,88,77		
(27) Banking and insurance	91,92		
(28) Hotels and restaurants	78		
(29) Other services	93–97,99		986,987
(30) Housing[a]			
(31) Public administration	98	986,987	

[a]Includes rented and privately owned buildings.

The selection of a specific function is based on both statistical and plausibility criteria. Although personal disposable income is the main determinant of consumer behavior, additional variables are introduced in the estimation procedure to account for special impacts, such as extraordinary levies on cars or luxury items. Price variables are not included in AUSTRIA II, although certain functions are estimated that take into account reactions to price changes.

The consumption functions are estimated at consumer values. The projections are then transformed into producer values using constant trade margins for the sales of each supply sector. Projections of the major components of private consumption that were used in the Austrian Case Study are displayed in Figure 5, Figure 6, and Figure 7. (Figure 5 may give the impression that the share of food in total private consumption increases, but

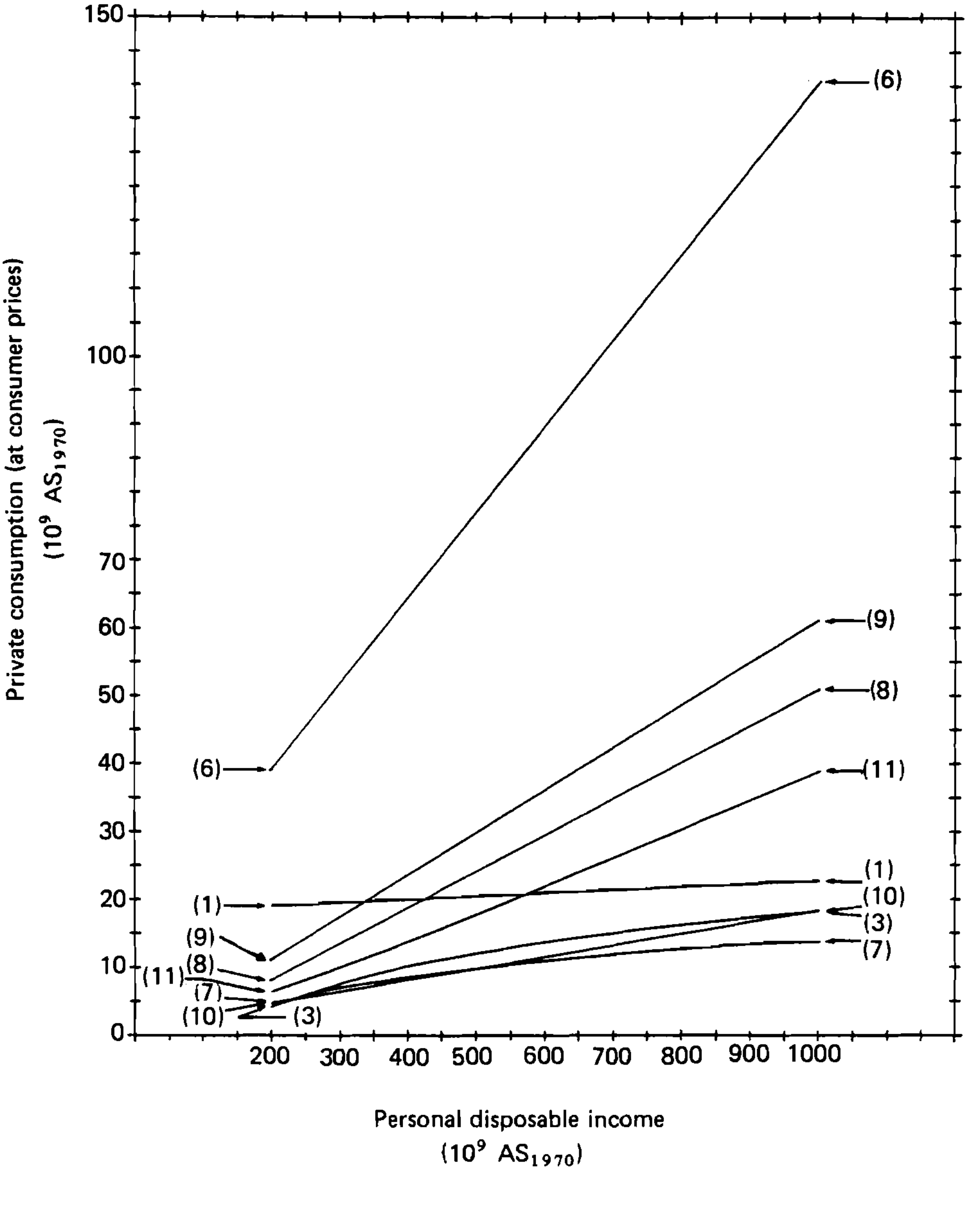

FIGURE 5 Projections of major components of private consumption in Austria in relation to personal disposable income – I. Sector (1) is agriculture and forestry; Sector (3) is petroleum and natural gas; Sector (6) is food; Sector (7) is tobacco, Sector (8) is textiles; Sector (9) is clothes; Sector (10) is leather; and Sector (11) is chemicals. Cf. Table 4.

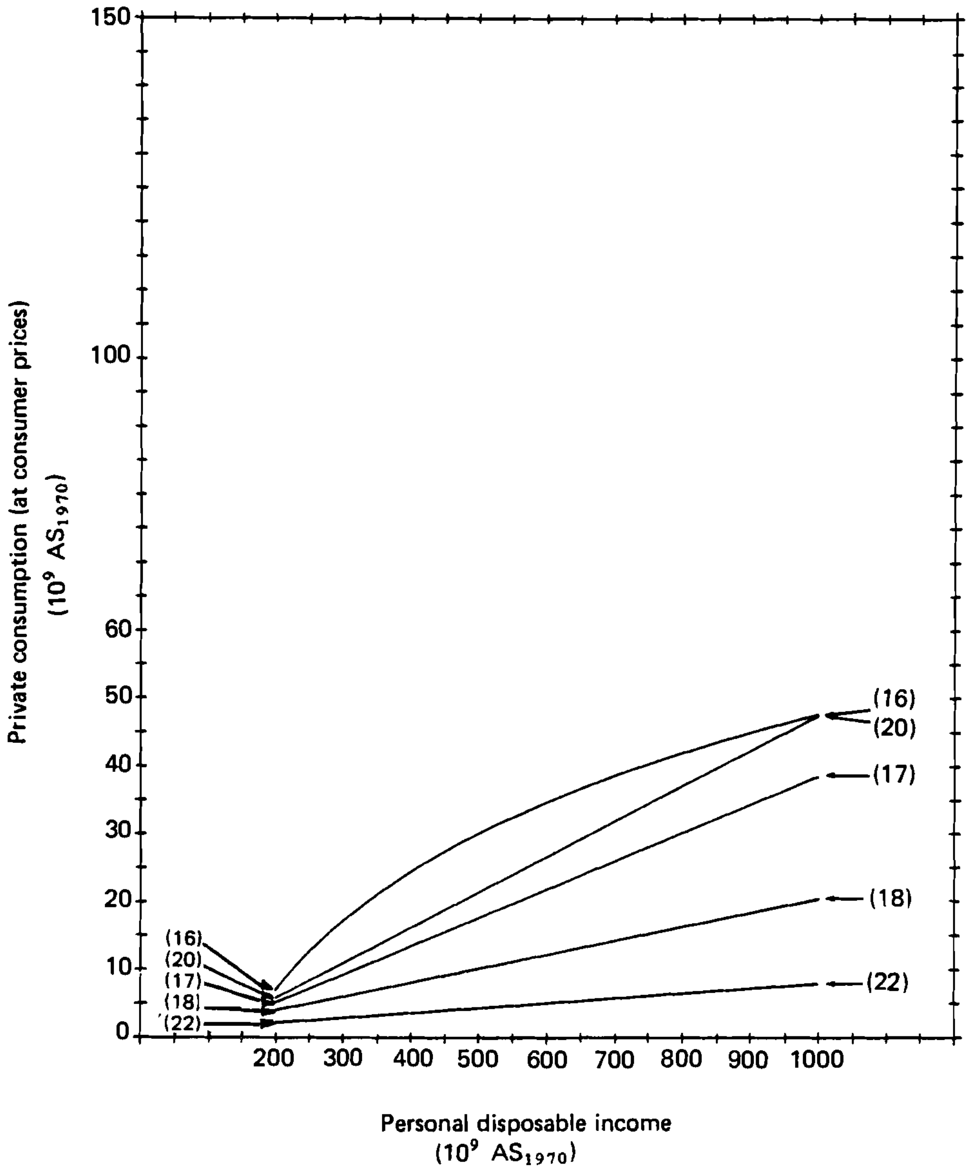

FIGURE 6 Projections of major components of private consumption in Austria in relation to personal disposable income – II. Sector (16) is iron and metal products; Sector (17) is electrical machinery and equipment; Sector (18) is construction and repair of vehicles; Sector (20) is wood products; and Sector (22) is paper products, printing, and publishing. Cf. Table 4.

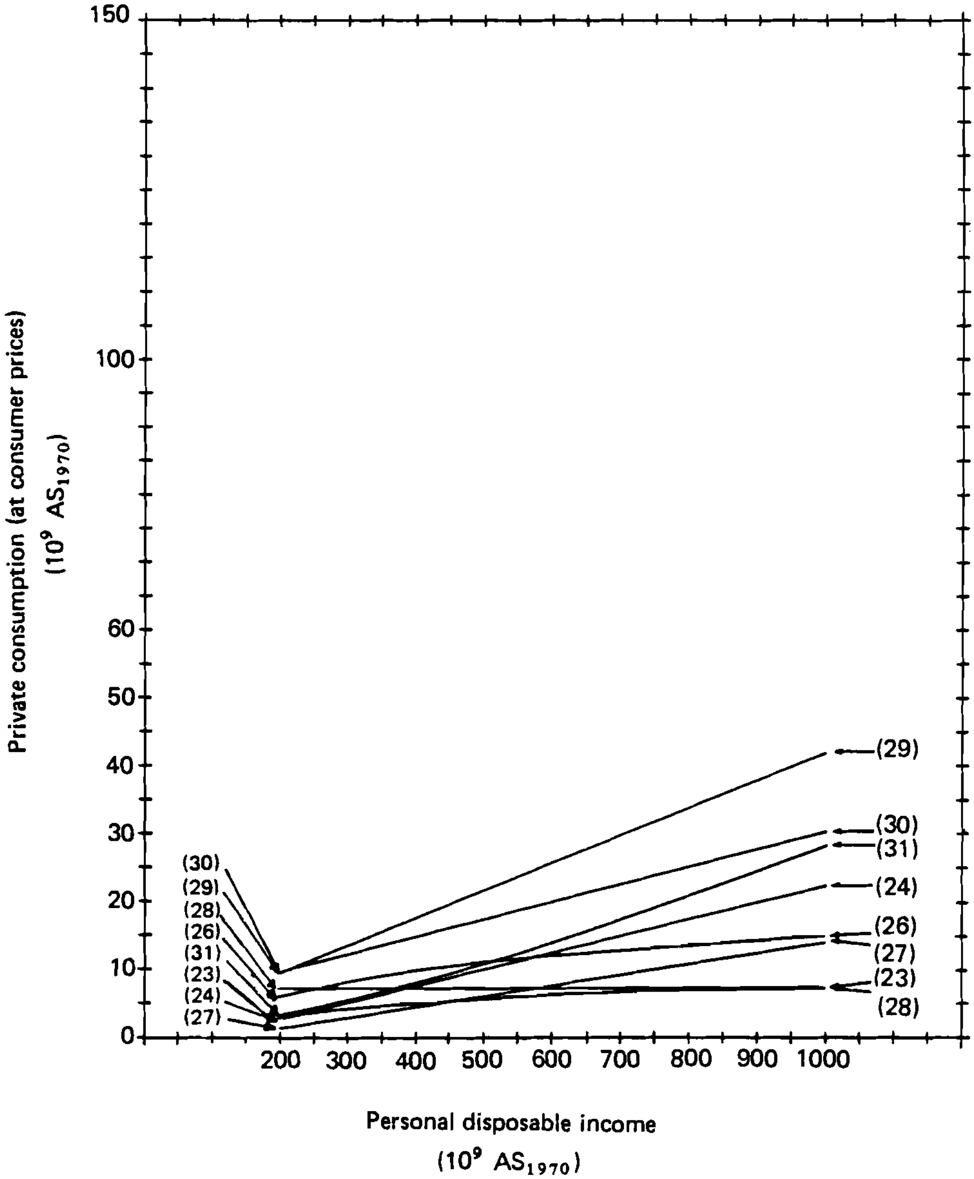

FIGURE 7 Projections of major components of private consumption in Austria in relation to personal disposable income – III. Sector (23) is construction; Sector (24) is electricity, gas, and water supply; Sector (26) is transportation and communications; Sector (27) is banking and insurance; Sector (28) is hotels and restaurants; Sector (29) is other services; Sector (30) is housing; and Sector (31) is public administration. Cf. Table 4.

actually its share decreases over the given range of personal disposable income – namely, 200×10^9 AS_{1970} to $1{,}000 \times 10^9$ AS_{1970} – from 23% to 20%).*

Public Consumption

The final demand category includes the total sum of expenditures by public authorities for consumption purposes. (Public investment is recorded as part of investment in machinery and buildings, demand categories that will be described later.) However, expenditures of nationalized companies (such as railways and the communications sector) are not included in the public consumption category. They are treated as intermediate transactions or investments. The largest component in the public consumption category is transfer payments from the public service sector, which are equal to the total value added in the public service sector** after deduction of direct compensation of expenses.

Total public consumption is projected by an econometric function dependent on the development of the Austrian GDP. Projections are not made on a more disaggregated basis. The structure of public consumption is generally kept constant, but can be changed exogenously for any year of the projection period. One example of such a change is the inclusion of the effects of policy measures such as free school books for all children.

Gross Investment

According to the system of national accounts, investment is defined as the initial purchase or internal production of investment goods. Repair services that increase the value of investment goods are considered investments, but the purchase of used investment goods is not.

Gross investment is divided into investments in construction and investments in equipment, machinery, and transport utilities. These investments are recorded by supply sector.

As with the approach used in projecting public consumption, only the sums of gross investments is projected. An econometric function is used to make the projections, with GDP as the independent variable. The structures of both investments in construction and investments in machinery are assumed to be constant, although one can use other assumptions for the projections for any year of the time period considered. In Austria many intermediate sectors are dominated by one or only a few enterprises; for this reason information on investment plans in the public sector and plans of large enterprises can be used to test the results derived from the equations describing the total investment.

Inventory Changes

The "inventory change" category shows the change in the stocks of raw materials, intermediate goods, semifinished and finished products, and articles of commerce, disaggregated by supply sector. No distinction is made in regard to the sector that keeps the stocks.

The AUSTRIA II Model calculates the level of inventory changes by means of an econometric function, with GDP as the independent variable. The inventory changes

*In 1970 personal disposable income in Austria equalled 236×10^9 AS_{1970}.

**This includes such items as wages and salaries and depreciation.

projected in this way are not intended to represent the changes resulting from business cycle fluctuations, but rather should be interpreted as representing the expansion of stocks to be expected as economic activity grows. The structure of inventory changes is generally assumed to be constant.

Expenditures of Foreign Tourists in Austria

The "foreign tourist expenditure" category includes all expenditures made by foreigners in Austria. The sum of these expenditures is projected by means of an econometric function; the GDP of the Federal Republic of Germany is used as an indicator for the projections. The main components are the services of hotels, restaurants, and the transportation sector, and the purchase of goods. The structure of these expenditures is generally assumed to be constant. However, the insertion of individual projections is possible without major effort.

Exports and Imports

Two categories of exports are considered in the AUSTRIA II Model – the export of services and the export of commodities. The export of commodities is broken down by country or groups of countries of destination. Variables describing economic activity in the country of destination and variables indicating competitiveness (including relative prices and exchange rate fluctuations) enter into the approximately 150 export equations as explanatory variables.

On the import side, services are again treated separately from commodities with no distinction made about the country of origin. Imports of commodities are divided into competitive and noncompetitive imports.

Noncompetitive imports are defined as imports of commodities that are not produced within Austria. There are a great number of such commodities, but only the most important ones are specifically identified in the AUSTRIA II Model, such as cotton, natural rubber, bauxite, and hard coal. Noncompetitive imports are calculated in the AUSTRIA II Model by means of technical coefficients describing the level of output of the receiving sectors. Just like the input–output coefficients, these coefficients represent strong technological dependencies. This method is also used for imports that are not noncompetitive in the strict sense of the word, but for which the domestic production is limited and cannot be increased to meet rising demand. Iron ore production and crude oil extraction are examples of such cases.

Competitive imports of commodities and imports of services are projected by means of econometric equations that link these imports to general indicators. These classes of imports are recorded as negative components of final demand.

Technical Coefficients

The description of the technological structure in the AUSTRIA II Model is based on a 1970 table of intermediate transactions. Since technological structure can change considerably over a long period, the model allows for changes in the technical coefficients. Changes in the input–output coefficients and in the coefficients for noncompetitive imports are introduced exogenously into the model. Estimates derived from time-series analyses are used for some of the coefficients, but most information comes from enterprises. The use of data reflecting the expectations of business is of special importance in sectors that are dominated by one or only a few enterprises, for the installation of a new technology can lead to abrupt changes in coefficients.

2.3.5 Limitations of the AUSTRIA II Model

Since AUSTRIA II is a demand-oriented model, it considers only a few factors describing the supply side. Some special cases, such as crude oil extraction and iron ore production – where limits in domestic capacities are known – are accounted for explicitly. Other bottlenecks in production that might result from insufficient resources are assumed not to occur. To check this assumption, auxiliary computations for labor and capital have been carried out outside the formal structure of the model.

Another limitation in the model stems from the convention of valuing all variables at constant prices. Prices or relative prices do not appear in many parts of the model. This shortcoming is partly due to the lack of data. Another reason is that model results are primarily used for product planning, investment planning, and marketing design strategies; for such applications users have a distinct preference for volume figures. Although prices are not formally incorporated into the model, relative prices are reflected in the variables describing Austria's competitive position in world markets. Changes in prices and relative prices also influence changes in technical coefficients in an important way.

In the AUSTRIA II Model priority has been given to achieving flexibility, rather than a high degree of complexity. The structure of the model and its computer organization enables users to intervene in nearly all stages of the computations. This flexibility makes it possible to consider experts' expectations and to substitute estimates generated within the model with exogenously generated estimates. Such substitutions may, however, cause a certain degree of inconsistency.

2.3.6 Input and Output

The scenario variable describing Austria's degree of competitiveness on foreign markets and the variables describing the economic development of Austria's trading partners must be specified throughout the projection period. The countries or groups of countries distinguished in the model are the Federal Republic of Germany, Switzerland, Italy, other European Economic Community (EEC) countries (1975 members), Council of Mutual Economic Assistance (CMEA) countries, other countries belonging to the Organization for Economic Cooperation and Development (OECD), and the rest of the world.

Technological structure, as defined by the input–output coefficients and the coefficients for noncompetitive imports, is generally assumed to be rather constant. Some coefficients are projected on the basis of time-series analyses, and quite a few are based on information received from enterprises. For instance, the following changes are considered in the input structure of the food sector: a relative decline in inputs from agriculture; an increase in the share of internal inputs (division of production); an increase in inputs from the chemical industry (e.g., chemical preservatives, plastic material for packaging); and an increase in inputs from the fabricated metal sector (e.g., cans). Well-founded assumptions about technological changes are built into the model as default assumptions. Further assumptions can be included in model runs, in order to study a particular scenario on the basis of additional statistical information or to make sensitivity analyses.

The structure of most of the final demand categories, such as public consumption, investment in machinery and equipment, investment in buildings, inventory changes, service exports and imports, and expenditures by foreign tourists in Austria, is also generally assumed to be constant. However, other assumptions about this structure can be introduced if new information becomes available or for analytical purposes.

The output of the AUSTRIA II Model includes a listing of the input data and an input–output table for every year of the projection period, which specifies intermediate and final demand by sector. Value-added figures can be derived from this information. The model also provides, in a summary printout, a time series of the sales of each supply sector, gross production, noncompetitive imports, exports by country of destination, and some general indicators (Gross Domestic Product, Personal Disposable Income, Balance of Trade, and Balance of Payments). A comparison of the structure of gross production and final demand categories in the starting and end years of the projection period is also included in the model output.

2.3.7 Data Sources

AUSTRIA II is based on a 31 by 31 sector input–output table for 1970. This table was derived by updating the official Austrian input–output table for 1964, the only official table available (a 54 by 54 sector table) (Richter and Teufelsbauer 1974). The 1970 input–output table is completely consistent with national accounts. Auxiliary matrices for imports, import duties, gross investment, and trade and transport margins were also available for 1970.

Most of the time-series equations in the model have been estimated on the basis of annual time-series data at constant prices, starting in 1961. Time-series data by groups of commodities and services were provided by the Oesterreichisches Statistisches Zentralamt for the consumption equations; in a few cases transformation matrices had to be used subsequently to obtain the necessary level of disaggregation.

2.3.8 Final Comments on the AUSTRIA II Model

The AUSTRIA II Model represents the most detailed and consistent description of the current Austrian economy. The great sectoral detail provided by the model has three advantages for deriving energy demand projections:

(1) One can capture the change in the level and structure of energy demand that is attributable to different rates of expansion in the intermediate sectors.*

(2) The introduction of assumptions about technological changes and changes in the evolution of final demand is transparent.

*Bayer (1975) has shown that the elasticity of energy consumption in Austrian industry observed between 1960 and 1974 would have been considerably smaller if all branches had grown at the same rate as the average for industry as a whole.

(3) The sectoral detail facilitates the analysis of environmental effects associated with the production and consumption of energy.

One limitation of the model deserves special note. In the application of the model for the case study on regional energy/environment management in Austria, the model's usual time horizon of 15 years was extended to 45 years. Becuase of the static nature of the model its suitability for such an application may be questioned.

Many of the parameters used in the model are estimated from time-series data and held constant over time. However, this is not an inherent feature of the model. Rather, it reflects the (rather conservative) decision not to develop a scenario describing a future economic structure that is drastically different from the current structure when there is not a sufficient basis for quantifying such a scenario.

Another important shortcoming of the model is that it is demand-oriented; supply shortages therefore cannot be directly simulated. The inclusion of explicit supply constraints would require a major restructuring of the model.

2.3.9 Concluding Observations

The Austrian Case Study, and more recently a study of energy systems in Mexico (Richter *et al.* 1980), has shown that input–output analysis can play a key role in evaluating development strategies in regard to energy/environmental issues. Input–output models characterized by a high degree of disaggregation of the final demand categories aid in the identification and analysis of sectors important for energy use. Such models also make it possible to examine the sensitivity of sectoral output and energy use to variations in technology. In the case studies a straightforward linkage technique was used to relate end-use energy demand to the sectoral activities described by the input–output model. The linkage procedure made it possible to use an already existing macroeconomic model to simulate the sensitivity of the energy/environment situation to exogenous factors – such as foreign demand for Austria's products and the competitiveness of Austrian products in world markets.

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3 ENERGY DEMAND MODELS

3.1 INTRODUCTION

In the regional energy/environment management studies, major emphasis is placed on the demand for energy. Although energy demand is only one side of the demand/supply picture, this emphasis is appropriate for two reasons. First, a detailed understanding of the structure of energy demand is a prerequisite for the development and assessment of energy supply alternatives. Second, at the regional level energy demand can be influenced by policy measures more easily and more directly than can energy supply. For example, only one of the four regions studied had major mineral fuel resources (coal), and only two had significant hydropower resources.

In the case studies the energy demand modeling and assessment were carried out at the point of final (end-use) demand. The level of disaggregation of the final demand depended on the minimum requirements for defining the structure of the demand, on the policy analysis objectives of the demand assessment, and on data availability. In general, a five-sector classification of energy demand was adopted, covering the residential, commercial/service, industrial, agricultural, and transportation sectors. A separate demand model was developed to examine the energy consumption within each sector. The policy issues prominent within a given region and data availability determined whether the sectoral demand models were disaggregated further. Energy consumption was analyzed by fuel type and, when possible, by physical process. The end-use demand components are depicted on a three-dimensional basis in Figure 8.

The demand models used in the case studies are simulation models with one year time steps. The models may best be characterized as technological process models, with socioeconomic variables used as exogenous inputs. In general, socioeconomic feedbacks from the demand models are not formally implemented within the models, but are rather taken into consideration by the intervention of the model user. The general structure of these relationships is shown in Figure 9.

The *residential* model focuses on the household. Household demand for energy is analyzed in terms of base appliances (mainly space and water heating but also central air conditioning in some regions) and secondary appliances (e.g., refrigerators, stoves, televisions, and so forth). Important variables in the model include the number, type, and quality of housing units, the heating sources used by housing units, the number of household appliances, and the energy use of these appliances. The same analytical approach was used in all of the regions to study energy demand in the residential sector; however, the characteristics of the housing units varied considerably between the regions.

The models developed for the *commercial/service*, *industrial*, and *agricultural* sectors were based upon the level of sectoral (or subsectoral) economic activity and the energy intensity per unit of activity. The same general approach was used in all study regions, although there were regional differences in the classification of economic sectors

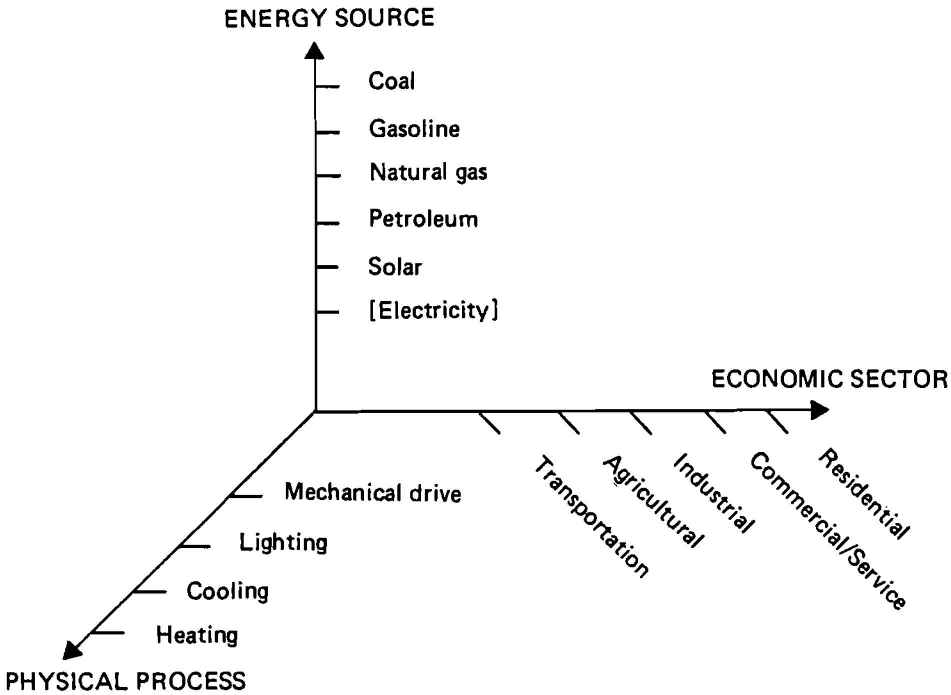

FIGURE 8 Description categories in models of end-use energy demand.

and subsectors, the level of aggregation of subsectors, and the unit of measure (i.e., value added, sales, net material product, and so forth). There were also major regional differences in the modeling procedures used for describing future economic activity levels. Official planning projections were used for the GDR. Current trends were extrapolated in the Rhône-Alpes region. An input–output model projection based on economic growth rate projections for trading partners was applied in Austria. Finally, state growth rates were adapted to national projections in Wisconsin.

Two different approaches were used for projecting the fuel mix in these sectors. In the Austrian study an overall energy intensity by subsector was determined and then a fuel mix was projected. In the GDR, Rhône-Alpes, and Wisconsin studies energy intensity by fuel was estimated directly.

In the *transportation* sector, the methodological approach entailed disaggregating the sector into "personal travel" and "freight" components. Personal travel energy use was projected by estimating personal travel in terms of person-kilometers by mode, converting the result to vehicle-kilometers on the basis of the characteristics of vehicle use, and finally converting vehicle-kilometers to energy use on the basis of the technological characteristics of vehicles. This procedure was altered in the case of the GDR, where official projections of vehicle-kilometers were available. For the freight component, ton-kilometers by mode were directly related to industrial, commercial/service, and agricultural activity. In the Austrian study transportation activity was included as a sector in the AUSTRIA II Input–Output Model.

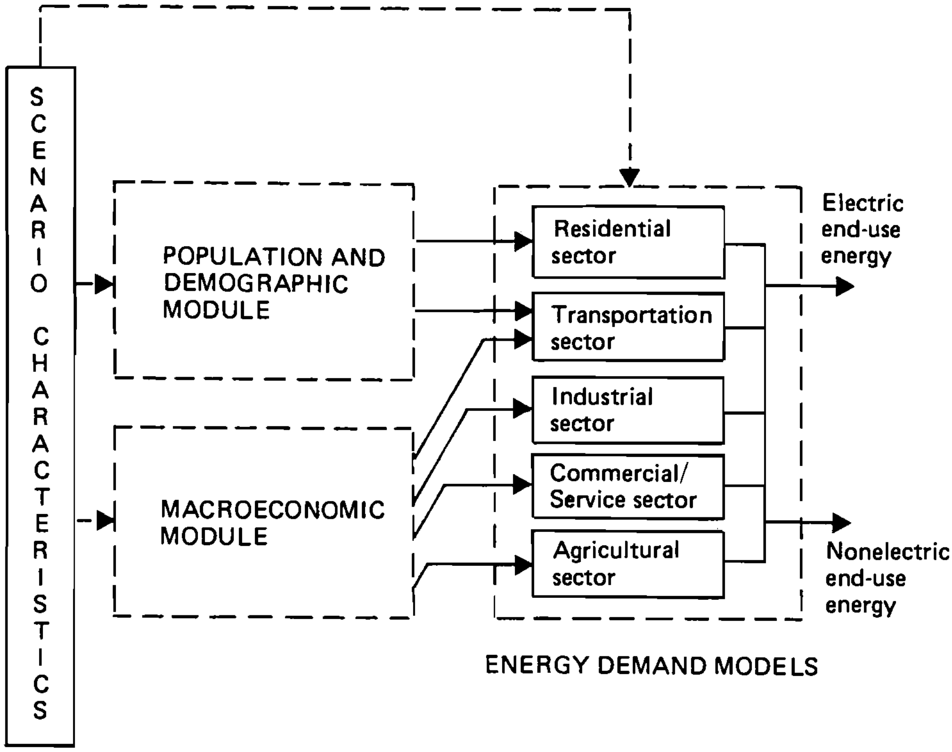

FIGURE 9 Energy demand models structure.

The model for the residential sector is presented in Section 3.2. The model for the industrial, commercial/service, and agricultural sectors is discussed in Section 3.3. Finally, the model developed for the transportation sector is set forth in Section 3.4.

3.2 ENERGY DEMAND MODEL FOR THE RESIDENTIAL SECTOR

3.2.1 Purpose

The residential energy use model is a computer simulation model that calculates the annual energy demand for the residential sector. The model was first developed at the University of Wisconsin (Frey 1974) and then extended and generalized at IIASA (Pönitz 1978). Although this report focuses on the version that was operationalized at IIASA and applied in the Austrian case study, residential energy use models with the same general structure were used in the other three case studies.

The model calculates energy use for space and water heating for seven types of energy sources, on the basis of parameters such as floorspace, heat loss, heating hours, hot water demand, and appliance efficiency. The housing stock is broken down into different types of housing units, and the characteristics of each home type are described in terms of these parameters. Energy demand for fourteen household appliances is also calculated, on the basis of the fraction of households owning each appliance and the average energy use per appliance.

One purpose of the residential energy use model is to calculate the annual energy demand for the residential sector, using as input population data and physical parameters such as home size, fuel use, and insulation levels. Another purpose is to assess trends and proposed policy measures affecting the residential sector. This can be done by comparing the results of model runs in which varying assumptions about new home construction policies, retrofitting of existing homes, insulation measures, appliance mix, and fuels are used. Thus, the model may be used as a tool for analyzing the impact of alternative policy measures on energy use. A third function of the model is to provide input for the environmental and energy supply models.

The model may be used to examine the following types of questions:

- How could the demand for electricity, gas, oil, coal, wood, and district heat in the residential sector develop in the future?
- What energy savings could be achieved if new construction were better insulated in the future or if old housing units were retrofitted?
- What role could alternative technologies such as solar energy or heat pumps play in the future?
- What impact would improved efficiency of space heating systems have on energy consumption?
- What impact would the construction of larger new housing units have on energy consumption?

3.2.2 General Structure of the Model

Figure 10 shows the linkage of the residential energy use model to other models and the interaction of the model's main subroutines. The Population Allocation Model is directly linked to the residential model and specifies the number of urban and rural families to be housed – a major driving function of the residential model. The subroutines of the residential model focus on the following features of the residential sector:

Changes in the housing stock. The "demolition" and the "simulation of new construction" subroutines interface to describe changes in the housing stock. The rate of demolition and the rate of formation of new families determine the need for new housing.

Composition of the housing stock. This subroutine disaggregates the housing stock into different types of housing units, such as apartments and single-family houses.

Energy for space and water heating. This subroutine calculates energy consumption for space and water heating by energy source and type of housing unit. The subroutine is based on parameters such as size of housing units, heat losses, and type of heating appliance. Retrofitting of old housing units and the use of alternative energy sources can be taken into account in the subroutine.

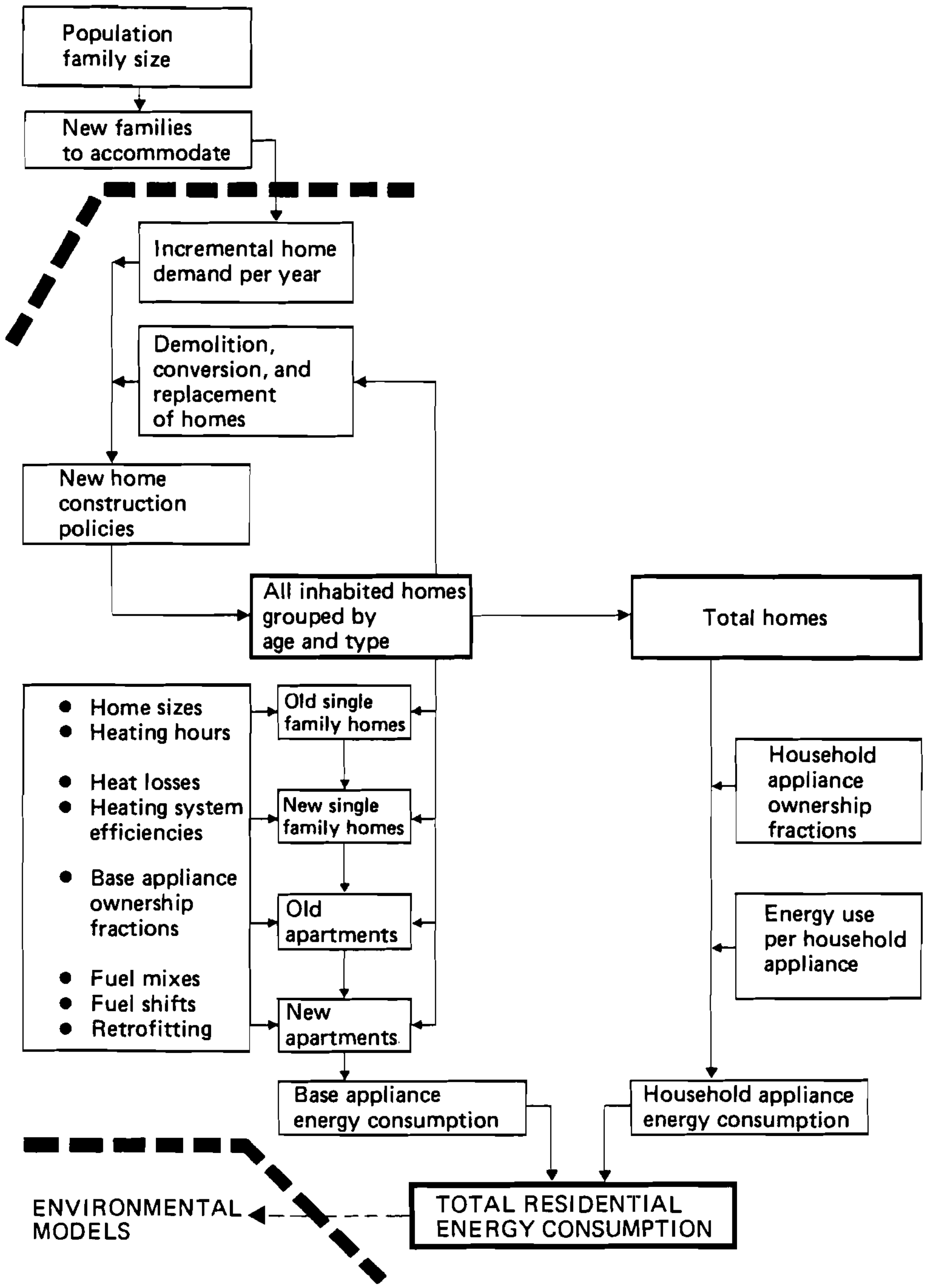

FIGURE 10 Flow of information in the Residential Energy Use Model.

Energy demand for household appliances. This subroutine calculates ownership fractions for 14 different household appliances. Exogenous data determine starting and saturation values, saturation rate, and consumption levels for each appliance.

These major subroutines and several auxiliary subroutines are described in more detail below. Important definitions, assumptions, limitations, basic equations, and flow diagrams are provided.

Changes in the Housing Stock

The number of occupied housing units, the ratio of single-family units to apartments, and the average size and quality of housing units are major determinants of residential energy consumption. (The term "quality" refers to the type of heating system and the level of insulation in a home.) The annual construction of homes is driven by two factors: the growth of population and/or decline in family size; and the necessary replacement of obsolete homes or other losses to the housing stock. It is important to note that the annual changes in the housing stock are relatively small compared to the total housing stock.

Housing Demolition Subroutine. A change in the housing stock occurs if a housing unit is destroyed or undergoes a change in function (for instance, conversion into an office) and thus must be replaced. In the residential model housing units are grouped according to their age in years (from 1 to 130 years). Each year a certain fraction of the housing units in each age-group is destroyed or converted to purposes other than housing. The probability of demolition is assumed to increase exponentially with the age of housing units, regardless of the type of unit. Housing units older than 130 years provide an exception, however. They are thought to represent an historically valuable fraction of the housing stock that will be preserved throughout the simulation period.

Changes in the function of a housing unit are most likely to occur in the centers of cities that are losing their inhabitants and gaining more service sector enterprises. It is assumed that these changes in function can be described by an age-dependent relationship similar to that established for the demolition of housing units.

The functional relationship underlying the housing demolition subroutine is

$$P_k = [RPK \times e^{(RDM \times k)}] - k_{\max} \tag{3.1}$$

where P_k is the probability of demolition of a housing unit of age k, k is the age of the housing (1 to 130 years), $k_{\max}$ is the maximum age of housing (130 years), and RPK and RDM are estimated parameters.

The number of housing units that are destroyed within each group of age k is derived from the relation

$$D_k = H_k \times P_k \tag{3.2}$$

where D_k is demolished housing units of age k and H_k is total housing units of age k. These values can be summed for $k = 1$ to $k = 130$ in order to calculate the total number of housing units demolished in a given year.

Incremental Housing Units Subroutine. Incremental housing units are the housing units constructed each year to house the net increase in the number of urban and rural families. The development of population and family size are the driving functions in this subroutine. A basic assumption is that each new family will get a housing unit. The number of housing units exceeding the number of families are considered either to be uninhabited or to have changed to uses other than housing.

Composition of the Housing Stock

The housing stock must be disaggregated by type of housing unit to account for differences in modes of heating, in energy sources, and in heat losses. The subroutine that performs this disaggregation categorizes housing according to size, time of construction, and location.

Size. A housing unit located in a building containing no more than two dwellings is considered to be a single family unit. A unit located in a building containing three or more dwellings is classified as an apartment. Since multifamily dwellings (especially high-rise buildings) have a smaller number of exposed surfaces, smaller window areas, and often smaller floor areas, the heat losses per dwelling are considerably lower than for detached single-family units with similar levels of insulation. These two types of housing units are also characterized by significant differences in heating modes and energy sources.

Time of Construction. All housing units constructed before the starting year of the model are lumped together as "old housing units" and distinguished from "new housing units," constructed after the starting year. There are major differences between the average "old home" and the homes constructed at any time after the starting year. These include varying probabilities that given base appliances and energy sources are used.

A high correlation also exists between the age of housing units and housing condition. Old homes in bad condition can be demolished or retrofitted during the simulation period. Retrofitting entails replacing base appliances and/or changing energy sources and reducing heat losses.

Policies that govern the construction of new housing units vary over time, reflecting changes in lifestyle and technologies. The scenarios constructed for the residential sector and simulated in model runs reflect the policy alternatives.

Location. Single family units and apartments are classified as either urban or rural, depending upon the communities in which they are located. Some energy types, such as district heat and gas, are much more likely to be used in urban areas than in rural areas. This is due to such factors as regional supply characteristics (e.g., the availability of gas pipelines) and the greater density and size of urban areas. (Differences in population densities and fuel mixes in urban and rural areas lead to differing pollution problems, as will be discussed in Chapter 5.)

Table 5 shows the disaggregation of the housing stock by type of unit. The subroutine that performs this disaggregation interfaces with a second subroutine that calculates energy consumption for each type of housing unit.

TABLE 5 The disaggregation of the housing stock into types of housing units. SFH is single-family home. APT is apartment.

Size	Time of construction	Location
SFH	Old SFH	Old urban SFH
		Old rural SFH
	New SFH	New urban SFH
		New rural SFH
APT	Old APT	Old urban APT
		Old rural APT
	New APT	New urban APT
		New rural APT

Base Appliances for Space and Water Heating

The residential model distinguishes two kinds of base appliances: space heating appliances (subgrouped into single oven appliances and central heating appliances) and water heating appliances. Six energy sources plus one alternative energy source are considered.

Single oven heating and central heating are treated separately, in order to make it possible to account for the differing technical problems posed by fuel shifts in the two heating modes. Separate handling of single oven and central heating also permits simulation of shifts from one heating system to another (e.g., substitution of gas, oil, or district heat for coal, or substitution of district heat or gas for oil).

In the model the energy demand for *space heating* is a function of dwelling size (in m^2), heat losses (in kcal/m^2/hr), heating hours per year, efficiency of the heating appliance by energy type, and a temperature coefficient that accounts for differences in subregional climates. The model can be used to analyze the effect on heating requirements of reducing the amount of heated floorspace, decreasing heat losses, heating fewer hours per year, and improving heating system efficiencies. The energy use for *water heating* depends on the average amount of hot water used per dwelling per year and the average efficiency of the hot water appliance.

For each housing type the "base appliance ownership probability" must be specified – i.e., the percentage of housing units that have a particular base appliance and use a specific energy source. Initial values are available from census data and related studies. During model runs, the probabilities are recalculated to simulate fuel and appliance substitution in "old housing units," as well as new construction policies characterized by shifts towards or away from given energy types and/or heating systems.

In Table 6 the data for energy source use and base appliance ownership probabilities by type of housing unit are shown in matrix form. Seven energy sources (electricity, gas, oil, coal, wood, district heat, and an alternative energy source) have been considered, and others could be included. As an example, the probability (P) that a new single-family unit has oil central heating has been indicated in the matrix.

Conversion Subroutine for Base Appliances. A conversion subroutine was developed to account for future major fuel shifts expected within the residential sector. One factor

TABLE 6 Format used to organize data on base appliances and their energy characteristics. SFH is single-family home; APT is apartment. Alternative energy sources include solar energy and heat pumps. P denotes the probability that a new single-family home has oil (energy source 3) central heating.

		Types of base appliances \ Energy sources	1	2	3 (oil)	4	5	6		Alternative energy source
NEW HOMES	S	Single oven							sum = 1	
	F	Central heating			P					
	H	Hot water							sum = 1	
	A	Single oven							sum = 1	
	P	Central heating								
	T	Hot water							sum = 1	

underlying such fuel shifts is the changing mix of base appliances and energy sources used in new construction. A second factor is substitution of base appliances and energy sources in old housing units. For the subroutine, a matrix with the probabilities for 1971 (which serves as data input for the starting year of the model) and 1975 was derived from existing data for each type of housing unit (old single-family units, new single-family units, old apartments, and new apartments). A matrix for the year 2000 was then constructed, on the basis of assumptions about fuel shifts and ownership trends for certain base appliances. These assumptions implicitly took into account future energy prices, the availability of energy resources, and environmental considerations.

The three probability distributions for 1971, 1975, and 2000 were used to determine transition matrices. The matrices correspond to a Markov chain with constant transition probabilities. The stationary values of these probabilities are approximately equal to the hypothetical values for the year 2000. This transition matrix, in combination with the probability distribution for the starting year, can be used to calculate the desired probability distribution for each simulation year.

The efficiencies of base appliances in combination with energy sources are organized in matrix form as input to the subroutine. Additional parameters make it possible to consider demand characteristics influenced by socioeconomic factors. For instance, people living in housing units fitted with a single oven that uses solid fuels (such as coal or wood) usually heat only half of their floorspace at any one time. Data input for the subroutine includes eight matrices with a total of 168 parameters.

Alternative Energy Sources for Space and Water Heat. It is assumed in the model that future alternative energy technologies for the residential sector will be limited to small-scale technologies for single-family units. These include all forms of solar energy use and heat pumps. It is also assumed that these technologies require a supplementary system that is based on conventional energy sources. The model expresses fuel savings achieved by alternative energy technologies in terms of the amount of fuel that otherwise would have been used by the backup system.

Numerous researchers have examined the extent to which alternative technologies can be substituted in the residential sector. R.H. Pry (1973) and J.C. Fisher (1970) have shown that the substitution of one technological process for another conforms remarkably well to an S-shaped (logistic) curve. The substitution process can be characterized by two parameters:

$$\text{alpha} = 2 \ln 9/\text{delta } t \tag{3.3}$$

$$f(t) = \exp \text{alpha } (t - t_0)/1 + \exp \text{alpha } (t - t_0) \tag{3.4}$$

where delta t is the "take-over time," i.e., the time period required to increase the market share from 10 to 90 percent, t_0 is the time at which substitutions are half complete, and alpha is a constant rate that can be defined in terms of delta t.

In most countries not all housing units can be fitted with alternative energy technologies (such as solar systems). For this reason several assumptions about restrictions on penetration of such technologies have been introduced into the model:

- Alternative energy technologies are only feasible for a certain fraction of single-family units. (Direction of roof and the microclimate must be appropriate.)
- Only limited fractions of the total energy demand can be provided (approximately 50% of demand for space heating and approximately 70% of demand for water heating).
- Electrical energy is needed to drive the alternative system (i.e., circulation pumps, heat pumps) and must be accounted for in the model.
- The remaining fraction of energy is provided by conventional heating systems. This auxiliary heating is automatically controlled.
- It is uneconomical to combine single oven heating systems based on electricity or gas with alternative energy technologies because of the additional construction this would require.

All assumptions can be changed before or during simulation.

Secondary Appliances

The term secondary appliance applies to all energy-consuming household appliances other than those used for space and water heating. Fourteen types of secondary appliances are considered in the model. All are based on electricity, except for gas stoves and gas clothes dryers.

Ownership fractions indicate the percentage of all housing units that contain a secondary appliance of a given kind. These fractions change over time. The evolution of ownership fractions is simulated by growth curves dependent on the starting and saturation values and the time at which the midpoint of saturation is reached. The saturation values and the "mid-saturation" points can be varied to reflect different economic scenarios.

The energy consumption of a given secondary appliance is calculated as follows:

$$C_n = f \times H \times E_a \tag{3.5}$$

where C_n is the yearly average energy consumption of secondary appliance type n, f is the fraction of housing units having secondary appliances of type n, H is the number of housing units, and E_a is the average yearly energy consumption of appliance n per home per year. The sum of energy consumption of the fourteen types of secondary appliances is assumed to equal the final electricity and gas energy consumption of all secondary appliances.

The appliance ownership equations are of the form

$$f_{t+1} = f_t + (f_{\text{sat}} - f_1) \times (1 - e^{k/t_h}) \quad (3.6)$$

where f is the fraction of homes having secondary appliance n, t is the year (1 is the starting year), f_{sat} is the saturation fraction, k is equal to -0.693, and t_h is the time that lapses until the mid-saturation point $(f_{\text{sat}} - f_1)/2$ is reached. Examples of saturation curves for selected secondary appliances are shown in Figure 11. The curves are taken from the case study of "Bezirk X" in the GDR.

3.2.3 Input and Output

In order for the residential model to calculate energy consumption for space and water heating, the following major inputs have to be provided.

- Development of population and family size;
- Types of housing units grouped according to age in the starting year;
- The number of single-family units and apartments in the starting year;
- Average floor area by type of housing unit;
- Average yearly heat loss per square meter per hour by type of housing unit;
- Average heating hours per year;
- Base appliance ownership probabilities by type of housing unit;
- Average efficiencies for base appliances for the starting year;
- Specification (in the form of transition matrices) of fuel shifts and trends toward ownership of different base appliances during the simulation period.

The following inputs are required for the calculation of energy consumption by secondary appliances:

- Development of population and family size;
- Starting and saturation ownership fractions for secondary appliances;
- The time period that elapses until the difference between the saturation ownership fraction and the starting fraction is halved;
- Average energy consumption per appliance per home.

Figure 12 shows a typical output of the residential model – annual sectoral energy demand by source over a simulation period extending to 2015.

3.2.4 Concluding Observations

The residential energy use model was developed for the purpose of calculating end-use energy demand in the residential sector on the basis of population data and physical

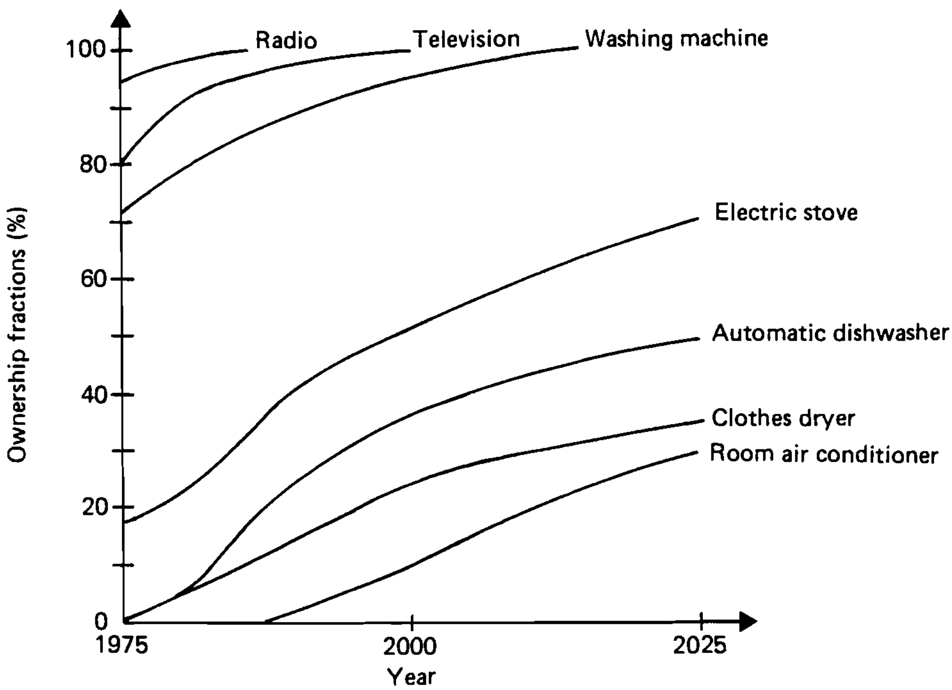

FIGURE 11 Saturation curves for secondary appliances used in the case study of "Bezirk X," German Democratic Republic.

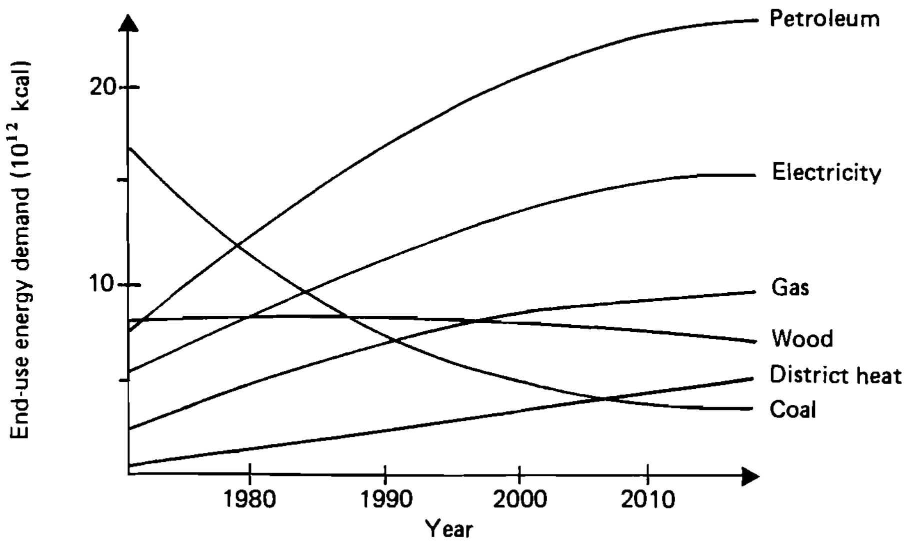

FIGURE 12 Annual residential energy demand by source, 1971–2015: Scenario S1, Austrian Case Study.

characteristics such as home size, insulation levels, and efficiency of energy-using equipment. The model has proven to be a useful systematic tool for handling the large quantities of demographic and technical data required for these calculations on both a national and subnational basis. Because the model is disaggregated according to end-use energy consumption technologies, it allows examination of important policy measures and sectoral trends. These include new-home construction trends, insulation standards, appliance market penetration, and fuel substitution measures. With the rise in fuel prices, these measures have been given increasing attention in all of the regions studied. The model has been particularly useful for this purpose in Austria, where detailed information is available on housing location, age, and type.

In the Austrian study, the residential model was applied at the level of the nine provinces (Bundeslaender). The results were then summed to give national totals. The calculations by province made it possible to estimate subregional pollution emissions, which in turn provided input for air quality analyses (see Chapter 5). This is an important capability of the model, which would not be available if a more aggregated approach had been taken to the energy/environment analysis.

Until now neither energy prices nor income have been treated explicitly in the model. A present research goal is to incorporate these factors in the model in a manner similar to that employed in the transportation model (see Section 3.4).

3.3 ENERGY DEMAND MODEL FOR THE INTERMEDIATE SECTORS OF THE ECONOMY

3.3.1 Purpose

The model described in this section assesses the end-use energy demand of the sectors whose energy requirements are most directly related to economic activity. These include agriculture, industry and handcrafts, and the commercial/service sector. The residential sector (private households) and personal transportation by car are excluded from the model.

In the model the intermediate sectors of the economy are disaggregated into numerous subsectors, to assure that energy consumption patterns within each subsector are highly homogeneous. A high level of disaggregation makes it possible to assess the impact on the aggregate end-use energy demand of such factors as

- Structural shifts in the economy, which occur when certain branches grow faster than others;
- Technological changes within the subsectors, including increased automation, improved efficiencies of devices or processes, or substitution between energy sources;
- Changes in management, including better housekeeping, integration of process steps, special conservation efforts, and so forth.

An additional reason for the high level of disaggregation in the model is to permit analysis of environmental effects associated with energy use. These effects are often industry-specific and dependent on fuel types. For this reason it is necessary to have sufficiently detailed information about energy use patterns.

Because environmental effects are of a local nature in many cases, their analysis requires knowledge about the spatial distribution of energy consumption. A spatially-detailed regional study of environmental impacts is currently infeasible in most countries, because subregional data on economic activity and energy consumption are usually poor. However, work force and population indicators (for which better subregional statistics generally exist), make it possible to derive a rough picture of the spatial distribution of energy consumption and environmental impacts.

In brief, the model of the intermediate sectors of the economy is a tool for assessing the overall impact of policies or directions proposed for individual subsectors. These could include a change in the product mix, a restructuring of production processes, conservation measures, or fuel shifts. The model is not a tool for analyzing the policies themselves.

The model described in this section is based on an earlier model of the industrial sector in the state of Wisconsin (Shaver *et al.* 1975). The model has since been modified and applied to the Rhône-Alpes region (France), the German Democratic Republic (GDR), and Austria.

Because the model relies entirely on exogenous data, it is crucial to check the validity of the assumptions about the future evolution of the activity level and the energy use patterns of each subsector. In the case studies several different methods were used to derive future levels of activity and energy use patterns. Formal optimization methods were employed in the case of the GDR; simulation with an input–output model driven by assumptions about the activity of trading partners was used in the case of Austria; and specification of plausible activity levels and surveys of energy use patterns were employed in the Rhône-Alpes region and in Wisconsin.

In the following discussion emphasis will be placed on the adaptation of the model for the Austrian Case Study. However, since the procedures used for the GDR, Rhône-Alpes, and Wisconsin were somewhat different, the modeling approach used for these regions will be briefly discussed first.

3.3.2 Modeling Approaches in the Regional Case Studies

The general model developed for the intermediate sectors of the economy calculates end-use energy demand by sector and by energy type, based on two parameters: an indicator of sectoral activity, and the specific energy consumption of a sector, broken down by energy type.

Sectoral Activity

In the approach used for Wisconsin, the intermediate parts of the economy were grouped into three sectors: (a) industry, (b) freight transporation, and (c) the commercial/service sector. Industry was further subdivided into 20 branches, corresponding to Standard Industrial Classification (SIC) categories 20 through 39. Value added, in constant dollars, was used as an indicator of the activity of each industry branch. The demand for freight transporation, measured in ton-kilometers (ton-km), was derived from industrial activity by assigning to each branch coefficients expressing its specific demand for transportation by mode (i.e., ton-km per unit value added). In the commercial/service sector, floor area was used as an indicator of sectoral activity, and the evolution of the floor area was linked to the projected evolution of value added.

The same indicators were used in the case of Rhône-Alpes as for Wisconsin. In the GDR study, net material product was used as a measure of industrial activity. Growth in floor area was tied to the evolution of the number of workers in the service sector.

Energy Consumption

Specific energy consumption by energy type reflects the importance of energy in the activity of a given sector. Econometric models may include energy as a factor input; however, in most cases energy is handled on a very aggregated level, because it represents only a small fraction of the production costs in industry (except in some heavy industry branches, such as iron and steel, cement, and paper). For the purposes of the regional energy/environment case studies, it was necessary to treat energy inputs in a more explicit form.

In the Wisconsin study, a distinction was made between electric and nonelectric energy, in order to account for differences in end-use efficiencies and in the conversion systems required for the supply of energy. Nonelectric energy forms were further broken down into coal, oil, and gas. This distinction was made primarily because of the different environmental impacts associated with each of the fuels. (Since almost all coal, oil, and gas are imported in Wisconsin, the supply and conversion systems required for these fuels are of minor interest.)

Electric generation is the only large-scale conversion activity in Wisconsin. In contrast, because the energy supply system in the GDR is based on domestically available lignite, this region has a very complicated conversion system covering electricity and district heat generation and production of coke, lignite briquettes, and city gas. Because of the importance of the energy sector within the national economy, and because of the central planning system, the short- to medium-term energy future is strictly planned in the GDR. Optimization models are used in much of the planning activity. Thus the evolution of the energy system was pre-specified to a great extent in the GDR case study.

In the case of energy consumption by the intermediate sectors in the Rhône-Alpes, a primary distinction was made between electric and nonelectric energy forms. The results of a national study were used to specify the evolution of the specific energy requirements in the future. The energy requirements for a number of sectors were analyzed in terms of categories of processes (specific uses of electricity, specific uses of coke, furnaces, steam generation, space and water heating), as well as in terms of the penetration of electricity into thermal processes (for furnaces, steam production, and space and water heating). In brief, the specific future energy requirements were projected on the basis of assumptions about improvements of process efficiencies and the use of electricity for thermal processes.

3.3.3 Adaptation of the Model in the Austrian Case Study

General Description

A schematic representation of the end-use energy demand calculations for the intermediate sectors of the economy in the Austrian Case Study is given in Figure 13. In this

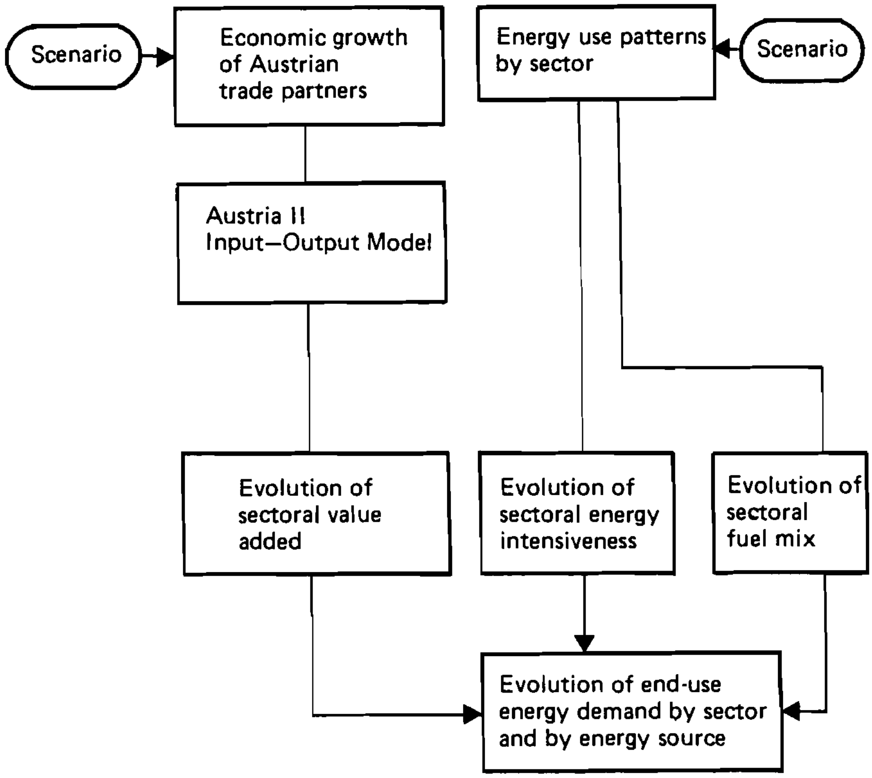

FIGURE 13 A schematic representation of the end-use energy demand calculations for the Austrian case study.

case, the energy demand of the agricultural sector, manufacturing (including mining, quarrying, and crude oil and gas extraction), freight transport and mass transit, and other services are treated in the same way. Certain parameters of the AUSTRIA II input–output model are specified, according to a scenario of the future evolution of overall energy intensiveness and fuel mix in each sector. This represents an addition to the assumptions about the future evolution of input–output coefficients that are normally included in the model. Projections of domestic end-use demand and its components are linked to the Austrian GDP by econometric equations. Assumptions about the economic growth of Austria's trading partners are required, because their exports of commodities are linked to their GDP.

The value added of each sector is calculated by subtracting from its projected gross output both the intermediate inputs (energy, raw materials) and the noncompetitive imports (imports required by the intermediate sectors of the economy that are not produced or produced to only a limited extent in Austria). The end-use energy demand by energy source in each sector is then calculated by multiplying the sector's value added by the specific requirements for a given energy source per unit of value added. The critical phase of the calculations is the projection of the future evolution of energy intensiveness and the fuel mix of each sector.

Definitions

It is necessary to offer some explanation of the variables on which the end-use energy demand calculations are based, namely

- Value added (at constant prices);
- Overall energy intensiveness, defined as total energy input* per unit of value added; and
- Fuel mix, i.e., the distribution of the total energy input among the various energy sources.

Value added is the value of primary inputs (labor and capital) required by an economic sector for its gross production during one year. Conversely, it is the value of gross production minus the value of intermediate inputs (energy and raw materials). Since the value-added figures should reflect a real increase or decline of activity in a sector, they have to be provided at constant prices. Care is required in interpreting these figures because the sectors are not completely homogeneous.

Value added at constant prices can change because of a change in either the level or the quality, i.e., composition, of the output. A change in the level of output would cause a proportional change in the level of inputs, including energy inputs, but a change in the quality of the output (e.g., a change in the product mix due to different rates of growth in the output of specific products) can be – but need not be – accompanied by a change in the level of energy consumption.

Energy intensiveness may be defined as the ratio of energy inputs (measured in physical terms) to the value added. It may be used to describe individual subsectors or the economy as a whole.

In his analysis of energy consumption in Austrian industries between 1960 and 1974, Bayer (1975) found an elasticity of 0.76 between the growth in value added and the growth in energy consumption in industry as a whole. When he looked at each of the 20 industrial branches separately, he found that the overall decrease in industrial energy intensiveness resulted from two factors, namely, structural changes due to different growth rates of individual sectors and changes in energy intensiveness within the sectors. The first factor proved to be dominant.

Assuming that a subsector is homogeneous, i.e., that its product mix does not change significantly over time, energy intensiveness is a good indicator of the subsector's specific energy requirements. In this case a change in energy intensiveness is really a measure of the impact of technological and management changes. However, most subsectors are in fact not completely homogeneous. Thus, in interpreting historical data as well as in assessing the possible future evolution of the energy intensiveness of a given subsector, it is important to consider possible shifts in the product mix, in addition to improvements in the efficiency of devices or processes, fuel shifts, or increased automation. Highly heterogeneous subsectors include the petroleum industry (extraction and

*The energy input is measured in physical units, using the thermal energy equivalent of each energy type.

refining) and the chemical industry. (While the fertilizer, rubber, and basic industry products subsectors are very energy intensive, plastic products and pharmaceuticals require relatively small amounts of energy.)

The term *fuel mix* denotes the distribution of total end-use energy consumption among various energy sources. By looking at the shares of each energy source, rather than just the absolute level of energy consumption, one can better analyze the substitution processes between energy sources. The approach is useful for the substitutable part of energy demand, i.e., the portion that can be met by more than one energy source. In such cases the choice of a particular energy source depends mainly on its availability and attractiveness (price, convenience of handling, and so forth).

There is, of course, also a nonsubstitutable part of energy demand, e.g., coke for the production of pig iron, electricity for aluminum production or other electrolytic processes and for mechanical devices and lighting, and motor fuel. The distinction between the substitutable and nonsubstitutable portion of energy demand was suggested by Chateau and Lapillonne (1977). In the approach taken by these analysts, only nonsubstitutable energy is considered just in terms of final or end-use demand. The substitutable energy demand is first calculated in terms of useful energy;* the final or end-use energy demand is then calculated in a second step, which takes into account the thermal efficiencies of devices and energy types. In the Austrian Case Study, a lack of data about industrial processes and end-use efficiencies prevented the analysis from penetrating to the level of useful energy demand.

One should note that the fuel mix distributions discussed in this report give the split between fuel types in terms of end-use energy rather than useful energy. In this definition of the fuel mix, the overall energy intensiveness is dependent on the fuel mix. For instance, if the end-use energy intensiveness is kept constant, a relative increase in the use of electricity for thermal processes implies an increase in useful energy intensiveness. This is due to the higher thermal end-use efficiency of electricity relative to fuels like coal or gas. In light of the absence of relevant data, this method was considered adequate for the Austrian Case Study.

3.3.4 Modeling of Value Added, Energy Intensiveness, and Fuel Mix in the Austrian Case Study.

Value Added

The procedure for deriving sectoral value-added projections using the AUSTRIA II input--output model was explained in Section 2.2. The value-added projections depend mainly on the assumptions made about the economic growth of Austria's foreign trade partners. The influence of the assumptions about energy intensiveness and fuel mix is comparatively small, because valuation was done at constant prices of 1970, i.e., with pre-energy crisis energy prices, and assumptions concerning future changes in energy intensiveness were moderate (reflecting expectations for lowered economic growth rates in the future). The investments necessary to bring about changes in energy intensiveness are not

*Useful energy is the minimum energy required for a given thermal process.

considered explicitly, i.e., it is assumed that the changes could be achieved with a continuation of past investment patterns.

Energy Intensiveness

The energy intensiveness of each sector is projected with the help of saturation curves whose starting point is 1974. Historical values are used for the years 1970 and 1974 and the values for 1971, 1972, and 1973 are obtained by interpolation. The parameters used to determine the saturation curve were the 1974 energy intensiveness, the assumed ratio of the energy intensiveness in 2000 to the initial (1974) value, and the fraction of the total change achieved by the year 2000 (to indicate whether the changes are expected in an early or later phase of the time period under consideration). The year 1974 is used as the initial year because the energy consumption data for that year are more reliable than those for previous years, especially in the nonindustrial sectors.

The assumptions about the evolution of energy intensiveness in each sector are based on four factors, namely, growth in value added, the current level of energy intensiveness, changes in the product mix, and changes in the fuel mix. All factors except the current level of energy intensiveness are dependent on investments. Energy intensiveness is an indicator of the importance of energy costs relative to total production costs; thus, it may reveal the extent to which one can expect investments to be specifically aimed at reducing energy inputs.

The four factors are, however, only qualitatively taken into consideration, based on an analysis of the evolution of energy intensiveness within Austrian industrial branches between 1960 and 1974. This analysis may be briefly described as follows.* Figure 14 shows the change in energy intensiveness for the industrial sector as a whole during the

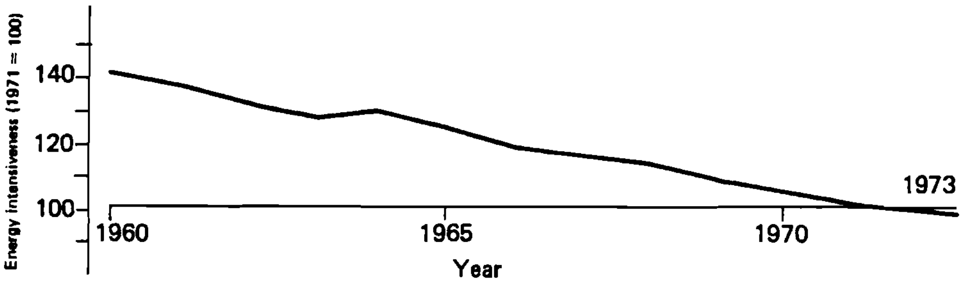

FIGURE 14 Decline of energy intensiveness in the Austrian industrial sector as a whole between 1960 and 1973. Source: Bayer (1975).

1960–1973 period; one can observe an almost continuous decline. This does not hold, however, for individual branches. Figure 15 shows the evolution in those branches with the strongest decline in energy intensiveness, namely, chemicals, iron and steel, electrical equipment, and transportation equipment. In contrast, Figure 16 shows the evolution in

*The analysis is based on Bayer (1975). Bayer also provided the data and suggested how the analysis could be extended.

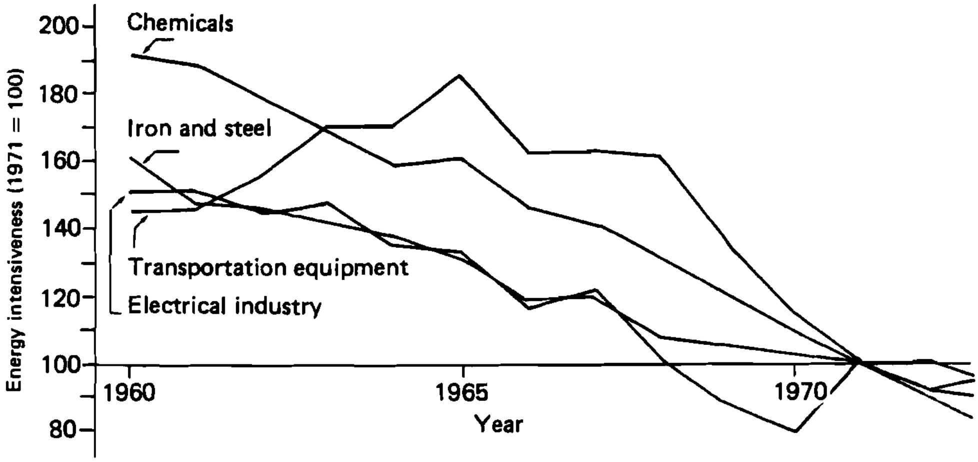

FIGURE 15 The four Austrian industrial branches exhibiting the largest decrease in energy intensiveness between 1960 and 1973. Source: Bayer (1975).

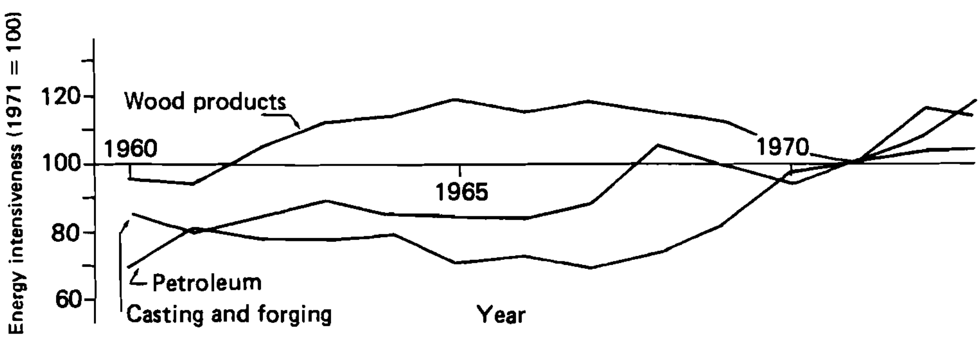

FIGURE 16 Three Austrian industrial branches that exhibited increasing energy intensiveness between 1960 and 1973. Source: Bayer (1975).

those branches that experienced a marked increase in energy intensiveness during the 1960–1973 period. In addition to these contrasting trends, one can discern short-term fluctuations, which can be attributed to capacity utilization. Since total energy consumption depends on both capacity and the production level, an increase (or decrease) in production levels leads, in the short-term, to a disproportionate increase (or decrease) in energy consumption, and in turn decreases (or increases) the energy intensiveness. The reason is that in the short-term capacity cannot be adjusted to the required production level. Such fluctuations can be neglected, however, in analyses of the medium- to long-term evolution of energy intensiveness.

In the following discussion the relationship between the observed evolution in the various branches and the four factors listed above will be examined. Figure 17 shows the change in energy intensiveness versus the change in net production within 20 Austrian

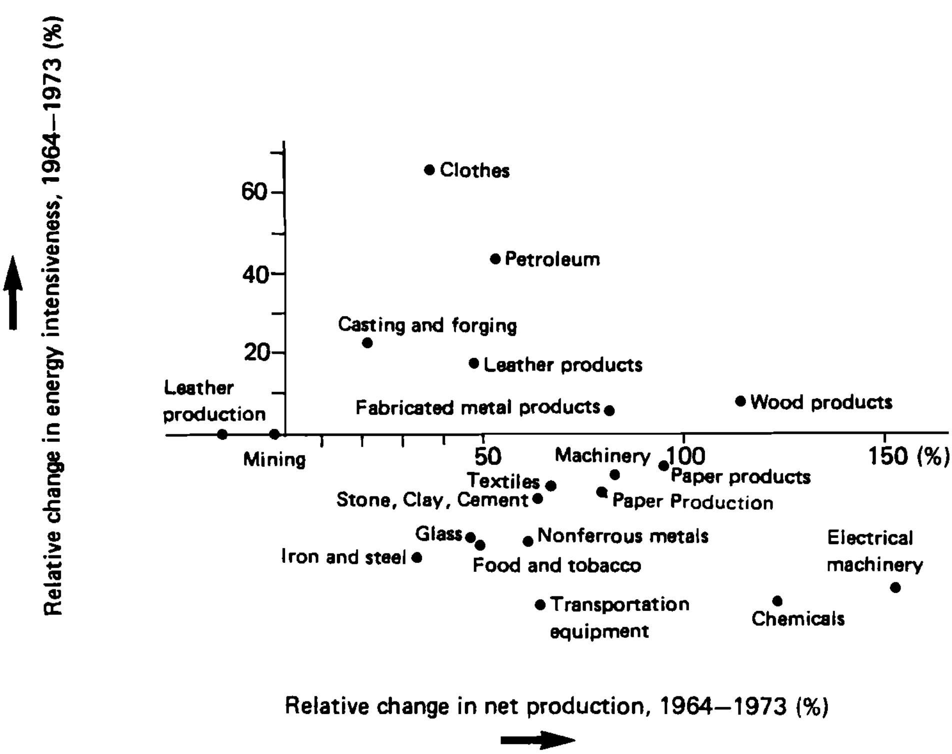

FIGURE 17 The change in energy intensiveness versus the change in net production of Austrian industrial branches between 1964 and 1973.

industrial branches. The graph indicates that branches characterized by strong expansion in terms of net production* generally achieved a major decline in energy intensiveness. This seems plausible, because a growth in net production requires either expansion of capacity or replacement of old capacity by new and more efficient equipment. However, investment alone is not a sufficient indicator for changes in energy intensiveness, for investments aimed at general rationalization do not necessarily include rationalization of energy use. The large variation apparent in Figure 17 stresses the fact that there are other factors involved.

In Figure 18 the branches are ranked by energy intensiveness as measured in 1973. If one compares this figure with the previous graph, one can see that the most energy-intensive branches, such as iron and steel, paper, building materials (stone, clay, cement), and nonferrous metals were able to lower their energy intensiveness considerably, despite a comparatively modest growth in net production. This can be partly explained by special

*The meaning of the term "net production" is close to that of "value added" at constant prices, but not identical.

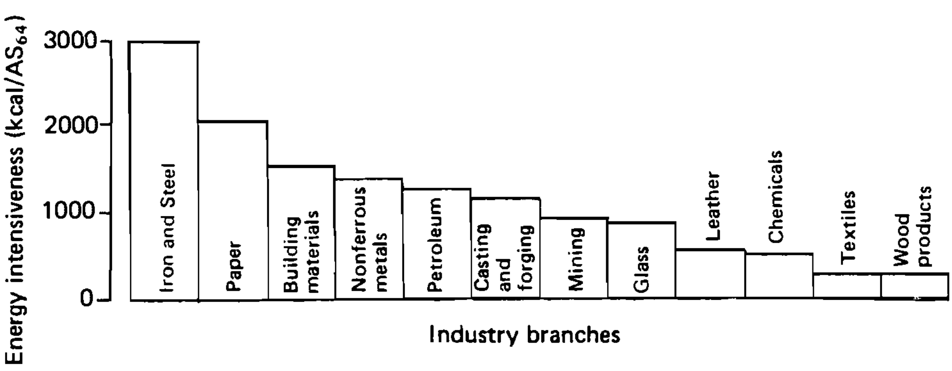

FIGURE 18 The Austrian industrial branches with the highest energy intensiveness in 1973. The energy intensiveness of the iron and steel branch in 1973 was 2,863 kcal per 1 AS_{1964} of value added, while the average energy intensiveness for the industrial sector as a whole was 728 kcal per 1 AS_{1964} of value added. Source: Bayer (1975).

TABLE 7 Historical distribution of total net production among natural gas production, crude production, and refining in the Austrian petroleum industry.

	Natural gas production	Crude oil production	Refining
1958	9%	77%	14%
1964	16%	60%	24%
1973	15%	43%	42%
1976	16%	36%	48%

efforts to reduce energy costs in these sectors. However, the petroleum and casting and forging branches experienced an increase in energy intensiveness, even though their initial energy intensiveness was relatively high.

In the case of the petroleum sector, this increase in energy intensiveness may be attributed to a change in the product mix. Table 7 shows the shift from extraction to refining in the petroleum industry. Recent statistics indicate that the ratio of energy intensiveness for extraction versus refining is 1:5. This suggests that the increase in energy intensiveness in the petroleum industry is clearly attributable to the shift in the product mix. However, such an explanation could not be found for the increase in energy intensiveness in the casting and forging industry.

In order to determine the influence of product mix on energy intensiveness, one would have to analyze large amounts of data. This would require much more time than was available in the Austrian Case Study. However, Figure 19 gives an indication of the extent of changes between 1964 and 1973 in the mix of certain categories of products.

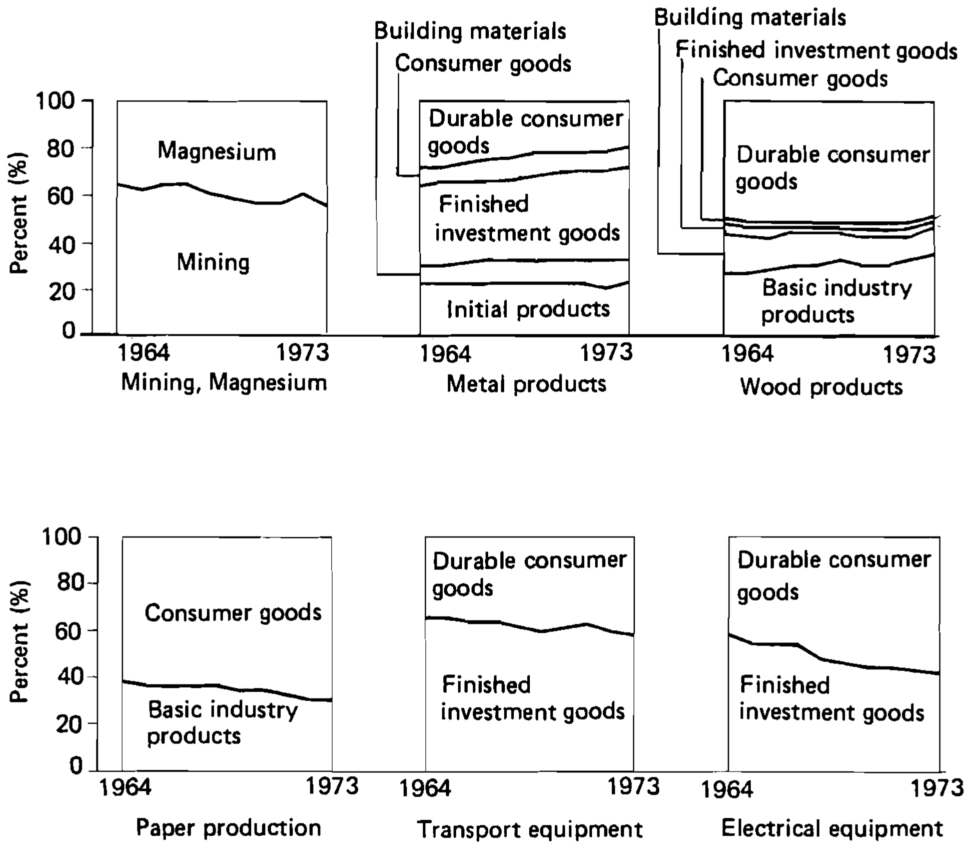

FIGURE 19 Distribution of net production within selected Austrian industrial branches, 1964–1973.

In the case of paper production, the shift from basic industry products (pulp, cellulose) to consumer goods probably contributed to the decline in energy intensiveness. A similar shift from finished investment goods to durable consumer goods can be observed in the transportation equipment and electrical equipment industries. In the mining industry, the increasing share of magnesium products may have contributed to the small increases in energy intensiveness. The fabricated metal products branch experienced a slight shift from durable consumer goods to finished investment goods. In the case of wood products, basic industry products increased their share at the expense of building materials. The latter two branches showed a slightly increasing energy intensiveness during the 1964–1973 period, but the extent to which this is due to shifts in the product mix is not clear.

It was not possible in the course of the analysis to isolate the influence of the fourth factor – changes in the fuel mix. Available statistics on energy consumption in industry show only a modest increase in the share of electricity, indicating that a significant penetration of electricity into thermal uses is unlikely. The main substitutions have been between coal, oil, and gas. Since the end-use efficiencies of these fuels are not significantly different, it can be concluded that changes in the fuel mix probably had a minor influence on the evolution of the overall energy intensiveness.

Fuel Mix

Transition matrices with constant coefficients are used to project the fuel mix in the intermediate sectors of the Austrian economy. The transition matrices approximate the actual fuel mix observed between 1970 and 1974, and then become stationary at a prespecified distribution. The end-use energy sources considered are electricity, hard coal, coke, lignite, fuel oil, gases, gasoline, diesel, and an "other" category. The choice of these energy forms is influenced mainly by their current shares, the supply/conversion system required,* and environmental considerations.

The chemical industry provides an example of the procedure used for projecting the fuel mix in the Austrian Case Study. Table 8 shows the historical fuel mix in this branch between 1970 and 1975; in addition the distribution towards which the fuel mix is assumed to evolve is given in the last column of the table. Important shifts that occurred in the 1970--1975 period included a slight decline in the share of electricity and a strong decline in the share of fuel oil, compensated by a relative increase in the use of gas.

TABLE 8 Fuel mix in the Austrian chemical industry, 1970--1975 (percent). H is a hypothetical distribution towards which the fuel mix is assumed to evolve in the Austrian Case Study. Source: Turetschek (1972, 1973, 1974, 1975, 1976, 1977).

	Year						
Energy source	1970	1971	1972	1973	1974	1975	H
Electricity	30.8	30.0	26.9	28.0	27.2	27.1	23.5
Hard coal	0.3	0.2	0.2	0.1	0.1	0.0	0.0
Coke	4.4	2.8	2.2	2.1	1.9	1.8	1.5
Lignite	4.4	2.3	1.7	0.9	1.1	0.2	1.0
Fuel oil	41.5	35.4	31.3	28.2	20.0	18.8	5.0
Gas	14.3	24.2	33.0	38.0	46.9	48.6	65.0
Gasoline	3.4	3.2	3.0	0.8	0.8	0.8	0.5
Diesel	0.6	0.9	0.8	0.8	0.9	1.1	1.0
Other	0.4	1.0	0.9	0.9	1.2	1.6	2.5

The final, hypothetical distribution of the fuel mix is determined in the following manner. First a transition matrix is calculated to simulate** the shift between energy

*From the point of view of energy demand, another breakdown would be preferable; namely, energy sources for specific uses, such as electricity, coke, and motor fuel, and energy sources for substitutable thermal uses. A disaggregation on this basis was suggested by Chateau and Lapillonne (1977).

**It may be better to simulate first the shifts between electricity, motor fuels, and other fossil fuels, and then the shifts between the latter two groups, in order to distinguish between energy sources with different end-use efficiencies for given applications.

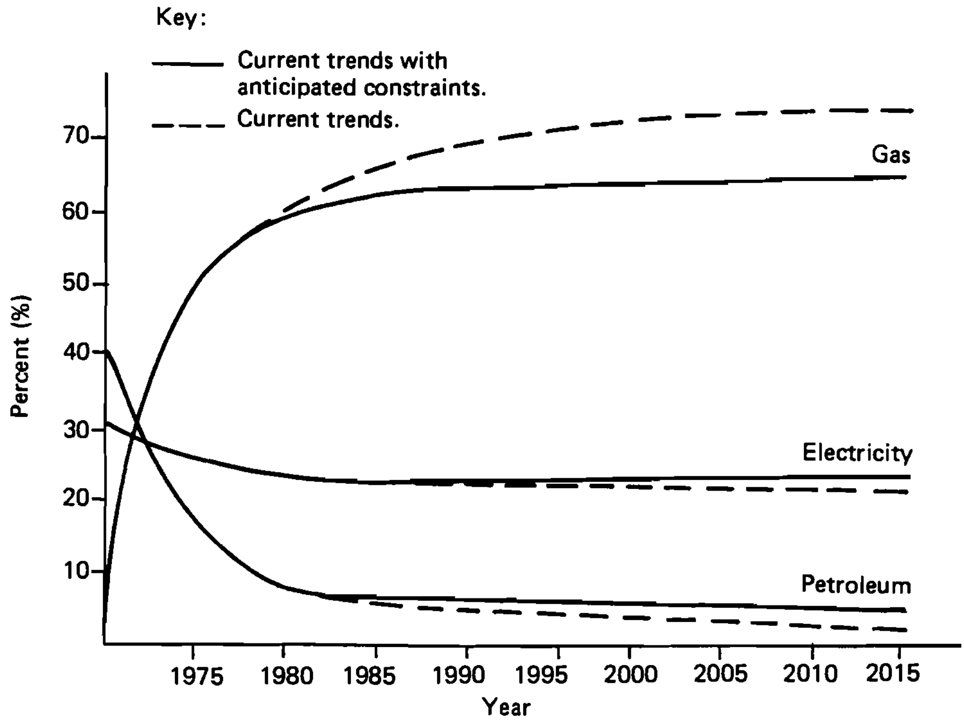

FIGURE 20 The estimated evolution of the fuel mix in the Austrian chemical industry, 1975–2015.

sources for internal combustion engines (gasoline and diesel) and other sources. Then two other matrices are calculated to simulate the shifts within these two groups. Figure 20 shows the estimated evolution of the fuel mix in the chemical industry, both with and without specification of the hypothetical distribution given in Table 8.

The estimated transition coefficients are an implicit function of the conditions prevailing during the period of observation. Therefore, if these conditions are assumed to change in the future, it would be necessary to model the change in the coefficients. But because it is not possible to establish causal relationships, no attempt is made to change the coefficients over time; instead, it is assumed that the characteristics of the fuel mix will stabilize.

3.3.5 Input and Output

The model output required for supply sector calculations and environmental impact analyses include time series of end-use energy demand by sector and by fuel type. The input needed for the model consists of a description of the evolution of economic activity and the specific energy requirements in each intermediate sector. The definition of sectors, categories of fuels, and indicators are dependent on the data base available for a given country or region.

It must be emphasized that the model described here is not a general purpose model for deriving energy demand projections, but rather a framework that must be adapted for each application. Therefore, the input varies from case to case. The following inputs were used for the version employed in the Austrian Case Study:

- Projections of value added by sector in three-year time steps;
- Energy intensiveness by sector in 1970 and 1974;
- The ratio of energy intensiveness in 2000 relative to the 1974 level;
- The fraction of the potential change in energy intensiveness exhausted by the year 2000;
- The fuel mix by sector in 1970;
- Transition matrices for simulating the shift between motor fuel and other fuels, between gasoline and diesel (motor fuels), and between electricity, hard coal, coke, lignite, fuel oil, gas, and an "other" category (energy forms other than motor fuels.

3.3.6 Data Sources

In the Austrian Case Study the value-added data were taken from the AUSTRIA II Input–Output Model (Richter and Teufelsbauer 1973). This assured, to a certain extent, the plausibility of the economic projections. Information about value added and energy consumption by energy type in the industrial sectors was available for the 1960–1974 period from the Oesterreichisches Institut fuer Wirtschaftsforschung (Bayer 1975). Because the industrial sectors used in the IIASA model do not correspond to the manufacturing sectors in the AUSTRIA II Model, it was necessary to rely on the energy balances published by the Oesterreichisches Statistisches Zentralamt for the 1970–1975 period (Turetschek 1972, 1973, 1974, 1975, 1976, 1977). Information about the product mix was obtained from production indices published for the 1964–1973 period by the Oesterreichisches Institut fuer Wirtschaftsforschung (Bayer 1975).

3.3.7 Concluding Observations

The model developed to calculate energy demand in the intermediate sectors of the economy is actually a simple framework that forces one to consider the subsectors of the economy independently and to analyze the activity and specific energy requirements of each subsector. The model is a tool for assessing the impact of policy measures affecting economic activity, energy consumption, and environmental protection.

The first step in deriving energy demand projections with this model is a careful analysis of each subsector. This analysis must take into account (at least in a qualitative way) characteristics such as financial situation, type of ownership (private or governmental), degree of concentration (a few big plants or many small plants), location of major plants and resulting supply options, and types of production processes involved. A statistical analysis of available data on output and energy consumption can then reveal important historical changes in the relative position of a subsector and its primary products. By identifying the factors that may have caused these changes, one obtains a basis for formulating assumptions about the future evolution of a subsector.

The use of this model in the four case studies to date has permitted the identification of factors that play an important role in influencing the future evolution of energy demand in the intermediate sectors. However, for each industry the modeling effort was carried out at a high level of aggregation, and this precluded an explicit analysis of the impacts of factors such as price, cost of capital, and specific technological changes. This type of microanalysis requires detailed process descriptions of industry-specific technologies. Such an approach has recently been applied to the food and paper industries in Wisconsin (Foell 1980a, 1980b).

3.4 ENERGY DEMAND MODELS FOR THE TRANSPORTATION SECTOR

Transportation activity has two behaviorally distinct components – personal travel and the movement of goods. Different models are required to describe the two types of transportation. The Personal Transportation Model will be presented first, followed by a discussion of the Freight Transportation Model.

3.4.1 Purpose of the Personal Transportation Model

The objective of the model is to assess the implications of alternative developments in the following areas:

- Settlement patterns;
- Transportation technology;
- Travel behavior;
- Disposable income and fuel prices.

Development in these areas would affect three important sets of variables, namely,

- Numbers of trips, passenger-kilometers, and vehicle-kilometers;
- Annual energy consumption by fuel type;
- Annual area emissions of carbon monoxide, hydrocarbons, nitrogen oxides, particulates, and sulfur oxides.

By changing the values of such variables as population density, city size, vehicle ownership, vehicle characteristics, load factors, modal preference, per capita disposable income, and fuel price trends, the user of the model may create and analyze alternative energy and environment futures for the personal transportation sector. Similarly, policy measures aimed at the transportation system may be assessed in terms of their influence on travel, energy use, and emissions. Changes in these variables may be analyzed jointly or separately by changing variable input and parameters at one or more points in time.

Settlement Patterns

Detailed spatial disaggregation makes the model sensitive to settlement patterns and permits consideration of air pollution emission concentrations within individual communities. As will be described below, the frequency, length, velocity, and operating conditions of trips are a function of city size, density, and vehicle ownership levels. The objective of including a high level of spatial disaggregation in the model structure is to permit community development choices affecting transportation energy use – and therefore air pollution emissions – to be brought explicitly into the decision process. The SO_2 Health Impact Model discussed in Section 5.5 accounts for SO_2-related health impacts associated with all the energy demand and supply sectors.

Transportation Technology

The model is useful for assessing changes in the technological characteristics of the vehicle fleet, particularly in the case of the automobile. It explicitly accounts for the time lag associated with the rate at which the automobile fleet changes through the addition of new vehicles and demolition of old ones. The model also takes into consideration the annual distribution of vehicle-kilometers within the fleet; this is important, because new vehicles are used more than older ones.

These capabilities permit evaluation of the impacts of such policy measures as fuel economy or emission standards, including the rate at which the impacts occur. Regulation of vehicle performance characteristics is a key policy tool aimed at the personal transportation sector in the USA, and, to some degree, in the other regions.

Travel Behavior

Travel behavior and vehicle use characteristics, such as vehicle load factors and travel velocity, can be easily assessed within the model framework. The main applications of this model capability have been analyses of the effects of car pooling and shifts to and away from mass transit.

Price Considerations

The model can also be used to assess the influence of disposable income and fuel prices on travel behavior and vehicle choice. The growth of income and decline of fuel prices over time in real terms has contributed to increases in automobile ownership, use, emissions, and fuel consumption. Due to increasing oil prices and tax policies, fuel prices are expected to rise in real terms in the future. The model is designed to calculate the impacts of such price increases. The model can also be used to assess the effect of trends in income, such as a significant slowing of economic growth.

3.4.2 General Description of the Personal Transportation Model

The Personal Transportation Model was originally developed at the University of Wisconsin–Madison (Hanson and Mitchell 1975). A detailed description of this simulation model is provided by Hanson (1979). Empirical data and relationships are used in the mathematical formulation of the model, based on travel data available in the study regions. Because significant interregional differences in travel behavior exist, many of the mathematical relationships have been reparameterized for each region.

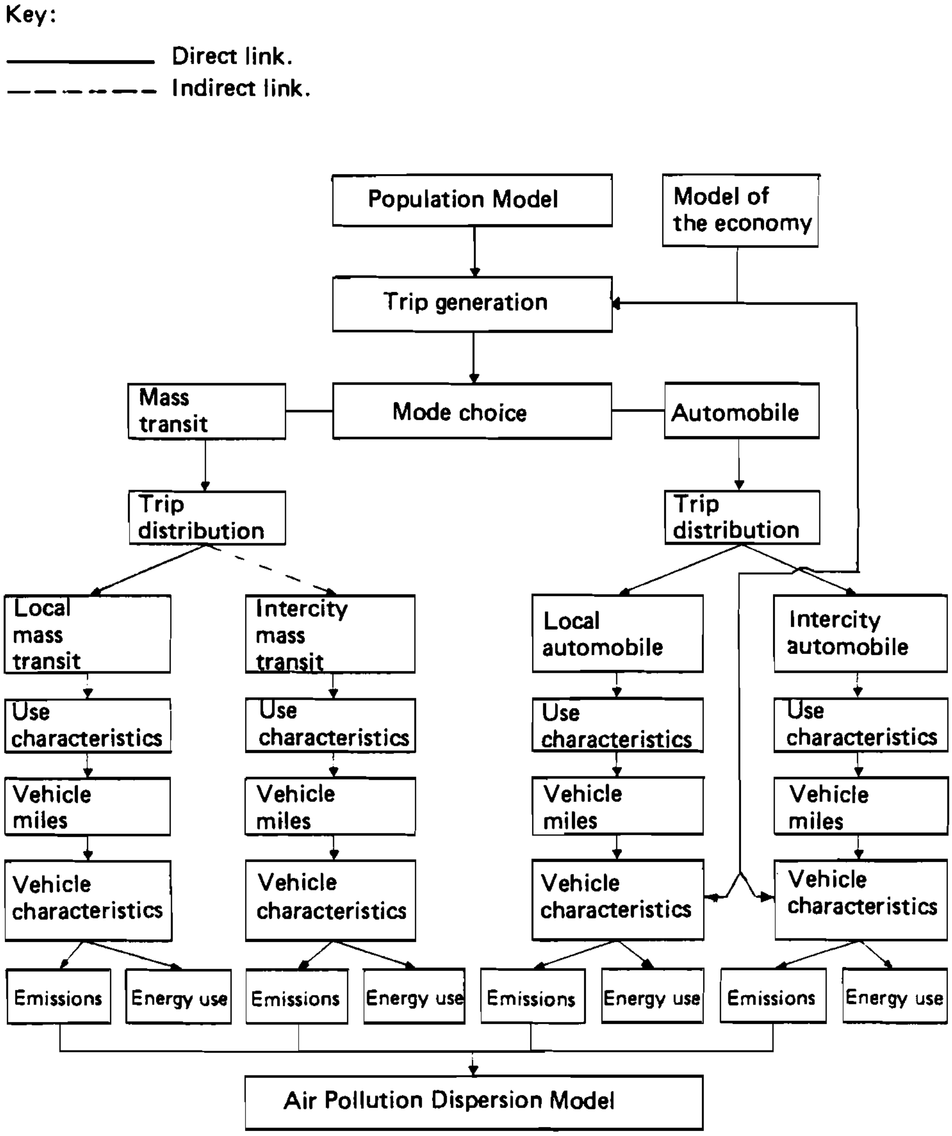

FIGURE 21 Flow of information in the Personal Transportation Model.

Figure 21 provides a schematic diagram of the model, showing the process by which estimates of travel, energy, and air pollution emissions are derived from initial demographic data. This figure reveals the similarity of the model to other models of personal transportation generally used for transportation system planning, for it includes the trip generation, modal split, and trip distribution steps (Hutchinson 1974). However, the Wisconsin–IIASA model does not have the route assignment step, which is usually included in planning models.

3.4.3 Major Components of the Personal Transportation Model

Demographic Characteristics

Considerable spatial disaggregation is required for the estimation of travel and the ensuing energy use, emissions, and emission concentrations in urban areas. In the model the spatial disaggregation is based on the place of residence of the trip maker, as the point of trip origin. The demographic data necessary for the spatial disaggregation is supplied by the Population Model (see Section 2.2), as indicated in Figure 21.

The specific spatial breakdown used in the Personal Transportation Model focuses on functional regions within the larger region under analysis. Each functional region (or subdistrict) consists of up to six community types. The spatial organization of the subdistricts and the number of community types included in a particular study depended on the availability of demographic data. In the Austrian study the subdistricts consisted of a core – generally a major Austrian city – and two concentric rings. In the Wisconsin study each subdistrict usually included a major city.

The demographic data in Austria allowed the specification of four community types: core cities, main cities, other cities, and rural areas. In the Wisconsin study, six community types were considered: central cities and mature suburbs, suburbs and fringes, exurban areas, satellites (with a population of 5,000 to 20,000), adjacent communities (with a population of 2,500 to 5,000), and rural and small communities.

The four future settlement patterns that have been analyzed in the Wisconsin studies have been labeled "suburban extension," "exurban dispersal," "urban containment," and "small city containment" (Wisconsin State Planning Office 1974). Suburban extension represents a continuation of post-World War II development patterns. Exurban dispersal places new development beyond the suburbs on 0.2 to 0.4 hectare lots. In both containment patterns development occurs within present urban areas, filling in much of the previously unutilized land. The main difference is that "urban containment" allocates most of the new development to the large urban areas, while "small city containment" allocates new development to smaller cities, bringing their population to the 50,000–100,000 range.

Trip Generation and Modal Choice

Trips are estimated in the model on a per capita daily basis for each community. Two major trip equations are used to project total vehicle trips and mass transit trips. Automobile trips are equal to the difference between these two functions, as shown in Figure 22 for the Wisconsin Case Study. Figure 22 is based on the hypothesis that as population density increases and automobile ownership decreases, the total number of vehicle trips decreases and the number of mass transit trips increases.

The trip functions shown in Figure 22 are for the year 1970. As the transportation system is simulated over time, these functions are likely to change. The response of the total vehicle trip function to income and gasoline price changes is a primary dynamic effect built into the model. As income increases, the public is expected to increase its travel; at the same time increasing gasoline prices are expected to depress travel. These effects are represented by allowing the "constant" 2.6 (shown in Figure 22) to be changed by price and income variation via price and income elasticities.* Estimates of the responsiveness of

*Price elasticity is defined as $E = \frac{\partial Q}{Q} / \frac{\partial P}{P}$; in this case, Q is the "constant" 2.6 and P is the real price of gasoline.

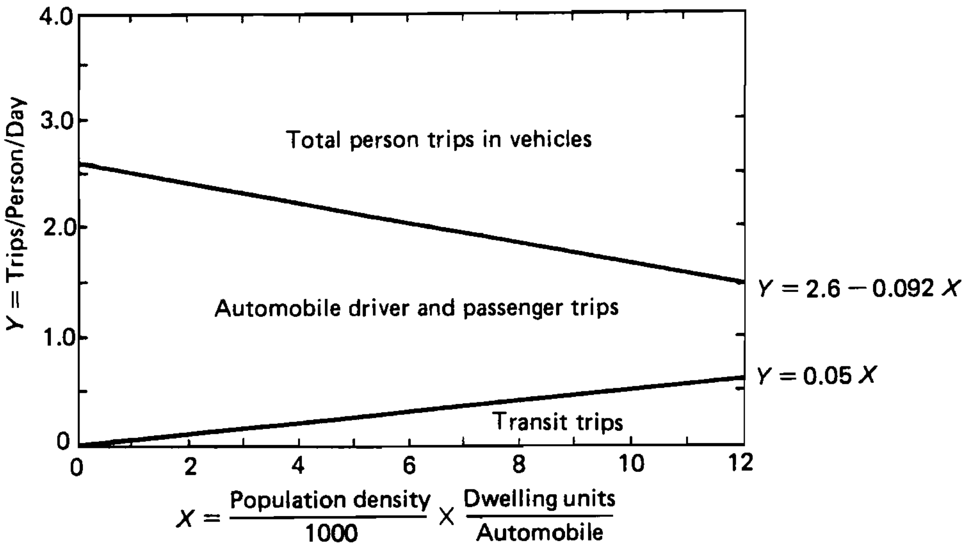

FIGURE 22 Trip generation in the Personal Transportation Model, Wisconsin Case Study (Levinson and Wynn 1962).

the public to income and fuel price trends are uncertain. For this reason the model is structured to allow a user to easily substitute alternative estimates of the elasticities.

Trip Distribution

The term "trip distribution" refers to the allocation of trips to local and intercity modes, and the assignment of trip length to each of these trip types. Studies of intercity travel have found that the number of intercity trips per capita decreases as the size of a city increases (Highway Research Board 1969). The Austrian and Wisconsin Case Studies utilized the following function to describe intercity trips:

$$\text{intercity trips/person/day} = 11/(\text{cordon population})^{0.39} \qquad (3.7)$$

In the case of rural areas and small cities the cordon population is the community population. For larger urban areas, the cordon population is the urban area population, which is equal to the sum of the population of all communities in the urban area. The number of local trips is the total number of trips minus the number of intercity trips.

After calculating the number of trips, their mode, and type (local and intercity), the model assigns trip lengths. The relationships used to generate the length of local trips in the Wisconsin and Austria studies are shown in Figure 23. US data were used to estimate the relationship in the case of Wisconsin, while Austrian Microcensus data for 1971 were used in the Austrian study (Oesterreichisches Statistisches Zentralamt 1972). The functions

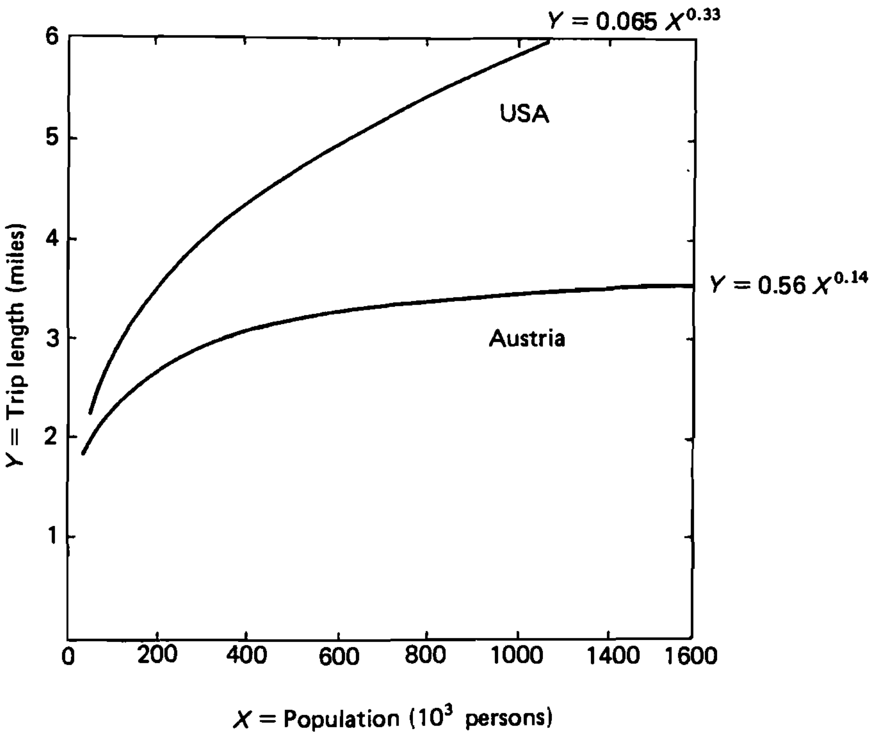

FIGURE 23 Generation of mean trip length for local trips in the Personal Transportation Model.

are similar for the two regions, but the Austrian data indicate a shorter average trip length than in the US, especially in the case of Vienna, Austria's largest city. Figure 24 shows the relationship of city size to trip length that was utilized for intercity trips in the Wisconsin study. Time was converted to kilometers traveled on the basis of an assumed average automobile velocity of 72 km/hr.

Vehicle Use Characteristics

Vehicle use characteristics describe the conditions under which a vehicle fleet is operated. The important operating conditions are load factors by vehicle type (needed to relate passenger-kilometers to vehicle-kilometers), speed of operation (needed to estimate vehicle fuel consumption by distance traveled), frequency of cold starts, ambient air temperature, and the use of vehicles by age. The load factors (number of people per vehicle) used in the case studies have typically been 1.4 people per automobile for local trips and 2.4 for intercity trips. Data on the use of vehicles by vehicle age and the age structure of the vehicle fleet are available for the US (Shonka *et al.* 1977). For the other regions estimates were based on automobile sales, automobiles in circulation, total vehicle-kilometers driven, and international experience.

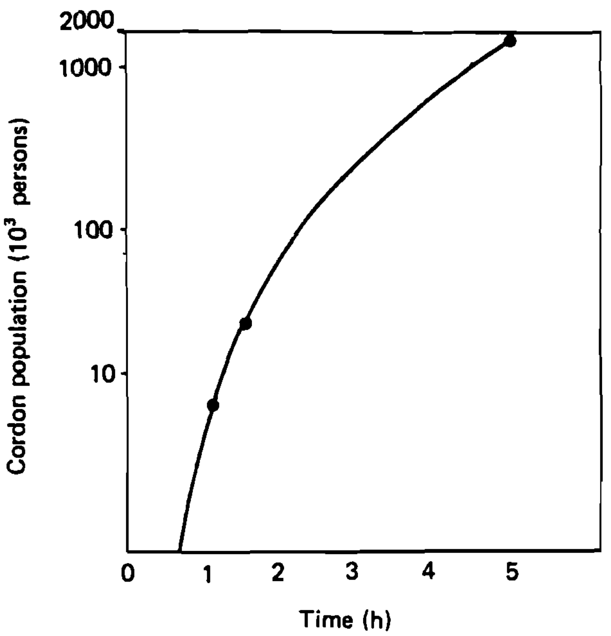

FIGURE 24 The relationship between city size and trip length for intercity trips, Wisconsin Case Study.

Technological Characteristics of Vehicles

In the model, vehicle technology is specified by vehicle model year in terms of vehicle-kilometers per unit of fuel used and grams of emissions per vehicle-kilometer. Analysis by model year is necessary because of the marked changes in vehicle emissions and fuel economy from year to year. An additional technological factor is vehicle size. In the model the vehicle fleet is divided into large, small, and urban cars. The definitions of these sizes vary considerably between regions, as do the fuel economies and emission levels. Environmental Protection Agency (EPA) test cycles, adjusted to simulate actual operating performance, provided information on fuel economy and emissions in the Wisconsin Case Study (Kircher and Masser 1975).

In the Personal Transportation Model mean annual fuel economy (in units of miles per gallon or liters per 100 kilometers) for local trips for the automobile fleet is computed by means of the following equation:

$$M = \sum_{i=1}^{14} \sum_{j=1}^{3} C_{ij}B_{ij} \left(O_iW_i \Big/ \sum_{i=1}^{14} (O_iW_i) \right) \tag{3.8}$$

where i is the automobile model year, from the current year to 14 years, j is automobile size (large, small, urban), M is the mean annual vehicle fleet fuel economy (local trips),

C is the vehicle fuel economy in local trips by vehicle type and model year, B is the fraction of vehicle types by model year, O is the fraction of vehicle fleet by age, and W is mean annual vehicle-kilometers by vehicle age. A similar function, in which intercity fuel economies are substituted for C, is used to calculate mean annual fuel economy for intercity trips.

A combination of market and regulatory forces determine the fuel economy of the automobile fleet in future years in the model. Mandated fuel economy standards are assumed in the model to be fully or partially met. In addition, income and fuel price trends are expected to influence the selection of fuel economy characteristics, if these trends are strong enough to push fuel economy levels beyond the regulated levels. If there are no regulations within a region, market forces determine the fuel economy (variable C in Eq. (3.8)). As in the case of price and income elasticities for trip generation, the model allows the user to easily change the estimates of income and price elasticity for the fuel economy of new automobiles entering the vehicle fleet.

The simulation of emissions for carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), particulates, and sulfur oxides (SO_x) are based directly on vehicle-kilometers. Emission factors are expressed in terms of grams per vehicle-kilometer. Because these factors vary with the type of driving (local and intercity), the model year, and the age of the vehicle, the same accounting framework is used as in the fuel economy computations. Carbon monoxide emissions for intercity travel are estimated as follows:

$$P = \sum_{i=1}^{14} K_i \left(O_i W_i \Big/ \sum_{i=1}^{14} (O_i W_i) \right) + D_i \left(O_i W_i \Big/ \sum_{i=1}^{14} (O_i W_i) \right) \tag{3.9}$$

where i is automobile model year from the current year to 14 years, P is mean CO emissions per vehicle-kilometer in intercity travel (emission factor), K is base emissions of CO per vehicle-kilometer for intercity travel by model year, D is additional emissions of CO per vehicle-kilometer by model year and age, due to deterioration, O is the fraction of vehicle fleet by age, and W is mean annual vehicle-kilometers by age.

The emission factor relationships are similar for CO, HC, and NO_x, except that the deterioration factors for CO and HC are linear functions of vehicle age, while the deterioration factor for NO_x is an exponential function.

In order to allocate air pollution emissions, the location of the vehicle travel must be taken into account. Vehicle-kilometers are divided into "central area" and "outlying area" travel. Central area vehicle-kilometers are traveled in the central areas of core, main, and other cities. They are allocated to the community where they occur. Outlying vehicle travel includes intercity vehicle-kilometers emanating from the central areas, as well as local and intercity travel emanating from and/or occurring in the outlying areas. The emission results, disaggregated by place of travel, provide input to the Air Pollution Dispersion Model described in Section 5.3.

3.4.4 Input and Output

Four categories of input are required for the Personal Transportation Model, namely, *demographic*, *behavioral*, *technological*, and *economic* inputs. As shown in Figure 21, the demographic inputs are provided by regional population models. The population model used to project demographic trends in the Austrian study is described in Section 2.2 of this report. Similar models were utilized in the other regions. The specific demographic inputs required by the Personal Transportation Model are population, population density, and automobile ownership by community for each of the subdistricts in a given region.

Trip-making rates, length, mode, and load factors constitute the behavioral inputs required for the model. Behavior changes endogenously in the model, as a function of change in demographic variables. For certain "constant" demographic and economic characteristics, behavior is assumed to remain fixed. However, this assumption can be altered exogenously, by specifying changes in trip-making rates, load factors (due to car pooling, for instance), modal choice (increased availability or willingness to use mass transit), or trip length.

Technological inputs include the distribution of vehicles by age and by size (less than or greater than 1,500 cc engine displacement in the case of Austria), the fuel economy by size classes of vehicles under different driving conditions, emission characteristics, the life expectancy of vehicles, and the amount of use (by age) of the vehicle. The technological input required for the model is summarized in Figure 25 and Figure 26, drawing on data from the Wisconsin Case Study. Economic inputs to the model include income and gasoline prices.

The four main categories of model output are *passenger-kilometers*, *vehicle-kilometers*, *energy use*, and *air pollution emissions*. The first two categories constitute intermediate model output; they may serve as one means of checking model results with available transportation statistics. Energy use and air pollution emissions, by community, district, or for the entire region, constitute the final output of the model. This output permits the further

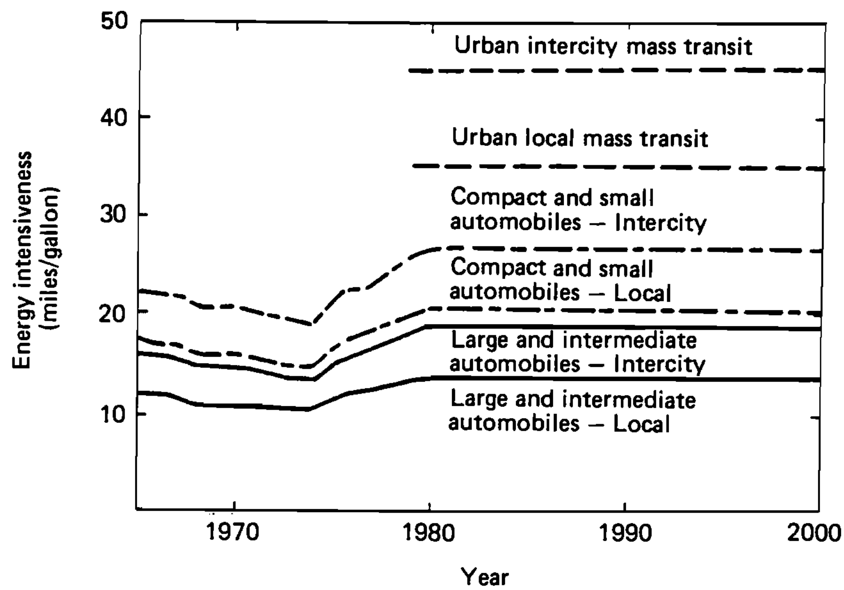

FIGURE 25 Energy intensiveness by vehicle type and model year, Wisconsin Case Study.

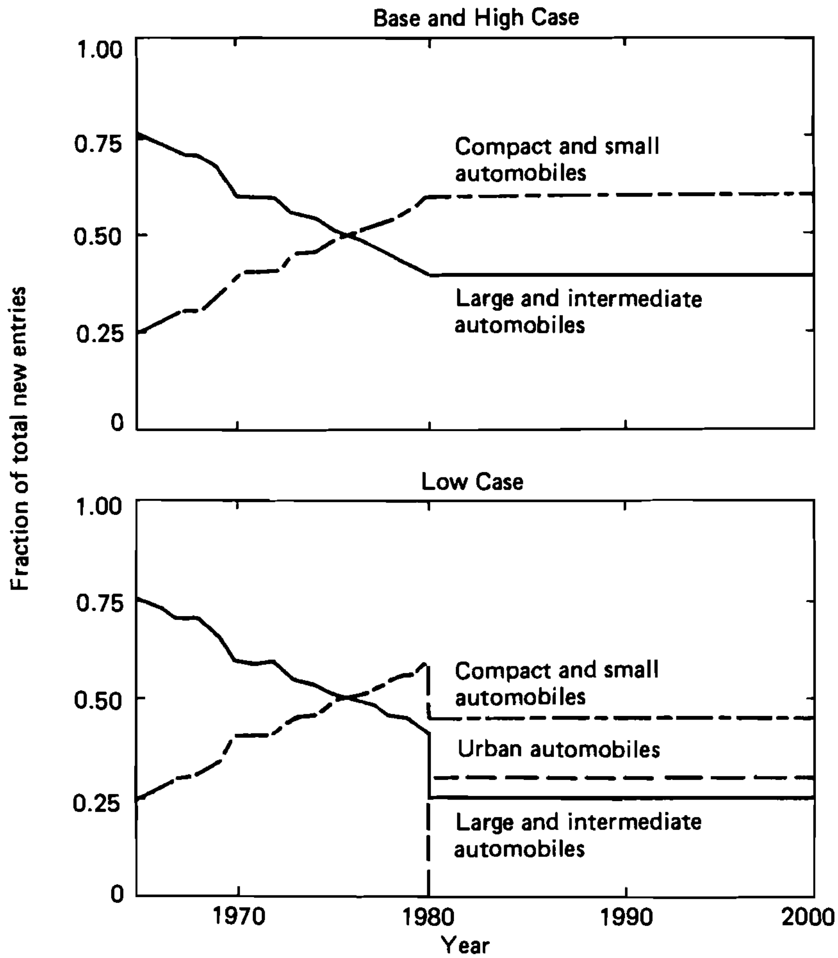

FIGURE 26 Automobile entries into the vehicle population by type and model year, Wisconsin Case Study.

calculation of per capita energy use by district, which is useful for comparing energy use and emissions assoicated with different urban forms and settlement patterns. The model output includes emissions of hydrocarbons, nitrogen oxide, carbon monoxide, sulfur dioxide, and particulates.

Figure 27, Figure 28, and Figure 29 provide examples of the third and fourth categories of model output, i.e., energy use and air pollution emissions. Figure 27, taken from the Austrian study, shows changes in energy demand resulting from policy measures, such as regulation or price incentives, that increase fuel economy in new automobiles. The present average efficiency of automobiles in Austria is 12.3 liters/100 km; if the automobile fleet economy averages are lowered to 8.9 liters/100 km and 7.0 liters/100 km in sensitivity tests of the model, the system responds with a rapid decrease in energy demand in the 1980–1990 period.

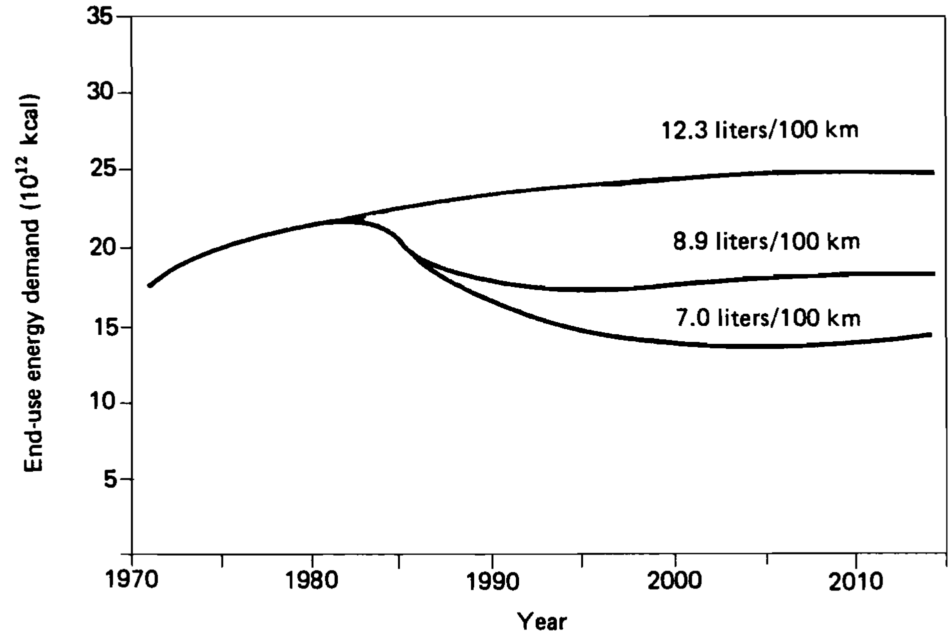

FIGURE 27 The sensitivity of energy demand for personal travel in Austria to different levels of vehicle fuel economy.

Figure 28, also from the Austrian study, indicates the effects of policy actions directed at the control of emission levels. The marked difference in hydrocarbon air pollution emissions from uncontrolled vehicles versus vehicles meeting US standards is shown for Vienna and Salzburg.* Present Austrian standards for new automobiles fall between the two levels depicted in the figure.

The final example of model output, presented in Figure 29, is drawn from the Wisconsin study. Here the output illustrates the effect of alternative future settlement patterns on energy use. An extension of current settlement patterns towards continued suburban expansion was assumed in the Base Case Scenario developed for Wisconsin. Other settlement alternatives considered in the Wisconsin scenarios were exurban dispersal (development on 0.2 to 0.4 hectare lots beyond the urban fringes), urban containment (development within present urban areas), and development of small compact cities. The output of model runs using different assumed settlement patterns showed the highest level of energy consumption for the exurban dispersal case. This was to be expected, because dispersed settlement patterns are associated with relatively many long automobile trips. The results of the urban containment case were not as favorable for energy demand as initially anticipated. The results produced by the relationships contained in the model

*The analysis assumes full compliance with US Environmental Protection Agency standards. Experience has revealed disparities between test vehicles and fleet averages, as well as considerable vehicle modification by vehicle owners.

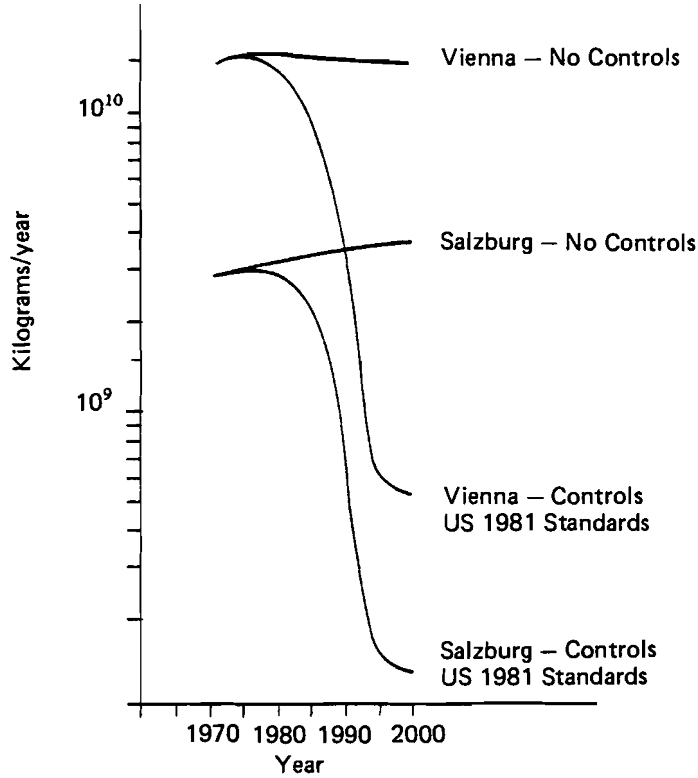

FIGURE 28 Hydrocarbon emissions in two Austrian cities, assuming alternative levels of emission controls.

revealed that large urban areas without effective transportation systems and rural areas are the most energy intensive for transportation. In the case of urban containment, most of the increment in population during the time frame of the case studies was added to large cities, and this also contributed to the relatively high levels of energy demand. A more favorable effect on energy demand was associated with small compact city development.

Model runs showed a very slow rate of response of the energy system to changes in settlement patterns. This reflects the gradual rate at which most communities in developed countries change demographic character. The steep decline in energy use beginning in the late 1970s and continuing until the mid-1980s is due primarily to the impact of the US fuel economy standards, rather than to demographic changes.

3.4.5 Concluding Observations

The Personal Transportation Model was initially developed to assess the implications of selected policy alternatives for energy use and emissions. The policies that can be

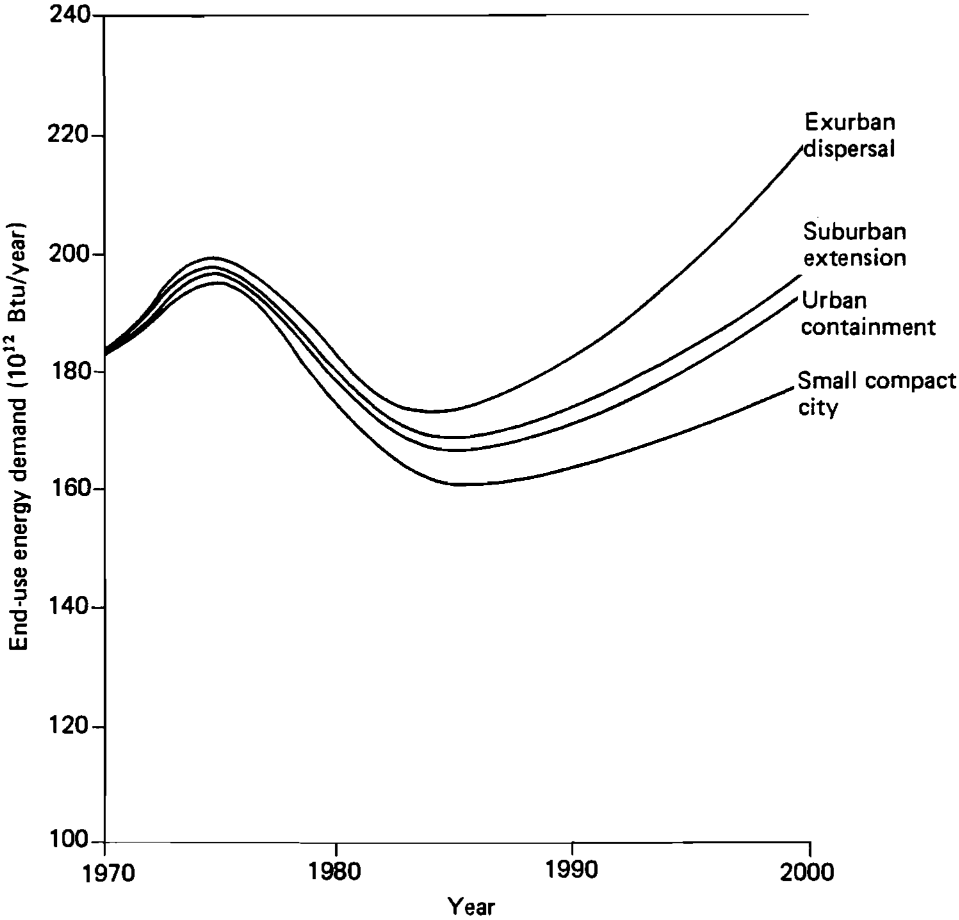

FIGURE 29 Personal transportation energy demand for Wisconsin under varying assumptions about population settlement patterns.

examined with the model relate to settlement patterns, transportation technologies, travel behavior, and fuel price and income trends. Analysis has shown that policy measures directed at transportation technologies have rapid and large effects on energy use and emissions (Hanson 1980). Policy measures affecting land-use patterns and travel behavior are more difficult to implement and produce a slower and considerably smaller response, in terms of energy conservation or emission reductions. This does not diminish their importance, however, especially for the long run. As for pricing policies, the growth of per capita income has supported the growth of transportation, and very large fuel price increases would be needed to significantly reduce the use of fuel.

The model has proven to be a straightforward and useful tool for analysis of selected transportation policies at the regional level. It should be noted, however, that there are many questions that the model does not address; for instance, the model cannot assess the effectiveness of policies encouraging mass transit rather than automobile use for work trips – it can only calculate the changes in energy use and emissions that would result if the shift actually occurs. The model is also not appropriate for assessing the implications of settlement patterns at the individual neighborhood or community level. A more spatially-detailed model would be required for such a microlevel analysis.

3.4.6 Purpose of the Freight Transportation Model

In the case studies freight transportation has typically accounted for one-third to one-half of total energy use for transportation purposes. Because of the significant energy requirements of the freight sector, it is useful to have a model to assess the general trends of energy demand in the sector and to evaluate the potential for conservation.

The model used in the case studies provides a means of assessing the effects on energy use associated with policy actions that change modal distribution and energy efficiency. The methodological approach focuses on the amount of freight transportation activity, measured in net ton-kilometers, and the energy intensity per unit of activity, measured in kcal per ton-kilometer.

The potential for conservation in this sector is found in three areas: first, energy requirements for a given amount of goods moved by a given mode could be reduced; second, shifts from more energy-intensive modes, such as truck, to less energy-intensive modes, such as rail or ship, could occur; and third, the amount and/or distance that goods have to be moved could be decreased. The model provides a structure for assessing conservation measures in the first two areas, given projections of freight movement in ton-kilometers.

3.4.7 Model Description

The structure of the Freight Transportation Model is shown schematically in Figure 30. The conceptual approach used in the construction of the model is closely related to the approaches underlying the industrial and service sector models; each of the models is structured around the amount of sectoral activity and the energy required per unit of activity.

The model's starting point is the determination of activity (in terms of net ton-kilometers) of all goods transported in a given region. In various case studies the sophistication of this determination has varied greatly. Simple linear relationships relating growth of ton-kilometers to the growth of industrial or all economic output were used in Rhône-Alpes and Wisconsin. That is, a direct estimate of ton-kilometers was made on the basis of economic output measured in terms of value added. In the case of the GDR, optimization models were used to determine freight requirements in ton-kilometers by mode. These requirements were forecasted as a part of the GDR's overall 5-year economic plan.

In the Austrian case, the AUSTRIA II Input–Output Model (see Section 2.3) included a transportation/communications sector; energy use in this sector was dominated by the transportation component. The output of the AUSTRIA II Model provided

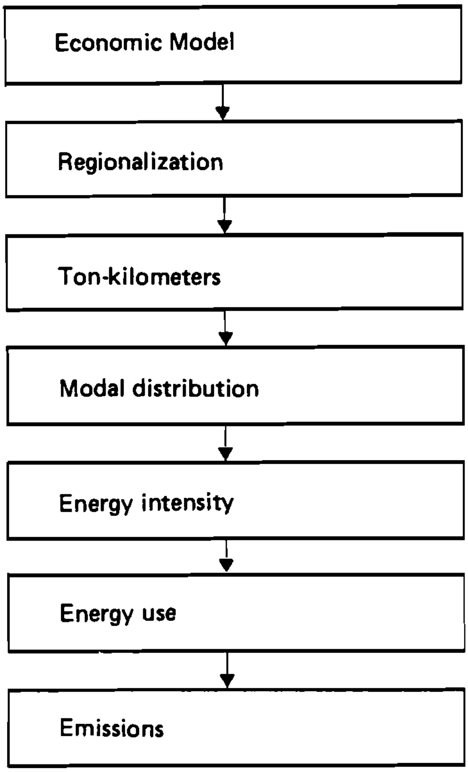

FIGURE 30 The general structure of the Freight Transportation Model.

estimates of activity levels in the transportation/communications sector in terms of value added in Austrian schillings. To convert the activity levels expressed in value added to levels expressed in ton-kilometers, it was necessary to make two assumptions that were not included in the AUSTRIA II Model. First, it was assumed that the ton-kilometers are directly proportional to value added in the transportation/communications sector. Second, it was postulated that both the transportation and communication components of the sector grow at equal rates. If evidence is found that shows that these assumptions do not hold, it is necessary to make adjustments in the conversion from value added to ton-kilometers.

After activity levels in the freight sector are determined, the ton-kilometers representing this activity must be assigned to the various modes, namely, rail, truck, ship and barge, and pipeline. Except in the case of the GDR, where this allocation was provided, assumptions about modal distributions were built into the scenarios. In general, existing trends were followed in the Base Case and High Case scenarios; some shifts away from trucking and back to rail were included in the Conservation Case.

Figure 31 shows recent trends in the freight modal distributions in Austria, and a projection of this distribution (Kohlhauser 1976). The distribution of ton-kilometers by

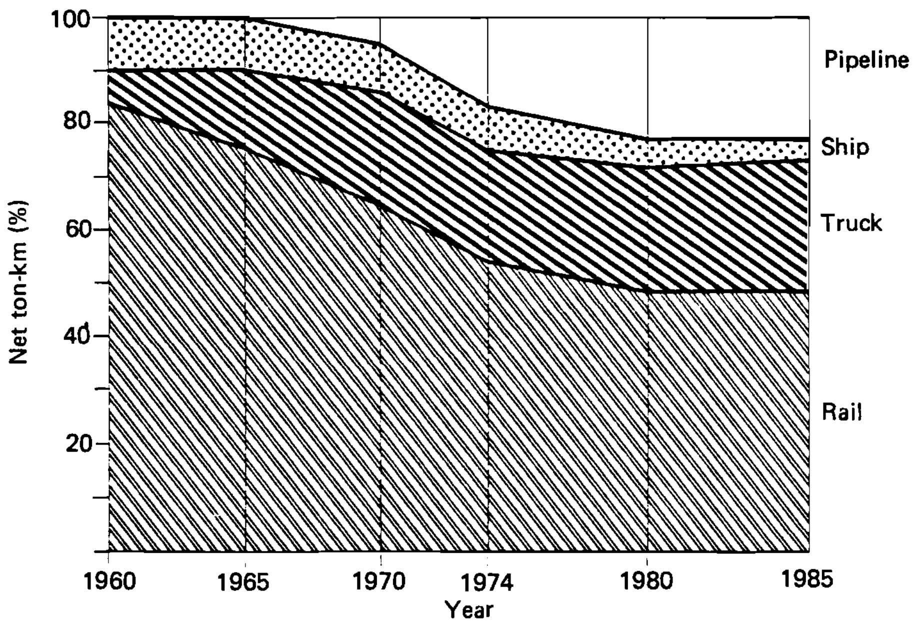

FIGURE 31 The share of net ton-kilometers by mode in Austria, 1960–1985. The figure is based on a projection by Kohlhauser (1976). Transit travel (i.e., freight movement across Austria) is not included.

mode used in scenarios S1, S2, and S3 of the Austrian Case Study was similar to the 1985 distribution in Figure 31: railroads – 48.7%, trucks – 23.5%, ships and barges – 6.4%, and pipelines – 21.4%. In Scenario S4, a modal shift from truck to railroad transportation was assumed, resulting in the following distribution: railroads – 56.4%, trucks – 15%, ships and barges – 8.1%, and pipelines – 20.5%.

After the level and modal distribution of ton-kilometers are determined, the final step in the calculation of the energy use of the freight sector can be carried out. This step involves specification of the intensiveness of the various freight modes and possible changes in the intensiveness. Table 9 presents the estimates of intensiveness used in the Wisconsin analysis.

Despite their large share of ton-kilometers, pipeline and ship and barge modes are quite energy efficient and account for only small fractions of total freight energy use. In 1970 ships and barges accounted for only 5% and pipeline for 4% of total energy consumption in the transportation sector in the USA. Therefore significant reductions in energy intensiveness were not assumed for these modes in the regional analyses. The same assumption was made for rail transport, which accounted for only 4% of total US energy consumption in the transportation sector in 1970.

Trucks accounted for 23% of energy consumption in the transportation sector as a whole in 1970 in the USA. Here a significant potential exists for reduction of energy intensiveness. Assumptions about such a reduction were included in the Conservation Case scenarios and to a lesser degree in the Base Case scenarios in the regional studies. For example,

TABLE 9 US freight energy intensity by mode in 1972 (Shonka *et al.* 1977).

Mode	Kcal/ton-kilometer
Rail	110
Truck– intercity	310
Ship and barge–domestic	20–80
Pipeline–oil (36" pipe, light crude, low flow)	30
Air	3,700

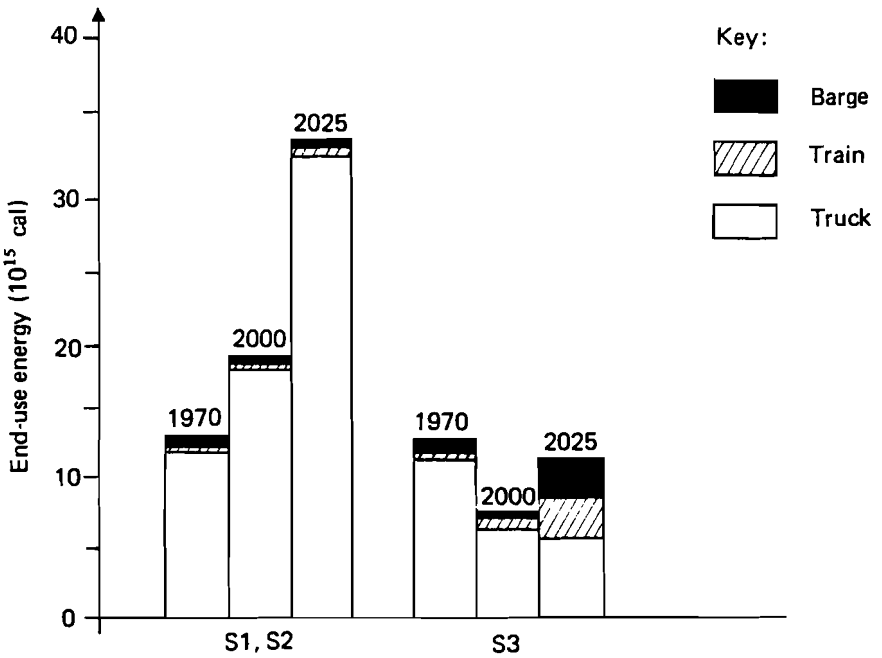

FIGURE 32 Freight transportation energy use by mode in three Rhône-Alpes scenarios.

in the Austrian study truck intensiveness is assumed to decline by 20% by 1995 in the Base Case and 35% in the Conservation Case.

3.4.8 Input and Output

The primary input to the Freight Transportation Model is either a projection of freight activity in ton-kilometers or statistical data permitting an estimate of the historical relationship between economic activity and freight activity, and a projection of economic activity. Historical information on modal distributions and energy intensiveness by mode is also required. Alternative policy actions affecting modal distribution and energy intensiveness can be evaluated by means of the model, taking into account anticipated future developments in freight transportation.

The output from the model consists of projections of energy use by fuel type and mode for each year of simulation. Figure 32 depicts the total energy requirement for the principle types of freight transport in Rhône-Alpes for three selected years and three scenarios. The effect of lower economic activity, conservation, and a modal shift from truck to train and barge is evident in the low energy use in the Conservation Case, compared with the results of the other two scenarios.

3.4.9 Concluding Observations

The freight transportation model is a simple analysis tool. It provides a framework for assessing the effects of modal shifts and changes in modal intensity. It does not, however, constitute a method for assessing the effectiveness of policy actions directed at changing modal intensities and distributions. The paucity of data on freight movements proved to be a severe analytical limitation for the parameterization of the model in all of the regions.

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4 ENERGY SUPPLY MODELS

4.1 INTRODUCTION

It is the task of the energy supply system to deliver the amounts of primary energy by source required to meet end-use energy demands. The energy supply system, as defined in the regional studies, encompasses the entire fuel system, including resource extraction, transportation, conversion, and delivery processes.

In the case studies two approaches were used to study energy supply questions. First, a *demand/supply balance technique* was employed, in which energy supply was essentially matched to the energy demand specified by the sectoral demand models. However, it was necessary to determine supply options for electricity and district heat generation. Although no formal computer-implemented model was used in supply/demand balance analysis, it reflected the regions' historical experience and future plans for electricity and district heat generation.

In the demand/supply balance approach, a "reference energy system" was used to trace the flow of energy from resource extraction to the point of final consumption. Within this scheme the amounts of primary energy required to meet end-use demands were determined by accounting for transportation, refining, conversion, and distribution losses, as well as plant thermal efficiencies in the electricity and district heat sectors.

In addition to the descriptive energy demand/supply balance approach, a *formal resource optimization model* was used to a limited extent to examine interfuel competition and resource supply strategies. A version of the Brookhaven Energy System Optimization Model (BESOM), modified to reflect the characteristics of the Austrian energy system, was run on the computer system at Brookhaven National Laboratory.

4.2 THE ENERGY DEMAND/SUPPLY BALANCE APPROACH

4.2.1 Purpose

The energy demand/supply balance technique is used to calculate the quantities of primary energy needed to meet end-use energy demands, as specified by the sectoral demand models. Within the framework, supply options are determined for the production of electricity and district heat, based on historical trends and plans of the utility companies in each study region. Primary energy utilized in such conversion processes is added to primary energy requirements for fuels burned at the point of end-use, to determine total requirements for primary energy. This procedure makes it possible to compare future supply needs with the availability of energy – both in terms of domestic resources and imports.

The demand/supply balance approach used in each of the regions involved (a) analyzing historical data, including on-line supply systems, (b) accounting for announced energy system-related construction plans, (c) examining domestic resource and reserve estimates, including long-term fuel availabilities, (d) assessing existing and potential fuel import and export contracts, and (e) reviewing official and ad hoc energy supply forecasts and studies.

4.2.2 Description

The calculations in the demand/supply balance approach are based on a "reference energy system," which traces the flow of energy from resource extraction to the point of final consumption. Complete fuel cycles are described by the system, including extraction, transportation, refining, conversion, and end-use. Primary energy requirements are determined by taking into account losses occurring at each point of the supply chain, as well as the efficiency of conversion from primary fuels to other forms of energy. The general structure of the reference energy system used for the supply calculations is shown in Figure

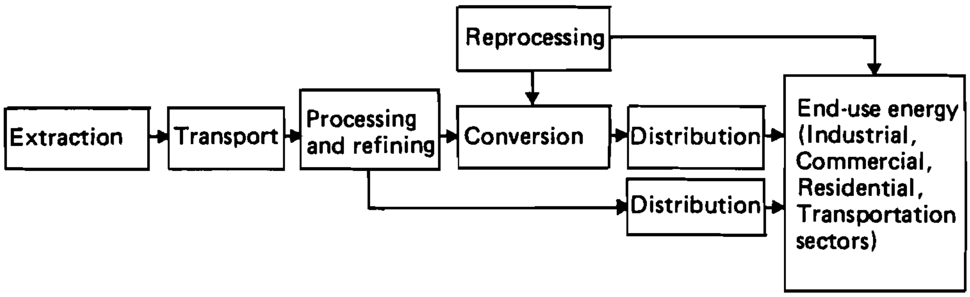

FIGURE 33 The general structure of the reference energy system used in the demand/supply balance approach.

33. In practice the reference energy system is defined in more detail for each supply category, in order to account for specific steps in the energy chain. As an example, the reference system for nuclear power is shown in Figure 34. Supply categories considered in the reference system include lignite, hard coal, crude oil, natural gas, wood and waste, hydropower, solar power, and nuclear power.

Three types of information are required to carry out the supply calculations: (1) end-use energy demands; (2) fuel mixes used in the generation of electricity and district heat; and (3) extraction, transportation, refining, conversion, and distribution efficiencies. Each is discussed in turn below. Figure 35 then summarizes the information used in calculating the primary energy requirements needed to satisfy end-use demand.

End-Use Demands

The output of the sectoral demand models (see Chapter 3) provides the end-use requirements for energy sources, as well as the amounts of electricity and district heat consumed. The mix of fuels needed to supply end-use demands for energy, other than

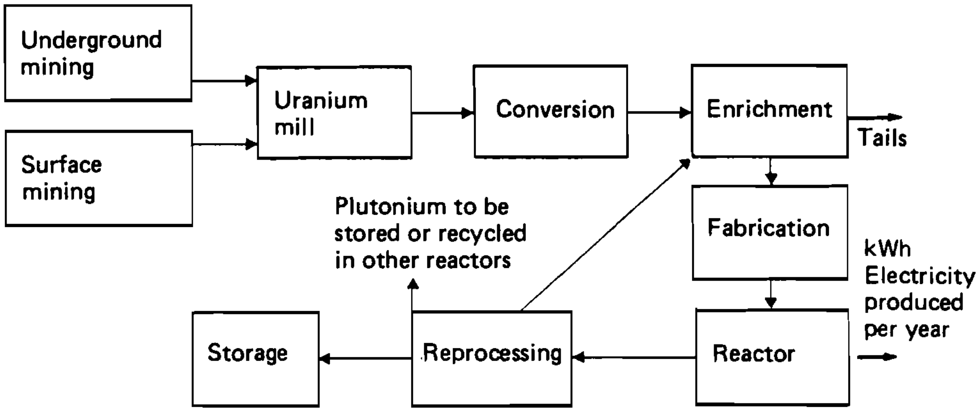

FIGURE 34 The reference system for nuclear power.

electricity and district heat, is thus specified by the sectoral demand models. The mix of these fuels depends upon the specific characteristics of the region under study, e.g., its industrial structure and natural resources. In most scenarios it was assumed that the availability of these fuels was not restricted by shortfalls.

Energy sources used to meet end-use energy demands include coal, petroleum, natural gas, solar space heating and water heating, synthetic fuels, and geothermal energy, as well as electricity and district heat.

Fuel Mixes for the Generation of Electricity and District Heat

The specification of the fuel structure for electricity and district heat production is based upon an evaluation of a region's energy supply history, the plans of its utility companies, policy options, and natural resources, rather than upon a formal model. Requirements for an appropriate mix of base-load, intermediate-load, and peaking plants are taken into account. The supply options considered in the electricity sector include hydropower, coal, petroleum, natural gas, nuclear fission, and solar power. There were wide differences in the electrical supply patterns assumed for the four regions that have been studied to date. Reasons for this variation include differences in hydropower potential and in domestic reserves of various energy resources. Fuel options for district heat generation in the studies included petroleum, waste materials, and coal.

Efficiencies

Cleaning and transport efficiencies for lignite, coking and transport efficiencies for hard coal, refining and transport efficiencies for petroleum, transport efficiencies for gas, and transmission and distribution efficiencies for electricity and district heat are taken into account in the supply calculations. Thermal efficiencies for electricity and district heating plants are assumed to improve as a function of time, with the introduction of improved conversion technologies.

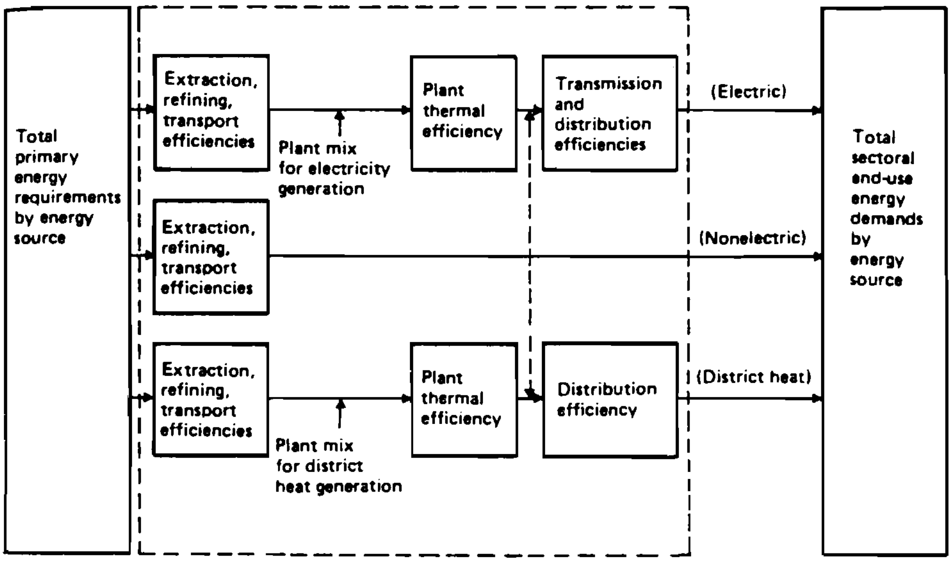

FIGURE 35 Factors considered in the calculation of primary energy requirements using the energy demand/supply balance approach.

4.2.3 Input and Output

Information provided by the demand/supply balance approach includes:

- Primary energy requirements by energy source for fuels burned directly at the point of end-use. These are associated with the annual end-use demands produced by the sectoral demand models for a given scenario.
- Primary energy requirements by energy source for the production of electricity and district heat. These are associated with end-use consumption of electricity and district heat, as specified by the sectoral demand models on an annual basis for a given scenario.

Sample results of the calculations are presented in Figure 36. Here the total end-use demands for energy in the Austrian Case Study are contrasted with the total primary energy requirements calculated to meet these demands (Foell *et al.* 1979). The divergence between end-use and primary energy is due to the overall transportation, refining, conversion, and distribution losses, as discussed above.

The structure of electricity and district heat production indicated in Figure 36 is based on historical trends, as well as on the construction plans of Austrian utility companies. The emphasis on hydropower for producing electricity follows from an assessment of the region's hydropower potential. The low utilization of fossil fuels for domestic production of electricity is based on the assumption that the growing reliance on imported fuels will have a negative effect on the expansion of present levels of fossil fuel-fired generation.

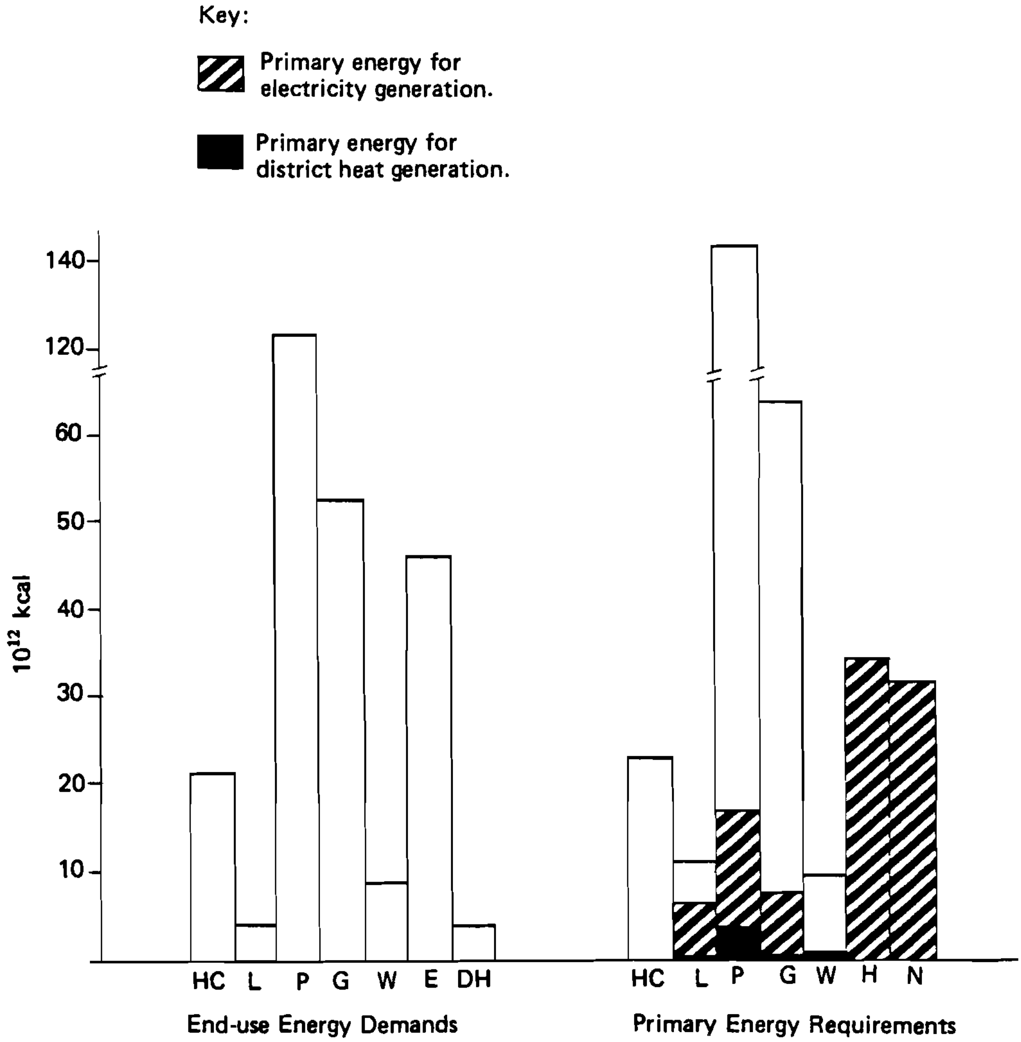

FIGURE 36 End-use energy demands and primary energy requirements in the year 2000: Scenario S1 of the Austrian Case Study. E is electricity; DH is district heat; HC is hard coal; L is lignite; P is petroleum; G is gases; W is wood and wastes; H is hydropower; N is nuclear power. The solid portions of the bars denote primary energy for electricity generation, and the shaded portions denote primary energy for district heat generation.

Existing contracts and on-going negotiations with neighboring countries for imports of electricity formed the basis for the assumed levels of imported electricity. In the district heating sector, the fuel structure accords with utility company plans for emphasis upon waste- and petroleum-fired generation.

The structure of electricity production in the scenarios developed for other study regions differs greatly from the Austrian case (see Foell 1979). For instance, heavy reliance on coal-fired generation was assumed for Bezirk X in the GDR, because of the abundant reserves of coal present in that region. A continuation of the historical pattern of reliance on imported coal for electricity generation was assumed in the Wisconsin Case Study.

For each case study the input data for the supply calculations reflected the historical experience and published energy plans of the region being analyzed. Thus general transportation, refining, and distribution efficiencies, as well as plant thermal efficiencies were established individually for each study region, on the basis of an analysis of the existing supply system and feasible alternatives for future development.

4.2.4 Data Requirements

In order to project the structure of the electricity and district heat components of the supply sector in each study region, it was necessary to collect extensive historical data. The current stock of utility plants by fuel type, capacity, capacity factor, age, and thermal efficiency had to be researched. In addition, utility companies' plans for new construction had to be obtained. In order to build feasible alternative futures for electricity and district heat production it was also necessary to ascertain domestic energy resources and patterns of foreign fuel imports.

Important data sources include the published statistical records of utility companies in each region, the energy plans developed by regional energy planning agencies, and historical data on production, imports, and exports of energy. The publications of the Bundesministerium fuer Handel, Gewerbe und Industrie (1974, 1975, 1976a, 1976b), the Bundesministerium fuer Verkehr (1971), the Marktforscherteam (1977), and the Wiener Stadtwerke Generaldirektion (1975) are representative of the data sources used in the Austrian Case Study.

4.2.5 Concluding Comments

The framework for determining energy supply requirements presented in this section permits the evaluation of primary energy needs associated with end-use energy demands. The approach, structured around reference energy systems, makes possible the analysis of differences in total primary energy requirements following from alternative demand scenarios for the future. In addition, calculation of primary energy requirements provides a starting point for assessing the availability of domestic resources and imports to meet the energy requirements.

4.3 THE BROOKHAVEN ENERGY SYSTEMS OPTIMIZATION MODEL (BESOM)

4.3.1 Introduction

This section provides a brief overview of the Brookhaven Energy Systems Optimization Model (BESOM), which was developed at Brookhaven National Laboratory. BESOM is a static energy resource optimization model designed to examine interfuel substitution subject to various constraints and resource availabilities. A version of this model was used in the Austrian study to analyze electrical sector interfuel competition for the year 1990. The calculations were carried out at Brookhaven National Laboratory. Analysis was conducted at IIASA and the University of Wisconsin.

4.3.2 Purpose of the Model

BESOM is a linear programming model that was developed for the quantitative evaluation of energy technologies and policies within a systems framework (Hoffman 1972). The model is designed to examine interfuel substitution within a framework of constraints on the availability of competing resources and technologies and their associated costs. BESOM can be used to develop an optimal energy system configuration for a single year. It may also be applied in a sequential manner for the examination of a planning horizon.

4.3.3 Description

BESOM is a static model that provides a "snapshot" of the energy system configuration at a single year in time. The model is structured around a special, highly detailed Reference Energy System (RES), which is a framework that depicts the flow of energy from resources to the point of actual end-use utilization (Hoffman 1972, Cherniavsky 1974). The RESs are a specialized format for representing the detailed technological structure of the energy system along with resource consumption and emissions. Each of the links that form the various supply trajectories of the RES have an associated technical efficiency and environmental emission coefficient. These coefficients are supplied endogenously, while future energy demands and costs are supplied exogenously for each scenario.

BESOM uses the technological and environmental coefficients and costs to focus on the technical, economic, and environmental characteristics of the energy conversion, delivery, and utilization processes that comprise the total energy system. A typical RES, reflecting the general characteristics of the Austrian energy system, is shown in Figure 37.

BESOM may be used in either an optimization mode or a simulation mode. When used in the optimization mode, BESOM calculates the optimal supply–demand configuration of the energy system under consideration, subject to exogenously specified constraints. These constraints usually include limits on the availability of various resources, the market penetrations of various technologies, and electrical generation balances and constraints.

The model may also be used as a simulation tool for analysis of total system costs and environmental impacts. This can be accomplished by constraining the model so that it duplicates the desired supply–demand system, and then using it to calculate the costs and impacts for that system. Within the simulation mode, BESOM can also be used to rank advanced supply or demand technologies in order from most attractive to least attractive. This is accomplished by forcing in small amounts of these technologies and analyzing the resulting marginal values in conjunction with the assumed prices. BESOM's important characteristics may be summarized as follows:

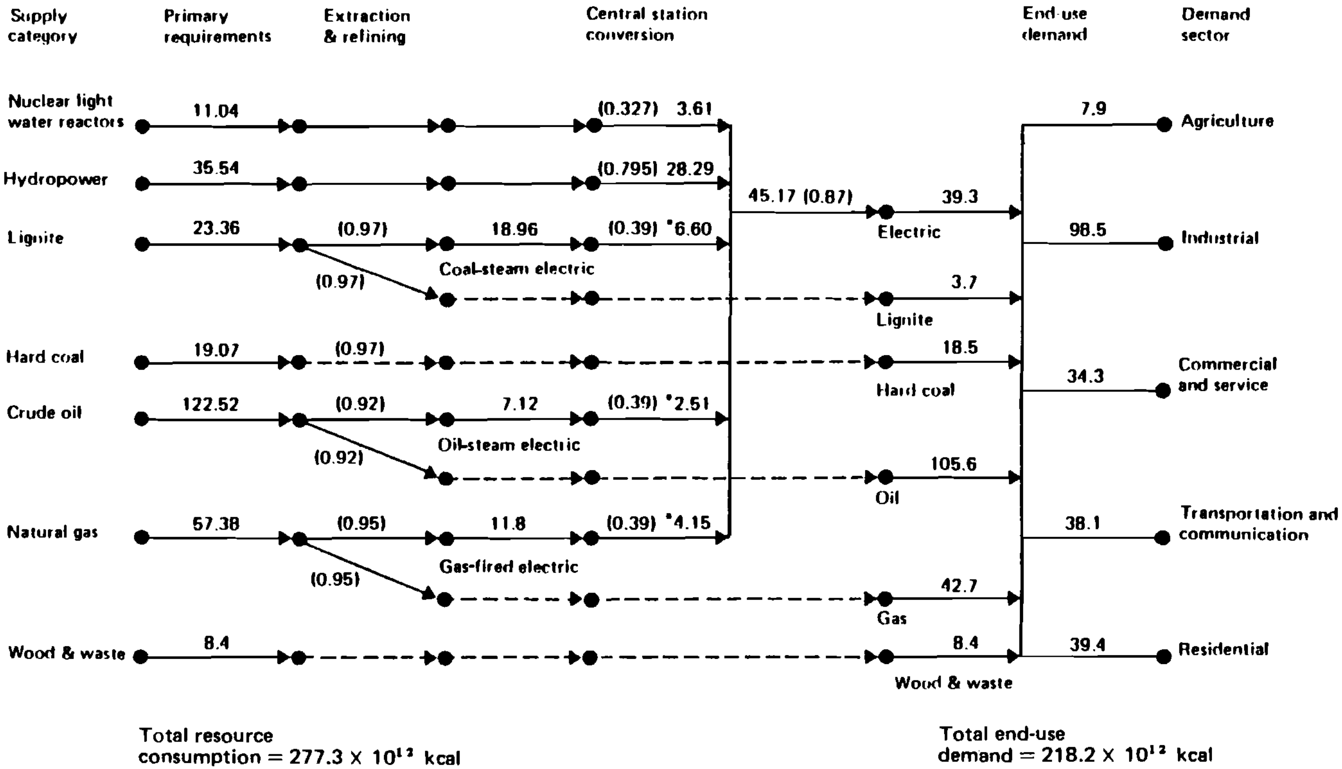

FIGURE 37 A simplified flow diagram of the Austrian reference energy system: Scenario S1, 1990. Energy flows are indicated in 10^{12} kcal. Conversion efficiencies are in parentheses. The 0.39 efficiency for central station conversion of lignite, crude oil, and natural gas refers only to power plants and to combined cycle plants.

(1) The model has a comprehensive structure capable of including numerous alternative energy resources and both electric and nonelectric energy demands.
(2) The model reflects a wide range of interfuel substitutability.
(3) Technical, economic, and environmental characteristics of both supply and utilization energy conversion devices are incorporated in the model.
(4) The load-duration characteristics of electrical demands are included in the model.
(5) The model is applicable to both regional and national energy planning.

The supply efficiencies in BESOM, which are used to relate intermediate energy forms to primary resources, include a refining efficiency, electric conversion efficiency, transmission and distribution efficiency, and a synthetic fuel manufacturing efficiency. The refining efficiency represents a combined extraction, cleaning, and transportation efficiency.

The costs considered in BESOM include plant capital costs, operational and maintenance costs, transmission and distribution costs, resource costs, and end-use device costs. The model calculates capital recovery costs for each individual electric supply category and end-use device. Environmental impacts are associated with each of the links that form the various fuel trajectories from primary resource supply to end-use. The environmental features of BESOM were not used in the IIASA regional studies.

BESOM's linear programming format lends itself to the investigation of alternative objective functions, such as minimizing total system costs, oil imports, capital requirements, environmental effects, and natural resource use. In addition, multi-objective analyses have been performed at Brookhaven National Laboratory, in which a number of these alternative objective functions were minimized to derive trade-off curves between competing objectives (Hoffman *et al.* 1976, Cherniavsky *et al.* 1977). The objective function used for the Austrian study was a minimization of total system costs.

A version of the Brookhaven Model, modified to reflect the specific characteristics and structure of the Austrian energy system, including appropriate technologies, coefficients, and costs, was adapted to the computer at IIASA. Several test cases were completed with BESOM on that system. At the present time, however, the cost of running BESOM on the IIASA computer system is extremely high due to certain model characteristics and machine conversion requirements. As a result, full implementation of BESOM on the IIASA computer system was not completed, and the BESOM computer runs for the Austrian Case Study were done at Brookhaven National Laboratory.

4.3.4 Input and Output

A BESOM run for a single year provides the following information about the energy system being examined:

(1) Activity levels for the intermediate energy forms associated with the reference energy system trajectories;
(2) Total resource use for each resource category and fuel type;
(3) The capacities and load factors for the electrical generating plants;
(4) Environmental effects, totaled over all supply–demand trajectories. These effects are expressed in various units of measurement, such as tons, acres, and curies;

(5) The shadow prices, or marginal values, of the variables and constraints;
(6) Total system cost associated with the optimal supply–demand configuration. If the objective function formulation is a minimization of total system costs, then this would also represent the optimal solution.

The results of a BESOM run, in reference energy system format, are shown in Figure 37. The energy flows, in units of 10^{12} kcal, are indicated above the individual energy trajectories in the diagram. Process efficiencies are indicated in parentheses.

4.3.5 Data Sources

Large amounts of data are required for BESOM, including detailed cost coefficients, efficiencies, technologies, and environmental coefficients. These data are crucially dependent on the country or region they are meant to define. The reference energy system, defined for a particular year, provides a common framework upon which a consistent and detailed set of coefficients can be based. A set of reference energy system projections have been made at Brookhaven National Laboratory (Cherniavsky *et al.* 1977). The results of BESOM's applications to the Austrian energy system can be found in Foell *et al.* (1979).

4.3.6 Concluding Comments

The Brookhaven model is designed to provide a unified framework for energy technology assessment and policy analysis. Within this context, the model emphasizes the technological details of energy supply and demand devices, including the load characteristics of the electric sector. In a general sense, the model has the capacity to incorporate technological, economic, and environmental considerations into technology assessment and policy analysis. The model is sufficiently general and offers enough flexibility to have widespread applications to both regional energy planning and energy system planning at the national level.

To date the use of BESOM in the IIASA studies has been limited in scope. Only one objective function was investigated, namely, minimized total system costs. Current research is being directed toward the use of multi-attribute objective functions that will aid the incorporation of a wider range of attributes in the formal analysis (see Chapter 6). At the University of Wisconsin–Madison, a multi-objective function is used in a dynamic programming approach to evaluate alternative gas supply options based upon synthetic fuels and liquefied natural gas (Peerenboom 1981). At the International Energy Agency, the MARKAL model is being applied to the assessment of specific R & D options in the end-use sectors in balance with supply technologies (Sailor and Roth-Nagle, in preparation).

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5 ENVIRONMENTAL MODELS

5.1 INTRODUCTION

The purpose of the environmental models is to calculate energy-related environmental impacts and environmental impact indicators. Environmental impacts are broadly defined as the effects of the energy system on land, air, water, structures, and living organisms, including humans.

Since the coordination of the entire energy system is needed to provide end-use energy, a *systemwide perspective* underlies the impact models. The energy system for which the environmental impacts are calculated encompasses the complete fuel chain for each type of energy consumed within a given region. The fuel chain consists of such steps as resource extraction, transportation, refining, conversion, and consumption at the point of end-use. The fuel chain is defined in terms of the "reference energy system" presented in the discussion of energy supply (see Chapter 4).

Impacts are tabulated at each point in the fuel chain, as indicated in Figure 38. These impacts represent the "final" effects of impact pathways. For instance, excess risk

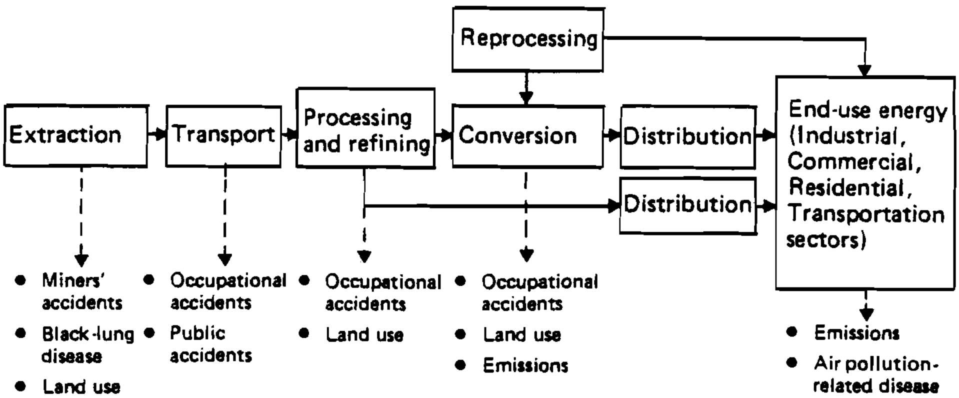

FIGURE 38 Typical environmental impacts associated with each point in the fuel chain.

of emphysema is considered to be the end result of pollution emissions, pollution transport, human exposure, and damage to health. Figure 39 shows several impact pathways associated with electricity generation, one type of conversion process included in the fuel chain. It should be noted that the impacts are expressed in varying units, such as fatalities, acres of land use, and quantities of radioactive waste. Value judgments have not been made to obtain a single figure of merit as output of the environmental models. However, this

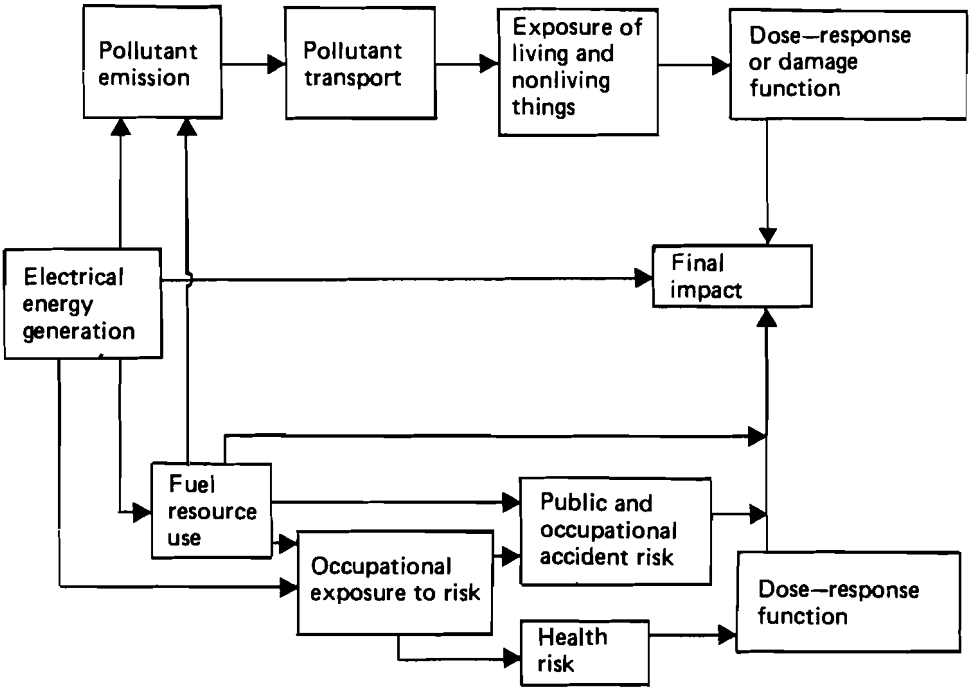

FIGURE 39 Impact pathways for electricity generation.

issue is addressed in Chapter 6, in the discussion of the application of multi-attribute utility theory.

The boundaries of the energy system have been defined to include only the fuel supply chain and end-use energy activities. Thus, impacts associated with coal mining are included, but not the impacts associated with the production of coal mining equipment. The fuel supply chain often contains steps that take place outside the study region – for instance, mining and transport of imported fuels. Therefore, environmental impacts associated with a region's energy use are disaggregated into a component occurring "inside" the region and a component occurring "outside" the region. This puts individual regional environmental impacts into the context of the energy system as a whole. This disaggregation has important policy implications, for it enables one to judge the extent to which a region is "exporting" energy-related environmental impacts or is burdened by impacts associated with energy resources ultimately consumed in other regions.

The impacts calculated by the environmental models are *quantified impacts* only. They do not represent all the impacts known to occur – e.g., they do not include unquantified impacts. Quantified environmental impacts are those for which an adequate scientific basis exists for evaluation and characterization in mathematical terms. Quantification allows a detailed examination of assumptions and results, and permits a direct association to be made between the energy system and environmental impacts. This provides a basis for policy analysis.

It must be stressed that the Wisconsin–IIASA set of environmental models is continually evolving. At the present time certain impact pathways have not been incorporated into the models. Of the pathways that are included, not all have been analyzed with comparable degrees of detail. The methodology discussed below does, however, provide a unified framework for organizing current and future research.

5.1.1 Character of the Models

The environmental models are of two basic types: aggregated or "reference system models" and disaggregated or "local system models." Reference system models focus on average or representative characteristics of the system under study. For example, they would make use of national averages to describe risks of industrial accidents in electricity power generating stations per unit of installed capacity, without specification of the site of the risk. Local system models may use a mixture of averages and localized information, but some spatial detail is always required. Reference system models and pure local system models represent the extremes; there is a continuum of models in between.

Utilization of a local versus a reference system model depends on the impact category under analysis and the associated policy issues in a given region. For example, if nuclear waste storage takes place outside a study region, it might be sufficient to consider only the average risk of accident and exposure. However, if the storage occurs inside the region, it would be important to consider the risk of accidents and exposure on a localized basis. Some impact pathways, such as exposure to air pollution from nonelectric sources, require a local system model. In no case should a model be more detailed than necessary to answer relevant policy questions. Often sufficient information for long-range policy-making purposes can be obtained using the reference system approach with little local detail.

Five models are included in the Wisconsin–IIASA set of environmental models. The *Reference Energy System Impact Model* calculates impacts associated with the fuel chain, including conversion of primary fuels to electricity. These impacts are not treated on a site-specific basis in the model. The *Air Pollution Dispersion Model*, a local system model, calculates the urban exposure to air pollutant species produced by combustion of fuels at the point of end-use. It requires a *Localization Model* to interface with the energy demand models, which do not produce output at a sufficient level of spatial disaggregation. The localization model distributes the emissions that result from energy consumption on a geographical basis, and thus permits the localization of air pollution impacts. The *SO_2 Health Impact Model* is used in combination with both the Reference Energy System Model and the Air Pollution Dispersion Model to calculate SO_2-related human health impacts for certain population groups. The *River Body Thermal Pollution Model* has been used to a limited extent to study the thermal effects of power plants on rivers. Each of these models is described in turn below.

5.2 THE REFERENCE ENERGY SYSTEM IMPACT MODEL

5.2.1 Purpose

The Reference Energy System Impact Model is designed to calculate quantified environmental impacts associated with the supply of primary energy, conversion of primary energy into secondary energy sources, and processing and reprocessing of fuels to meet the energy requirements of a given region. The term "reference energy system" indicates that the impacts are computed on an aggregate level for a region as a whole, without consideration of specific plants or supply networks at the local level.

The Reference Energy System Impact Model can simulate environmental impacts associated with alternative energy supply systems. For instance, it is possible to assess impacts that would result from alternative fuel mixes for generating electricity by comparing the output of model runs. The model can also be used to simulate effects of technological advances or legal measures designed to protect the environment. An earlier version of the model was developed at the University of Wisconsin–Madison to calculate systemwide impacts of electricity systems (Buehring 1975, Buehring and Foell 1976).

5.2.2 General Model Structure

The Reference Energy System Impact Model tabulates environmental impacts associated with each point in the fuel chain. The structure of the fuel chain is based on the reference energy system developed for the energy demand/supply balance model described in Chapter 4 (see Figure 33). The general framework of the impact model is shown in Figure 40.

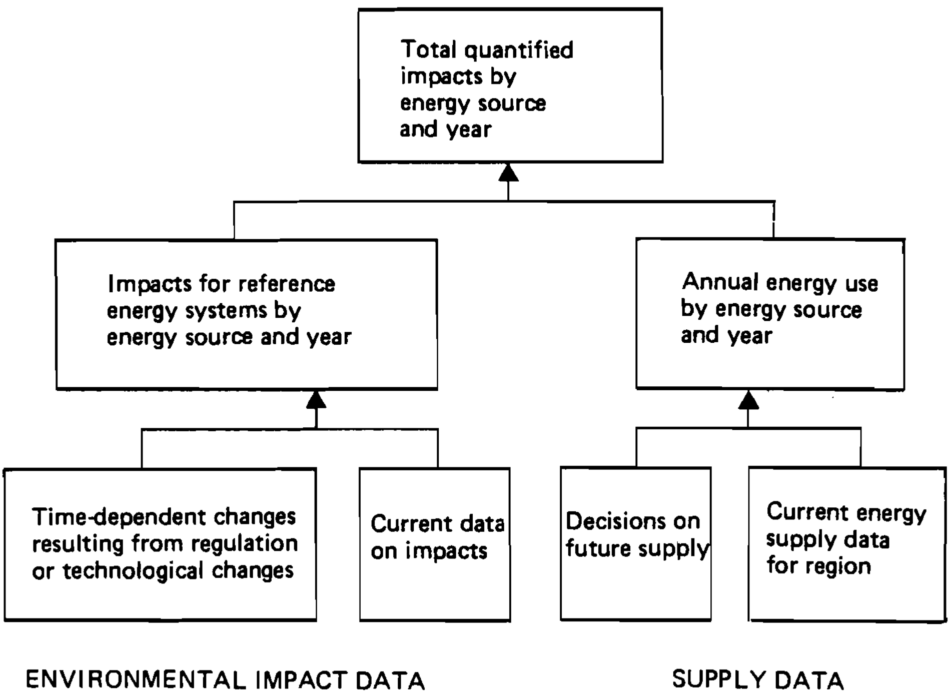

FIGURE 40 General structure of the Reference Energy System Impact Model.

The input required for the Reference Energy System Impact Model is the year and the quantity of energy required by type of fuel. It is also possible for the user to change the numerous parameters built into the model that define the characteristics of the reference energy systems for each fuel. The output from the model is quantified environmental effects that result from the energy use and the supporting fuel system activities along the fuel chains. As the flow diagram in Figure 40 indicates, the fuel supply data for each year of computer simulation are combined with impacts associated with reference energy systems to obtain total quantified impacts by fuel type and year.

5.2.3 Specification of Impacts

Impacts are calculated in this model by means of "impact factors," which have been derived through analysis of available data in the literature. The factors are specified in the model as a function of energy, e.g., kilowatt-hours (kWh), or in some cases, electrical capacity (kW). As a simple example of one of the numerous impact factors associated with the reference energy system for coal, an employee fatality rate of 4.1×10^{-12} per kWh – deduced from historical occupational accident statistics – was set for coal-fired power plants in Wisconsin. More than 60 impact factors have been associated with the coal fuel cycle (Buehring 1975). Each of the factors can be modified during a simulation run, in order to reflect such measures as occupational safety standards or lowering of emission standards.

The total annual quantified impacts associated with a particular reference energy system are calculated by multiplying the matrix of impact factors for a particular year and a particular energy source by the use of that source. The following equation describes this operation:

$$Q_{ijk} = E_{jk} * I_{ijk} \qquad i = 1, 2, \ldots, n \tag{5.1}$$

where Q_{ijk} is equal to the quantified environmental impacts of type i in year j resulting from energy source k, E_{jk} is the quantity of energy source k used in year j, and I_{ijk} is the 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 or over index k to obtain totals for all energy sources in a particular year.

5.2.4 Time-dependency of the Impact Factors

The impact factors that have been deduced from the existing literature and historical statistics most likely will not remain constant in the future. For instance, the enforcement of legislation concerning environmental protection or safety at the workplace may be expected to lower the values of the impact factors. Because the Reference Energy System Impact Model is concerned with the future evolution of energy systems, in addition to their present structure, it was necessary to construct the model to allow for such time-dependent changes in impact factors.

As one example, underground coal miners face the well-known health hazard of black-lung disease (technically named coal workers' pneumoconiosis). A certain fraction of underground coal miners became disabled in 1970 because of this disease. If their disability rate is related to coal production over a period of time, a certain quantity of coal miners' disability can be associated with each unit of coal obtained by underground mining. However, the disability rate should diminish as new standards become operative and new miners join the work force. Therefore, it was necessary to incorporate into the model a coal workers' pneumoconiosis factor that decreases as a factor of time. Estimates of this factor were deduced from available data and statements of experts (Buehring 1975). Nearly every impact factor is a direct function of time or is affected by other impact factors that vary with time, e.g., a change in overall power plant efficiency affects all impact factors because of the change in output from the same fuel input. Similarly, addition of a cooling tower to a reference power plant with once-through cooling would change all the impact factors associated with the plant.

Another aspect of the time-dependency of impacts is the fact that there may be a time lag between the occurrence of impacts at some point along the fuel chain and final use of the fuel. For instance, several years may elapse between mining of coal and its combustion in an electricity generation plant or a home furnace. Also, the health impacts of some processes along a fuel chain may be insidious – coal workers' pneumoconiosis may manifest itself years after a worker has left his job. This problem is handled in the model by assigning all impacts associated with the fuel cycle of a particular energy source to the year in which the energy is used. A mathematical expression that describes the impacts at time t_1 because of energy use at time t is

$$q(t) = e(t)\int_{t_1} c(t,t_1)\,\mathrm{d}t_1 \qquad (5.2)$$

where $q(t)$ are the quantified environmental impacts associated with energy use at time t, $e(t)$ is energy use at time t, and $c(t,t_1)$ are impacts that occur at time t_1 per unit of energy use at time t. Because the impacts are associated with the final *use* of energy, the actual time at which they occur or are manifested is not specified in the model.

5.2.5 Specification of the Reference Energy Systems

In the present version of the Reference Energy System Impact Model, the most intensive effort has been given to the modeling of the reference coal and nuclear systems. Generally stated, the environmental impact characteristics of each reference energy system are specified by means of a set of parameters describing the features of the energy system in the region under study. Definition of these parameters is a critical step in the modeling procedure, for they determine the magnitude of system-related environmental impacts. For instance, in the coal reference system the values of such parameters as the distance over which coal is transported and the sulfur content of coal have direct importance for health and the environment; the number of transport-related accidents is dependent on distances traveled, and the quantity of emissions is proportional to the chemical composition of the fuel.

Although there is not sufficient space here to provide an example of a complete parameter-listing, Table 10 and Table 11 indicate some of the important initial conditions in the reference coal and nuclear energy systems developed for Austria.

An important aspect of the model is the user's ability to simulate changes in the energy system over time by redefining critical parameters. For instance, in the coal system,

TABLE 10 Initial (1975) conditions of the reference coal system defined for the Austrian Case Study.

	Parameter values	
Parameters	Hard coal	Lignite
Fraction of coal used in Austria	0.52	0.42
Total heat content per unit mass (kcal/kg)	7,000	3,500
Sulfur content (weight percent)	0.5	1.0
Ash content (weight percent)	10.0	10.0
Source of coal	Outside Austria	Inside and outside Austria
Percent surface-mined	30	28
Coal mining fatalities per 10^6 metric tons mined		
Underground	0.7	0.7
Surface	0.19	0.19
Cases of disabling black-lung disease per 10^6 tons mined underground	3.0	3.0

TABLE 11 Initial conditions of the reference nuclear energy system defined for the Austrian Case Study.[a]

Parameters	Parameter values
Uranium mining fatalities per 10^3 metric tons U_3O_8	
Underground mining	0.79
Surface mining	0.25
Land disturbed for surface mining of uranium (m^2/metric tons of ore)	0.75
Source of uranium	Outside region
U^{235} content in enrichment tailings	0.25 percent
Uranium recycle	Yes
Plutonium recycle	No
Fresh fuel enrichment (percent U^{235})	3.3
Spent fuel enrichment (percent U^{235})	0.89
Tritium in spent fuel	0.021 curies (Ci) per MWd (megawatt-day of thermal energy)
Kr^{85} in spent fuel	0.34 curies (Ci) per MWd
Noble gas release at reactor	0.45 μCi/kWh[b]
Tritium release at reactor	0.045 μCi/kWh
Occupational radiation exposure at reactor	450 person-rem per 10^3 MWe-year[c]

[a]Because Austria does not yet have a nuclear power plant in operation, most of the reference system characteristics were adopted from an American system.
[b]μCi = 10^{-6} Ci.
[c]A person-rem is a measure of population exposure to radiation. One person exposed to one rem and one million people exposed to 10^{-6} rem are both equivalent to one person-rem.

enforcement of occupational safety standards in the future could be taken into account by decreasing the coal mining fatalities per tons mined as a function of time.

Redefinition of such parameters is always the main task of an investigator who wishes to apply the model to new regions. The original version of the model was developed for the state of Wisconsin in the USA. To date the model has been reparameterized for the Rhône-Alpes region of France, the German Democratic Republic, and Austria (Foell 1979) and work is under way for Mexico (Peerenboom *et al.* 1980). To a great degree the success of a model transfer depends on the investigator's ability to gather sufficient data to accurately define the initial conditions of the energy system in the study region, and to develop insight into the probable evolution of the system.

5.2.6 Examples of Output from the Reference Energy System Impact Model

Table 12 provides a detailed listing of the results of a model run for the Austrian Case Study. The impacts are associated with the production of 3.2×10^9 kWh of electricity at coal-fired utility plants under current system conditions. It should be noted that in this sample of output the impacts do not refer to the entire reference coal system, i.e., do not include impacts associated with the use of coal for purposes other than generating electricity.

TABLE 12 Quantified impacts associated with the production of 3.2×10^9 kWh of electricity in a coal-fired power plant, under current reference energy system conditions in Austria.

Impact	Unit	Quantity
Fuel resource, Efficiency, and Solid waste		
1 Coal requirement after cleaning losses	Tons	.305 + 07
2 Transportation and handling loss of coal	Tons	.305 + 05
3 Coal plant thermal discharge to water	kWh (t)	.572 + 10
4 Coal plant thermal discharge to air	kWh (t)	.111 + 10
5 Total train-miles for coal shipments	Miles	.134 + 05
6 Input energy required throughout coal fuel system	kWh (t)	.101 + 11
7 Ash collected at coal power plant	Tons	.296 + 06
8 Sulfur retained at coal power plant	Tons	000
9 Limestone mined for sulfur removal	Tons	000
10 Coal cleaning plant solid waste	Tons	.101 + 07
Land use		
11 Land disturbed for surface mining of coal	Acres	.257 + 03
12 Land disturbed for coal surface mining – not reclaimed	Acres	.257 + 02
13 Land subsidence from underground coal mining	Acres	.439 + 03
14 Land for ash disposal at power plant	Acres	.640 + 01
15 Land for sulfur sludge disposal at power plant	Acres	000
16 Land for disposal of solid waste from underground mining	Acres	.194 + 01
17 Land for disposal of solid waste from cleaning	Acres	.864 + 01
18 Waste storage area for coal fuel cycle	Acres	.170 + 02
19 Land use at plant and fuel cycle facilities – coal	Acres	.967 + 03
Impacts on water		
20 Acid mine drainage from coal mining (mostly water)	Tons	.212 + 06
21 Sulfuric acid in coal mine drainage	Tons	.148 + 04

TABLE 12 *Continued.*

Impact	Unit	Quantity
22 Dissolved iron in coal mine drainage	Tons	.370 + 03
23 Siltation from surface mining	Tons	.184 + 04
24 Coal cleaning plant blackwater solids	Tons	.102 + 04
Impacts on air		
25 Flyash emission at coal power plant	Tons	.616 + 04
26 Sulfur dioxide emission at coal power plant	Tons	.305 + 05
27 Nitrogen oxides (NO_X) emission at coal power plant	Tons	.120 + 05
28 Carbon dioxide emission at coal power plant	Tons	.342 + 07
29 Carbon monoxide emission at coal power plant	Tons	.531 + 03
30 Hydrocarbon emission at coal power plant	Tons	.171 + 03
31 Aldehyde emission at coal power plant	Tons	.342 + 01
32 Mercury emission at coal power plant	Tons	.604 + 01
33 Beryllium emission at coal power plant	Tons	.247 + 00
34 Arsenic emission at coal power plant	Tons	.616 + 00
35 Cadmium emission at coal power plant	Tons	.616 − 02
36 Lead emission at coal power plant	Tons	.111 + 01
37 Nickel emission at coal power plant	Tons	.247 + 01
38 Vanadium emission at coal power plant	Tons	.203 + 01
39 Uranium (U-238) or Ra-226 emission at coal power plant	Curies	.555 − 01
40 Thorium (Th-232) or Ra-228 emission at coal power plant	Curies	.125 − 01
41 Coal cleaning plant dust emission	Tons	.102 − 01
Health impacts		
42 Coal mine accidents – fatalities	Deaths	.260 + 01
43 Coal mine accidents – nonfatal injuries	NFI	.816 + 03
44 Coal mine accidents – severity in person-days-lost	PDL	.571 + 06
45 Coal cleaning plant occupational fatalities	Deaths	.457 − 01
46 Coal cleaning plant occupational nonfatal injuries	NFI	.427 + 01
47 Coal cleaning plant occupational severity	PDL	.445 + 03
48 Coal transportation accidents – occupational fatalities	Deaths	.430 − 02
49 Coal transportation accidents – occupational nonfatal injuries	NFI	.430 + 00
50 Coal transportation accidents – occupational severity	PDL	.391 + 02
51 Coal transportation accidents – public fatalities	Deaths	.497 − 01
52 Coal transportation accidents – public nonfatal injuries	NFI	.128 + 00
53 Coal transportation accidents – public severity	PDL	.324 + 03
54 Coal power plant accidents – occupational fatalities	Deaths	.131 − 01
55 Coal power plant accidents – occupational nonfatal injuries	NFI	.576 + 00
56 Coal power plant accidents – occupational severity	PDL	.119 + 03
57 Cases of total disability from black-lung disease	Cases	.659 + 01
58 Cases of simple black-lung disease (some disability)	Cases	.144 + 02
59 Public fatalities from acute SO_2 exposure	Deaths	000
60 Days of aggravation of heart and lung disease from SO_2	Days	.102 + 04
61 Excess asthma attacks from acute SO_2 exposure	Attacks	.260 + 03
62 Total occupational fatalities, health and accident, for coal	Deaths	.925 + 01
63 Total occupational nonfatal injuries for coal	NFI	.836 + 03
64 Total occupational severity for coal	PDL	.972 + 05
65 Total deaths in coal fuel cycle – annual	Deaths	.930 + 01
66 Total nonfatal injuries in coal fuel cycle – annual	NFI	.212 + 04
67 Total person-days lost in coal fuel cycle – annual	PDL	.988 + 05

NOTES: NFI stands for nonfatal injury, PDL are person-days-lost, and .305 + 07 means 0.305×10^7.

Table 13 shows, in highly aggregated form, selected quantified impacts associated with the total petroleum energy system in Austria for the year 1971. The format in which these data are presented permits comparison of the impacts associated with electric versus nonelectric components of the energy system, as well as the type and quantity of impacts occurring inside and outside the region. One may note that the health impact associated with the nonelectric component of energy use is many times greater than that for the electric component. Also, about half of the 'electric' health impacts affect people living outside the region under study.

TABLE 13 Selected quantified impacts associated with the petroleum energy system for 1971, Austrian Case Study.

	Nonelectric			Electric		
Impact	Inside	Outside	Total	Inside	Outside	Total
Deaths	0.9	1.0	1.8	0.1	0.2	0.3
Occupational accidents (10^3 PDL)	8.7	9.5	18.3	0.7	1.8	2.5
Public accidents (10^3 PDL)	0.0	0.0	0.0	0.0	0.0	0.0
Occupational disease (10^3 PDL)	0.0	0.0	0.0	0.0	0.0	0.0
Public disease (10^3 PDL)	75.0	0.0	75.0	2.2	0.0	2.2
Total nonfatal health and safety impacts (10^3 PDL)	83.7	9.5	93.3	3.0	1.8	4.7
Extraction land use (km^2)	1.2	2.3	3.5	0.0	0.4	0.4
Facility land use (km^2)	0.6	1.2	1.8	2.7	0.2	3.0
Total land use (km^2)	1.8	3.6	5.3	2.7	0.7	3.4
SO_2 emissions (10^3 tons)	163.0	0.0	163.0	53.3	0.0	53.3

NOTES: "Inside" means inside Austria, and "outside" means outside Austria. "PDL" means person-days-lost. Rows and columns may not add up because of rounding.

5.3 THE AIR POLLUTION DISPERSION MODEL

5.3.1 Purpose

The purpose of the Air Pollution Dispersion Model is to describe the air pollution impact pathway, beginning with emissions, continuing through air pollution transport (dispersion), and ending with air pollution exposure. Using air pollution emissions as an input, the model calculates spatially-averaged annual ground-level concentrations (i.e., exposure).

The dispersion calculations in the model are based on a "smeared concentration approximation" method (Dennis 1978, 1980). This method describes air pollution dispersion on an urban scale with minimum data requirements and without the direct use of complex and large air pollution dispersion models. The method is designed for use in scenario analysis.

5.3.2 General Features of the Model

The focus of the model is on urban areas. It calculates urban ground-level air pollution concentrations and then adds them to a rural background pollution concentration.

Air pollution concentrations are much larger in urban areas than in rural areas. It is thus to be expected that air pollution-related health impacts are greatest in urban areas.

The basic assumption underlying the model is that the mobility of the population is high relative to the spatial variation of ground-level pollution concentrations. It follows from this assumption that an annual average ground-level concentration averaged spatially over the entire urban area is a sufficiently precise indicator of air pollution exposure for impact analysis. In the model the spatially-averaged annual ground-level concentration represents the collective annual exposure to the urban area -- or, in terms of health, it represents the average annual exposure to air pollution that an average person receives in the urban area (the "self-imposed" exposure). A single annual exposure value is associated with each urban area, as depicted in Figure 41.

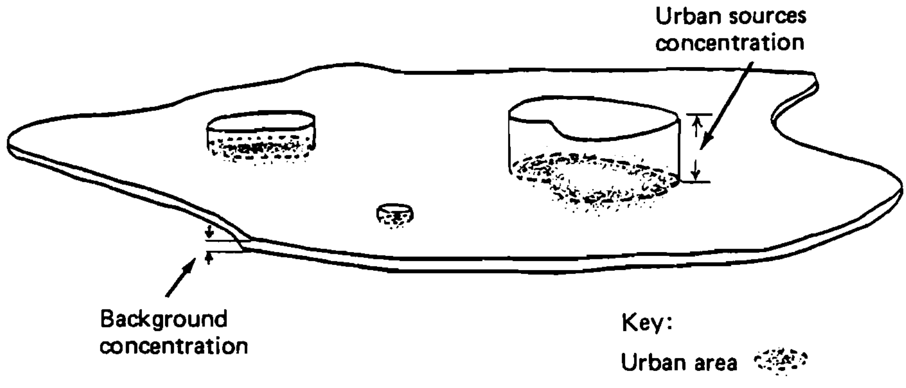

FIGURE 41 A schematic view of the smeared urban pollution concentration added to a flat rural background concentration.

The spatially-averaged annual ground-level concentration, normalized by the total annual emissions from the urban area, is defined as the Smeared Concentration Approximation (SCA) Dispersion Parameter D; it is expressed in microgram/m^3/ton/yr emitted. The essential features of air pollution dispersion are described by defining an SCA Dispersion Parameter for each of three classes of emission sources:

D_1: Class 1 (low-level) sources, e.g., those associated with space heating and transportation.
D_2: Class 2 (medium-level) sources, e.g., industry.
D_3: Class 3 (high-level) sources, e.g., power plants.

Each of the three SCA Dispersion Parameters is a function of a set of parameters that are defined with respect to wind speed, atmospheric stability, and average urban radius. Differences in dispersion in different parts of a region, due to geography or weather patterns, are thus accounted for in the SCA Dispersion Parameter. The SCA Dispersion Parameters can be defined for reference systems or for local systems.

The primary variable that determines the value of the *D*s is the size of the urban or metropolitan area. It is sufficient to use an average radius, which can be obtained from the area or average density of cities. The dispersion parameters are thus greatly influenced by the urban patterns of the region under study.

5.3.3 Model Description

Annual air pollution emissions, disaggregated into rural emissions and urban emissions, are needed as input to the model. The urban emissions must be further specified by class of emission source and localized to cities or city size classes. This site-specific disaggregation of the emissions is calculated by the Localization Model, which will be described in Section 5.4.

For each city the air pollution dispersion model first calculates the annual "self-imposed" urban exposure. The annual rural background concentration is then calculated and added to the self-imposed urban dose to obtain the total annual exposure for the population of the city.

The calculation of the self-imposed urban exposure *UC* is shown schematically in Figure 42. UC_j, the self-imposed urban exposure associated with city j, is calculated for the urban emissions UE_{ij} in each emission class and then summed, i.e.,

$$UC_j = \sum_i D_i(R_j) \times UE_{ij} \tag{5.3}$$

where i is the emission source class and R is the average radius of city j in km.

The SCA Dispersion Parameter $D_i(R)$ is a composite of the set of SCA Dispersion Parameters $D_{ikm}(R)$ which describe wind speed m and atmospheric stability k. The form of D_{ikm} is

$$\ln D_{ikm}(R) = \mathrm{S_{ikm}} + \mathrm{T_{ikm}} \times (\ln R) + \mathrm{V_{ikm}} \times (\ln R)^2 \tag{5.4}$$

where R is the urban radius in km, and $\mathrm{S_{ikm}}$, $\mathrm{T_{ikm}}$, and $\mathrm{V_{ikm}}$ are meteorological constants for each emission class.

Each D_{ikm} is multiplied by the frequency of occurrence of each combination of wind speed m and atmospheric stability class k and combined as a function of R to form the SCA Dispersion Parameter $D_i(R)$. The form of $D_i(R)$ is the same as Eq. (5.4). One set of meteorological statistics is considered sufficient for each mesoscale weather area. D_i is assumed to remain constant over time, i.e., climate is not assumed to change.

The SCA Dispersion Parameter $D_i(R)$ does not depend on the location of the emissions within an urban area, only on the total quantities of emissions. This greatly simplifies data needs. The dispersion parameter does, however, strongly depend on the average radius R of city j. It is important to model the radius of the urban area because the radius may

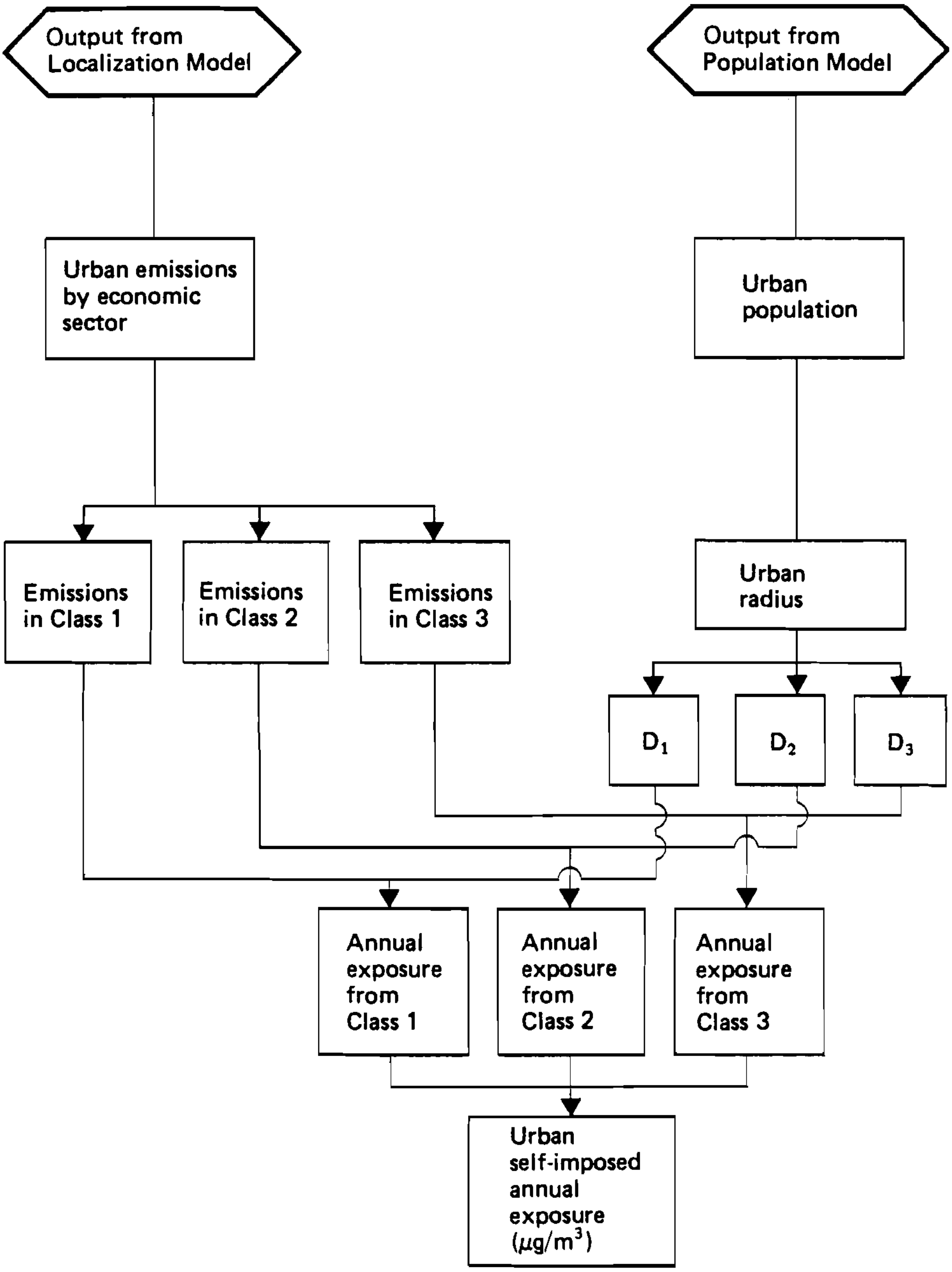

FIGURE 42 Calculation of the "self-imposed" exposure for an urban area.

change as the population grows or declines. A negative exponential model of urban population distributions is used to parameterize the urban area in terms of its population (Bussiere 1972):

$$\text{Urban Area} = q \times \text{Population}^{-0.88} \tag{5.5}$$

The coefficient q is defined for every city on the basis of historical data and is assumed to remain constant over time (Tobler 1976). For example, q is equal to 0.00205 for a city with a population of 203,000 and an area of 96 km^2. The urban radius is then defined on the basis of the urban area.

As the population changes in each city (see the discussion of the Population Model in Section 2.2), the urban area is assumed to change in accordance with Eq. (5.5). Each year the new area is calculated for each city, leading to a new set of SCA Dispersion Parameters. The dispersion parameters thus dynamically follow the change in population and urban patterns. The annual exposure calculated for a city is a function of both the emissions and the urban form.

The total annual urban exposure C_j is calculated by adding the background concentration B to UC_j, i.e.,

$$C_j = UC_j + B \tag{5.6}$$

The background concentration is calculated on the basis of total emissions, as shown in Figure 43. Given an initial value for B at time $t = 0(t_0)$, the background concentration at time t is calculated as

$$B(t) = B(t_0) \frac{eE_1(t) + fE_2(t) + gE_3(t)}{eE_1(t_0) + fE_2(t_0) + gE_3(t_0)} \tag{5.7}$$

where $E_1(t_0)$, $E_2(t_0)$, and $E_3(t_0)$ are the total annual emissions in each emission source class at $t = 0$, and the constants e, f, and g represent the relative impact of each emission source class on the background concentration. The initial value $B(t_0)$ must be obtained from empirical data or from an estimate based on other information.

5.3.4 Examples of Input and Output

The constants listed below are defined on the basis of empirical data for the study regions. These constants define the physical system and are input as fixed data into the model:

- q_j for each city or city category (based on city area);
- S_{ikl}, T_{ikl}, and V_{ikl} (based on regional meteorological statistics), used for defining $D_i(R)$; and
- e, f, and g, used for calculating the background air pollution concentration (assumed to be the same in all regions).

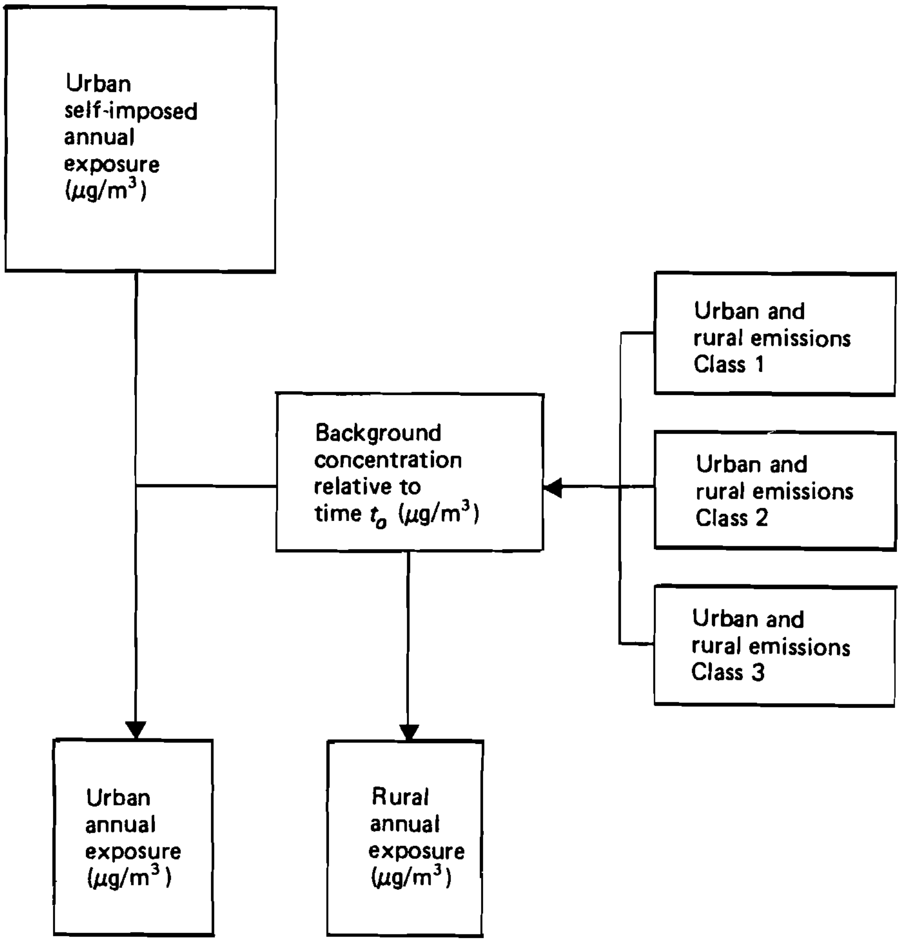

FIGURE 43 Calculation of total air pollution exposure.

Figure 44 shows the values of $D_1(R), D_2(R)$, and $D_3(R)$, calculated on the basis of annual meteorological statistics for Vienna, Austria.

Other model inputs include air pollution emissions from the Localization Model (see Section 5.4) and the Transportation Models (see Section 3.4) and the localized urban and rural population provided by the Population Model (see Section 2.2). It is desirable to have Class 1 and Class 2 emissions disaggregated by economic sector. Some economic sectors may have emissions in more than one emission class – e.g., in the residential sector, both district heat (Class 2 sources) and individual gas furnaces (Class 1 sources) are used for space heating.

Model outputs are localized emissions, annual exposure in cities and city categories by economic sector, and annual rural exposure. The annual exposure output serves as

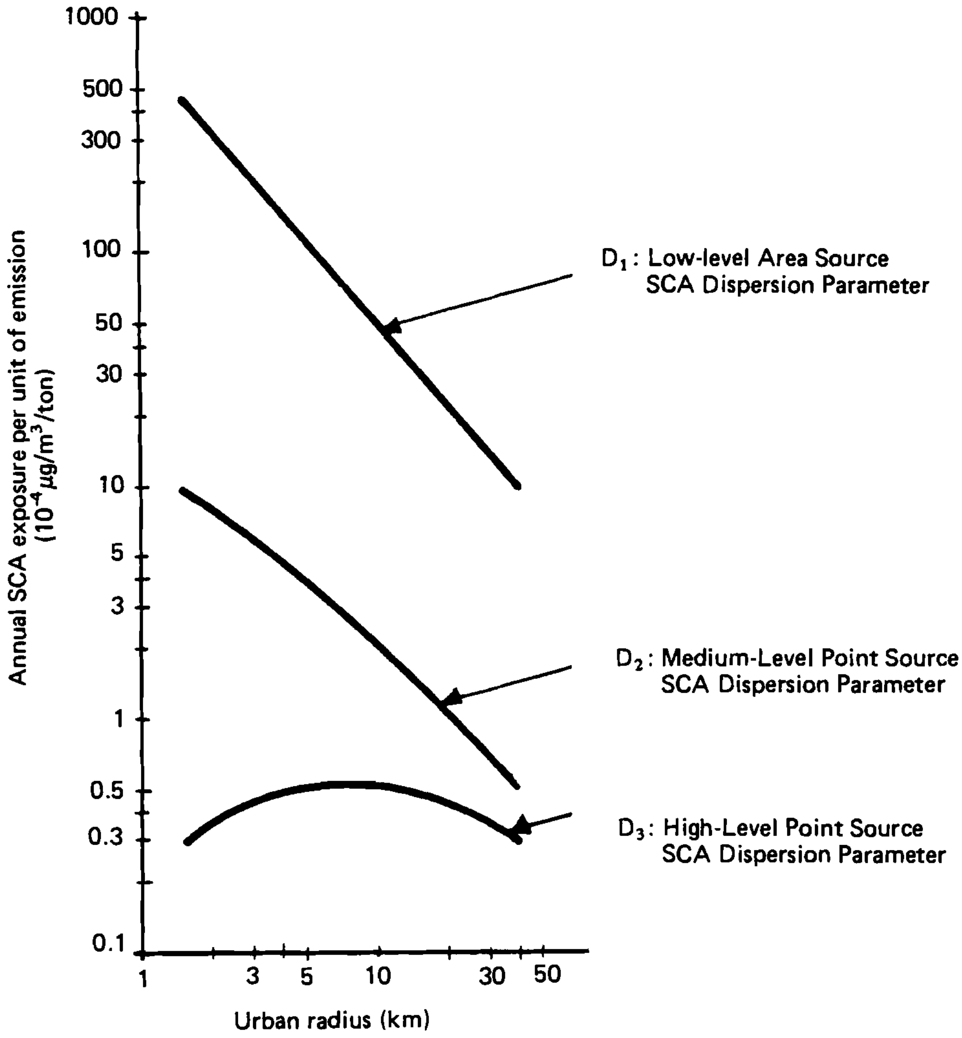

FIGURE 44 SCA Dispersion Parameters $D_1(R)$, $D_2(R)$, and $D_3(R)$, calculated using the meteorological statistics for Vienna, Austria.

input for the SO_2 Health Impact Model discussed in Section 5.5. Table 14 gives examples of both model input, i.e., emissions for the year 1970, and output, i.e., annual exposure to SO_2 pollution, for three cities: Milwaukee (Wisconsin), Vienna (Austria), and the "main city" of Bezirk X (a composite district in the German Democratic Republic).

TABLE 14 Examples of input (SO_2 emissions) and output (annual exposure) of the Air Pollution Dispersion Model, by sector, for three cities: Milwaukee, Wisconsin, USA (population – 1,320,000; "radius" – 13.6 km), Vienna, Austria (population – 1,610,000, "radius" – 11.5 km), and "Main City," Bezirk X, GDR (population – 540,000, "radius" – 6 km).

	Milwaukee, Wisconsin		Vienna, Austria		Main City, Bezirk X	
Sector	SO_2 emissions[a] (tons)	Annual exposure ($\mu g/m^3$)	SO_2 emissions[a] (tons)	Annual exposure ($\mu g/m^3$)	SO_2 emissions[a] (tons)	Annual exposure ($\mu g/m^3$)
Residential	7,300	15.3	8,200	32.6	13,200	98.2
Commercial/Service	9,600	20.2	8,500	33.7	4,900	36.5
Transportation	740	1.6	640	2.5	100	0.7
District heat	0	0	0	0	16,700	6.7
Industry	21,400	4.6	24,800	6.7	25,100	10.0
Electricity	139,800	1.7	14,300	0.2	12,000	0.6
Estimated background concentration		4.0		2.0		5.0
TOTAL	178,840	47.4		77.7		157.7

[a]The emissions are results of the Localization Model (see Section 5.4) and the Transportation Models (see Section 3.4) for 1970.

5.3.5 Concluding Comments

Two approaches were used to calculate air pollution dispersion in the four regional case studies. Dispersion associated with emission Classes 1 and 2 (i.e., emissions from low- and medium- level sources) (see Section 5.3.2) was calculated with the Air Pollution Dispersion Model described above. The dispersion of Class 3 emissions, i.e., emissions from electricity generating plants, was assessed with the Reference System Impact Model discussed in Section 5.2. Because the impacts associated with Class 3 emissions were only 1 to 2 percent of the total pollution-related impacts for Austria and only 5 to 10 percent in the case of Wisconsin, the Reference System Model was considered adequate for handling this class of emissions. If impacts such as damage to vegetation had been quantified in the models, a different approach might have been chosen. But for the type of long-range analysis performed in the energy/environment case studies, joint use of the Dispersion Model and the Reference Energy System Impact Model proved to be satisfactory.

The calculation of annual exposure based on self-exposure at the urban scale must be treated carefully in cases where the damage-inducing agent is not the primary pollutant emitted. Examples are sulfates and aerosols. For these cases, long-range transport on the scale of hundreds of kilometers may need to be included in the model. For nonreacting species, this does not seem to be necessary.

In the approach described above only the largest cities are modeled explicitly; smaller cities are modeled on an aggregate basis. This leads to an underestimation of the total exposure calculated for an average aggregate city. The degree of underestimation is related to the standard deviation of the population densities of the cities that are aggregated.

5.4 THE LOCALIZATION MODEL

5.4.1 Purpose

The Localization Model allocates sectoral energy use and air pollution emissions for input to the location-specific Air Pollution Dispersion Model (see Section 5.3). This requires specification of the location of energy demand and/or supply in the study regions.

With the exception of the transportation model, which requires detailed data to establish travel patterns, none of the energy demand and supply models described in this report are location-specific. Thus the Localization Model must provide a link between these models and the local system impact models. The degree to which the urban population must be localized for input to the Air Pollution Dispersion Model is very close to that required by the Personal Transportation Model. The Dispersion Model requires somewhat more disaggregation, but the framework is similar.

5.4.2 Model Description

The Localization Model constructed for Austria will be described here, because it contains all of the features of the Localization Models used in the other three case studies, as well as a few special features.

The localization framework must be developed with the entire modeling effort in mind, because it is needed for purposes other than just the environmental impact calculations. The spatial organization of the demographic data is used to define the localization framework. The disaggregation of demographic data on the basis of functional urban regions (see Section 2.2) has been found to accord with the input requirements of the diverse models used in the case studies. Functional urban regions consist of a core city and one or more rings of surrounding territory that are economically linked to the urban core (Sherrill 1976). As shown diagramatically in Figure 45, two rings were defined in the Austrian Case Study, on the basis of work-force commuting data: an inner ring ($> 15\%$ of work force commuting to the urban core) and an outer ring ($< 15\%$ of work force commuting to the urban core).

Thirteen urban cores, each with two urban rings, were defined for Austria. The population for each ring was aggregated into three groups: (1) the population of the largest town in each of the counties comprising the urban rings; (2) the population of all the smaller towns and villages; and (3) the rural population. Each core city was treated individually, and the rest of the cities and towns were treated on an aggregate basis. This framework was constructed so that the functional regions could be disaggregated and reaggregated into political regions for policy analysis purposes.

In the Austrian Case Study energy use and air pollution emissions were thus allocated to 91 categories [13 urban cores + (13 functional urban regions $\times$ 2 urban rings $\times$ 3 population groups)] for each end-use demand model. This allocation was carried out for the residential, the industrial, and the commercial/service sectors by the Localization Model. The output of the Transportation Model was available at the required level of spatial disaggregation.

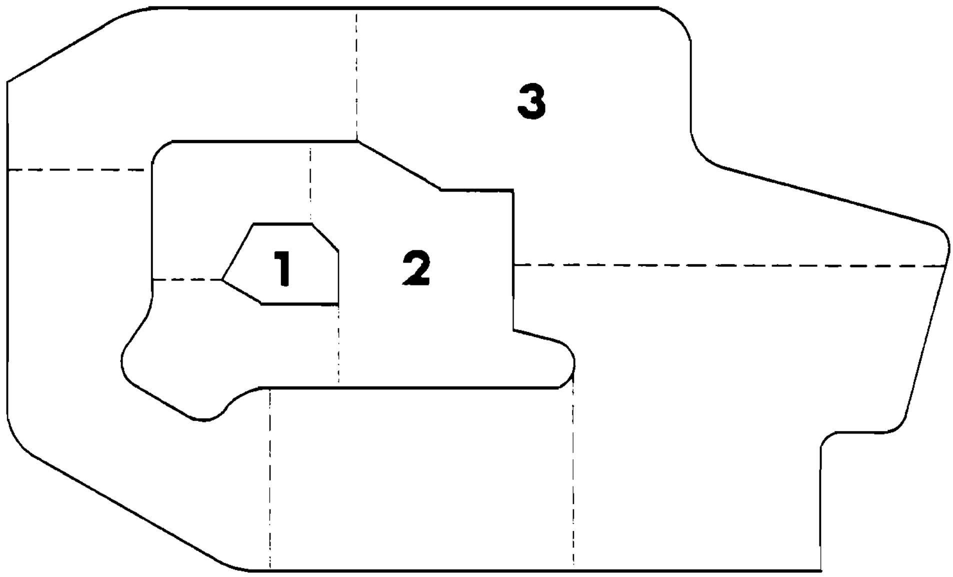

FIGURE 45 A representative functional urban region as defined for the Austrian Case Study. Area 1 is the urban core, Area 2 is the inner urban ring, and Area 3 is the outer urban ring.

Localization in the Residential Sector

Allocation of the residential sector's energy demand and air pollution emissions to functional urban regions in Austria was straightforward. Homogeneity was assumed for housing characteristics within each Austrian province. For each province

$$\text{Residential energy}_{ijm} = (\text{Housing unit type}_k)_{ij}/\text{Total housing units}_k \times \text{Energy}_m \quad (5.8)$$

where $k = 1$ is urban apartment, $k = 2$ is urban single-family home, $k = 3$ is rural apartment, $k = 4$ is rural single-family home, i is the core name, $j = 1$ is the urban core, $j = 2$ is the inner urban ring, $j = 3$ is the outer urban ring, and m is fuel type.

Emissions were localized on the same basis as energy. District heat was treated as a special case, for it was allowed only for urban apartments. Solar space heat was also restricted, primarily to rural single-family homes.

Localization in the Industrial and Commercial/Service Sectors

The activity of the industrial and commercial/service sectors is not distributed within a region in the same manner as the population. Work force is an appropriate basis for localization in these sectors. Since individual subsectors differ in their energy use and air pollution emissions, each subsector should be treated individually.

The population projections for Austria take into account historical trends in local population in- and out-migration. To be consistent, it was important that the local projections of work force for Austria also took migration into consideration. In the Localization Model for the Austrian industrial and commercial/service sectors, the labor demand associated with each economic sector was simulated on the basis of annual growth in economic activity, taking into account changes in labor productivity. Then the model was used to localize the labor demand on the basis of historical trends in local labor migration for each subsector. Homogeneity of energy use per worker within each economic branch was assumed.

The total labor demand (workers W) for each economic sector k may be expressed as

$$\text{Labor demand, } W_k(t+1) = VA_k/\text{Productivity}_k(t+1) \quad (5.9)$$

where VA_k is value added in sector k, Productivity $(t + 1)$ = Productivity $(t) \times (1 + PGR(t + 1))$, Productivity = value added per worker VA/W, PGR is the productivity growth rate, $PGR(t + 1) = PGR(t = 0) \times (VARG(t + 1)/VARG(t = 0))$, and $VARG$ is the annual value added growth rate. The productivity growth rate was based on historical value-added data for the years 1967 and 1973. This rate was assumed to be proportional to value added because capital investment structure remains constant in the AUSTRIA II Model.

The change in total labor demand for sector k may then be defined as

(5.10)

The change in total labor demand was then allocated to each functional core region (i, j) on the basis of historical data for the change in the number of workers in each region between 1967 and 1973. For the initial year the historical data was converted to annual changes in the total labor demand for each sector k, defined as delta$W_k(t = 0)$, and annual changes in regional labor demand for each core region, defined as delta$W_{kij}(t = 0)$. The quotient

$$Q_k = \text{delta}\, w_{kij}(t=0)/\text{delta}W_k(t=0) \quad (5.11)$$

was assumed to remain constant over time, because the migration matrix of the Population Model also remains constant over time.

The local labor demand for sector k is then

$$w_{kij}(t+1) = w_{kij}(t) + Q_k \times \text{delta}W_k(t+1) \quad (5.12)$$

The localization of energy use was carried out as follows:

$$\text{Energy}_{kij} = \text{Total energy}_k \times w_{kij}(t+1)/W_k(t+1) \quad (5.13)$$

5.4.3 Calculation of Emissions

In all sectors except the transportation sector, the emissions were calculated by multiplying the energy demand of each fuel type by an appropriate emission factor, modified by a control factor, as shown in the following equation:

$$EM_{kmp} = EN_{km} \times EF_{kmp} \times (1 - CF_{kmp}) \tag{5.14}$$

where *EM* is air pollution emissions in tons, *EN* is energy demand in 10^9 kcal, *EF* is the emission factor in tons per 10^9 kcal, *CF* is the control factor or the fraction of the emissions removed, *k* is a subscript denoting economic sector, *m* is a subscript denoting fuel type, and *p* is a subscript denoting pollutant type.

The value of the control factor – a scenario variable – is a function of time. In a scenario the value of the control factor reflects new emissions control equipment, new standards or technological improvements, or changes in combustion processes. For a given fuel type and air pollutant, the emission factors vary considerably by economic sector. The air pollutants calculated for each sector are particulates, sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2).

5.4.4 Concluding Comments

The Localization Models have provided practical algorithms for specifying air pollution with more spatial detail than that available from the end-use energy models. The general approach has been similar for all of the regions studied, although the actual equations used have depended upon data availability in each study region.

Several limitations of the modeling approach should be noted. First, the assumption of homogeneity of the fuel mix over large regions is generally not valid. For example, modeling of the industrial end-use energy demands allocated to Vienna was based upon production activity; in reality some of the energy demand represents space heating requirements for office workers in a given industrial branch. Second, for localization in the industrial and commercial/service sectors, it would have been preferable to have a model that deals with both work force and population growth simultaneously (Willekens and Rogers 1977, Ledent 1978). This is an area for further exploration.

5.5 THE SO_2 HEALTH IMPACT MODEL

5.5.1 Purpose

The SO_2 Health Impact Model provides a quantified estimate of human health impacts associated with a given SO_2 air pollution exposure. The impacts are expressed in terms of excess morbidity and premature mortality in certain groups of at-risk populations. The SO_2 Health Impact Model is an example of a damage function model that can be used either with a local system model or with a reference system model that calculates annual exposure.

5.5.2 Model Description

The dose–response relationships used in the SO_2 Health Impact Model are based on the work of Finklea (Finklea *et al.* 1975, Nelson *et al.* 1976). The relationships make it possible to estimate some of the health effects that may be associated with various levels of sulfur dioxide concentration and exposures to acid-sulfate aerosols; SO_2 is considered an indicator of the impact rather than the causal agent, which is thought to be acid-sulfate aerosols.

The dose–response relationships remain highly uncertain, but evidence has been compiled that indicates that increased emissions of SO_2 can lead to

- Premature mortality from acute exposure,
- Aggravation of heart and lung disease in people over age 65,
- Aggravation of asthma,
- Excess acute lower respiratory disease in children ages 0–13, and
- Excess risk of chronic respiratory disease symptoms in smoking and nonsmoking adults.

These five categories of impacts are treated in the SO_2 health model.

The dose–response functions set forth by Finklea *et al.* (1975) that link acid-sulfate aerosol exposures to the above health effects are reproduced in Table 15. The first three impact categories represent acute effects, and the last two categories represent chronic effects.

TABLE 15 "Best judgment" dose–response functions linking acid-sulfate exposure to selected health effects.

Adverse health effect[a]	Threshold concentration of suspended sulfates for given exposure duration	Slope	Intercept
Increased daily mortality (acute episodes)	25 $\mu g/m^3$ for 24 hours or longer	0.00252	–0.0631
Aggravation of heart and lung disease in elderly patients	9 $\mu g/m^3$ for 24 hours or longer	0.0141	–0.127
Aggravation of asthma	6–10 $\mu g/m^3$ for 24 hours or longer	0.0335	–0.201
Excess acute lower respiratory disease in children	13 $\mu g/m^3$ for several years	0.0769	–1.000
Excess risk for chronic bronchitis			
Nonsmokers	10 $\mu g/m^3$ for up to 10 years	0.1340	–1.42
Cigarette smokers	15 $\mu g/m^3$ for up to 10 years	0.0738	–1.14

[a]The adverse effects refer to the percentage by which the mortality or morbidity rates exceed the expected rates, e.g., a 100 $\mu g/m^3$ sulfate concentration for one day is estimated to increase expected mortality on that day by 18.9 percent.

NOTES: The threshold concentrations for increased daily mortality, aggravation of asthma, and excess acute lower respiratory disease in children are based on four studies, the threshold concentration for aggravation of heart and lung disease in elderly patients is based on two studies, and the threshold concentrations for excess risk for chronic bronchitis are based on six studies.

SOURCES: Finklea *et al.* 1975, Nelson *et al.* 1976.

It should be noted that these relationships take into account synergistic interactions between particulate matter and acid-sulfates. The functions in Table 15 are not applicable in regions where large emissions of catalytically active metals (e.g., iron oxides) occur or in regions with a large amount of photochemical smog. These factors greatly enhance atmospheric sulfate formation.

The ratio of SO_2 to sulfates is uncertain. Finklea has used suspended sulfates as a proxy for acid-sulfate aerosols and -- on the basis of studies of US cities -- has given two possible ratios of 24-hour levels of suspended sulfates to SO_2 concentration.

$$\text{Suspended sulfates } (\mu g/m^3) = 9 + 0.03 \times SO_2 \; (\mu g/m^3) \tag{5.15}$$

$$\text{Suspended sulfates } (\mu g/m^3) = 9 + 0.05 \times SO_2 \; (\mu g/m^3) \tag{5.16}$$

Equation (5.15) applies to regions with no significant impinging sulfates, while equation (5.16) is appropriate for regions with significant impinging sulfates. For the purposes of the model under discussion here, the dose--response functions given in Table 15 were rewritten in terms of SO_2 concentrations on the basis of equation (5.15). In addition, the population at risk was specified for each adverse health effect in the table. The details of the relationships expressed in terms of SO_2, along with explanations about the choice of functions, are given in Buehring *et al.* (1976). The model uses the annual arithmetical mean SO_2 exposure and the population exposed as inputs. The flow of calculations in the model is shown in Figure 46.

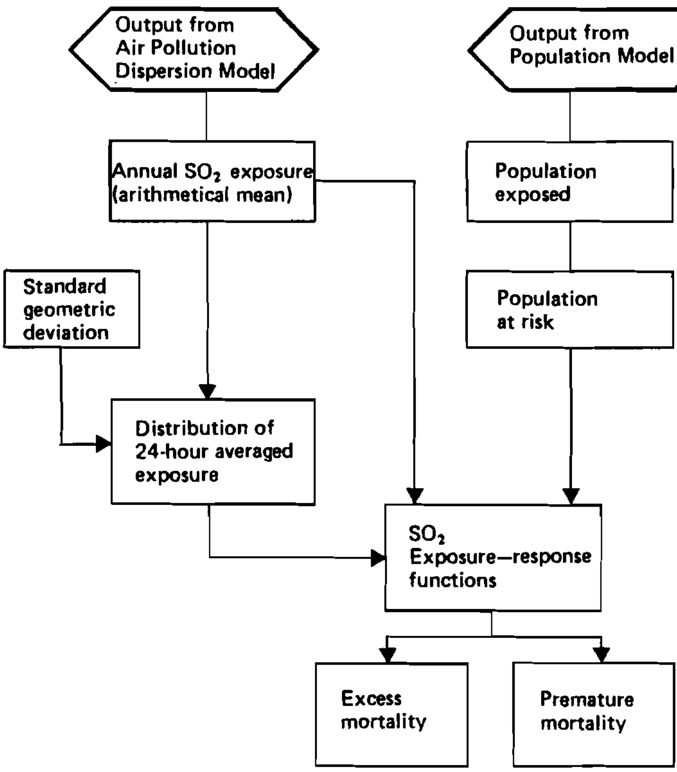

FIGURE 46 Flow of calculations in the SO_2 Health Impact Model.

The 24-hour average concentrations are obtained by assuming the log-normality of the distribution of daily concentrations that comprise the annual average. Under this assumption the standard geometric deviation can then be used to calculate the distribution of the 24-hour averages. The model can handle data for individual cities, aggregations of cities, and rural populations.

By assigning a given number of person-days lost (PDL) to each incident of excess morbidity, the individual impacts can be added together to obtain one composite impact indicator. The use of PDL as an indicator allows the output of the SO_2 Health Impact Model to be combined with the output of the Reference Energy System Impact Model, which covers other human health and safety impacts.

5.5.3 Sample Output

Sample output of the SO_2 Health Impact Model for the Austrian Case Study is shown in Figure 47. Total PDL associated with air pollution is presented, broken down by major cities, large towns, and small towns, villages and rural areas. The preponderance of the impacts in the largest cities supports the arguments presented in the discussion of the Air Pollution Dispersion Model, i.e., that it is sufficient to analyze in detail only the largest cities.

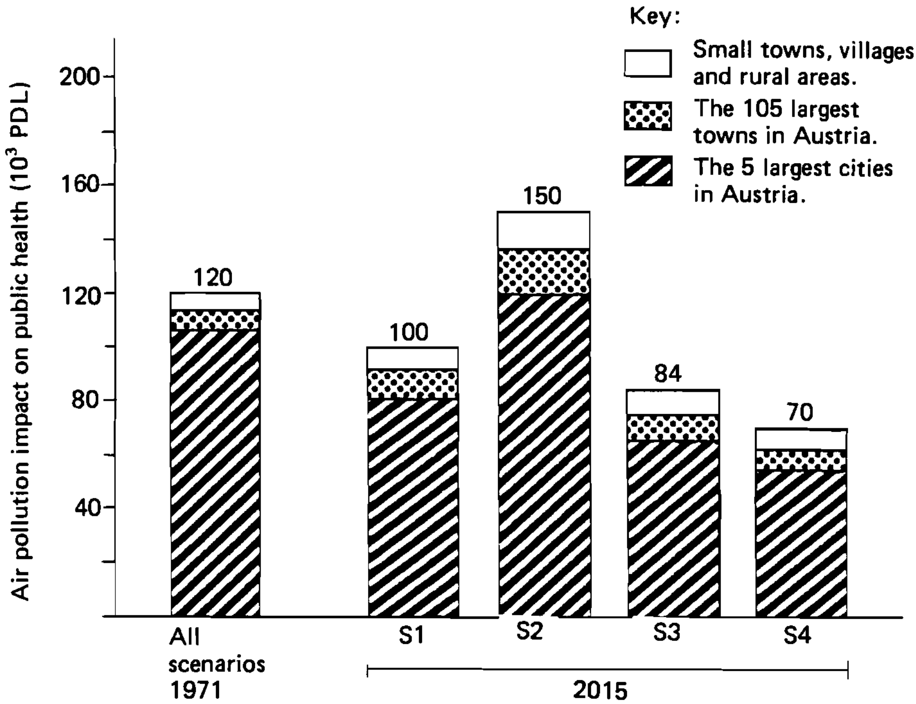

FIGURE 47 Air pollution-related impacts on public health, expressed in 10^3 person-days lost (PDL), for three types of settlements. The data is taken from Scenarios S1–S4 of the Austrian Case Study.

Figure 48 shows the air pollution PDL per capita in the five major Austrian cities as a function of the SO_2 emissions per capita in these cities. This figure was drawn using the combined output of the Air Pollution Dispersion Model and the SO_2 Health Impact Model.

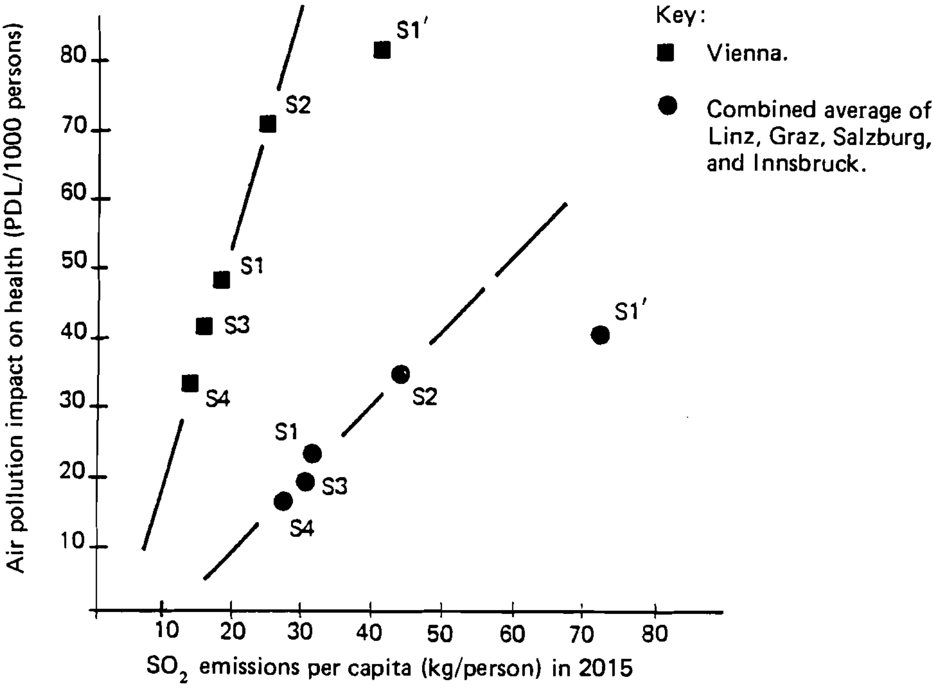

FIGURE 48 Air pollution impact on public health as a function of SO_2 emissions in five Austrian cities. The data shown in the figure are model output for Scenarios S1–S4. The two points labeled S1′ indicate the absence of SO_2 controls.

Because the types of emission sources (from the industrial, commercial/service, and residential sectors) are combined differently in the five cities, there are intercity differences in the public health impacts resulting from changes in air pollution emissions. The coupling of the two models provides a sounder basis for analysis than use of each alone.

5.6 THE RIVER BODY THERMAL POLLUTION MODEL

The River Body Thermal Pollution Model was used in two of the four study regions. The model examines environmental impacts of waste heat released from electric power plants. Two direct consequences of disposal of heat are an increase in the temperature of the water body and evaporation of water. Since these consequences are associated with impacts that are in many cases 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 passing from river through condenser back to the river), wet (evaporative) cooling towers, and dry (nonevaporative) cooling towers. Waste heat is fed into water bodies together with once-through cooling water and blowdown water* from cooling towers. Water is evaporated artificially from both wet cooling towers and heated surfaces of water bodies.

In the model the increase in river temperature is calculated as a function of distance along the river, waste heat rejected, width of the river, and windspeed. Radiative, evaporative, and convective heat losses are included in the calculation.

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

The meteorological impact is measured in the model by the artificial increase in relative humidity. If local phenomena from single towers or single warm water plumes are disregarded, the increase in humidity over a region can be calculated approximately. A Gaussian plume model that provides an estimate of the increase in relative humidity at ground level is used for the dispersion calculation. More information on this model is contained in Faude *et al.* (1974) and Foell (1979).

5.7 CONCLUDING COMMENTS

The environmental models described in the preceding pages have provided a means of calculating many energy-related impacts on land, air, water, and human health. The process of integrating the quantifiable impacts from all components of the energy system has provided a broad systems perspective that may give new insights to regional energy and environmental planners. Although the incompleteness of the array of impacts in these models is obvious, this shortcoming needs to be continually emphasized to the users of the model results. It must also be stressed that the set of environmental models is continually evolving as additional impacts are recognized and quantified, and known impacts are analyzed in more detail.

The most important contribution of the impact models is to provide a unified framework for organizing the analysis and discussion of impacts. One final methodological observation that deserves note is that the environmental impact models will almost always require a greater spatial disaggregation of the system than do the energy models.

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*Blowdown is the intermittent release of water from cooling tower systems in order to prevent the build-up of salts.

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6 A PREFERENCE MODEL FOR APPRAISAL OF ENERGY/ENVIRONMENT SYSTEMS

6.1 INTRODUCTION AND PURPOSE OF THE MODEL

The preceding chapters of this report have presented a set of models for describing energy and environmental systems. These "descriptive" models have played a leading role in our analysis of regional energy systems. In addition, "prescriptive" models (for example, the BESOM model discussed in Section 4.3), can complement this analysis through the introduction of an objective function that provides one criterion for the comparison of alternative strategies. However, because of the complexity of the decision processes in the management of these systems, we have taken yet another approach, namely, the development of so-called "preference" models based upon multi-attribute utility theory.

These preference models assist in coping with the following difficulties of energy management:

(1) *Uncertainties* about the impact of any alternative, especially considering the time frame involved;

(2) The *multiple objective* nature of energy/environment problems, and the necessity of making trade-offs among various levels of attributes, or among measures of the state of the system; and

(3) The differences among the *preference structures* of the individual members of the decision-making groups associated with the systems, and the lack of systematic procedures for articulating and resolving these differences.

6.2 GENERAL DESCRIPTION OF THE MODEL

As stated above, a preference model can provide a convenient framework to help evaluate alternatives in terms of the degree to which each of a set of objectives is met. In this section we refer to the models discussed in earlier chapters using the general term "energy/environment impact model."* The relationship between the energy/environment impact model and the preference model is illustrated in Figure 49. The outputs of the impact model are impact levels of the attributes, i.e., the altered state of the system. For instance, the policy of introducing nuclear power facilities may result in certain levels of radioactive wastes, power generation, employment, water use, land use, and deaths due to producing the energy (or due to the lack of energy). The impact model would give point estimates of such levels or present the information in a probabilistic fashion.

*This does not refer only to environmental impact models; energy impacts are also included – e.g., the impacts of the supply system and energy consumption upon the total system.

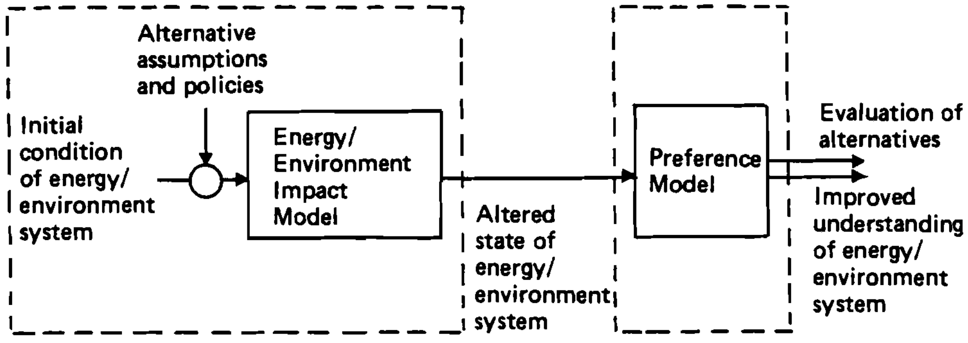

FIGURE 49 The relationship between the energy/environment impact model and the preference model.

The preference model that we construct is then used as a formal approach to couple these impacts with the preferences of a decision maker. The preferences are quantified through use of a utility function; when multiple objectives are involved, we use a so-called multi-attribute utility function. This multi-attribute 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 desirability of that alternative.

6.3 AN EXAMPLE OF AN APPLICATION

The application of multi-attribute decision theory is described in detail by Keeney and Raiffa (1976). Its application to energy system problems of the type treated in this report has been described by Buehring (1975), Keeney (1976), and Buehring *et al.* (1978). Only a brief overview is given here. The example used is the evaluation of alternative electricity supply strategies for the state of Wisconsin.

The generalized framework of the composite environmental model in Figure 49 is elaborated upon in Figure 50. The assumptions that define a policy in this example, namely a specified regional electricity demand and supply mix over a period of time, are provided as input to the Reference Energy System Impact Model (see Section 5.2). The primary input to this model is a set of assumptions about quantity and sources of electrical generation as a function of time, and certain 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 and the supporting fuel industries. The system-wide 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 occur outside the region where the electricity is generated. For example, uranium mined in the western part of the United States fuels nuclear reactors located in Wisconsin.

Since not all impacts can be quantified, the output of the Reference Energy System Impact Model cannot be considered a complete set of impact information. Environmental

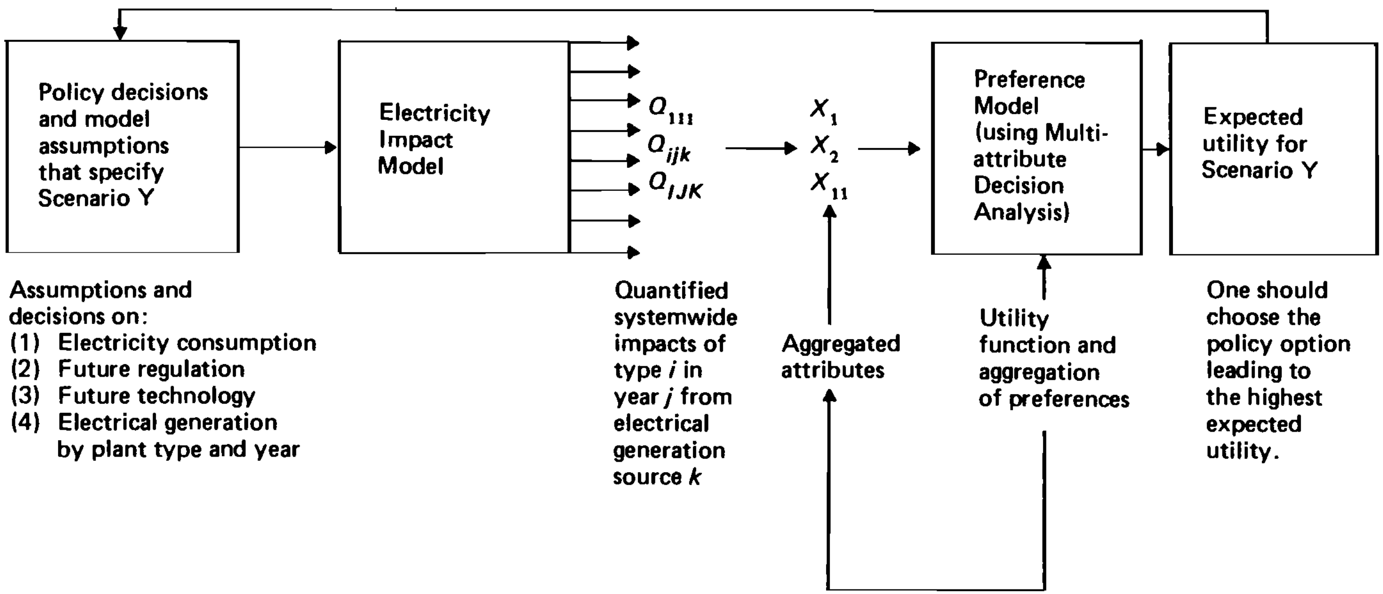

FIGURE 50 Framework of the composite environmental impact model.

impacts can be divided into quantified impacts (those included in the model) and unquantified impacts (i.e., all other environmental concerns not included in the model). Sometimes representative, or proxy, variables can be calculated by the impact model and then used as an indicator of the impact of concern in the preference model; for instance, the quantity of carbon dioxide released may be considered an indicator of the long-term potential for climate modification. Since there is uncertainty associated with each quantified impact factor in the Reference Energy System Impact Model, levels of impacts determined by the model could be expressed in terms of a probability distribution. Within the present model, however, most of the estimated impacts are not associated with explicit probability distributions; in general, the available data do not warrant the increased effort required to incorporate probability distributions into the model.

The preference model is a multi-attribute utility function that is a formalization of the subjective preferences of an individual. With reference to the Energy/Environment Impact Model of Figure 49, for example, 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 $(x_1, x_2, \ldots, x_{11})$, where x_1 is defined to be a specific level of attribute X_1. This utility function $U(x)$ is expressed for the 11 attributes, i.e.,

$$U(x) = U(x_1, \ldots, x_{11}) \tag{6.1}$$

For example, if X_1 is measured in number of deaths, then $x_1 = 230$ means a consequence of 230 deaths.

If a U has been assessed, we can say x is preferable to x' if $U(x)$ is greater than $U(x')$. The theory can also account for preferences under conditions of uncertainty. If the total impact of an alternative was quantified by the probability density function $p(x)$ over consequences $x = (x_1, \ldots, x_{11})$, then the expected utility $E(U)$ for that alternative is given by

$$E(U) = \int U(x)\, p(x)\, \mathrm{d}x \tag{6.2}$$

integrated over all consequences. The expected utility is the appropriate measure of desirability for that alternative.

Providing that certain assumptions are justified (Keeney and Raiffa 1976), the 11-attribute utility functions of equation (6.1) can be obtained by assessing 11 one-attribute utility functions, U_i, plus 11 scaling constants, k_i. These can then be combined in an additive form to give the multi-attribute function:

$$U(x_1, \ldots, x_{11}) = \sum_{i=1}^{11} k_i U_i(x_i) \tag{6.3}$$

where

$$k_1 + k_2 + \cdots + k_{11} = 1$$

Under other conditions a so-called multiplicative form is used to combine the single attribute functions. More details about these forms, including procedures for assessment are found in Keeney and Raiffa (1976). 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.

Figure 51 shows single-attribute utility functions for six selected attributes of the impact model, for two individuals involved in Wisconsin energy planning (Buehring 1975).

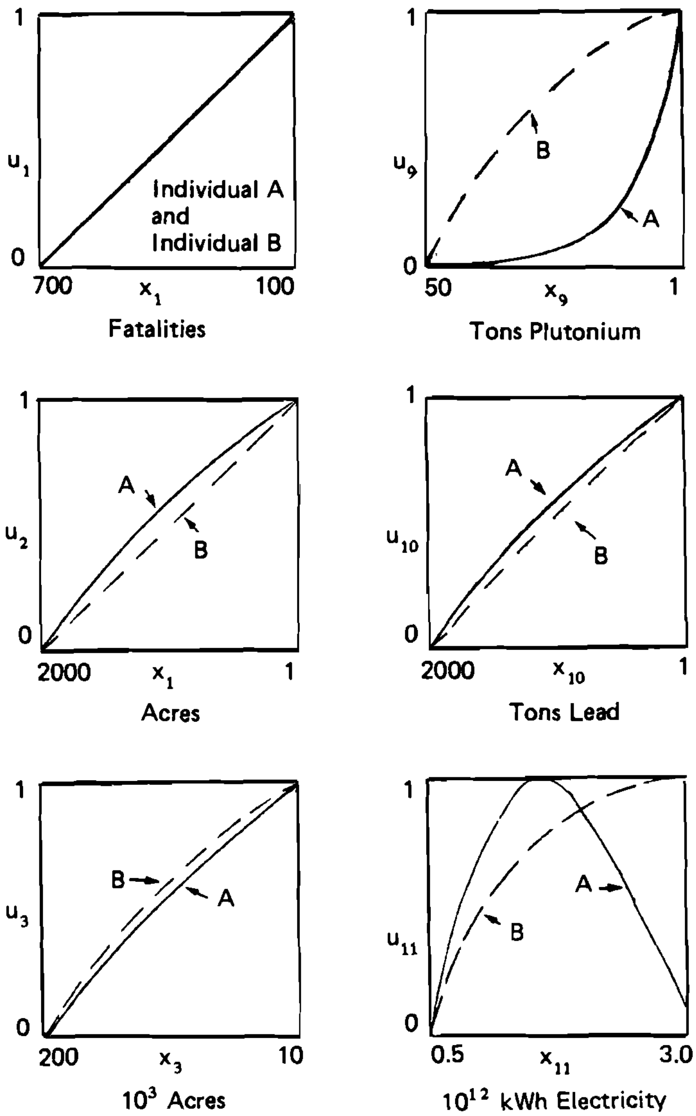

FIGURE 51 Selected single-attribute utility functions for two individuals.

The scaling constants for the utility functions are shown in Table 17. Comparison of the k_i's for an individual indicates the relative importance of each attribute for the specified ranges (also shown in Table 17). The 11-attribute utility functions were used to evaluate expected utilities associated with several energy policies concerning electrical generation in Wisconsin over the period 1970–2000.

TABLE 17 Utility function scaling constants and attribute ranges.

Attribute	Range of attributes	Scaling constants, k_i	
		Individual A	Individual B
X_1 = total quantified fatalities	100–700 deaths	0.354	0.267
X_2 = permanent land use	1–2,000 acres	0.004	0.018
X_3 = temporary land use	10,000–200,000 acres	0.033	0.021
X_4 = water evaporated	0.5–1.5 × 10^{12} gallons	0.083	0.016
X_5 = SO_2 pollution	5–80 × 10^6 tons	0.008	0.060
X_6 = particulate pollution	0.2–10 × 10^6 tons	0.008	0.008
X_7 = thermal energy needed	3–6 × 10^{12} kWh(t)	0.017	0.011
X_8 = radioactive waste	1–200 metric tons	0.132	0.057
X_9 = nuclear safeguards	1–50 tons of plutonium produced	0.177	0.152
X_{10} = health effects of chronic air pollution exposure	1–2,000 tons of lead	0.118	0.339
X_{11} = electricity generated	0.5–3 × 10^{12} kWh(e)	0.066	0.051
		$\Sigma = 1.0$	$\Sigma = 1.0$

6.4 BENEFITS OF CONSTRUCTING A PREFERENCE MODEL

Using the methods described above, first-cut preference models have been described for energy specialists and decision makers in Wisconsin, Rhône-Alpes, and the GDR (Buehring *et al.* 1976). From these experiences and others, we believe that a preference model can assist one in evaluating alternative energy policies, and that, in addition, the process of constructing the preference model also 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; communicating among several decision makers; and in the application summarized above, identifying improvements needed in the impact model.

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7 SOFTWARE AND HARDWARE: SIMULATION CONTROL LANGUAGES

7.1 INTRODUCTION

The purpose of a simulation control language is to provide an independent control system for running the submodels in a model system. On the one hand, when parameterizing or developing a particular submodel for a region, an individual researcher must be able to write, test, and make meaningful simulations with the submodel independent from other parts of the model. On the other hand, if necessary or desired for the simulation of the full scenarios, it must be possible to run all submodels as a coherent whole. Thus the need to be able to run submodels both independently and as a whole requires a control system that is independent of the models. The programming necessary to provide input and output capabilities, including dynamic interaction during simulations, re-initialization of the model for repeated simulations, and production of reports and graphs on request, is both time-consuming and complex. It is important that this programming need not be repeated for each model.

Two simulation control languages have been used in the four regional case studies: WISSIM at Wisconsin (Buehring 1976, Buehring and Kishline 1974, Kishline and Buehring 1974) and SIMCON at IIASA. The general character of these two systems, which is quite similar, is described briefly below. Then SIMCON is discussed in greater detail to illustrate some of the features of the simulation control languages.

The systems are primarily useful for models that simulate discrete-time systems. Their application thus differs from event-oriented simulation systems, such as GASP (Pritsker and Kiviat 1969) and SIMSCRIPT (Markowitz *et al.* 1963). DYNAMO (Forrester 1968) was not chosen because a compiler was not available, because researchers would have to write their programs in DYNAMO rather than in FORTRAN, and finally because the models would in some cases be too large to be handled with ease on smaller computers.

FORTRAN was chosen as the programming language because a Fortran compiler is available at most computer installations and is usually well-documented and relatively error-free. Since FORTRAN is a widely used language, it was anticipated that many researchers working on simulation models would be familiar with it – thus facilitating eventual distribution and transfer of the models.

The simulation control systems are based on three concepts. The first is the ability to locate all variables during execution by FORTRAN name. The second major feature is the ability to read commands; when a command supported by the control system is entered, a corresponding subroutine is called by the control program to execute the command. The third major feature is a set of subroutines that control the output of the simulation. This ranges from plotting certain variables during simulation to dumping the entire blank common block of FORTRAN variables. These three concepts make the simulation control languages useful and flexible.

7.2 GENERAL DESCRIPTION OF SIMCON

The SIMCON simulation control language was originally developed at the University of British Columbia (Hilborn 1973). It was implemented by W. Webb and J. Curry on the IIASA in-house computer, a PDP-11/45,* to provide a convenient interface between simulation models and their users and to facilitate the elaboration of the models. Many submodels in the model system developed to analyze energy/environment futures for Austria can be interactively executed with the help of this control language.

Since these models are highly parameterized, an advantage of SIMCON is that it offers an easy way to use default values for all parameters, to display and change the parameters, to show the progress of results over time, to observe how values change by modifying some special parameters, and to produce graphs and tables of values.

SIMCON also permits the creation of files containing a list of commands, that then can be executed by reference to the file name (an example is given in Section 7.3 below). This makes it possible to run different scenarios in an easily reproducible way. Such command files can be created during a simulation run without leaving SIMCON.

The basic set of SIMCON commands are used to

- Initialize the user model;
- Save or load the values of all variables in the blank common block;
- Set or display the current values of variables or arrays included in the blank common block;
- Establish or clear a table of "queue" commands, i.e., commands to save variables after every time step in a simulation run, so their values can be printed or graphed over time – either during or after a simulation run – given certain identifying and scaling options;
- Establish or clear a table of "at" commands, i.e., commands to be executed at a preset time in a simulation run;
- Perform a simulation run;
- Interrupt a simulation;
- Help with debugging;
- Stop SIMCON.

In addition, it is possible to use arguments in command files or to execute a UNIX command without stopping the simulation.

The details of the integration of SIMCON with the user models are beyond the scope of this description. Briefly stated, most user submodels used in the case studies are in the form of a FORTRAN subroutine named UMODEL that contains the code for the actual simulation from one time period to the next. Since the subroutine is executed with SIMCON, it need contain no input, output, or control functions. Another subroutine named UINIT that is used for the initialization of the submodels must also be provided. In addition, a special file must be created that contains the declarations of the variables that SIMCON is to recognize for input or output purposes.

*This is a medium-size computer with 128K words (256K bytes) of core memory, which runs under the UNIX operating system. UNIX is an interactive time-sharing system developed by Bell Telephone Laboratories for the PDP-11 series.

7.3 EXAMPLE OF INPUT AND OUTPUT

To demonstrate the use of SIMCON, a sample run of the residential model used in the Austrian Case Study (Poenitz 1978) is presented below. First, the elementary SIMCON commands are briefly described, followed by a listing of the command files used in the sample run. Then a listing of the sample run itself is given.

7.3.1 SIMCON Commands

The functions of the elementary SIMCON commands used in the sample run presented in Section 7.3.3 may be summarized as follows:

SIMCON	starts the simulation control program, initializes the user model, and asks the user to enter commands. A '<' sign indicates that another command may be entered.
DO	executes the SIMCON commands contained in the specified file.
QUEUE	(abbreviated as 'q') puts the specified items into a queue so that their values are recorded after each time step during a simulation run, permitting them to be examined after the run with the print and view commands.
QDISPLAY	(abbrevaited as 'qd') displays the current queue.
MON	performs a simulation run for the specified time periods (in this example 1 to 10).
STOP	ends the control program.
TY	types a message.
SET	(abbreviated as 's') assigns the given list of values to the given list of variables.
AT	causes the execution of a SIMCON command in a simulation run after a specified time step.
PRINT	displays the values of the specified variables, stored during the previous simulation period, after a run.
$	is an escape switch to UNIX for a single command.

7.3.2 Listing of Command Files

A listing of the command files used in a sample run of the residential model (see Section 7.3.3) is given below. Scenario S4, the conservation scenario, is examined in the run.

AT-S4 (This command writes a short title, gives the current date, resets a switch, and modifies the insulation values and home size for Scenario S4.)

TY

TY

```
TY    scenario IV -- strict conservation
TY
$DATE
TY
SET RZZALF=0
AT 05 S RPNINS(ALL)=.90
AT 05 S RPXINS(ALL)=.99
AT 05 S RPNHMS(ALL)=108.00      70.00      108.00      70.00
AT 10 S RPNINS(ALL)=.80
AT 10 S RPXINS(ALL)=.98
AT 10 S RPNHMS(ALL)=110.00      72.00      110.00      72.00
PVIEW (This command is used to produce a table or a graph of the output of the
      simulation run.)
P DEMR(1) DEMR(2) DEMR(3) DEMR(4) DEMR(5) DEMR(6)
TY
TY
TY       0.       5000.       10000.       15000.       20000.
V DEMR(1) DEMR(2) DEMR(3) DEMR(4) DEMR(5) DEMR(6)
TY       0.       5000.       10000.       15000.       20000.
TY
TY
```

7.3.3 Simulation Run

The capitalized words in the sample run reproduced below are commands typed in by the user. The rest is response by the terminal. The '%' sign appearing at the beginning is the UNIX prompt character. This example makes use of the SIMCON commands presented in Section 7.3.1, and the command files listed in Section 7.3.2. Following the PVIEW command, a table and a graph of the output of the simulation run are presented, just as they would be printed out by the computer. Residential energy demand by source for 10 time periods, under assumptions of strict energy conservation are provided in the output.

```
% SIMCON
simcon initializing
umodel initializing
```

```
enter commands
< DO AT-S4
scenario IV – strict conservation
Mon Nov 14 16:47:43 CET 1977
< Q DEMR(1) MAX=20000 NAME=ELEC
< Q DEMR(2) MAX=20000 NAME=GAS
< Q DEMR(3) MAX=20000 NAME=OIL
< Q DEMR(4) MAX=20000 NAME=COAL
< Q DEMR(5) MAX=20000 NAME=WOOD
< Q DEMR(6) MAX=20000 NAME=DIHEAT
< QD
ELEC      ( 0.000   , 0.200e 05)   7 <-->
GAS       ( 0.000   , 0.200e 05)   7 <-->
OIL       ( 0.000   , 0.200e 05)   7 <-->
COAL      ( 0.000   , 0.200e 05)   7 <-->
WOOD      ( 0.000   , 0.200e 05)   7 <-->
DIHEAT    ( 0.000   , 0.200e 05)   7 <-->
< MON 1 10
< DO PVIEW
```

elec	gas	oil	coal	wood	diheat	time
0.444e 04	0.312e 04	0.757e 04	0.107e 05	0.628e 04	726.	1
0.490e 04	0.336e 04	0.819e 04	0.100e 05	0.608e 04	892.	2
0.526e 04	0.365e 04	0.880e 04	0.941e 04	0.601e 04	0.100e 04	3
0.560e 04	0.391e 04	0.938e 04	0.886e 04	0.595e 04	0.109e 04	4
0.592e 04	0.416e 04	0.994e 04	0.836e 04	0.591e 04	0.118e 04	5
0.621e 04	0.437e 04	0.104e 05	0.781e 04	0.582e 04	0.124e 04	6
0.649e 04	0.458e 04	0.109e 05	0.737e 04	0.579e 04	0.131e 04	7
0.676e 04	0.478e 04	0.113e 05	0.697e 04	0.577e 04	0.138e 04	8
0.702e 04	0.496e 04	0.118e 05	0.659e 04	0.575e 04	0.145e 04	9
0.748e 04	0.525e 04	0.125e 05	0.586e 04	0.567e 04	0.157e 04	10
elec	gas	oil	coal	wood	diheat	time

```
      0.           5000.         10000.        15000.           2
time |!!!!!!!!!!!!!!|!!!!!!!!!!!!!|!!!!!!!!!!!!!|!!!!!!!!!!!!!!
   1 |  d      g  e |   w   o     | c           |
   2 |  d      g   e|  w      o   c             |
   3 |   d      g   |e w        oc|             |
   4 |   d       g  | ew        co|             |
   5 |   d        g |  *       c  o             |
   6 |    d       g | w e    c    |o            |
   7 |    d       g | w  e c      |  o          |
   8 |    d        g| w  ec       |   o         |
   9 |    d         g w  ce       |    o        |
  10 |     d        |gwc  e      |     o       |
time |..............|.............|.............|..............
      0.           5000.         10000.        15000.           2
```

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