Description and Comparison of Energy Impact Assessment Models

by
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April 1977

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DESCRIPTION AND COMPARISON OF ENERGY IMPACT
ASSESSMENT MODELS

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ABSTRACT

During the past few years the need for more comprehensive analytical techniques for assessing the environmental, economic, and social impacts of energy supply-demand systems and related public policy-making activities has increased. The research and academic communities have responded to this need by developing a wide range of models and other analytical tools for energy impact estimation. The models generally fall into two categories: large-scale and specialized.

This report examines the general features and shortcomings of current large-scale and specialized modeling efforts from the point of view of energy impact assessment. Characteristics deemed desirable in large-scale energy impact assessment models and related studies are discussed. An outline of criteria for describing and comparing such models is presented, from which seven large-scale energy models and one impact assessment study are described and compared in considerable detail. Tables are also presented which summarize the results of the categorizations.

This work was prepared for the EPA/ERDA cost/benefit study (EPA Pass Through).

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DESCRIPTION AND COMPARISON OF ENERGY IMPACT ASSESSMENT MODELS

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INTRODUCTION

Energy-related public policy making requires thorough techniques for systematic analysis of the implications of alternative actions. The plethora of questions raised by discussions of energy supply enhancement, cumulative impacts of regional development, or population distribution measures illustrates the need for more adequate analytical tools than now exist. In many areas, this need is a necessity due in part to the comprehensive impact statements required by the 1969 National Environmental Policy Act (NEPA).

This work was prepared for the EPA/ERDA cost/benefit study (EPA Pass Through). It was felt that the impact assessment model being developed for this program has a basis for comparison with other models in its genre. At the time of this writing the EPA Pass Through model was in conceptualization stages. This report is intended to assist in the process of model development, not as a basis for evaluating the merits of the models discussed herein. The model is a scope broadening activity, incorporating aspects of both "specialized" and "large-scale" models characterized below. The EPA Pass Through model itself is not described in this document.

The need for more comprehensive analytical techniques has been apparent for the past several years. The research and academic communities have been responding to this situation by developing a wide range of analytical tools for socioeconomic and environmental impact estimation, land use planning, regional systems analysis, and related tradeoff studies. For example, the Regional Environmental Systems Program of the National Science Foundation has focused on the study of regional environmental and resource problems in order to establish the scientific basis for their management and use. "The current state of understanding is rudimentary, yet the problems may be quite pressing. Efficient and effective realization of coordinated interdisciplinary research which contributes to management strategies is essential."¹

The common basis for much of the methodological development is modeling. However, there does not appear to be a common basis for the methodology or content of the modeling as applied to impact assessment problems. Because there may be little time or opportunity to survey the field in search of the emergent tools suitable to their particular needs, model makers seldom receive much feedback on the practical usability of their creations or on fruitful directions for further work. The purpose of this discussion is to provide a basis within which several large impact assessment models may be described and compared, hopefully to help bridge the gap between model developers and potential model users.

The notion of assessing models of various types is not novel or recent. In the area of regional environmental models, Meyer's² literature review is one example. The Council on Environmental Quality (CEQ) has been interested in evaluating probable environmental consequences of alternative energy policy options for a number of years. One result of this interest is the model evaluation performed by Decision Sciences Corporation in 1972,³ which discusses evaluative criteria, with reviews and an annotated bibliography. A more recent review, by Cohen and Costello⁴ is based on the applicability of large scale energy models to regional impact assessment. A tutorial guide to computer simulations with potential value in assessing national growth, prepared for Congress last year,⁵ includes discussion of a number of energy-related assessment models.

An energy model is a set of mathematical relationships between the elements of the energy system and related variables, often economic. For our purposes this definition is much too narrow. Current efforts are concerned not only with economic theory but with technological development, environmental quality, and the evaluation of alternative policies, the ultimate purpose of such studies being the assessment of impacts.

The models and other tools that could be considered within the domain of energy impact assessment may be classified as being either "large-scale" or "specialized." In general, large-scale models are designed to analyze

the impacts of national or regional policies on the availability, supply, or consumption of energy at a relatively high level of aggregation. Specialized models represent a smaller, somewhat unique geographic region and/or deal with the assessment of a limited number of specific impacts.

To date, large-scale energy modeling has proceeded in three major directions.⁶ Optimization models (e.g., linear programming) contain an objective function that minimizes the costs of meeting certain postulated energy demands from available supplies. Such models are usually static.⁷ Economic structure models of an input-output nature fit into a second class. These models, also static, attempt to describe the effects of changes in one sector of the economy on the other economic sectors.⁸ A third class of models are those which track the time path of development from current to projected future values under different policy assumptions. These may be described as dynamic simulation models which use econometrically fitted parameters to predict the nature of the energy-economic system as it evolves over time. Such models attempt to represent the feedback interaction between supply and demand. The Baughman model⁹ and the Wisconsin energy model¹⁰ are examples of this type.

Most specialized impact models provide quantitative information in the form of primary, or direct, impacts. In order to assess "ultimate" (secondary or indirect) impacts, it is often necessary to externally analyze the model outputs. Many key policy decisions concerning energy development continue to rely on qualitative, opinion-based forecasts of these secondary impacts.

Several approaches are evolving to meet this need. Leontief and others are extending input-output analysis to include environmental factors.^{11,12} Input-output models associate specific pollutants with specific economic activities directly, but they do not evaluate social or secondary consequences (e.g., health effects). Another current approach for environmental planning is to utilize cross-impact, Delphi, and similar techniques.¹³

NEPA has inspired procedures to assist in impact assessment. Better known examples are Battelle's Environmental Evaluation System,¹⁴ the USGS "Environmental Assessment Matrix",¹⁵ and the Brookhaven data system.^{7,16,17} These data bases/procedures help identify and sometimes quantify specific impacts of individually proposed energy projects.

MODEL DESCRIPTION CRITERIA

Energy impact assessment models vary in scope and purpose. Their comparison must be preceded by a definition of the criteria upon which the comparison is to be based. It is unreasonable to expect or to postulate the existence of an all-inclusive energy impact assessment model. This, however, does not imply that a reasonably complete set of criteria for their comparison cannot be established.

The gap between large-scale and specialized energy assessment models is closing on two fronts. First, efforts are being taken to make the results of large-scale models more tractable at regional and local levels, thus improving the available information base for specific models. Second, the specific models are being enlarged in scope, allowing fuller assessment of secondary impacts. This entails a broadening of disciplines included within the modeling activity.

The EPA Pass Through study is a scope-broadening activity. It includes methodological development for the quantifications of secondary as well as primary impacts. Also included is a measure of interdisciplinary activity involving the environmental, economic, and social aspects of impact assessment.

The set of existing specialized impact models is quite large and growing. Within the environmental sector there exist numerous solid waste, land use, water quality and quantity, and air quality models for local impacts. Among economic impact models there are economic growth models, income distribution, business location, fiscal impact, employment, and transportation models. Demographic projection, housing, public facility location, and recreation demand models may be placed within the social sector. Enumeration and description of specific impact models is beyond the scope of this activity. It is, however, important to be aware of current research and model development in the above areas and perhaps others. The EPA Pass Through study incorporates aspects from a number of these specific types of models.

Included in the realm of secondary impacts from energy development are numerous socioeconomic studies. The economic studies often attempt to measure the magnitude of expected future change in various indicators of development. Alternatively, those parameters are estimated and used to predict the capacity of regional institutions to accommodate the change. An excellent review of local economic impact modeling and current studies is given by Stenehjem.¹⁸ Considerable attention is also being directed toward social impact assessment of energy development. Within this area, modeling is severely hampered by lack of standardized methodology. The most comprehensive review of social impact assessment available is that of Wolf, et al.¹⁹ Current research in social impacts is focused upon the development of methodology, particularly that of social indicators.

National and regional energy policies impact at all levels. To trace the full effect of policy changes, it is essential to have a representation of all the complexities of the energy availability/supply/consumption situation. This, however, does not imply the need for more comprehensive global models nor local models with larger scope. It simply indicates the need for communication between the two. The indicators of national policies (technologies, environmental and price regulations, etc.) must be quantified and perhaps transformed into information consistent with specific models.

Likewise, at the local or specific level, methods for secondary impact assessment must be improved. This requires increased understanding of the localized socioeconomic and environmental systems. Also needed is enhanced interdisciplinary activity in the development of such models. Each discipline usually has or is developing models that describe its science. However, incorporating different disciplines into the same model can be difficult unless the bases are harmonious; successful incorporation, though, should be effective in assessing energy impacts.

Despite the difficulty of comparing impact assessment models, it is possible to enumerate a set of desirable model characteristics and features. For example, consider the following list of attributes (after Hall¹⁹):

- Relevancy
- Structural integrity
- Reproducibility
- Tractability
- Accessibility
- Flexibility
- Common sense
- Credibility
- Efficiency

For this study, a number of characterizations and comparisons were performed for a set of large-scale models. The EPA Pass Through methodology, although specialized, has many of the attributes of large-scale impact assessment models. Thus, it is important to consider its potential efficacy within the context of large-scale models rather than specific models having no integrating methodology.

The Comparison/Characterization Criteria outline below is a guide for the review and comparison of energy impact assessment models. Each model included in a comparison must be reviewed objectively. The outline specifies those characteristics to be considered. The process describes each model and then compares them based on characteristics which span the class of those considered. Discussion within the text of the outline elaborates certain points; this is often in the form of questions of concern which should be asked by the reviewer. The outline is intended to apply to all types of energy impact assessment models.

Its purpose is to help assess the efficacy of the methodology being developed for the EPA Pass Through program.

Comparison and Characterization Criteria Outline

I. Introduction and Purpose; Application to Energy Impact Assessment

This section is intended as an overview of the stated purpose and viewpoint taken by the model developers. It is expected that the model achieve its purpose, following the methodology it purports.

A. Types of Impacts to be Assessed and the Particular Area of Emphasis or Value Measures

- Environmental.
- Resource availability.
- Economic.
- Social.

B. Types of Impact-Generating Activities Considered

- Governmental policies or legislation.
- Technological development.
- Energy facility siting.
- Energy extraction and distribution.
- Changes in consumptive patterns.

C. Type of Analysis - Purpose

- Policy assessment (regulatory, social, etc.)
- Assessment of technological change (substitution, efficiencies, intensiveness, etc.)

D. Time Horizon

E. Input-Output

1. Major input parameters.
2. Exogenous variables.
3. Major outputs and graphical formats.

II. Methodological Features; Key Model Attributes and Philosophy

The methodological features of models are one basis for their comparison. The stated purpose of a model often indicates a given methodology for achievement of that purpose.

A. Modeling Approach

1. Static or dynamic

Does the study describe dynamic phenomena or merely present static "snapshots" of a possible future situation? That is, does the study show the value of some indicator in 1990? Or does it plot the indicator's value versus "time" for the period from 1975 to 1990? An example of a dynamic phenomenon which cannot be adequately portrayed with a "static snapshot" is the boom/bust cycle of development in small western towns.

2. Type of model

Does the model involve continuous simulation, discrete event, probabilistic risk, utility, decision input-output, optimization, econometric, forecasting, information retrieval, etc.?

B. Major Assumptions (factors not considered)

Major factors not considered are an important indication of the methodology. The assumptions made for a model are often constraining factors for the application of a given analytical technique. The degree of detail is a comprehensiveness feature, yet the assumptions and analytical philosophy strongly characterize the amount of detail required.

C. Structural Hierarchy (levels of aggregation)

Does the study deal with effects at several levels of aggregation or is the analysis confined to a single level? Many studies, for example, deal only with effects at the local level and ignore state-wide, interstate, and national effects. Many national models are useless for regional and local decision makers. If the study treats effects at the local level, is it site specific? Or does it speak in terms of hypothetical plants such as "northeast urban" or "midwest rural?"

D. Measurement and Evaluation of Impacts

1. Method of quantifying "qualitative" impacts (externalities)

2. Types of quantitative indicators ("figures of merit") used for formal evaluation and comparison of alternatives.

Does the study attempt to quantify the impacts not valued by the private market mechanisms? Some externalities are easy to measure while others are very difficult. For example, material damages such as paint corrosion are fairly easy to handle. Health effects are more difficult because there is a "pain and suffering" component in addition to work

time lost and treatment costs. The value of reduced visibility is harder yet and something like loss of cultural diversity may be most difficult. The methods used to quantify each type of externality may be very different.

3. Formal evaluation

Does the study formally evaluate the impacts by combining numerous indicators having

- different units (such as asthma attacks per year versus occupational man days lost per year),
- different location (asthma attacks in the West versus asthma attacks in the East), and
- different time behavior (low damage in the short term versus high damage in the long term)

with a statement of values (avoiding an asthma attack is worth \$20) to form a quantitative measure to be used to rank various alternatives, one against the other?

III. Comprehensive Features

This section characterizes the scope and completeness of a given model. Together with the methodological features, this section serves as a comparative basis among models.

A. Energy Supply Network

1. Fuel types considered

- Primary (coal, petroleum, natural gas, solar, geothermal, uranium, tidal, hydro, etc.)
- Secondary (electricity, distillates, waste heat, solid waste, gasification, liquefaction, etc.)

Does the study treat only electricity or natural gas or oil or coal, or all of them? This feature complements the economic feature below, interfuel substitution in demand for fuels.

2. Phases of supply and/or fuel cycle considered

- Exploration, extraction, processing, transportation generation, conversion, distribution
- Nuclear fuel cycle
- Supply alternatives

Does the model represent all the alternatives supplying the end use demand for energy? These alternatives may include delivery of oil, gas, or electricity. They also include alternative means of generating electricity (hydro, coal-fired, or geothermal, for example).

Similarly, does the study cover the entire fuel cycle including exploration, extraction, processing, transportation, generation or conversion, transmission, and distribution; or all phases of the nuclear fuel cycle?

3. Demand/consumption components

- Coverage by economic sector (residential, commercial, industry, transportation, agriculture, etc.)
- Coverage by process/end use (lighting, space heat, industrial steam, air conditioning, etc.)

4. Future technologies

- Impact on existing system based upon assumptions about the date of commercialization, cost, input requirements, and other features of the new technology.
- Characterization of the new technology (when will it be commercialized, how much will it cost?, etc.)

In long-range planning studies the consideration of technologies which are not in current use is both important and difficult. What does the study do about questions like when (and if) fusion power plants become a commercial reality? Many studies represent future technologies only as far as the new technology alters the environment within which existing technologies must operate. The commercialization of fusion power, for example, may reduce the demand for electricity from fossil fuel plants and might be included indirectly in a study of the future of fossil-fueled electric utilities. Does the study represent new technologies directly, indirectly, or not at all?

B. Spatial Detail

1. Geographic distribution (people, resources, energy facilities, environment, etc.)
2. Coverage (international - global; national; regional - census, basin, state, local, etc.)

Does the study represent the spatial distribution of people, energy facilities, and natural elements (rivers and wind, for example) that determine the extent of the impact of power production?

C. Economic Content

1. Interfuel competition - substitution

Is the interaction between competing fuels considered at the level of the ultimate consumer? If people don't buy electricity, they may buy natural gas or fuel oil for, say, home heating. So the expected use of substitutes for electricity must be considered when the expected use of electricity is determined for a future time period. Is this explicit or only implicit?

2. Interregional competition

Is the competition between explicit geographic regions for supplying the same or similar fuel types considered? Are factors such as transportation and regional cost differences considered in determining the result of this competition?

3. Induced development

Does the study represent the social and economic development induced by the construction and operation of energy facilities? Examples of induced development include the boom/bust development in small western towns and the location of new industry in the West near the sources of cheap energy.

4. Exogenous or endogenous demand specification

Does the study consider supply only, with an assumed consumption level to meet, or is the determination of this consumption level part of the model? Also, how is the demand forecast done? Is it simply an exponential growth driver or is it built so that increasing fuel scarcity will automatically curtail use through higher prices?

5. Energy - economic interdependence

Does the study represent the interdependence between energy and economic growth? Over history the growth in energy and GNP have been very closely correlated. Most studies include the causal influence of GNP growth on energy demand - that is, projections of GNP are used to estimate future levels of total energy demand. Yet very few studies include the causal influences of the energy system on the growth in GNP.

D. Environmental Content

1. Sectors (air, water, land, ecosystems, bioproductivity, health, etc.)
2. Pollutants/emissions/residuals (airborne particulates, NO_x , SO_x , metals, solid waste, etc.)

Does the study cover the impacts from all residuals, or does it concentrate on two or three major residuals? In what sectors of the environment are impacts considered?

3. Impacts (air quality, water quality, land disturbance, soil fertility, biological productivity, ecosystem effects, health, aesthetics, etc.)

Does the study quantify the impact of residuals or merely quantify the residuals themselves?

Does the study deal with effects which arise from the interaction of the individual energy systems and the surrounding environment? For example, the damage to health from power plant SO_2 emissions depends on the state of the surrounding environment.

E. High Damage, Low Probability Events

Does the study calculate the damage to be expected from events such as:

- Nuclear reactor accidents
- Diversion of plutonium by terrorists
- Sabotage of nuclear facilities
- Leaching of underground stored wastes by ground water?

F. Socioeconomic Effects

IV. Data Base

A. Source(s)

- Quality
- References
- Validation (see VI-C)

B. Structure and Organization (imbedded within model, external, data file structure, etc.)

Any model needs data in order to assign values to its variables and parameters. Is the data available and is it compatible with the model? Has the model given adequate references concerning data sources and quality? Is there discussion concerning the reliability and validity of the model's data? Is the data base in a form which is readily accessible to the model user?

V. Computer Implementation

The computer implementation of models is a practical matter. When using a model, such items of concern are:

- Computer(s) utilized
- Computers to which a model can be directly transferred
- Language(s)
- Remote terminal access
- Other features (interactive, graphical display, etc.)

How much time will be required to exercise a study utilizing the model? Does the model require significant computer resources for its exercise? How much actual cost is incurred in its use?

VI. Documentation/Validation

The development and implementation of models may lead to more "open" communications regarding methodologies. This is affected by complete documentation. Normally documentation takes the form of detailed reports which describe the rationale for model conceptualization, the structure and characteristics of the model, and a compilation of the testing results.

A. Documentation of Model Description

- Types of documents available (journal articles, research reports, memoranda, etc.)
- Intended audience for model description and use (as opposed to purpose)

B. Documentation of Model Results

- Types of documentation available
- Intended audience for results

C. Validation of Model and Results

1. Method used (historical track, expert opinion, measurements from physical systems, analyst's opinion, etc.)
2. Is the model effective in its intended purpose? Does it compare with the mental and descriptive models that would otherwise be used? Does it compare with similar models or studies? Are the results consistent with the real world system?

D. Performance and Testing

1. Historical and measurement
2. Cost of execution

How useful, used, and usable does the model appear to be?
Is the model plausible to policy makers as well as
scientists and technicians?

E. Cost of Documentation/Model/Data Base

VII. Sponsor, Principal Investigator, Current Status

VIII. References

- Model Documentation
- Evaluation Support

The above outline and comments characterize various energy impact assessment models. The evaluation then, is a qualitative discussion of the various aspects of the model. Our objective in the evaluation was to go beyond the often sterile model review process and elicit the potential for application to energy impact assessment studies. Where possible, available abstracts and reviews have been used in discussing items in the outline.

Each of the major areas of the outline were also considered, within the context of the following evaluative or qualitative aspects of the model's practical usefulness:

- Communicability and understandability of the model description
- Communicability and interpretability of the model's results
- Flexibility of the model's operation
- Ease with which the model can be transferred to and used by decision makers or other intended users
- Adaptability for energy impact assessment studies
- Compatibility for use in conjunction with other models and/or analytical techniques
- Transparency of assumptions.

Another major factor is the appropriateness of the level of aggregation. Beyond the questions of too little or too much detail are the various dimensions of generalization a model may take on. For example, in spatial detail, one should ask: is the model unique to a particular state or region or can it be readily applied to other areas? The economic level of aggregation must also be considered. Any energy system having some defined boundary must be dependent on effects outside its boundary. The model boundaries may also include environmental, sociological, or demographic boundaries or assumptions which may limit the model's utility.

Beyond the descriptive characterization of a model's data base and machine implementation are the relevance of both the data base and choice of machine in meeting the objectives of the model. Similar arguments may be made concerning a model's adaptability. The data base's accuracy and the reliability of its sources are also important. In the computer, the appropriateness of language choices, the ease of transfer to other machines, and the operational convenience are all of prime consideration. The flexibility of the model's structure must also be evaluated on the basis of its effective communication of results.

Aside from actually exercising and testing a model, its evaluation is dependent on the documentation concerning it. Both the model structure and its results need to be addressed in terms of clarity, validation, and completeness to evaluate its potential application.

To summarize the above discussion, our evaluation has proceeded on two levels. The first level is that of classification or categorization of the model itself. Second, the evaluative questions are addressed.

Eight model studies have been evaluated following the above procedure. The models are:

1. SRI-Gulf Energy Model. Cazelet and North Stanford Research Institute
2. Project Independence Evaluation System. Federal Energy Administration
3. RESPONS. Bechtel Clean Coal Energy Model
4. Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy. WASH-1224, U.S. Atomic Energy Commission
5. Strategic Environmental Assessment System (SEAS). House, Environmental Protection Agency
6. Wisconsin Energy System Simulation (WISE). Foell, University of Wisconsin
7. The State of the System Model (SOS). House, Environmental Protection Agency.
8. Brookhaven National Laboratory Energy Models

To obtain an overview of the content of each of the eight models as it pertains to energy impact assessment, a matrix of impact-generating activities (government policies; technological change; energy facility siting and operation; energy extraction, transportation and distribution, changes in energy consumption patterns) versus categories impacted (environmental, resource availability, economic, social) was prepared for

each model. The categories in the matrix follow sections IA and IB in the Comparison and Characterization Criteria Outline. The matrices are quick visualizations of the energy activity-impact (cause-effect) relationships treated by each model; they also facilitate comparison among models.

Figures 1 through 8 are the energy impact matrices for the eight models evaluated. Matrix elements containing an X indicate that the activity-impact relationship is addressed to a significant degree by the model in question.

The eight models evaluated are clearly neither comprehensive, nor do they cover the gamut of the types of models discussed in the introduction. A number of large scale energy models and many specialized models with potential application to impact assessment, have not been considered here. A partial list of other large-scale energy models with similar potential is given below. Enumeration of specialized and local impact models is beyond the scope of this task.

- C. H. Chilton, Battelle Columbus: National Energy Model
- American Gas Association and Decision Science Corporation: Total Energy Resource Analysis (TERA) Model
- F. C. Schweppe, et al., MIT: Economic-Environmental System Planning Model
- Morrison and Readling, Bureau of Mines: Bureau of Mines Energy Model
- Alan Manne, Harvard: Energy Technology Assessment (ETA) Model
- Institute for Energy Analysis: IEA Energy Simulation Model
- Jay Forrester, MIT: National Economic Model
- Dennis Meadows, Dartmouth: Long-term Energy Model
- Virginia Polytech Institute: LORENDAS Model
- Clopper Almon, Maryland: INFORUM Model

- Center for Advanced Computation, Illinois: Input-Output Model
- Battelle Columbus and EPA: Energy Quality Model
- Baughman-Joskow, MIT: Regional Electric Utility Model
- Battelle-Northwest: LP Model Electric Power
- MacAvoy-Pindyck, MIT: MIT Gas Model
- National Petroleum Council: Oil and Gas Supply Model
- Gordon Kaufman, MIT: Probabilistic Model of the Oil and Gas Discovery Process
- University of Pennsylvania: Wharton Model
- Data Resources, Inc: DRI Long Term Model
- Chase Econometrics: Chase Forecasting Model

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
	Government Policies	X	X	
	Technological Change	X	X	
	Energy Facility Siting and Operation			
	Energy extraction, transportation, and distribution	X	X	
	Changes in energy consumption patterns	X	X	

FIGURE 1. SRI - Gulf Energy Model Energy Impact Matrix

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
	Government Policies	X	X	
	Technological Change	X	X	
	Energy Facility Siting and Operation			
	Energy extraction, transportation, and distribution	X	X	
	Changes in energy consumption patterns	X	X	

FIGURE 2. Project Independence Evaluation System Energy Impact Matrix

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
Government Policies			X	
Technological Change			X	
Energy Facility Siting and Operation			X	
Energy extraction, transportation, and distribution			X	
Changes in energy consumption patterns				

FIGURE 3. RESPON (Bechtel Clean Coal Energy Model) Energy Impact Matrix

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
Government Policies				
Technological Change				
Energy Facility Siting and Operation	X	X	X	X
Energy extraction, transportation, and distribution	X	X	X	X
Changes in energy consumption patterns				

FIGURE 4. Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy (WASH-1224) Energy Impact Matrix

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
	Government Policies	X		
	Technological Change	X	X	X
	Energy Facility Siting and Operation			
	Energy extraction, transportation, and distribution	X		
	Changes in energy consumption patterns	X	X	X

FIGURE 5. EPA's Strategic Environmental Assessment System (SEAS) Energy Impact Matrix

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
	Government Policies	X	X	
	Technological Change			
	Energy Facility Siting and Operation			
	Energy extraction, transportation, and distribution	X	X	
	Changes in energy consumption patterns	X	X	

FIGURE 6. Wisconsin Energy System Simulation (WISE) Energy Impact Matrix

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
Government Policies	X			
Technological Change		X		
Energy Facility Siting and Operation	X		X	X
Energy extraction, transportation, and distribution	X	X	X	X
Changes in energy consumption patterns	X		X	X

FIGURE 7. EPA's State of the System (SOS) Model Energy Impact Matrix

Impact Generating Activities	Impact Categories			
	Environmental	Resource Availability	Economic	Social
Government Policies	X	X		
Technological Change	X	X	X	
Energy Facility Siting and Operation	X		X	
Energy extraction, transportation, and distribution	X	X	X	
Changes in energy consumption patterns				

FIGURE 8. Brookhaven National Laboratory (BNL) Energy Models Energy Impact Matrix

MODEL DESCRIPTIONS

Following the format of the Comparison and Characterization Outline, we have reviewed the following eight models. References in each analysis are made to the documentation for each model, rather than to the references cited at the end of the report.

SRI-GULF ENERGY MODEL

I. Introduction and Purpose; Application to Energy Impact Assessment

The SRI-Gulf model is a national energy model in support of a decision analysis of synthetic fuels strategy. Its purpose is to compute market clearing prices and flows by balancing supply and demand in an economic framework. The model was developed jointly by SRI and Gulf Oil Corporation under SRI leadership. It represents several geographic regions and covers all major energy forms, technologies, transportation modes, and demand sectors. According to its developers, "it explicitly models supply elasticity, interfuel competition, and end use demands; treats energy market dynamics such as investment, financing, technological change, demand growth, and resource depletion from the present to the year 2025; and computes market clearing prices and quantities by balancing supply and demand."¹

The model was designed to help Gulf Oil Corporation decide whether to participate in coal gasification ventures in the Powder River Basin in Wyoming and Montana. Clearly such an undertaking requires significant investment. The objective was first to determine the profitability of such an activity over a realistic lifetime. As the analysis grew, the need to address such decisions in the perspective of the future national energy arena became apparent.

A. Types of Impacts Assessed

The key factors determined by the SRI model are economic in nature. The model presently provides physical and economic properties of energy-related quantities under both free market or regulated market scenarios. The principal outputs of the SRI model are the regional market clearing prices for fuels, associated production quantities, flows through transmission links, capacities of conversion processes, and demands for distributed fuels.

B. Types of Impact-Generating Activities Considered

The model was built specifically to analyze investment decisions relevant to the firm (Gulf). The model does not explicitly treat extra-market production and consumption (externalities), however, attempts are under way to incorporate some environmental impacts into the model.

C. Type of Analysis - Purpose

Its authors indicate that the model is flexible and may be readily adapted to the needs of various users. It may ultimately be used to evaluate industrial investment decisions or forecast markets and evaluate policy decisions. "In the government, applications could include analysis of specific research and development projects, alternative research and development policies, regulatory policy, leasing policy, government incentives, and other public policy decisions relating to energy."¹

D. Time Horizon

The time frame is from 1975 to 2025.

E. Input-Output

In the SRI model, energy production, processing, transportation, and end-use consumption are described by a network. The network itself is comprised of locations, materials, and processes. Associated with each set of network variables are a number of economic factors (both fixed and variable), including the evolution of costs over time. Likewise, cumulative resource supply functions describe the source of the network for each primary fuel. To initiate the model, an energy balance is required. The model also requires input forecasts of future usable energy demand for the end-use categories of the network. A number of behavioral economic parameters are also required.

The principal outputs of the SRI model are the regional market clearing prices for each fuel, associated production quantities, flows through transmission links, capacities of conversion processes, and demands for distributed fuels.

II. Methodological Features

A. Modeling Approach

As mentioned, the model is based upon the market clearing process of balancing energy supply and demand. A large number of supply and demand curves which evolve over time are balanced by the model. Associated with each market clearing price for energy is its form, location, and time. The location of the energy commodity is within a network comprised of both elements and regions. A successive approximation technique is used over a decomposed portion of the network to balance supply and demand.

The SRI-Gulf Energy Model may be characterized as a dynamic econometric model. The authors' philosophical motivation is that models must be tailored to answer specific questions. The need for a large-scale model in this case stems from the difficulty in separating a specific technology (in this case coal gasification) from the energy system in which it must operate. Likewise, the economics of end use must determine to some degree the production, transportation, and ultimate consumption of the energy resource.

B. Major Assumptions

The use of economic equilibrium as a model of the energy system of the United States is the basis for the model. Their equilibrium approach entails simultaneous balancing of many supplies and demands which evolve over time. Final demand is assumed to be perfectly inelastic; that is, prices and incomes do not explicitly influence the final equilibrium quantities. However, the final demand is apportioned to each sector of processed product and matched with supply functions (nonlinear price and time dependent) to determine equilibrium prices and quantities for each product.

C. Structural Hierarchy

The model is national in scope with regional submodels. The unique characteristic of the SRI model is that production, processing, transportation, and end use consumption of energy materials is described by a network. On the computational level, there also exists a structural hierarchy. The equilibrium is determined by an iterative algorithm which moves through the network computing prices and allocating required quantities of resources. Several such iterations are required to achieve convergence.

D. Measurement and Evaluation of Impacts

No formal impact assessment is available within the model. The key outputs of the model are those indicated above. Specific assessment of various scenarios with regard to their relative impacts must be performed exogenously from the model results.

III. Comprehensiveness Features

A. Energy Supply Network

The SRI-Gulf Energy model is national in scope with 8 demand regions and 14 supply regions. Its time frame extends 50 years from the present and output is generated for 17 time periods over its horizon. The principal elements of the network are: locations where energy is produced, processed, or consumed; energy materials or forms, such as electric power; and processes which convert energy into different forms. Processes explicitly include primary resource production, synthetic production, refining, transportation, electrical generation, energy distribution, and end use conversion.

All major energy forms are included within the model, which also includes hydrogen and methane. Only solar energy and more exotic forms are excluded. Supply elasticity, interfuel competition, and end use demands are endogenously determined. End use demand levels and locations; the underlying network parameters for transport, conversion, distribution, etc.; and process thermal efficiencies must be specified apriori.

B. Spatial Detail

As a national model, each network parameter is located by geographic region. There is an arbitrary resource region for nuclear fuel. There are a total of eleven resource regions, three import regions, six refinery regions and eight demand regions. Each resource and refinery region is treated as a single location. Each demand region includes four market sectors. The network's hierarchical nature includes resources, refinery, demand gateway and end use locations. The full network describes the continental U.S. at this level of detail.

C. Economic Content

Economic characteristics input to the model include capital and operating costs for each network element, technological projections and tax estimates. Supply elasticities are input as functions of cumulative consumption of resources. All process price elasticities are initially specified.

Computationally, the supply curves are utilized to provide cumulative production and resource reserves for a given location and time in the network. From this information, the necessary price is determined iteratively on the supply curve for additional production and then adjusted for inflation, technological, and short-run economic effects.

The model has several specific features which are discussed in greater detail in Reference 2. Economic rent (the increment above marginal cost that must be paid to a resource owner to induce sale) is included in the economics of the model. End use elasticities are used in determining demand and may allow testing of consumer conservation activities. Likewise, provisions for technological change are included based upon data on extant and new technology, and nominal dates for commercial availability of new technology.

The model is quite large; for example the energy network contains approximately 2400 elements including materials, processes, and transportation links. Included are approximate submodels of secondary industries producing critical energy-related items, as well as behavioral lags for changing economic conditions. The model purportedly accounts for differences in financing practice, accounting conventions, and taxation in the various sectors of the energy market. The long-term implications of investment practices in the short term, and institutional and human behavioral characteristics are supposedly incorporated in the model.

D. Environmental Content

No environmental issues are currently addressed.

E. High damage, low probability events

None

F. Socioeconomic effects

No socioeconomic issues are currently addressed.

IV. Data Base

The model contains a reasonably extensive data base. The original data for the model was compiled by the Gulf Oil Corporation as part of an internal decision analysis of synthetic fuels alternatives. This data was then adjusted by SRI to reflect 1975 economic conditions. The initial data was also reviewed by a panel chosen by the CEQ.

Essentially there are five data bases supportive of the energy network: process economics, resource economics, national energy balance, end use demand forecasts, and behavioral material. The first four are discussed to some detail in Reference 2. No information is available on the data base formal structure or in its facilities.

V. Computer Implementation

The SRI-Gulf Energy model is programmed in FORTRAN and operational on Gulf Oil Corporation's machine. The model is currently being modified and converted in contract work for the U.S. Government.

VI. Documentation/Validation

The original version is proprietary property of Gulf Oil Corporation. Access to the actual computer code is unavailable at this time, as is much documentation regarding the actual model structure. Reference 2 contains information on the data base and discussion of the model's potential. Present plans include further documentation, and current support is being used to extend the model and to support its public dissemination. At this time its originators caution analysis of its available results due to the assumptions and data limitations which must temper such analysis. Likewise, the use of judgment and expert opinion in its utilization as an effective tool is prerequisite for its effective use.

VII. Sponsor, Principal Investigator, Current Status

Sponsor:

Gulf Oil Corporation, National Science Foundation, Stanford Research Institute internal research funds.

Principal Investigator:

Edward G. Cazalet, Director
Decision Analysis Group
Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, CA 94025
(415)326-6200

Status:

The version of the model developed for Gulf Oil Corporation is operational and has been exercised. SRI has acquired funding to support significant reprogramming and modification of the program to resolve its proprietary nature.

VIII. References

1. "SRI-Gulf Energy Model - Overview of the Methodology," Edward G. Cazalet, Stanford Research Institute Internal Research and Development Report, Menlo Park, CA, January 1975.
2. "Western Energy Resources Study: Economics Energy Model Structure, Data Base and Nominal Cost Study," Edward G. Cazalet, et al., Stanford Research Institute Report, Menlo Park, CA, May 1975.
3. "A Comparative Analysis of Methodologies Used in Large Scale Energy Modeling," Edward G. Cazalet, et al., Stanford Research Institute, Draft Report SRI Project 4340, Summer 1976.

PROJECT INDEPENDENCE EVALUATION SYSTEM (PIES)

I. Introduction and Purpose; Application to Energy Impact Assessment

The stated purpose is "to assess the effect of alternative policies on the supply, demand, and price of all forms of energy in the United States."¹ The model is intended to be as comprehensive and inclusive as possible, and was designed to investigate broad options such as increasing domestic energy supply, managing energy demand, and/or establishing standby emergency programs.

According to Hausman² the PIES model is the "first large-scale economic model which attempts to integrate macroeconomic factors with the key micro-economic fact which must be recognized in any successful energy model -- the depletable nature of energy supplies." It attempts to answer questions of policy impacts on energy supply and demand. The PIES model is currently used by FEA for policy evaluation.

The report¹ itself is devoted to a detailed discussion and analysis of eight scenarios for the energy arena in the U.S. in 1985, using four policy options: business as usual; conserving and managing energy demand; increasing domestic supply; and establishing emergency programs. Although the report's scenarios are purportedly presented to illustrate the model's use, the report stresses such discussion. The underlying need for making explicit the dependence of supply, demand, and policy alternatives on price, the regional nature of domestic supply, and the desirability of structuring the overall energy system under one framework are also emphasized throughout. The purpose expressed is to provide a tool to evaluate alternative energy initiatives and not to make policy recommendations per se.

A. Types of Impacts Assessed

The PIES model was developed as an evaluation tool for policy analysis and technology development rather than as an impact assessment tool. A minimal amount of direct environmental impacts, including air pollutant emissions and water pollution effluents are analyzed in each policy scenario simulation run. As indicated above, the key emphasis of the model is resource availability. The PIES energy system simulation is one of the most

comprehensive available - it includes all possible sources of energy. For each source, potential supplies as well as resource requirements necessary to produce these supplies are analyzed in detail.

B. Types of Impact-Generating Activities Considered

The PIES model has potential as a tool in evaluating alternative energy sources at a national level on an interregional basis. Its level of supply and demand detail provides a reasonable base for conducting interfuel competition analysis. While some segments of the model may have faults, the model is a serious attempt to provide an integrated framework for energy policy evaluation in the near term.

The model is designed to provide an evaluation system to analyze impacts of relative prices, substitution of energy sources, variation of production and conversion technologies, resource limitations, economic impacts, environmental effects, regional variations in production and consumption, dynamics of the energy system, and other energy related policies.

C. Type of Analysis - Purpose

The Project Independence Report¹ does not claim to make any specific policy recommendations. A large portion of the report, however, is devoted to a detailed analysis of eight scenarios for the energy situation in the U.S. in 1985. The scenario evaluation is based upon a detailed analysis of the PIES model output. As a result, it is difficult to separate the model description from the specific outputs it has produced.

The structure of the project was organized by task forces to establish data and project guidelines. Among them, the Policy Analysis group considered the impacts of various policy options on various sectors of the economy and consumers. In particular, the above mentioned policy objectives were set by this group.

D. Time Horizon

For each fuel considered, potential production was estimated for 1977, 1981 and 1985. Although some projections beyond 1985 were made, these are considerably less thorough.

E. Input-Output

Energy prices are specified exogenously as a time series over the years of interest. National demand forecasts and elasticities are also estimated over the time path. Key model inputs are equilibrium prices consistent with exogenously specified production capacity, material constraints, resource constraints, and environmental constraints. Major outputs are economic impact, vulnerability assessment, supply/demand forecasts and environmental effects.

II. Methodological Features

A. Modeling Approach

The energy system is depicted as a network wherein production, processing, conversion, distribution, transportation and consumption take place. The prices and capacities of these activities are specified exogenously by macroeconomic model forecasts. Given exogenous prices, demand is forecast dynamically for derived energy products in three sectors of the economy: household and commercial; transportation; and industry. The demand is then compared to exogenous supply curves and equilibrium is determined by a linear programming technique (the integrating model). The integrating model takes demand estimates, supply schedules, resource requirements, and elasticities and calculates equilibrium prices. The supply, demand, and equilibrium prices are combined with models of the economy, assessments of non-energy resources, and report writers which evaluate the solutions in terms of environmental, economic or resource impacts.

The PIES model utilizes simulation concepts of econometrics, linear programming, and simple accounting for the relevant portions of the problem. The model of macroeconomic activity has its roots in the simulation developed by Data Resources Incorporated.³ The separate models of domestic oil supply, natural gas, and coal are the products of each of the task forces. The fourth major source of domestic energy, nuclear, is considered along with the production of electric power and is part of the integrating model.

B. Major Assumptions

The major assumptions of the model concern the likely evolution of U.S. energy policy. Clearly the forecasts will be conditional upon policy assumption. A shortcoming noted by several reviewers^{2,4,5} is the model's failure to make alternative forecasts under wide policy assumptions. These criticisms deal more with the exhibited results than with the assumptions of the model structure. Some clarification is expected regarding such criticisms. For example, the model assumes that tax laws and the depletion allowance will remain unchanged; since this has been recently contradicted, new scenarios will be evaluated.

The key policy assumption in the "business as usual" case is deregulation of crude oil prices and phased deregulation of natural gas prices. A key criticism is that current regulatory policy cannot be evaluated. In the model, the world oil price is exogenously fixed at three prices; Canadian natural gas is treated similarly. The third major assumption in PIES is the absence of limits or constraints in the development of domestic resources. The model does have the option of testing alternative assumptions under the available framework.

C. Structural Hierarchy

The structure of the model follows closely the task forces associated with its development. Demand and supply models provide preliminary estimates which are iterated upon within the integrating model to give equilibrium. The integrating model, which is a linear programming model, uses the demand estimates and elasticities over the demand regions and the supply schedules and resource requirements over the supply regions to calculate the energy market equilibrium. The output equilibrium prices, demands, and supply are all given on a regional level of aggregation. Ex post macroeconomic assessments are then made by the macroeconomic, international assessment (vulnerability), and environmental submodels.

D. Measurement and Evaluation of Impacts

Most of the Project Independence Report evaluates economic impacts. The major impact areas addressed are environmental, economic, and social.

No formal evaluation methodology is followed. Since the model itself is not well documented in impacts, it is difficult to identify specific outputs of the model.

III. Comprehensiveness Features

A. Energy Supply Network

The PIES model with its associated supply sectors is perhaps the most comprehensive and all-inclusive energy model presently in use. All possible sources of energy presently available are included in the model, as are detailed analyses on their potential supplies at various prices. The resource requirements to produce the supplies were developed for 62 different manpower skill categories and 30 types of materials associated with production. They do not have, however, a direct effect on the establishment of equilibrium solution as noted in the third assumption above.

Energy demands are estimated for the residential and commercial, industrial, transportation, and utility sectors. Total demand is decomposed for residential and commercial into electricity and a number of heating fuels. The industrial sector is represented by 24 2-digit SIC industries and for substitution among electricity and boiler fuels, excluding coal. Transportation demand is characterized by fuel types but does not include substitution.

The electrical generation base fuels are substituted by the linear program contained in the integrating submodel. Fuels are allocated on the basis of minimizing total costs of present and future generation capacity. The costs include fuel price, capital equipment, interest, and load factors. Demand is characterized for base, peak, and intermediate loads.

B. Spatial Detail

The energy and fuel supplies are determined on a regional basis as discussed above. Demand is also divided among a distribution of census regions. The economic aspects of the demand model are discussed in detail by Hausman.²

C. Economic Content

The Demand Forecast Model is an econometric simulation model, which is a variation of the Energy Policy Model developed by Data Resources, Inc.³ The model predicts quantities of energy demanded by the residential and commercial, industrial, and transportation sectors. In the residential and commercial sector, demand is determined by the housing stock, per capita income, and the price index for fuel and power. Market shares are explicitly considered by separating demand into electrical consumption and heating fuel. Electricity consumption is determined by electricity prices, heating fuel prices, and per capita income. The difference between the endogenously estimated total demand and electricity consumption is the heating fuel estimate. A market-share equation is then used to partition demand for heating fuels among the various products (i.e., natural gas, distillate, residual).

Interfuel competition in the residential/commercial/industrial sectors is handled by a logic probability model that assumes the sum of the market shares equals unity. Market shares are a function of relative energy prices and either time or the lagged value of the share. The industrial demand for energy is assumed to be a function of industry activity and the price index for total fuel and power. The level of activity in specific manufacturing industries is determined using input-output coefficients that calculate the potential industrial demand for each major fuel.

D. Environmental Content

Environmental factors considered within the production sector of the model as constraints include both technological as well as legislative constraints. Some of the emissions and environmental residuals for each level of production and consumption by region are included in the model. The residuals are by no means complete; for example, sulfur content in coal, crude oils and other fuels is not considered.

E. High Damage, Low Probability Events

Not considered

F. Socioeconomic Effects

Socioeconomic effects beyond the general direct effects of prices on demand and supply of energy are not addressed. The report itself details a number of such effects which relate to the specific scenarios tested, yet such effects are not direct outputs of the model.¹

The analysis used in the report is based upon a forecasting system in which a price sensitive input/output table is linked to a macroeconomic forecasting model. For each of the scenarios, impacts on the national economy in terms of economic growth, housing, price stability, and balance of payments are discussed. Regional energy price and consumption effects are also discussed. Although the analysis is related to the model (scenario) outputs, the analysis is performed exogenous to the PIES model.

IV. Data Base

Data was obtained from task force collaborators and is reported in the Project Independence documents, several of which are referenced here. The actual structure of both the model and data base are not well documented. It would be helpful for proper evaluation to have facsimilies of the actual program and data base structure. Data, of course, is extensive and the quality and content varies in accordance with the assumptions and the task force which prepared it.

V. Computer Implementation

PIES is operated on both CDC 6600 and IBM 370/168 computers. The supply and demand models are primarily FORTRAN and the auxiliary data manipulation and linear programming algorithms are standard software packages.

VI. Documentation/Validation

The actual model documentation is via the mathematical equations, which are laced throughout the report. The demand forecast model based upon the Data Resources, Inc. Energy Policy Model is presently undergoing thorough documentation. Also unavailable is the report describing the modifications which were incorporated in the construction of PIES.

The model results are extensively documented. These, however, are evaluated, based on plausibility of scenarios rather than on validation by testing historical data.

Cost and potential availability of the model as well as actual running times are not known.

VII. Sponsor, Principal Investigator, Current Status

Sponsor:

FEA budget appropriations.

Principal Investigator:

William W. Hogan (currently at Stanford University)

Office of Quantitative Methods

Federal Energy Administration

12th and Pennsylvania Avenue N.W.

Washington, DC 20461

(202)961-8462

Status:

Completed and operational, presently being updated and evaluated.

VIII. References

1. Project Independence Report, Federal Energy Administration, Washington D.C., U.S. Government Printing Office, G.P.O. No. 4118-00029, November 1974.
2. "Project Independence Report: An Appraisal of U.S. Energy Needs Up to 1985," J. A. Hausman, Bell Journal of Economics, Hellerman Press, Worchester, MA, Autumn 1975, pp. 517-551.
3. Data Resources Quarterly Model, Data Resources Incorporated, Lexington, MA, 1974.
4. "Regional Energy Modelling: An Evaluation of Alternative Approaches," A. S. Cohen and K. W. Costello, et al., Argonne National Laboratory, Argonne, IL, June 1975, pp. 76-90., ANL/AA-1.
5. "Testimony before Joint Economic Committee on the FEA's Project Independence Report," M. A. Adelman, J. A. Hausman, H. D. Jacoby and P. W. MacAvoy, March 18, 1975.

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6. Financing Project Independence, Financial Requirements of the Energy Industries and Capital Needs and Policy Changes in the Energy Industries, Federal Energy Administration, Washington, D.C., U.S. Government Printing Office, November 1974.
7. Nuclear Task Force Report, Federal Energy Administration, Washington, D.C., U.S. Government Printing Office, November 1974.
8. Quarterly Report, Fourth Quarter 1974, Federal Energy Administration, Washington, D.C., U.S. Government Printing Office, November 1974.
9. Report of the Inter-Agency Coal Task Force, Federal Energy Administration, Washington, D.C., U.S. Government Printing Office, November 1974.

RESPONS (BECHTEL CLEAN COAL ENERGY MODEL)

I. Introduction and Purpose; Application to Energy Impact Assessment

The RESPONS model was developed by Bechtel for ERDA as a system to "assist energy planners in evaluating large numbers of possible patterns of supplying U.S. energy demands and, within established constraints, in defining the optimal (least-cost) set."^{1,p.iii} The model is a large linear program of the U.S. energy supply system. Particular emphasis is placed on coal energy systems, including coal gasification and liquefaction; other energy sources are also included in less detail.

A. Types of Impacts

The utility of RESPONS for assessing impacts, per se, is somewhat limited. As RESPONS is a least-cost optimization model, the major impacts modeled are direct economic impacts (costs) associated with the construction and operation of various energy supply system configurations.

B. Types of Impact-Generating Activities

Components of the U.S. energy supply system (existing and proposed) comprise the major impact-generating activities in RESPONS. Mining/extracting operations, energy transportation, energy conversion, and energy distribution systems are included. Impacts of alternative operational constraints can be assessed.

C. Type of Analysis - Purpose

The major purpose of RESPONS is national or regional energy policy analysis. The RESPONS model calculated the minimum-cost energy supply system (in terms of energy facility types, locations, and operations) under a given set of assumptions and constraints. Sensitivity analyses can be conducted with respect to any of the input parameters.

Some specific uses which the authors suggest for the model include:

- Study the impact of new coal gasification and liquefaction plants on the total U.S. energy supply system.
- Determine preferred locations of new energy facilities.
- Investigate the economics of flue gas desulfurization systems.
- Determine the value of additional
 - Coal production capacity (by region)
 - Transportation capacity
 - Energy conservation measures.
- Study the effects of various levels of
 - Energy conversion costs
 - Projected energy demand
 - Coal quality at the mine
 - Environmental regulations (SO₂).

D. Time Horizon

The time horizon is theoretically limited only by the data base; the model structure, however, includes only those energy technologies expected to be significant during the next twenty years (i.e., to 1995). The data base which was used to test and demonstrate the model represents the year 1985.

E. Input-Output

The model is driven by an extensive data base. Input data, specified on a regional basis, include:

- Coal production capacities, reserves, prices, sulfur content
- Transportation networks, capacities, costs, efficiencies
- Energy conversion costs, conversion efficiencies, capacities
- Electricity transmission networks, costs, efficiencies
- Sulfur dioxide emission regulations
- End-use demand for each energy form
- Non-coal energy supply
- Capital costs of new (unscheduled) energy facilities

Model outputs, generated in report form, include:

- Quantity and type of coal mined in each region
- Energy transportation load for each fuel type
- Usage patterns for existing energy facilities and the number and preferred location of additional (unscheduled) facilities
- Incremental value of additional fuel supplies, facilities, capacities, etc.
- Sensitivity of model results to changes in various input data values.

II. Methodological Features

A. Modeling Approach

The RESPONS model is a linear programming (optimization) model. It is static in that the results for a given year are yearly totals and averages which are generated independent of data and model outputs for previous years.

B. Major Assumptions

An assumption inherent in the linear programming methodology is that relationships between variables are linear over the range of interest. Some of the specific assumptions in the model structure include:

- Energy demand is exogenously specified.
- Supplies of non-coal primary energy sources are exogenously specified.
- Intra-regional transportation and electric transmission costs were not included.
- Manpower and capital availability constraints were not included.
- No additional cost is associated with mixing coals of various types in an energy facility.
- Inter-regional transportation and transmission costs are modeled as if occurring between the centroid cities of the regions involved.
- Environmental regulations are limited to SO₂ emissions.

C. Structural Hierarchy

There are two levels of spatial aggregation in the RESPONS model: the conterminous U.S. as a whole, and user-specified geographical regions within

the U.S. The model is data-driven, allowing the user to define only those regions and/or portions of the model which he wishes to exercise.

D. Measurement and Evaluation of Impacts

RESPONS contains no measurement or formal evaluation of impacts other than direct economic impacts (costs).

III. Comprehensiveness Features

A. Energy Supply Network

The U.S. energy supply system is modeled as a network of energy-source to energy-end-use activities (operations). Each operation has a number of parameters associated with it, such as per-unit cost, efficiency, and capacity. The various operations in each geographic region are connected to other operations in other regions by transportation links.

Primary emphasis is placed on coal and coal conversion systems. Fifteen different types of coal are identified and categorized according to sulfur content, Btu content, and general mining area (Eastern, Midwestern, Western). Other energy sources are modeled at a considerably reduced level of detail. Included are petroleum, natural gas, and electrical generation. Electrical power plant types include coal, oil, gas, nuclear, hydro, and other (solar, geothermal, etc.).

RESPONS computes the costs associated with mining/extraction, processing, transportation, conversion, and distribution of each energy form. Demands for each energy form are exogenously specified as part of the input data. The model is constrained to produce enough of each energy form to meet or exceed each demand component in each region.

Both present and future energy technologies (to 1995) are included. Advanced coal technologies (gasification, liquefaction, advanced electric power generation) are modeled in considerable detail.

The transportation sector contains the largest number of variables in the linear program. Modes of transportation include mixed train; unit (dedicated) train; water transport; coal slurry pipelines; gas, crude, and

refined product pipelines; and electrical transmission. Transportation/ transmission distances are derived from distances between regional centroids, augmented by linear regression adjustments.

B. Spatial Detail

The user may select one of several configurations of geographic regions, from as few as five Petroleum Allocation for Defense (PAD) regions to as many as 32,000 census tracts. The data base used for the RESPONS test and demonstration runs used 16 Modified PAD (M-PAD) regions containing data aggregated from 243 Air Quality Control Regions. A centroid city was selected for each M-PAD region to represent the geographical center of both supply and demand for the region.

C. Economic Content

Inter-fuel and inter-regional competition are modeled to the extent that, within the specified constraints, the model produces the least-cost energy system which will satisfy a given demand level. With the exception of coal, however, fuel prices are exogenously determined. Coal prices are assumed to be a function of the region where mined and the sulfur/Btu ratio.

D. Environmental Content

Sulfur dioxide emission restrictions, on a regional basis, comprise the only environmental regulation included in RESPONS. Ultimate impacts such as health effects and environmental damage were not modeled.

E. High-damage, Low-probability Events

Not modeled.

F. Socioeconomic Effects

Not modeled.

IV. Data Base

The RESPONS model is data-driven; i.e., the number and location of regions, transportation links, etc., are determined by the data base, not the model itself. The model results therefore, depend on the quality of the data base.

A test and demonstration data base was assembled by Bechtel to simulate the 1985 ERDA Scenario 0 (ERDA-48 Plan) and, with some modifications, Scenario V. The objective was to demonstrate the potential usefulness of the model for energy policy analysis. Major data sources included ERDA publications, U.S. Bureau of Mines and Geological Survey, Federal Power Commission reports, Department of Transportation, Department of Commerce, and technical and trade publications. A total of 610 references are cited in an appendix to Reference 1. According to the authors, data limitations for this demonstration data base are of two main types: uncertain parameters related to new or developing technologies, especially coal gasification and liquefaction and advanced coal-based electrical generating systems; and extrapolation of historical data into the future.

V. Computer Implementation

The RESPON model was designed for implementation on IBM 360 and 370 series computers and cannot be directly transferred to any other type of machine. The model implementation consists of a complex system of computer programs and data files. "The generation, maintenance and reporting of the linear programming model requires the use of a complex series of file structures and computer programs using several different programming languages ... A knowledge of the MPS-III system, the DATAFORM Program Control Language (PCL), and the IBM Job Control Language (JCL) is required."^{2,p.2} The main program, written in the DATAFORM language, generates the linear program matrix from the data base. Other programs, written in FORTRAN, are used for file manipulation.

The documentation is unclear as to whether the model is accessible by remote terminal. There are no interactive or graphical features.

VI. Documentation/Validation

The Bechtel RESPON model is a well-documented large linear programming model of the U.S. energy supply system, with emphasis on coal and coal conversion systems. It is designed to be used as a policy analysis tool for computing least-cost energy supply options. Its chief advantage is its ability to handle large numbers of variables and to perform parametric

(sensitivity) analyses. The usability of the model by anyone other than the developers is restricted by the extreme complexity of the computer implementation and by the fact that the model can be run only on IBM 360 and 370 machines.

The model and data base (Reference 1) and the computer implementation (Reference 2) are, in general, very well documented. Inputs and results from the demonstration runs (1985 ERDA Scenarios 0 and V) are presented in Reference 1.

Validation is not directly addressed. The results of the demonstration run were used to estimate the usefulness of the model for policy and sensitivity analyses.

VII. Sponsor, Principal Investigator, Current Status

Sponsor: U.S. Energy Research and Development Administration

Principal Investigators:

Phiroze J. Nagarvala, George C. Ferrell, and Leon A. Olver
Bechtel Corporation
San Francisco, CA

Current Status: Completed (1976).

VIII. References

1. Phiroze J. Nagarvala, George C. Ferrell, Leon A. Olver, "Regional Energy System for the Planning and Optimization of National Scenarios (RESPONS): Final Report," ERDA-76-109, Bechtel Corporation, June 1976.
2. "Regional Energy System for the Planning and Optimization of National Scenarios (RESPONS): System User's Manual," Bechtel Corporation, June 1976.

COMPARATIVE RISK-COST-BENEFIT STUDY OF ALTERNATIVE SOURCES OF ELECTRICAL ENERGY (WASH-1224)

I. Introduction and Purpose; Application to Energy Impact Assessment

The end product of the WASH-1224 project, completed in 1974 by the U.S. Atomic Energy Commission (now ERDA), is not a model; rather, it is a voluminous 250-page report. This document resulted from a very comprehensive study of the relative costs, both direct and indirect, associated with the commercial production of a given quantity of electrical energy by alternative means. Because a model (computerized or otherwise) is not involved, the evaluation of this study must necessarily take a somewhat different format from the other evaluations. The comparison and evaluation outline will, however, be followed as much as possible.

WASH-1224 has direct application to energy impact assessment; its usefulness is, of course, limited to the information presented and referenced in the report. The report contains numerous tables and charts which present both statistically derived and estimated data for comparing costs and impacts from four types of electrical power plants and their associated fuel cycles: coal, residual fuel oil (RFO), natural gas, and light water nuclear reactors. Hydro power is also discussed, but very little comparative data is developed for this method of power generation.

A. Types of Impacts

A wide variety of impacts are addressed in WASH-1224. These are classified into four main categories:

- Diversion of capital, labor, and materials (direct economic impacts)
- Depletion of non-renewable fuel resources
- Degradation of the environment (both natural and man-made)
- Impacts on human health and safety

B. Types of Impact-Generating Activities

WASH-1224 is restricted to the study of impacts of electrical energy generation, including the impacts of the fuel cycles associated with each type of power plant.

C. Type of Analysis - Purpose

The purpose of the WASH-1224 study was to provide a quantitative basis for comparing societal costs of alternative electrical energy production systems.

D. Time Horizon

The data values were adjusted to apply, on the average, to plants going on-line in the year 1980.

II. Methodological Features

An extensive literature survey was undertaken to identify and quantify numerous types of impacts. Equilibrium fuel cycle material balances were used as a basis for the impact data; thus the results are static (scaled to the year 1980). Much of the report deals with the derivation and justification of methods used to measure and evaluate "external" costs (impacts) such as environmental damage and public health hazards. For comparative purposes, all impacts were normalized to a base of 1000 MWe of electrical energy generating capacity operating for one year at an average of 75% capacity. Where feasible, costs and impacts were expressed in equivalent dollars per unit of electrical energy produced.

III. Comprehensiveness Features

A. Energy Supply Network

WASH-1224 is limited to a consideration of electrical energy generation and its supporting fuel cycles. Four types of electrical generating plants are studied in detail: coal, residual fuel oil (RFO), natural gas, and light water nuclear reactors (LWR's). The latter category includes both boiling water reactors (BWR) and pressurized water reactors (PWR). A fifth power plant type, hydro, is discussed qualitatively, but very little quantitative cost/impact data is developed.

Each of the four fuel cycles is studied in all phases from extraction through electrical energy generation. Impacts from each fuel cycle phase are estimated.

Consumption is not considered in this study, nor are future technologies. Only current commercial power plant types are considered. HTGR and LMFBR nuclear reactors, for example, are not included.

B. Spatial Detail

The study is based on aggregate data for the United States.

C. Economic Content

WASH-1224 does not consider inter-fuel or inter-regional competition; it does allow for the effect of declining resource reserve levels upon fuel prices in computing relative costs (impacts) or non-renewable fuel resource depletion.

D. Environmental Content

Environmental impacts are extensively covered. Air, water, land use, and ecological systems are all addressed in detail. Gaseous emissions and airborne particulates, hydrocarbons, heavy metals, sludge, radioactive materials, waste heat discharge, and physical alternation of the environment are discussed and quantified. Pollution abatement costs are also addressed.

WASH-1224 attempts to quantify damage to both natural environment and man-made materials resulting from given amounts of each type of pollutant.

E. High-Damage, Low-Probability Events

WASH-1224 is restricted to the study of impacts from routine operations and events. Large-scale, low-probability events such as catastrophic failure of a nuclear reactor are not considered. Smaller scale accidents for which there are sufficient statistical data to establish probabilities of occurrence are included; their impacts are evaluated according to their relative probability of occurrence and the consequences of each event.

F. Socioeconomic Effects

Health and safety hazards constitute the principal socioeconomic effects studied in WASH-1224. Occupational and public health effects were treated separately. Health effects are measured in terms of man-day lost (MDL).

Conversion to an equivalent cost is made using a factor of \$50/MDL. Each life lost is considered equivalent to 6000 MDL (\$300,000). Public health effects of airborne fossil fuel pollutants were not quantified in terms of dollar cost.

IV. Data Base

Data sources too numerous to mention are referenced at the end of each major section of each chapter of the report.

V. Computer Implementation

(Not applicable)

VI. Documentation/Validation

The WASH-1224 report, while not a computer model, contains a vast amount of derived impact data and conventional cost data for four types of electrical power plants and their supporting fuel cycles. The results are static (base year 1980), normalized to a given quantity of electricity produced, and where feasible, converted to equivalent dollar costs for comparative purposes. The report is potentially a valuable data source for energy impact assessment models.

The WASH-1224 report is very well written and well organized; this is somewhat to be expected, since the report is the only visible product resulting from the project. There are numerous tables which compare and cross-compare the relative impacts of the four power plant types in almost every conceivable way. Some of the information concerning the ground rules and methodology of the study is repeated in several places. A more concise executive summary of the findings would have been desirable (the section entitled "Summary and Conclusions" is 20 pages long).

VII. Sponsor, Principal Investigator, Current Status

Sponsor: U.S. Atomic Energy Commission (ERDA)

Principal Investigator:

Shelby T. Brewer

ERDA/Div. of Reactor Research & Development

Current Status: Completed December 1974

VIII. References

Comparative Risk-Cost-Benefit Study of Alternative Sources of
Electrical Energy, U.S. AEC Report WASH-1224, December 1974.

STRATEGIC ENVIRONMENTAL ASSESSMENT SYSTEM (SEAS)

I. Introduction and Purpose; Application to Energy Impact Assessment

SEAS is a system of interconnected models developed by the United States Environmental Protection Agency (EPA) to provide an analytical means for assessing the long-range impacts of socioeconomic activities and policies on the environment. SEAS is intended to be "an 'environmental early warning system' to assist the Administrator of EPA, the 10 Regional Administrators of EPA, and others in forecasting the state of the environment and significant pollution problems that are likely to exist 10 to 15 years into the future."¹

"The 'users' of the model will be limited to a group of people ... who will do the policy analysis of the questions of the decision-makers."²

A. Types of Impacts

Assessment of environmental impacts is the major function of SEAS. Based on a given set of assumptions (model inputs), the SEAS Input-Output (I-O) model generates detailed forecasts of U.S. economic activity to 1985. Included in the SEAS system is a model which estimates energy use by fuel category. These forecasts of economic activity and energy consumption are used to forecast pollutant residuals at the national level. These residuals are then disaggregated to the ten Federal EPA administrative regions. The secondary effects and socioeconomic reactions resulting from these pollutant levels are also predicted. Economic and social impact assessment is thus a secondary function of SEAS.

B. Types of Impact-Generating Activities

The major types of impact-generating activities which SEAS was designed to analyze are consumption patterns and technological developments. To a lesser extent, SEAS can be used to evaluate impacts resulting from alternative governmental policies (e.g., environmental quality regulations) and from different mixes of energy extraction and distribution methods.

C. Type of Analysis - Purpose

The SEAS I-0 model contains technological coefficients which can be changed to represent different assumptions regarding future production and consumption patterns which directly and/or indirectly affect energy usage. The model can then predict the resulting impacts upon the economy and the environment.

The effects of substitution technologies can also be studied with the model. The prototype model is capable of simulating 17 different types of product and material substitutions.

Other types of energy-economic-environmental tradeoffs can also be analyzed with SEAS.

D. Time Horizon

The model generally operates on a time horizon extending from the present to 1985; extensions to 1990 are possible.

E. Input-Output

Major inputs to SEAS are projections of economic growth (including population, economic activity, consumer activity, technological factors, and other "change agents"); initial "stock" (resource) levels; initial pollution levels; and certain policy parameters such as pollutant emission standards.

Outputs are reported in considerable detail by geographic region and as national totals. Outputs for each forecast year include "stock" levels, amounts of residuals by category and specific type, and socioeconomic effects and reactions (e.g., pollution abatement costs; solid-waste recycling activity).

II. Methodological Features

A. Modeling Approach

The SEAS system is composed of various types of interconnected models.

The heart of SEAS is a modified version of INFORUM, a 185-sector inter-industry input-output (I-O) model developed at the University of Maryland and based on 1971 U.S. input-output tables. Independent projections of population (Series E), business activities, and technological growth are provided as inputs to the I-O model, which then generates material and energy flows through the economy on an annual basis through 1985. These results are then fed to several other models which determine the amount of residuals (pollutants) generated by each economic activity, the environmental and socioeconomic effects of these residuals, depletion of resource reserves, energy consumption, and socio-political reactions (such as pollution abatement costs and resource recycling activities).

Thus SEAS can be classified primarily as a collection of input-output and forecasting models. It is static rather than dynamic in that forecasts are produced for discrete points or intervals in time (e.g., yearly totals) by static-equilibrium models, as opposed to "continuous" time histories which would be produced by a dynamic simulation model.

B. Major Assumptions

The externally-derived projections for population, business activities, and technological change constitute major assumptions. In addition, the inter-industry I-O model inherently assumes linear relationships between industrial outputs and the material and energy (labor) inputs required to produce them. The other SEAS models also use many linear coefficients (e.g., residual generation coefficients).

C. Structural Hierarchy

SEAS operates on two levels of aggregation: national and regional (ten Federal EPA regions).

D. Measurement and Evaluation of Impacts

SEAS does not internally evaluate the results of the model forecasts in terms of composite or comparative indicators. Any formal evaluation of the model results must be done externally by the user.

III. Comprehensiveness Features

A. Energy Supply Network

Energy use is estimated by fuel category and by six consumer categories: industrial, commercial, residential, transportation, electric utility consumption, and electricity generation. Five system processes (fuel cycle phases) are considered: extraction, production, distribution, consumption, and disposal.

B. Spatial Detail

SEAS produces national forecasts and then disaggregates these forecasts to smaller geographical subdivisions "after the fact." These subdivisions can include Standard Metropolitan Statistical Areas, states, and the ten Federal EPA administrative regions.

C. Economic Content

The model has considerable economic detail. Some of the 185 industrial I-O sectors are further disaggregated by "side equations" according to product mix and technology mix within a given sector. The model can be classified as a demand model in that there are no real constraints on supply, although the resource depletion model does keep track of the amount of depletion of each major resource, and raw material costs are adjusted accordingly.

D. Environmental Content

Residuals (pollutants) are generated by five system processes: extraction, production, distribution, consumption, and disposal. Three categories of residuals are considered: airborne, water-borne, and solid waste. An extensive bookkeeping system, involving a ten-digit code, is used to categorize and trace a large number of specific residuals as they move through the environment.

E. High-damage, Low-probability Events

SEAS does not model either the probability or the expected results of high-damage, low-probability events.

F. Socioeconomic Effects

SEAS predicts some specific socioeconomic effects from and reactions to the forecasted pollution levels and depletion of resource reserves. The major effects/reactions include pollution abatement costs and resource recycling activities. However, SEAS fails to convert pollution and environmental quality levels into societal effects such as human health, property values, recreation, and aesthetics.

IV. Data Base

The comprehensive data base for SEAS includes compilations of "expert opinion" as well as historical time-series data and projections into the future. Data sources are numerous and include U.S. Bureau of Labor Statistics and Commerce Department economic forecasts; census data; EPA emissions and engineering cost data; energy data from the Federal Energy Administration; data on resource reserves from the Bureau of Mines, U.S. Geologic Survey; and the OBERS regional growth projections from the Department of Commerce and the USDA.

V. Computer Implementation

SEAS is programmed in FORTRAN IV on an IBM 360 model 158 in Bethesda, Maryland. The model can be operated from a remote terminal, but it does not at present contain any interactive capability. Output consists primarily of tabular data which can be generated in a wide variety of report formats, including executive-type summaries. A limited amount of graphical output is available.

VI. Documentation/Validation

The major strong point of the SEAS system of models is its economic and environmental comprehensiveness. Its vast bookkeeping and data handling system can provide a tremendous amount of information at whatever level of detail is required by environmental policy-makers. The fact that a team of analysts are required to act as interpreters between the decision makers and the model (at least on the input end) tends to limit the flexibility and usefulness of the model for applications other than that for which the model was specifically designed.

The early model development was rather highly publicized and well documented. The major SEAS document to date is a voluminous EPA report describing the prototype SEAS model.³ This report was published in 1974 along with a volume of computer program specifications and user's manual.⁴ These documents are comprehensive and generally well written.

Model validation is not well addressed. It appears that "expert opinion" and "common sense," combined with the incorporation of previously developed and tested models, comprised the major validation tools.

VII. Sponsor, Principal Investigator, Current Status

Sponsor:

U.S. Environmental Protection Agency

Principal Investigator:

Dr. Peter House, Assistant Director

Office of Research and Development

U.S. Environmental Protection Agency

Washington, DC

Status:

Phase II (Prototype Model) was completed in 1975.

Phase III (Full Operational System) was completed in 1975.

Phase IV (Expansion to include economic-energy-environmental tradeoffs) is currently in progress.

VIII. References

1. "Strategic Environmental Assessment System (SEAS)," Simulation in the Service of Society, Vol. 3, March 1973, pp. 1-3.
2. "Environmental Modeling vs. the 'Chicken Soup' Approach: Work in Progress," Peter W. House, Simulation, Vol. 20, June 1973, pp. 181-191.
3. "Prototype Development of the Strategic Environmental Assessment System (SEAS)," Washington Environmental Research Center, U.S. Environmental Protection Agency, Washington, DC, 1974.
4. "Program Specification: SEAS Extensions to Inter-industry Forecasting Model (INFORUM)," B. S. Miller (Control Data Corporation), U.S. Environmental Protection Agency, Washington, DC, 1974, and other SEAS program specification documents.

VIII. References (contd)

5. "Input-Output in Environmental Protection Agency's Strategic Environmental Assessment System (SEAS)," R. U. Ayres, et al., presented at the Sixth International Conference on Input-Output Techniques, Vienna, Austria, April 1974.

WISCONSIN ENERGY MODEL (WISE)

I. Introduction and Purpose; Application to Energy Impact Assessment

The Wisconsin Energy Model is being developed by the Energy Systems and Policy Research Group at the University of Wisconsin to provide quantitative tools for energy policy analysis.¹ Its purpose is to study energy conservation, transport, utilization, and environmental impact within a spectrum of alternative futures for the State of Wisconsin.

The stated objectives are:

- "Improvement of understanding of the causes and the dynamic behavior of society's long-term energy demand in Wisconsin
- Develop a capability to forecast energy demand in Wisconsin and to test the effect of various policies on that demand
- Modeling of the available supply options for meeting energy demands and the quantification of their potential for environmental impact
- Analysis of the policy implications of the above options and also their potential for actual implementation
- (Create) effective communication channels through the model results to government decision-makers, citizens, and private groups having a role in energy policy."¹

A. Types of Impacts

The WISE model has five major components, one of which is comprised of environmental impact submodels. The objective of the impact submodels is:

"To simulate on a year-to-year basis the total environmental impacts - to the degree quantifiable - arising from energy usage in Wisconsin."³

Impacts are broadly defined to include effects on land, air, water, structures, and living things, including health and safety of both the general public and those directly employed in the energy system. Although WISE is a subregional or state model, environmental impacts are treated in all stages of energy flow from extraction to distribution. In this case, the impact sector differs from the others of the model in treatment of effects both inside and outside the state.

B. Types of Impact-Generating Activities

Potential applications for the model are Wisconsin's alternatives for energy conservation, prediction of demand for electrical generating capacity, the evaluation of impacts of natural gas diversion, and state commercial and public building codes. The WISE model may be used to predict future energy requirements on a statewide basis provided past trends are valid. The model concentrates on the final demand and electric generation aspects of the energy system with the state.

The effects of resource availability and economic impacts are not considered as part of the model. The interacting supply and demand for energy under alternative scenarios are the key environmental impact-generating activities. It is possible to test for changes in consumptive patterns proscribed to the model and to determine the quantifiable environmental impacts. The model does not explicitly include technological development or governmental policies expected to directly relate to impacts.

C. Type of Analysis

A "pathway" approach is used in the model wherein five types of impacts may result from a given source. The first pathway includes impacts such as air pollution from coal-fired plants, chemical releases, and waste heat. Direct effects such as land and water use are the second pathway. Health and accident risk for the general population and for occupational exposure form the third and fourth pathways. Pollution from fuel resource use such as the nuclear fuel cycle forms the last route. The first and last paths include transport, exposure, and dose response or damage functions.

D. Time Horizon

The time horizon for the model extends from 1970 through the year 2000.

E. Input-Output

The model, as mentioned, is a dynamic model using exogenous inputs for the driving function of population. Likewise, it is necessary to provide the generation requirements and fuel end uses if the impact model is to be exercised separate from the overall model. The overall model has a detailed energy demand/supply system.

The major input parameters and exogenous variables for the overall model include:

- engineering/technological parameters (energy intensiveness coefficients, appliance efficiencies, etc.)
- alternative population and economic projections,
- policy parameters (regulations, constraints, etc.),
- energy supply (except electricity)

Output is total energy demand by fuel type and consuming sector, associated impacts, and tabulations of the scenarios. Separate exercise of the impact submodel requires specification of generation requirements and end uses of fuels over time as determined from the remainder of the model.

II. Methodological Features

A. Modeling Approach

The WISE model is best characterized as a dynamic simulation model which incorporates trend analysis. Many of the socioeconomic and technological driving forces (e.g., intensiveness) must be specified externally, thus the time histories of these parameters are major assumptions. The primary driving parameters of the model are population, value added, and other socioeconomic parameters. Integration is achieved by defining most parameters on a per capita basis, thus using population to drive the model.

B. Major Assumptions

A major assumption is that the use of energy intensiveness coefficients also invokes linear energy-use relationships for such items as retail sales, vehicle miles, etc. Because Wisconsin contains essentially no primary energy production but rather energy conversion in the form of electrical generation, the energy supply portion of the model is determined exogenously. Clearly it is therefore impossible to evaluate any secondary or feedback effects from demand to supply. With the above in mind, the WISE model may alternatively be characterized as a demand model.

C. Structural Hierarchy

For the purpose of treating environmental impact, the energy conversion and supply industry is divided into nonelectrical and electrical categories. The method for determining the impacts in the model is to use "impact factors" associated with each type of electrical generating capacity and each fuel consumed in the nonelectrical category. The factors have been determined from collection and analysis of available data and stored as functions of kilowatt-hours or Btu.

D. Measurement and Evaluation of Impacts

The impacts for electrical energy are calculated by multiplying the matrix of impact factors by the generation or capacity of each energy source in each year. These can be summed over the desired number of years to obtain cumulative impacts. They can also be aggregated for all sources to get totals for a given year or for impacts with similar units.

The impacts determined by the model are quantitative results which contain minimum of associated value judgment.

III. Comprehensiveness Features

A. Energy Supply Network

The overall model estimates the demand within the state of Wisconsin for coal, oil, natural gas, and electricity. Although built for Wisconsin, the concepts appear applicable to other states or regions. The demands are estimated for the residential, commercial, industrial, agricultural, and transportation sectors. The items in the industrial sector are identified by 2-digit SIC codes; the residential sector by urban single

family, multi-family and rural dwellings. The physical processes for industry are space and process heat whereas the residential sector also includes classes of primary and secondary appliances. Crop and livestock activity comprise the agricultural sector; transportation includes passenger and freight vehicles. The commercial sector primarily involves space heating and air conditioning based upon floor space estimates.

As mentioned above, the energy conversion and supply industry is divided into electrical and non-electrical categories. For the non-electrical category the three basic fuel flows modeled are coal, petroleum, and natural gas. For the electrical category, the systems are defined according to the type of conversion device used, including: coal, pressurized water reactor, boiling water reactor, high temperature gas cooled reactor, liquid metal fast breeder reactor, oil fired plants, hydro and peaking plants.

B. Spatial Detail

The spatial aspects of the model are separated into those impacts occurring within and outside the state. Fuel consumption impacts are considered only within the state. No ancillary fuels are considered in determining the impacts for the energy supply system. The end uses of primary fuels within the state are considered.

C. Economic Content

WISE cannot be classified as an econometric or economic model since demands are estimated by projecting population or some per capita quantity such as value added and then scaling by an intensiveness coefficient.

D. Environmental Content

Impact factors are associated with each generation capacity type and each fuel consumed in the non-electrical sector. A number of the coefficients are not final impacts. For example, the radionuclides released from a nuclear reactor form one set of factors, while population dose received from the radionuclides is another factor; the final impact is the somatic and genetic effects of the exposure.

The impact of alternative exogenously specified technical efficiencies (e.g., appliances) may be considered by sector, fuel type, or physical

process. Physical processes include lighting and some production process. The model is being extended to classify demands spatially and temporarily as well.

E. High-Damage, Low-Probability Events

Probabilities for health-related events are included. No analysis is made for low probability high-risk events.

F. Socioeconomic Effects

Social and demographic factors, as previously indicated, are exogenously determined. The user can choose from among several forecasts, all of which are primarily based on trend analysis. Population is disaggregated by age, sex, and geographically by counties. Associated with the demographic data are migration, fertility, and mortality figures which form a "reference" projection of total population growth plus high and low estimates.

IV. Data Base

A. Source(s)

The data base comes from diverse sources. Included are census information on business, manufacturing, government, and population; Wisconsin Utilities Reports; National Power Surveys; Wisconsin Department of Administration Population Projects; U.S. Commerce Projection of Economic Activity; and other sources.

B. Structure and Organization

The program utilizes external data files primarily scaled on a per capita basis. Many of the technological coefficients are generally input or internal to the model. Some can be changed by the user.

V. Computer Implementation

The WISE model is programmed in FORTRAN and executed on a UNIVAC 1110 machine. A command language, WISSIM, unique to the University of Wisconsin, is used in program execution. The model presently operates on a timesharing system and allows remote interactive or remote batch processing. Graphic displays are also available.

VI. Documentation/Validation

The model is well documented by a score of reports on portions of the model, methodology, and results. Some discussion of validation is scattered throughout the reports but is not well addressed. The criteria appears to be comparison of the model runs from 1970-1975 with historical data.

VII. Sponsor, Principal Investigator, Current Status

Sponsor:

Upper Great Lakes Regional Commission,
Project No. 10420214 and
National Science Foundation, Program
of Research Applied to National Needs
(GI-43088)

Principal Investigator:

W. K. Foell, Director, Energy Systems and Policy Research Group
Nuclear Engineering Department and the
Institute for Environmental Studies
University of Wisconsin
Madison, WI

Status:

The initial version is now operational and interacts with an "extensive" data base. Present research efforts are now providing energy forecasts, policy recommendations, data, etc., to several state agencies and to various parts of the private sector. Current research in the impact submodel is to develop a detailed geographic distribution of impacts and their relation to centers of population.

VIII. References

1. "The Wisconsin Energy Model: A Tool for Regional Energy Policy Analysis," W. K. Foell, Energy Systems and Policy Research Report No. 10, The University of Wisconsin, November 1974.
2. "A Model of Environmental Impact of Wisconsin Electricity Use" W. A. Buehring, W. K. Foell, Energy Systems and Policy Research Report, No. 6, The University of Wisconsin, November 1974.
3. "Environmental Impact of Regional Energy Use: A Unified Systems Approach", W. A. Buehring, W. K. Foell and R. L. Dennis, Energy Systems and Policy Research Group, Institute for Environmental Studies, University of Wisconsin - Madison, September 1974.
4. "Energy Use In Wisconsin - Survey of Energy Flow in the State of Wisconsin," W. K. Foell and J. E. Rushton, The Institute for Environmental Studies, Report #4, The University of Wisconsin, October 1972.
5. "Energy Use for Transportation in Wisconsin: A Mathematical Model," M. A. Caruso, Masters Thesis in Nuclear Engineering, University of Wisconsin, 1973.
6. "Modeling of Environmental Impacts for Electrical Energy Generation in Wisconsin", W. A. Buehring and W. K. Foell, Trans. American Nuclear Society, Vol. 17, November 1973, pp. 64-65.
7. "Alternative Future Electrical Generation Requirements for the State of Wisconsin," W. A. Buehring, W. K. Foell, and P. H. Hunter, Energy Systems Research Group, University of Wisconsin, November 1974.
8. "A Model of Residential Energy Use in Wisconsin," D. A. Frey, Institute for Environmental Studies Report No. 37, University of Wisconsin, Madison, December 1974.
9. "A Simulation Model of Long Range Expansion of Electricity Generation Capacity in Wisconsin," J. Peernboom, W. K. Foell and J. L. Pappas, Institute for Environmental Studies Report No. 38, University of Wisconsin, Madison, December 1974.
10. "A Model of Commercial Energy Use in Wisconsin," D. A. Jacobson J. W. Mitchell, and J. L. Pappas, Institute for Environmental Studies Report No. 36, University of Wisconsin, Madison, December 1974.
11. "Implications of Commercial Building Codes for Energy Conservation," J. W. Mitchell and D. A. Jacobson, Institute for Environmental Studies Report No. 42, University of Wisconsin, Madison, December 1974.
12. "The Wisconsin Industrial Energy Use Model: Description of the Model and Analysis of Alternative Futures," D. B. Shaver, J. L. Pappas, and W. K. Foell, Institute for Environmental Studies Report No. 43, University of Wisconsin, Madison, May 1975.

EPA'S STATE OF THE SYSTEM (SOS) MODEL

I. Introduction and Purpose; Application to Energy Impact Assessment

"The State of the System (SOS) Model is being developed as a technique to analyze different alternate approaches for melding the growth desires of a population with the limitations of the locale in which the populace exists."¹, p.40 The model used the ecological concept of a "regional carrying capacity" to test the feasibility of proposed comprehensive regional development plans.

SOS has potential application to energy impact assessment on a regional basis, but in a somewhat indirect way. Instead of attempting to determine directly the resulting impacts of hypothesized energy generation and consumption patterns, SOS evaluates whether the desired growth of a region (including energy aspects) can be achieved within the limits of constraints imposed by the region's environment and resource base and by the minimum acceptable living standards of the populace. Viewed another way, the model can be used to determine an optimum growth path to reach a set of desired goals, or to identify the dominant societal and environmental limiting factors with respect to those goals.

A. Types of Impacts

Although SOS does not directly evaluate impacts of proposed policies or events, the model may be described as a study of the impact of resource limitations and environmental constraints upon the realizable economic and societal growth patterns of a region.

B. Types of Impact-Generating Activities

SOS simulates growth patterns within a geographical region: growth in population, per capita consumption, private production, and public services.

C. Type of Analysis

SOS can be used to test a "comprehensive regional plan" for achievability within the constraints discussed above. It can generate an optimum growth path

for achieving a set of goals for the region. SOS can identify the dominant societal and/or environmental limiting factors with respect to a given growth plan.

D. Time Horizon

SOS simulation runs normally begin in 1970 and extend over a time horizon of up to 25 years.

E. Input-Output

Required input data includes parameters to describe the initial state of the region, a set of societal and environmental constraints representing the "carrying capacity" of the region, and a set of goal values representing the region's comprehensive plan (i.e., the desired state of the region at the end of the simulation time period). Available output is extensive and includes a year-by-year description of the state of the region in terms of population, production, resource levels, environmental quality, and measures of per capita living standards. The output also includes a description of the types and amounts of adjustments made to the system as a result of the imposition of constraints, and the extent to which the desired goals were achieved.

II. Methodological Features

A. Modeling Approach

The SOS model can best be described as a sub-optimization or goal-seeking dynamic simulation model. The model advances through time in one-year cycles using demographic and economic growth rates which are designed to achieve a set of pre-selected goals (comprehensive plan) for the region by the end of the total simulation time period. During each one-year cycle, the effects (impacts) of the proposed growth rates, in terms of such things as resource depletion, environmental pollution, and per capita living standards are computed and compared to pre-determined constraint levels. The constraints act as system limitors by forcing the system to make adjustments so as to

satisfy the requirements of the constraints. These adjustments may include growth rate alterations which prevent the region from achieving some or all of its desired goals.

B. Major Assumptions

A basic assumption inherent in the model is that the most cost-effective measures are always implemented and that a region will always achieve the growth pattern it desires, within the limits of the constraints discussed above. This highly optimistic assumption is tempered somewhat by the use of time delays to take into account the inertia which must be overcome when "system adjustments" are made.

C. Structural Hierarchy

SOS contains only one level of spatial aggregation, that of the region to which it is applied. (The region can be an entire nation.)

D. Measurement and Evaluation of Impacts

Eleven distinct indicators are computed by SOS as a measurement of the "State" of the System (region) for a given year. Included are such measures as education output per student and per capita, manufacturing output per worker and per capita, agricultural output per worker and per capita, and health services per capita. A composite quality-of-life indicator is also computed.

III. Comprehensiveness Features

A. Energy Supply Network

Six basic resource groups are considered: energy, minerals, food and fibers, land, labor, and capital. In SOS-1, these categories are further broken down into as many as 20 resource types. Energy sources are coal, oil, and electricity. (Omission of natural gas could be considered a serious deficiency.)

The model addresses some aspects of both supply and demand. Resource "reserves" including energy resources, are dynamic in SOS. As simulated economic, technological and resource depletion conditions change, portions

of the "total stock" of a resource which were formerly not included in the "reserve" category can become reserves due to that portion now becoming economically feasible to extract. Relative cost advantages drive the demand portion of the model.

B. Spatial Detail

SOS is intended to represent a single aggregated region (which may be an entire nation). Exports, imports, investment flows, and net population migration are determined entirely by conditions within the region. There is presently no differentiation between imported and internally-supplied resources.

C. Economic Content

SOS simulated interfuel competition and substitution, but this is done primarily in response to simulated changes in energy resource availability and per-unit costs rather than in response to specific policies.

Economic production activity is partitioned into a private production sector and a public services sector. Each of these two sectors is further disaggregated into five components. Output is measured in terms of annual levels of expenditure for maintenance and production.

Land use categories include commercial, industrial, residential, agricultural, recreational and other. Energy consumption, however, is not explicitly disaggregated by consumption sector or process.

The age structure of the population is simulated using four age groupings. The population is further partitioned according to educational and economic status in order to account for differences in consumption patterns and to better simulate the availability and productivity of labor.

Resource recycling activities and industrial process changeovers (including energy conversion processes) are simulated. These activities are driven primarily by relative cost advantages.

D. Environmental Content

Air and water are categorized as resources, but they are evaluated according to quality rather than quantity. Costs of treating air and water (pollution abatement costs) are also computed. Minimum acceptable air and water quality standards serve as system constraints by forcing investments in pollution abatement sufficient to meet those standards.

E. High-damage, Low-probability Events

Discrete events of this type are not simulated by SOS.

F. Socioeconomic Effects

Specific socioeconomic effects are calculated as a result of the adjusted growth patterns permitted by the imposed constraints of the region. These effects are evaluated in terms of the eleven system indicators mentioned previously.

IV. Data Base

The data base for the initial test version of the model (SOS-1) was chosen to approximate the United States in 1970. Sources include U.S. Census data (1970) from 1972 U.S. Statistical Abstracts. Economic growth rate trends were projected from 1950-1970 U.S. economic data. Other data sources were obviously used but were not documented.

V. Computer Implementation

SOS-1 was programmed in FORTRAN IV on the OSI IBM 360/158 in Bethesda, Maryland. The model is accessible via remote terminal but has no interactive capability. Both tabular and graphical (line-printer plot) outputs are available.

VI. Documentation/Validation

The SOS model is an interesting application of suboptimization (goal-seeking) modeling techniques. Its chief advantage is its capability for studying man's adaptability to changes and constraints in his environment. The model is probably over-optimistic in this regard, however. The SOS model

is not energy or policy oriented, and its utility for energy impact assessment is somewhat minimal.

The major documentation of SOS consists of a 1974 EPA report² which includes a description of the initial model implementation (SOS-1) and results from several test runs. This document is very comprehensive but it is rather poorly written from the standpoint of clarity and conciseness.

The only validation criterion seems to be that the results of the model tests "appear credible"; however, validation is not as critical for a goal-seeking model as for a forecasting model.

VII. Sponsor, Principal Investigator, Current Status

Sponsor:

U.S. Environmental Protection Agency

Principal Investigators:

Dr. Peter W. House and Edward R. Williams

Office of Research and Development

U.S. Environmental Protection Agency

Washington, DC

Status:

SOS-1 (initial example model) was completed September 1973.

SOS-2 (full working model) was completed in 1974.

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BROOKHAVEN NATIONAL LABORATORY ENERGY MODELS

I. Introduction and Purpose; Application to Energy Impact Assessment

The Brookhaven National Laboratory (BNL) Energy Modeling System is currently developing and operating a set of energy models for technology assessment and policy analysis. Models that make up this inter-connected set are:

- Energy Model Data Base (EMDB)
- Data Base Creation and Maintenance Program (ERODE)
- Energy Model Interface Program (EMIP)
- Energy System Network Simulator (ESNS)
- Energy System Generator (ESYG)
- Brookhaven Energy System Optimization Model (BESOM)
- Reference Energy System (RES)
- Perturbed Energy System (PES)
- Dynamic Energy System Optimization Model (DESOM)

Also currently under development is a combination of BESOM with an input-output model developed at the University of Illinois and a combination of BESOM with a model developed at Data Resources Incorporated.

As overview, the EMDM is the basis for all the BNL models and is intended to be a model-independent data system. The ERODE program is used to update and maintain the data files and EMIP acts as a data selector, converting it into a format that is compatible with other program's needs. The ESNS model determines an energy network using EMIP. The user specifies the network which may in turn determine a reference or perturbed energy system. Those two energy systems may also be determined via the ESYG and BESOM models. Instead of specifying an allocation of energy supplies as in ESNS, the BESOM model solves a linear programming problem which performs the allocation. ESYG performs the data interface in a manner similar to EMIP. The DESOM model adds the temporal dimension to the allocation.

With regard to impact assessment, the Reference Energy System (RES) or the Perturbed Energy System (PES) are the end products. These end products may be determined in several ways as indicated above.

A. Types of Impacts

The purpose of the Reference Energy System⁵ is to describe the major components of the energy system from resource to end use. It also provides a format for representing the technological structure and the associated emissions of the system. The RES utilizes existing technology; the PES substitutes alternative technologies. The objective is to perform comparative analysis between the alternate systems.

The key impact areas associated with the energy system are emissions, costs, and resource consumption throughout the system. Most of the information is stored in the EMDB and is used for system characterization.

The Energy Model Data Base contains two types of files, one dealing with processes associated with modes of energy supply, and one dealing with energy consumption. For each process or type of end-use there are as many as fifty categories of impact and cost data.

B. Types of Impact-Generating Activity

The key impact-generating activities are energy supply related. Included are efficiency factors, emission factors, health data, and annual cost data for various energy supply processes from extraction to end use.

C. Type of Analysis

Since the purpose of the modeling activity is to assess alternative energy (supply) technologies within the U.S. energy system, the analysis is to compare alternative hypothetical descriptions of the system. This allows, via specification of various supply system structures, testing the effect of alternate technologies, varying end-use patterns, and possible policies influencing the structure itself. Since the system may be exogenously specified, as via ESNS, restrictions such as resource availability may also be considered.

D. Time Horizon

Energy systems have been formulated for the years 1977, 1985, 2000, and 2020. This is also the time range for the dynamic system.

E. Input-Output

For a given year or years, output includes resource consumption, environmental effects, and costs for the system. If the ESNS model is utilized, the user formulates different scenarios on fuel use patterns. For the linear programming model, energy consumption patterns are computed internally.

II. Methodological Features; Key Model Attributes and Philosophy

A. Modeling Approach

The Brookhaven models, with the exception of the currently evolving DESOM, are static models. They are best characterized as descriptive models with information retrieval and optimization options. An alternative description is that the underlying structure is a non-economic accounting model.

B. Major Assumptions

The major assumptions of the model are econometric in nature. Market shares of fuels and energy prices are exogenously determined. Likewise, end use demands and the underlying structure of the energy systems are user determined. If the optimization options are utilized, the system constraints are established apriori. The model's utility is in reflecting the user's characterization of the energy system rather than in its ability to reflect the system's behavior.

C. Structural Hierarchy

The output Reference Energy System or its perturbations is essentially a detailed network flow model from resource to end use. As discussed, the various models interact in sequence to determine the output. All sectors in the network are technologically characterized and specified for the Reference System. New linkages may be added or deleted from the system by the user.

The system is described at several levels of detail. Included are elements, processes, activities, trajectories, and subsystems. The element is a single quantifiable impact from a given process, the process being a single technological operation. Activities are several processes such as electrical generation, which includes various generation processes. Activities may be likened to a cut through the network at a given point. The network itself links processes by a trajectory, several trajectories comprising a subsystem. It is possible to account for the system description on the basis of the processes, activities, trajectories or subsystems.

D. Measurement and Evaluation of Impacts

Impacts, either environmental or costs, are all accounted for on the basis of the energy output at one of the five levels of aggregation above. No formal evaluation is available beyond the specific impacts. Comparison of alternatives is not provided by the model aside from the user discriminating between various simulation outputs.

III. Comprehensiveness Features

A. Energy Supply Network

In terms of fuel types, the RES includes comprehensive categories of end-use marketable fuels including coal, oil, natural gas and electricity. Data has been added to the base over the past several years to include solar, geothermal, and advanced conversion technologies and their associated fuels.

The RES traces the flow of energy from extraction to end-use including the intermediate stages of refining, conversion, transport, transmission, and distribution. This level of detail yields environmental impacts. The EMDB contains a substantial set of data for national average supply and end use processes and the associated supply processes.

Energy end use is divided into four sectors; residential, commercial, industrial and transportation. Each sector is then substantially subdivided into use categories numbering over two hundred. The optimization models are more aggregated in detail at the end use than is ESNS. The utilization categories are classified specifying the supply source utilization sector and fuel type. The supply categories distinguish a comprehensive set of processes.

Primary fuel demands for the model are exogenously determined. For the base case Reference Energy System these have been estimated from independent results. All viable technologies for the base case years (1985 and 2000) are included.

B. Spatial Detail

The basic version of the RES models are national in scope. Some of the supply data, e.g., coal, is associated with a particular region due to varying emissions. Research is in process to regionalize the model. The key motive for these efforts is that impacts from environmental emissions will vary from region to region.

C. Economic Content

The basic model lacks any significant econometric effects. A key drawback is the lack of price as a factor in determination of end use demands. This plus the lack of a model for supplier's reaction to demands restricts the model. As mentioned, market shares of fuels and energy costs are exogenously determined. Likewise, no interregional fuel competition is included.

The BESOM and DESOM submodels, however, include some reflection of economic activity. The Brookhaven models have been heavily criticized for their economic assumptions. An excellent discussion of the economic content of the various submodels will soon be available.⁷

D. Environmental Content

As mentioned above, each process or link in the energy network has a set of associated impacts (elements) as part of the Energy Model Data Base. There are twelve efficiency factors including process ancillary energy requirements, twelve types of water emissions including various dissolved and suspended pollutants, eight air pollutants as well as solid waste, radiation, health, and cost data. All factors are recorded on a 10^{12} Btu basis of process energy. It is possible to output these factors for any process included in the energy system network.

E. High-Damage, Low-Probability Events

None are included in the model.

F. Socioeconomic Effects

None are included in the model.

IV. Data Base

The contents of the Energy Model Data Base EMDB form the starting point for the Brookhaven models. The EMDB is intended to be a "flexible open-ended, model independent data system".¹ The data base and network models are considered to be part of an evolving system, new capabilities and contents being continually added. As mentioned, EMDB contains two files - processes and end uses. The aggregation of the data was discussed above. The data is in a user-oriented form and BNL provided information on its access.

A significant amount of effort has been extended in development of the data base. For all numbers available there is associated a quality measure which indicates confidence in the number. Documentation is quite good and accessibility is reasonable via the BNL computer. The data base has become somewhat of a standard among energy models.

V. Computer Implementation

All of the Brookhaven Energy Models are FORTRAN-based and available via access to the BNL computer system or via regular channels of communication. The code is operational on a CDC 7600 machine and contains no graphical outputs.

VI. Documentation/Validation

Documentation of the BNL models is extensive. The references here are only a small sample. As indicated, the basic models essentially are accounting models. The exogenous specification of the system is based on the user's expert judgment. The Reference System base cases are extensively documented on all assumptions and estimates founded in the model. The environmental data within the model are based on both measurements of the physical system and an engineering analysis. No information is available on model execution costs.

VII. Sponsor, Principal Investigator, Current Status

Sponsor:

Brookhaven National Laboratory
Upton, NY 11973

Principal Investigator:

K. C. Hoffman
Energy Technology Assessment Group
Brookhaven National Laboratory

Current Status:

The Dynamic Linear Programming Model (DESOM) remains under development. Work was initiated on a forecasting model to generate demands for the RES and BESOM. This model uses a combination of process analysis and econometrics to forecast basic energy demands in all end uses. A new system called the Reference Materials System is under development as framework for analysis of substitution of materials and related energy environmental and economic factors. This system is similar in concept to the RES. Modifications and changes to the RES are continually being performed.

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MODEL COMPARISONS

Criteria were established in outline form for comparing energy impact assessment models. It should be clear from the reviews that none of the models contain all the desirable attributes listed. Although simple comparisons cannot be effectively made, a set of tables covering the features of the models is provided. The purpose herein has been to define a set of attributes to be used in guiding efforts for development of energy impact assessment methodologies. The comparisons facilitate these considerations.

Four summary tables have been constructed to assist in the comparison of the model reviews of the previous section. Figure 9 summarizes the methodological features of each of the models, following the format of Section II of the outline. A designation of the type of analysis used is included to keep perspective of the purpose of the model. The comprehensiveness features of the energy network and spatial details are covered in Figure 10. The economic aspects of the models and summaries of the impact-events detail are considered in Figures 11 and 12, respectively.

All of the models considered have policy assessment as their goal. Only the WASH-1224 study gave impact assessment as the objective of its analysis. The majority of models considered were static. Those with dynamic aspects (SRI-Gulf, WISE, SOS) did not contain the tightly coupled feedback paths (detailed interaction of events over time) which are characteristic of most systems dynamics models. Linear programming is often used for balancing supply and demand at given points of time in the simulation. Major economic assumptions often include demands which are not price elastic and are founded in the theory of economic equilibrium. Throughout, there was little or no measurement of externalities in impact assessments and no formal evaluation.

As reflected in Figure 10, most large-scale energy models contain detailed supply and demand structures. There is greater emphasis on conventional fuels, but this is usually consistent with the time frames of the analysis. Aside from the WISE model, all are national in scope with various aggregated subregions. The subregions for supply and demand often differ as well.

	Type of Analysis	Modeling Approach		Major Assumption	Structural Hierarchy	Measurement and Evaluation of Impacts	
		Status or Dynamic	Type			Externalities	Formal Evaluation
3.1 SRI-Gulf	Economic Analysis for sensitivity to policies	Dynamic	Econometric	Supply-demand balance at all time periods inelastic demand	National model with regional supply-demand structure	None	None
3.2 PIES	Policy analysis for national growth scenarios	Static	Econometric/linear programming	Exogenously specified scenarios - economic equilibrium	National model, equilibrium prices, demands, supply at regional level	None	None
3.3 RESPONS	Policy analysis; sensitivity analysis; minimum-cost energy supply system	Static	Linear programming	Linear relationships	National and regional	None	None
3.4 WASH-1224	Impact assessment	Static	Literature search and expert opinion (not a model)	One man-day lost = \$50; one life lost = \$300,000	One level (data represents U.S. averages)	Environmental and sociological damage quantified in dollars of cost	Partial
3.5 SEAS	Technological and policy analysis; impact assessment	Static	Input-output; econometric forecasting	Linear economic relationships; exogenous growth projections	National and Regional	None	None
3.6 WISE	Policy analysis for energy supply	Dynamic	Trend analysis	Energy intensiveness invokes linear energy use relationships	State Model with electrical and non-electrical factors	None	None
3.7 SOS	Optimum regional growth within system constraints	Dynamic	Sub-optimization (goal-seeking) simulation model	Most cost-effective measures are always implemented	One region	Eleven socioeconomic indicators incl. Quality-of-Life	None
3.8 BNL	Policy analysis for energy supply & environmental impacts	Static (Dynamic version under development)	Linear programming and Accounting	Exogenously specified supply and demand - Supply Demand balance	National model with several levels of detail	Worker accidents/days lost from production	None

FIGURE 9. Methodological Features

	Fuels		Supply/ Fuel Cycle Sectors	Demand		Technologies		Spatial Detail
	Primary	Secondary		Sectors	Processes	Type	Variables Affected	
SRI-GULF	Coal, Oil, Nat. gas, nuclear, hydro	All incl. hydrogen and methane, synthetic	Alt. stages of supply process with network location	Residential Commercial Transportation Industrial	By end use and regions	Synthetic fuels, all current	Price	U.S. with 14 supply and 8 demand regions.
PIES	Coal, oil, nat. gas, nuclear, hydro, Solar, Geothermal	All	All, including manpower & resource requirements	Residential Commercial Industrial (2 digit SIC), transportation, elect. utilities	by end use	All current & feasible overtime frame	Price	U.S. and Census region demand districts of fuel supply
RESPONS	Coal, oil, gas, nuclear, hydro (emphasis on coal)	Electricity (all types of power plants); synthetic	All stages from source to end-use; emphasis on transportation	End-use demand for each energy form is exogenously specified by region	—	current and future (to 1995); emphasis on advanced coal technologies	Price	U.S., variable regions (16 Modified Petroleum Allocation Districts (M-PADS), 243 Air Quality Control Regions used in test data base)
WASH 1224	Coal, residual fuel oil, uranium, nat. gas as fuels for electrical power plants	Electrical generation (current commercial power plant types)	All phases of fuel cycles supporting electric power generation	None	None	Current only	All impacts associated with electrical power generation	U.S.
SEAS	Coal, oil, nat. gas	All distillates, electricity	Extraction, production, distribution	Residential, industrial, commercial, transportation	Space heating, electrical generation and consumption, industrial processes	Substitution technologies (current and postulated)	Prices, residuals	U.S.; ten federal EPA regions; can treat major U.S. SMSA's individually
WISE	Coal, nat. gas, oil, nuclear, Hydro	Distillate, residual, kerosene, gasoline, electricity	Point of entry supply	Residential, Commercial, Industrial (2 digit SIC), transportation, elec. utilities, agriculture	by end use or industry	conventional	Engineering efficiency	State of Wisconsin
SOS	Coal, oil	Electricity	Point of entry supply	Aggregated	Aggregated	Alternative technologies driven by relative cost advantages	Resource availabilities	Hypothetical region
BNL	Coal, oil, nat. gas, nuclear, hydro	All distillate, synthetic, residual, kerosene, gasoline, electricity	All stages of supply process network	Residential, commercial, industrial, transportation, electrical utilities	By end uses	All current & feasible to year 2000	All dependent variables (technology trajectories)	U.S., some regional data

FIGURE 10. Energy Network - Spatial Detail

FIGURE 11. Economic Content

	Interfuel Competition	Inter-regional Competition	Induced Development	Demand Specification	energy-economic interdependence
SRI-Gulf	Equilibrium approach solved iteratively among supply demand sectors, fuel switching	Market shares for demand allocation	None	Elastic supply-demand interaction	Demand insensitive to model price changes
PIES	Market shares	Linear programming Total cost minimized	None	Econometric equations with long & short run elasticities	Demand sensitivity to economic growth
RESPONS	Linear programming Total cost minimized	Linear programming Total cost minimized	None	Exogenous	None
WASH 1224	None	None	None	None	None
SEAS	Limited	None (national results disaggregated to regional levels ex post facto)	None	Demand projections produced by an econometric forecasting model	None
WISE	None	None	None	Trend analysis exogenously specified	None
SOS	Cost minimized within system constraints	None	None	Desired growth rates (demand) Specified exogenously	None
BNL	Linear programming in BESOM and DESOM	None	None	Exogenous specification	None

	Sectors	Environmental Pollutants	Effects/Reactions	High Damage Low Probability
SRI-GULF	None	None	None	None
PIES	Pollutants related to energy production	Some residuals, by no means complete	None	None
RESPONS	Air	SO ₂ only	None	None
WASH 1224	Air, water, land, eco- systems, man-made materials	All primary	Health effects, eco- system effects, damage to materials, alterations of land use	None (routine, small-scale accidents included)
SEAS	Air, water, solid waste	Many residuals, indexed by 10-digit code	Pollution abatement and resource recycling	None
WISE	Selected set of impact factors	Primary from electrical production and fuel end- use	Residuals and radiation doses quantified	None
SOS	Air, water, land	Aggregated for each sector	Pollution abatement; effect is to restrict economic growth due to emission constraints	None
BNL	Air, water, land, solid waste, radiation	All primary	Residuals quantified	None

FIGURE 12. Impacts - Events

Induced development, a major factor in the assessment of secondary impacts at localized levels, is not considered in the models reviewed. The economic structure of the models, summarized briefly in Figure 11, is rich in most of the models. Energy demands are either provided exogenously or are estimated using trends of econometric techniques. The prices are used to determine demand in the PIES model. Consumption otherwise reflects economic activity and other indicators such as population.

Interfuel and interregional competition are simulated most often by either linear programming or econometric techniques. Prices are used in the determination of market shares under internal mechanisms in most cases. Market and other lags in the system are not considered in detail in the majority with the exception of the SRI model. Only the PIES, SRI, and RESPONS models are multi-regional. None of the models are sensitive to effects of energy development in their simulation of economic activity.

Impacts and events are summarized in Figure 12. The models which provide impacts behave essentially as accounting devices. Environmental residuals are output as functions of energy supply activity on a per Btu basis. High damage - low probability events are not considered in any of the models evaluated.

CONCLUSIONS

Some general comments about large-scale energy models can be based on the models reviewed. The models considered here have been developed and used, in most cases successfully, within the specific discipline and to the objective for which they were intended.

The immediate limitations of present models are reasonably understood. The models may not be particularly well known outside the community versed in the objectives the model was meant to satisfy. Other problems include documentation, adequacy of data sources, errors, difficulty in transfer from one machine to another, and lack of sensitivity to some external variables. These limitations can be expected to some degree in all models. In addition, some models may not be readily applicable to immediate impact assessment, and most large-scale energy models have had difficulty in predicting long-term effects. Further development in energy impact assessment methodologies is needed.

Large-scale energy models should act with specialized models to perform assessments. Gaps between these types of models should be closed; to enhance the interface of the two, large models need:

- better documentation
- better access or interface with current data
- better characterization of the choices and objectives essential for the model
- direction, guidance, and support from the users and decision makers.

The data base for large models, either as scenarios or technologic data, also drives specialized models. The data is a basic constraint on the model's credibility. Efforts are currently underway (at BNL and elsewhere) to establish large energy data bases. Measures of accuracy and documentation of sources must be contained in these bases. Alternatives and assumptions in scenarios or projections to be tested, must also be well-documented and transparent to the user.

Linking large and small models requires consistent data. It is also essential that models be based upon the data which will run them, rather than structuring data to fit the models.

The organization and structure of models and techniques of modeling are influenced by the objectives and judgment criteria of the decision makers. For energy models to be useful, model structures must reflect the viewpoint of the decision makers; this includes the political, social, environmental, and economic impacts associated with energy-related questions. Models must be concerned not only with technology, but with institutions and values, and with constraints. They must include the synergistic effects of energy, material flows, environment, and secondary impacts.

Many technical problems influence the nature and usefulness of modeling activities. No specific acceptable procedures exist for model validation or evaluation. Guidelines here would be a practical benefit. Also, value-oriented models do not presently serve any significant role in policy analysis. More emphasis on relating the physical structure of the model to the objectives of its user should be given.

It is our feeling that large-scale macro-economic energy models can make an essential contribution to the conduct of energy impact assessment studies. Minimum standards for acceptability, documentation, validation, data standards, transferability, etc., should be developed by sponsoring agencies. General long-term energy models require a great deal of basic development and commitments should be sustained. Direction, guidance, and financial support will be the key to success of such activities.

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