Energy/Environment Models: Relationship to Planning in Wisconsin, GDR, Rhone Alps

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ENERGY/ENVIRONMENT MODELS AND THEIR RELATIONSHIP TO PLANNING IN WISCONSIN, THE GERMAN DEMOCRATIC REPUBLIC, AND RHÔNE ALPES

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Preface

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

This memorandum contains a set of papers which describe and link models and institutional structures in each of the three regions studied in 1975. The papers were prepared for a three-region workshop held at IIASA November 10-14, 1975. Although they will appear in a modified form in a forthcoming book on this topic, they are being distributed as an IIASA Memorandum because of the widespread interest in the topic.

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

Wesley K. Foell

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*NOTE: These reports were translated into English at IIASA, and the translations presented here were not reviewed by their authors before this printing.

Abstract

This report is a description and cross-regional comparison of the institutional structures and modeling methodologies of the three regions participating in the IIASA Research Program on Management of Regional Energy/Environment Systems. Descriptions are presented for the state of Wisconsin (USA), the German Democratic Republic, and the Rhône-Alpes Region (France), by specialists and policy makers from the respective regions. These descriptions demonstrate quite vividly the relationships between the institutional structure of a region and its use of models and planning tools.

I. ENERGY/ENVIRONMENT MODELS AND THEIR RELATIONSHIP TO PLANNING IN WISCONSIN (USA)

A. General Institutional Setting for Energy/Environmental Planning and Decision Making

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Energy and environmental decision-making and planning in the United States is highly diffused; there is no single centralized planning or decision-making body. Not only are Federal responsibilities widely distributed, but various areas of jurisdiction are either the province of or shared with state and local governments. At the Federal level, power and responsibility for energy/environmental policy matters, as for other public policy areas, is "balanced" between the Executive and Legislative branches of government. The judicial branch serves as an interpreter and arbiter of the process. Although substantial authority for energy and environmental matters rests with the traditional Executive branch Cabinet agencies -- the Departments of Interior, Commerce, and Agriculture -- in recent years more and more power has been placed within a number of relatively independent agencies and other governmental bodies. These independent offices include the Energy Research and Development Administration (ERDA); Federal Energy Administration (FEA); Environmental Protection Agency (EPA); Federal Power Commission (FPC); National Science Foundation (NSF); Nuclear Regulatory Commission (NRC); and the Tennesee Valley Authority TVA). This listing is a partial one; and simply illustrates that there are many institutional factors that affect energy decisions and administer energy-related programs at the Federal level.

Wisconsin Institutions -- An Overview

A few states in the United States have been able to consolidate energy-related functions within a relatively few, or even a single agency; example states include Connecticut, California, and Kentucky. Most states, however, have a rather dispersed institutional framework for energy/environmental planning and decision-making. Wisconsin is more-or-less typical. State executive agencies are responsible for planning and administration of state legislated programs. However, many state authorities and actions result from federally-mandated programs and requirements. In Wisconsin, emphasis has been placed on strong functional planning by line agencies, such as the Departments of Transportation and Natural Resources. To coordinate these functional planning efforts and to provide an independent policy analysis capability to the Executive Office, a comprehensive State Planning Office exists within the State Department of Administration. This brief overview suggests the complexity of these arrangements. (The full names of the following department and groups are listed at the back of this report).

DOT-has the responsibility for all transportation planning, and its programs and decisions have major energy consequences. At present, planning and operating programs are largely segregated by mode. It has not been organizationally nor fiscally possible to examine transportation decisions from a multi-modal viewpoint; nor to fully evaluate economic development or energy use "tradeoffs" associated with various modal choices. State legislation is now pending that would reorganize DOT and its planning/decision-making functions, into an integrated, genuinely multi-modal transportation department.

DNR-is charged with planning for and management of the state's air, water, recreational, and biologic resources. Its environmental protection planning and management responsibilities exert great influence on a number of energy-related issues. The agency's air pollution control regulatory responsibility furnishes an excellent example.

For several years, even pre-dating passage of the Federal Clean Air Act in 1970, a national debate has been underway in the United States regarding air pollution and the issue of "non-degradation". The Supreme Court has upheld the position that state air quality plans must prevent significant deterioration of air quality. Much of the controversy has centered about the impact of such a policy on economic growth. States are charged with developing the requisite air quality implementation plans, and in Wisconsin the Department of Natural Resources (DNR) has primary responsibility.

In May 1975, three utilities submitted plans and specifications for the construction of Columbia II, a 527-megawatt power plant to be built in south-central Wisconsin at a location adjacent to its twin, Columbia I. Wisconsin's air pollution control regulations required DNR to review these plans for air quality implications. DNR found that although the proposed plant would not violate air quality standards and would meet federal emission requirements, it would cause significant degradation of air quality that would in effect preclude additional growth. The data showed that Columbia II would utilize 97% of the remaining air resource for one sulfur dioxide standard and 68% for another standard. DNR determined that this was a significant degradation of air quality and halted construction of the power plant in June. A hearing in the affected area to assess the public attitude on permitting construction of the power plant was held in July. Over 1,000 people attended the hearing, but hearing testimony along with other letters, resolutions and petitions submitted to the DNR reflected an almost even split between supporters and opponents of construction. Since the assessment of public attitude was inconclusive, DNR decided that construction of Columbia II could not be prohibited. Construction is proceeding under requirements that are to keep Columbia II's emissions at an absolute minimum. The Columbia II incident not only demonstrates the development implications of air quality regulations, but the intimate relationship between air quality and energy decisions and the powerful role of the state DNR in such matters.

PSC-is a three member quasijudicial regulatory agency. Each member is appointed by the Governor, and confirmed by the State Senate, for 6-year terms. The Commission regulates the rates and services of public utilities operating in the State which includes both privately-owned and municipally owned electric utilities, natural gas distribution utilities, water and combined water-sewer utilities. With the exception of major construction projects, the Commission does not regulate electric cooperatives. Also under Commission jurisdiction are intrastate common and contract motor carriers and railroad operations.

The Commission has the responsibility to set utility rates including the determination of a utility's revenue requirement and the structure of rates. Recently, the Commission has been implementing peak-load pricing as the basis for designing electric utility rates. Under this principle, rates are set on the basis of the costs customers incur by using electricity at times of peak demands.

Under a recently enacted law, electric utilities and cooperatives every two years must submit to the Commission 10-year advance plans covering major construction projects. The Commission must then approve, modify or disapprove the plans. Electric utilities and cooperatives must also receive Commission certification to construct specific major facilities included within the advance plans.

In addition to these reponsibilities, the Commission must approve issuance of securities, certify depreciation rates used by utilities, establish Uniform Systems of Accounts, approve affiliated transaction contracts and conduct audits and inspections of utilities.

DIHLR-has many programs with energy implications. None is more visible or impacts more directly on energy conservation than the Department's responsibilities for the administration and enforcement of state building codes. In January 1975, DIHLR promulgated building codes which, in addition to traditional public health, safety, and welfare considerations, included energy use standards for all new buildings. This standard was bases on extensive technical review, which involved key University of Wisconsin faculty; the Wisconsin Energy Model had been used in the analyses related to setting to standard. In

June 1975, these rules were "sidetracked" by a legislative committee, which was under attack from housing industry interests and from masons, who contended that the energy conservation standard would cause them to lose their jobs. At this writing, a Committee on Energy Conservation, formed by DIHLR, is trying to find alternatives to the controversial energy standard approved in January and abandoned in June.

OEEA-was created to deal with fuel hardships which arose during the Arab oil embargo in late 1973. Its existence was continued by the state legislature and the Governor until July 1, 1977. The office is empowered by federal regulations to order the delivery of fuels to individuals and fuel dealers who are unable to meet their energy needs. The fuels delivered are withdrawn from the state set-aside program, a theoretical inventory of the various types of petroleum fuels held by those private petroleum firms bringing fuels into the State.* The office has certain other powers, either under state or federal law, including the power to obtain information on use and inventories of fuels. This information is then compiled for use in preventing or alleviating shortages which occur because of imperfections in the market mechanism as controlled by federal regulations. The energy office serves as advisor to the State Legislature and the Governor on energy matters and has worked on developing legislation which bears on energy use within the State. The energy office has also reacted to legislation proposed by others within the State and has used energy modeling to determine the effects of various legislative proposals. The energy office reacts to various actions proposed, or already in place, by other state and federal agencies and seeks to protect the interest of the citizens of the State, as affected by the actions of the other agencies. The energy office seeks to minimize the negative effects of any happening in the energy area upon the businesses, citizens and workers within the State. The energy office attempts, through public speeches, press

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*The products are allocated to the states by the Federal Energy Administration based on historical usage before the Arab oil embargo. This was done so all states would share equally in any hardships.

releases and other attention getting devices, to give the general public and businessmen the facts on the energy situation and what they can do to improve it.

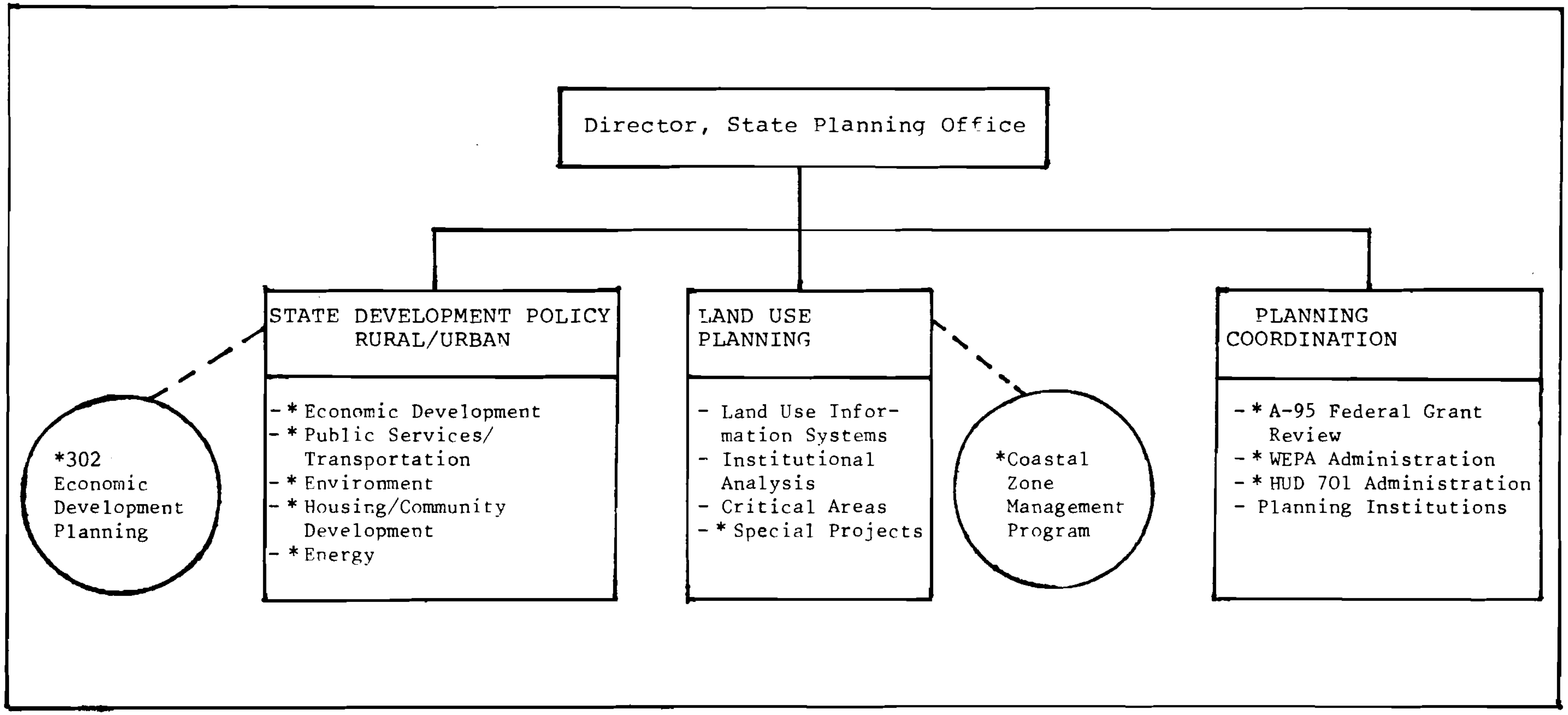
UW-has the tri-partite educational mission of research, teaching, and public service. Although best known to workshop participants for Energy Systems modeling activities, University energy researchers are involved in a wide range of studies--ranging from basic solar energy research to techniques for monitoring the environmental impacts of power plant siting. Students are trained in interdisciplinary approaches for dealing with environmental and energy problems staff key agency positions within state government; state governmental problems have furnished worthwhile applied research areas for many students. The University Cooperative Extension Service has taken research and demonstration results and brought them into the public forum through several public informational efforts. In short, there is a critical symbiosis between the University system and state government--a partnership that extends back through several decades. This cooperative spirit, pioneered in agriculture, but readily transferred to environmental and energy concerns, has been aptly named "the Wisconsin idea."

DOA-functions as the Governor's agency within the state bureaucracy. The Department is charged with preparation of the Executive Budget, which in recent years has become a major piece of policy legislation. DOA also houses the state's Federal/State Coordination Office and the Bureau of Facilities Management. The latter oversees all state buildings, and can initiate such procedures as life cycle costing in the planning of all state facilities. The Department of Administration also includes the State Planning Office, which is the state's comprehensive planning agency. This office is largely involved with physical, environmental, and economic planning.

The State Planning Office's programs are divided into three broad areas: State Development Policy Planning; Land Use Planning; and Planning Coordination (see Figure I). It has lead agency responsibilities in the areas of economic development planning and coordination, land use planning, and coastal zone

Figure I

STATE PLANNING OFFICE PROGRAM



* indicates energy-related functions

management, as well as in the process-oriented "planning coordination" area. In meeting its comprehensive planning and coordination responsibilities, the State Planning Office functions in several ways: (1) as a coordinator, liaison, or critical reviewer in working with inter-agency or intergovernmental groups or individual agencies; (2) as program developer and manager of new multi-functional, intergovernmental programs--such as Coastal Zone Management Planning or State Economic Development Planning; (3) as a policy analysis and research unit; (4) as a public involvement/educational agent; and (5) as a provider of Executive Office services--including legislative development and review, special projects/analysis, and limited budget issue involvement. As noted in Figure I, many of the Planning Office program areas and functions relate closely to energy and environmental concerns. One activity warrants special mention; close work between the University's Energy Systems Research group and Planning Office staff has led to an analysis of the costs of alternative physical development patterns, in terms of fiscal, land consumption, and energy costs.

One other aspect of Wisconsin's institutional setting as it pertains to energy and environment deserves special consideration. In 1972, Wisconsin passed the Wisconsin Environmental Policy Act, (WEPA). The Act, which is patterned after the National Environmental Policy Act of 1969 (NEPA), establishes a state policy to encourage harmony between human activity and the environment, promotes efforts to reduce damage to the environment, and stimulates understanding of important ecological systems. The act mandates a thorough analysis of environmental impact before any major state action is authorized. Agencies must consider alternative technologies and economic consequences of state-initiated projects; private actions regulated by state government are subject to the same procedures. The underlying premise of WEPA is that substantive policy decisions can be improved and a better balance will emerge between environmental and economic objectives if a broad range of environmental impacts, alternatives to the proposed action, and public comment are examined well before the final decisions are made.

Although the environmental impact statements and other documents are not binding on state governmental decision-making, WEPA (and NEPA) have had a far-reaching effect. Because of WEPA, environmental (including energy) considerations are now routinely a part of governmental decision-making, and the process is more accessible than ever before to citizens. Major energy related decisions--construction of a Great Lakes oil shipment terminal, construction of electric generating facilities and transmission lines, regulatory action related to utility rate changes, railroad line abandonments--have been subject to and delayed, modified, and even halted based on environmental questions raised by the Wisconsin Environmental Policy Act process. In fact, the environmental impact statement, and the associated review process, have become pervasive and extremely useful planning tools in energy decision-making.

Abbreviations Used in This Presentation

DOT - Department of Transportation

DNR - Department of Natural Resources

PSC - Public Service Commission

DIHLR - Department of Industry, Labor and Human Relations

OEEA - Office of Emergency Energy Assistance

UW - University of Wisconsin-Madison

DOA - Department of Administration

B. Energy System Modeling Activities in Wisconsin

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Energy System modeling activity in Wisconsin is comprised of a variety of efforts in both the public and private sectors, aimed at an analysis of problems associated with energy supply, demand, and environmental impact. The fragmentation of these efforts is extreme with many parallel modeling activities being carried on simultaneously.

The causality for the nature of both Wisconsin's energy system and the modeling activities associated with that system is found largely in the social, economic, environmental, and political structure of the state(1,2). Wisconsin is richly endowed with both natural and human resources. It does not, however, have any significant endogenous energy resources. Historically, agriculture, resource extraction and processing, and tourism or recreational activities have played major roles in the State's economy. An intensive, broad-based industrial sector has developed in the southeastern portion of the state and it is here that the vast majority of the state's populace now reside.

Wisconsin's energy system evolved in response to the energy requirements generated by this pattern of economic growth and development. This evolution occurred largely through the interaction of suppliers and consumers in a private market setting with virtually no integrated planning and relatively limited direct government intervention. This historical pattern of a limited government role in Wisconsin's energy system development stems from many factors. The virtual lack of energy resources in the state, however, is undoubtedly a major factor, particularly when coupled with a national policy aimed at making energy readily available in the private sector markets at relatively low prices. In short, the energy sector has historically been neither a major component of Wisconsin's gross state product nor a major constraint on the state's economic development. It has not, therefore, been an area of major concern to the state government.

Because of the primary reliance on private sector development of the Wisconsin energy system, and the relatively limited government concern related to this sector, the resultant disaggregation in energy analysis and planning makes it impossible to describe a unique well integrated energy modeling system for the state. Instead, one finds a variety of parallel modeling activities being carried on not only by the suppliers (and major consumers) of various energy resources in the private sector, but also, because of the recent realization of the importance of energy to the state's economic well being on the part of the state's political leaders, in numerous state agencies. Because of this disaggregation, we have chosen in this report to outline the various modeling approaches being used in both the private and public sectors and to describe the institutional mechanisms through which linkages occur.

While energy modeling in Wisconsin encompasses the entire range of activities associated with analyzing the state's energy system--from long-range forecasting and planning to operational management--most individual efforts are rather narrow in scope. That is, they focus on either a specific energy source, or on a particular energy policy problem. An exception to this generalization is the work of the Energy Systems and Policy Research Group (ESPRG) at the University of Wisconsin. This multidisciplinary research activity has resulted in the development of a computerized dynamic simulation model of Wisconsin's energy system. The WISconsin Regional Energy Model (WISE) combines an engineering and economic approach to model the state's energy system within a multidimensional framework that describes energy demand, conversion(1), transport and uses explicitly accounting for technological, economic, and environmental interactions. It consists of a collection of submodels which combine in simple mathematical terms data and information about energy flows in Wisconsin to describe or simulate the energy system and its relationship to other characteristics of the state, e.g. demographic, economic, and environmental. A simulation structure was chosen for several reasons. First, simulation is a convenient method of integrating the variety of analytical techniques likely to be employed in a multidisciplinary effort of this type. Second, a simulation structure provides a great deal of flexibility in both the modeling process and application of the model to system analysis. For example, it enables one to modify selected components of the system without the necessity of reworking the entire model, and to focus attention on specific areas of the energy system as well as on the system as a whole. Finally, the simulation structure lends itself to the scenario generating approach that is extremely useful in the analysis of major policy issues and alternatives. That is, simulation facilitates the application of the model to questions of the "what if" type.

Rather than dwell on the specific structure of the WISE Model (which is examined in detail in other ESPRG publications)(3), we shall limit our discussion of it in this paper to an overview of its capabilities and use. The WISE Model is designed primarily for intermediate to long-range planning analysis. The typical horizon employed is the year 2000. Among other applications, WISE has been used to: (1) forecast energy demands by energy source and user classification, (2) estimate the additions required to the electricity generating, transmission, and distribution facilities in the state and evaluate the financing requirements, total system costs, and environmental impacts of alternative generating systems (i.e., nuclear versus fossil fueled) designed to meet the additional requirements, (3) examine environmental impacts associated with alternative future energy use patterns, and (4) analyze the role that conservation can play in determining the state's energy future. From these applications, it should be apparent that the WISE Model is capable of both forecasting energy/environment futures for the state and analyzing the impacts of alternative policy decisions relating to both public and private sector activities in the energy area.

It is important to note that the development and actual employment of the WISE Model rests almost exclusively with the ESPRG at the University of Wisconsin, a research team not formally or institutionally linked to Wisconsin's energy system planning and operational decision making. Lacking a direct tie to the decision making bodies in the State, the use of the WISE Model for input into energy policy analysis has rested on its ability to provide timely and easily comprehended responses to important energy policy issues as they arise. This response capability has been designed into the WISE Model through the use of the simulation structure and an interactive control language which provides users with convenient access to both the models and data systems, and allows for intervention in simulated energy futures in order to test both the consequences of policy changes and the sensitivity of these futures to various assumptions employed in the analysis. It is further enhanced by the formal and informal working relationships that have been established by the ESPRG with several administrative and regulatory departments of the state of Wisconsin. The result is that while the ESPRG cannot be considered to be among the energy system policy making bodies in Wisconsin, it does play an important role as a provider of technical expertise in policy analysis and, as will become clear from the material which follows, it has had a significant impact on the development of an analytical approach to policy analysis within several of the Wisconsin state agencies which do have major decision making responsibility in the energy-environment areas.

Let us turn now to a brief look at other energy modeling activities in the state. We will structure this survey on the basis of model types and use.

Because of the virtual inseparability of energy use and economic activity, virtually all modeling activities incorporate a general economic forecast for the state. These forecasts are prepared in both the public and private sectors using a variety of methodologies, ranging from simple trend projections to complex econometric and input/output models. Within the state agencies, independent forecasts are prepared by the

Department of Industry and Labor and Human Relations, the Department of Revenue, and by faculty at the University of Wisconsin. Although these forecasts are prepared for a variety of different uses and are not often reconciled, there is a high correlation between the various projections. This undoubtedly stems in large part from the fact that Wisconsin's economy is inextricably tied to the entire U.S. economy and all state forecasts are inherently based on the same projections of national economic activity levels.

Population size and characteristics provide another basic input into all energy modeling activities. In Wisconsin this factor is modeled in detail by the Office of the State Demographer. This model is age, sex, and country specific and includes considerations of migration, fertility and mortality. Detailed population projections are provided out to the twenty-first century. Energy demand forecasts in Wisconsin (other than those prepared by the EXPRG) have typically been on a single energy source basis. Until very recently, virtually all of this work was done in the private sector and on a firm by firm basis. Thus, for example, individual electric utilities could be expected to project demand by major user categories within their respective service areas. Typically these projections entailed extrapolation of historical trends adjusted for any major structural change in user compostion which the utility was aware of (e.g. the planned expansion of a major industrial customer or the location of a major new industrial facility in the firm's service area). Such projections were used a input for investment planning and seldom extended beyond a five - seven year period. Ten year projections were very long run and went well beyond the relevant planning period. These simple demand models served quite well over an extended period due to the regularity which characterized the development and growth of not only electricity but also the entire energy system in Wisconsin until the beginning of this decade.

As a result of the disruptions which have characterized the entire energy system since 1970, the electric utilities are no longer able to rely on the patterns of historical trends for planning purposes. This has been accentuated by a necessary lengthening of the planning horizon for individual firms, brought about in part by the longer construction period associated with the use of nuclear technology and in part by the more active role in the planning process taken by government agencies and representatives of special interest groups in the public (e.g. environmentalists and conservationists). This change in demand forecasting requirements was both sudden and substantial, catching many electric utilities generally unprepared to respond adequately in the development of needed forecasting methodologies. It led to a contract between the major electric utilities in Wisconsin and the Stanford Research Institute, a large private consulting firm, for an indepth analysis and forecast of energy demands in Wisconsin through the year 2000.(4)

The nature of demand modeling in the other energy industries closely parallels that in the electric utility sector. Gas utilities and suppliers of coal, fuel oil, and gasoline have all tended to trend historical data on customer use, population and income growth, and market penetration to develop projections of future demand. For many cases the state of Wisconsin is not the relevant market area and, hence, no "Wisconsin" projection is forthcoming. This is particularly true for the coal and petroleum sectors where the primary suppliers tend to operate in a national or international market and for whom the Wisconsin market is an extremely small component part, so small, in fact, that it is often treated as some fixed percentage of the national market--usually around two percent. In the case of those natural gas transmission and distribution companies whose primary market area is Wisconsin, their lack of direct ties to the production of natural gas, coupled with a situation where the demand for their product far exceeds any forseeable supply, limits the benefits from detailed demand analysis and forecasting, and has limited development in this area.

Recently the State has moved into the arena of energy demand forecasting on several fronts. These activities began with the Public Service Commission (PSC) aggregating the forecasts of individual electric utilities to develop a clearer picture of the projected generation, transmission and distribution system in the state. They have relied to this point on the projections provided by the utilities and by the ESPRG at the University(5), while working on the development of an "in house" capability for demand estimation.

The other state agency currently involved in energy demand analysis and projection is the Office of Emergency Energy Assistance (OEEA). This newly formed agency is charged with responsibility for assisting in the allocation of energy resources when the market becomes inoperative because of a major imbalance between supply and demand (i.e., when price is not allowed to play its role as the allocative mechanism) and to assist in the development of an energy policy for the state. The OEEA is involved primarily with short-term energy issues and thus has not developed the capability for intermediate to long-range energy forecasting, relying instead on the ESPRG work and other externally generated projections in those instances where required. It has, however, developed an extensive set of computerized energy consumption data bases and retrieval software for analyzing that data. These data include a monthly allocation of all petroleum projects coming into the State, which shows for every distributor of petroleum products where he obtains his supplies and to whom the products are sold. These data are used to keep track of the origin of Wisconsin's petroleum supplies and to analyze the short run impacts of a disruption in that supply. Similar data are collected for both coal and natural gas flows in Wisconsin. An additional data file listing the primary fuel requirements, alternative fuel capabilities including storage and switching time, and daily use rates has been prepared for all interruptable natural gas customers in the State. These data are being used by the OEEA to analyze the impacts of a natural gas curtailment and the alternative allocation schemes that have been proposed for the remaining gas.

Investment planning activities in Wisconsin closely parallel those in the demand area. The vast majority of such efforts are carried on by the individual firms operating in the state. A variety of corporate planning models are utilized in these efforts. These models typically project the time pattern of finance requirements based on forecasts of future system capacity needs and estimates of the technologically available means of satisfying those needs. These corporate planning models are usually detailed engineering/economic models of either a simulation or mathematical programming nature. Where a linear programming approach is used, constrained cost minimization over the planning horizon is the typical objective. Although the electricity generating capacity submodel (GENCAP) in WISE is somewhat less detailed than most corporate planning models, it is representative of the simulation structure employed.

Probably the only energy firms where corporate planning models explicitly break out and model in detail a Wisconsin component are the electric and natural gas utilities serving the state. Electric utilities, for example, use extensive models to convert projected consumer demand into capacity requirements using load curve analysis. These forecasts of capacity requirements are in turn used to analyze the economic impacts of alternative generation and distribution systems and from this, detailed projections of capital investment and financing requirements are obtained. These models have typically employed a 5-7 year planning horizon in the past but recent events have lengthened this to 10-12 years.

Although the major coal and petroleum suppliers all utilize such corporate planning models, in most cases the Wisconsin component is small relative to their total activities--involving perhaps no investment where sales are channeled through independent distributors--and, hence, is either combined with surrounding states for a regional analysis or not disaggregated at all from the national model. In those situations where a Wisconsin component is analyzed it invariably relates to distribution facilities which typically are relatively low cost components with short planning horizons and, hence, are not major components in the model.

The only state agency that carries on any investment planning analysis in the energy system is the PSC and their effort is limited primarily to the electricity industry. The PSC approach is essentially equivalent to a corporate planning model in which system costing is the primary objective. The model structure is similar to GENCAP but with more detail concerning load flows by user class. It is used to evaluate the investment plans of individual electric utilities and for analysis of alternative rate structures. This effort has been done on a company by company basis and only recently has work begun on a system wide effort patterned after the work of the ESPRG.

A final area where energy related modeling is taking place in Wisconsin relates to environmental impact. Here the effort is more completely integrated into state planning activities due to the need to ensure compliance with both state and national environmental standards. In this effort the Department of Natural Resources (DNR) has responsibility for both developing standards to ensure compliance with the codes and for monitoring emissions in the state. In this effort, they are working closely with several other state agencies as well as developing their own models for some specific analysis. They are for example working closely with the PSC in the development of impact statements for future electric utility generating plants and transmission systems. Here the methodology is similar to that employed in the ESPRG Environmental Impact Model but with greater emphasis on its specific relationships. Similar work is being carried on by the utility firms in the state as part of the licensing for new plants.

The DNR is also working on broader models of air and water quality. One of these efforts involves DNR monitoring of primary fuel use by each of the major energy using facilities in the state. Emission data are then constructed from the fuel use survey and a physical diffusion model develops ambient concentration levels for various pollutants. These data then provide the basis for establishing pollution abatement requirements for the facilities.

The above methodology is also being employed for long-range environmental quality analysis and planning for southeastern Wisconsin, the most heavily industrialized and populated section of the state(6). Here an economic planning model provides specific industrial and transportation energy use projections through the year 2000. These fuel use figures are converted to emissions factors which are then combined with projections of area sources of pollution (e.g. residential housing and commercial areas) to develop estimates of air quality. A scenario generating capability allows the impact of alternative development plans and pollution abatement standards to be analyzed.

To summarize, energy/environmental planning in Wisconsin is highly fragmented and, hence, there is relatively little centralized effort in this area. Even in the case of the energy utilities (i.e., electric and natural gas distibutors) where the state has long played a major role in regulating activities, the individual firms are the primary decision makers and as such have historically done virtually all of the planning. Recently the PSC and DNR have taken a more active role in these planning activities due primarily to (1) mandates laid down in both Federal and State environmental protection legislation(7)(8), (2) concerns about the risks inherent in nuclear generation of electricity, and (3) major structural changes in the energy supply/demand relationship which indicate a long-term supply shortfall unless significant modifications in energy use patterns are forthcoming. Other state agencies (particularly the Office of Emergency Energy Assistance and the Department of Planning) are also moving rapidly to develop the data systems and modeling techniques necessary to more explicitly introduce energy relationships into state policy analysis. The efforts are being assisted by the work of the ESPRG and other research groups at the University of Wisconsin.

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II. ENERGY/ENVIRONMENT MODELS AND THEIR RELATIONSHIP TO PLANNING IN THE GDR

A. Planning of the Energy Industry in the GDR

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The socialist production conditions prevailing in the GDR create both the possibility and the necessity for planning of the entire social system. This applies to all spheres of the national economy, including the energy industry. The energy industry influences all areas of social life and comprises extraction, conversion, transportation, and use of energy sources.

1) Administrative Structure

The Ministry for Coal and Energy is responsible for the elaboration and implementation of the national energy policy, based on the resolutions of the United Socialist Party of Germany. The Ministry for Coal and Energy operates according to the principles of the economic policy of the country accepted by the Council of Ministers and is subordinate to this Council. The State Planning Commission, also subordinate to the Council of Ministers, is the most important staff organization which outlines the strategy of development of national industry and is therefore considered to be an important partner in the process of planning the energy industry. The Association of Nationally-Owned Factories (VVB) for Brown Coal, Hard Coal, Power Stations and Power Supply, as well as the Complex of Gas Factory Plants known as "Schwarze Pumpe" (Black Pump) are responsible to the Ministry for Coal and Energy. The single-product factories are, in turn, under the jurisdiction of the Association of Nationally-Owned Factories. The Association of Nationally-Owned Factories for Power Stations, for instance, is comprised of the large lignite, nuclear, gas turbine and pumpedstorage power stations as well as the power line network for voltages of 220kv and over. The Association of Nationally-Owned Factories for Energy Supply is divided territorially. In each district there is one energy supply factory, whereby two or three such factories are usually combined into larger enterprises. To the category of energy supply factories belong heating plants, larger heating works, gas works and stations for the distribution of electricity, gas and district heat. They are considered to be the marketing organs of the energy industry for these energy forms.

Thus the Ministry for Coal and Energy is responsible for the greatest part of the energy supply. The only exceptions are 1) the primary processing of petroleum, which falls within the sphere of the Ministry of Chemical Industry, 2) the extraction of natural gas which is controlled by the Ministry of Geology, and 3) the industrial power plants in the different branches of industry as well as the municipally-owned heating plants and other plants of only local significance. With regard to the responsibility for the development strategies for the energy industry, the Ministry for Coal and Energy has to fulfill a double function:

1. It is responsible for the supply of energy by the economic units under its control, i.e. about 78% of total primary energy, and,
2. It is responsible for the realization of rational principles of energy use, and thus for energy policy in all spheres of national industry and social life, (with respect to all forms of energy).

The most important instrument for the implementation of energy policy is the Plan, more particularly the Energy Plan. This Plan was worked out more than ten years ago by all high energy intensive factories, and by Institutes for Annual and Five-Year Planning. Since the aims of planning are subordinate to the interests of the society as a whole, the process of planning is led by the Central Government and is accomplished by means of coordination at all levels of leadership, through to the factories in which working people play a decisive role in determining the operative plans.

The GDR is a member of the Council of Mutual Economic Aid. The plans of the member countries, especially the five-year plans, are closely coordinated in order to gain a steady and quick development of national industries in all socialist countries. Planning is carried out by means of coordination over different periods: annual planning, five-year planning and long-term planning which usually covers several decades and is especially important in the energy industry. In this connection the forecasting of scientific/technical development of single processes and procedures within them is presupposed to be of great importance. The planning of the demand for end-use energy is regarded as the starting point for the planning of the energy industry. In this connection a detailed knowledge of the development of national industry is necessary, particularly with regard to the intended production of energy-intensive products and the development of the standard of living. Moreover, information about the scientific/technical development of processes in which energy is used, is required in order to derive data characterizing the specific energy consumption.

2) Models in Planning

By means of the so-called Substitution Optimization Model (SOM) the alternative which results in the lowest social cost (based on the production of a particular assortment of products) is chosen from the different possibilities of designing processes and of using a certain form of energy. From the energy requirements of the demand sectors, determined by means of economic/mathematical models and global methods, the necessary total energy demand as well as the demand for primary energy, in a second phase of planning, is calculated.

For long-term planning (about two decades) an optimization model that considers the relationship of the various forms of energy is applied. The application of this model--the Production Optimization Model (POM)--leads to a choice of combinations of energy extraction and conversion plants, such that the demand for end-use energy can be met with a minimum social cost. Certainly these calculations are also supplemented by calculations on the basis of global methods, particularly as far as it concerns periods past the year 2000. This phase of planning is associated with investigations of the scientific/technical development of procedures for extraction, transport and conversion of energy. These calculations require detailed knowledge of sources of energy available in the country and of availability of imports. Moreover, certain economic variables, such as investments, wages, prices of imported energy sources, etc. are of importance for these calculations.

After this phase of planning in the energy industry, there follow investigations about incorporating these results into the development of the energy industry as a whole, i.e. in relation to the demand for investments and manpower, the costs of importing energy and energy equipment, and to the factors of environmental impact. These investigations provide concrete tasks for scientific/technical research on the one hand (development of improved methods of extraction, processing, transport and use of energy etc), and starting points for new calculations of end-use and primary energy, on the other. This iterative process is repeated until a sufficient degree of correspondence between energy demands and the capacity of national industry is reached.

Special attention is paid to the relationship between the energy industry and environmental protection. Measures for environmental protection are systematically included in the development of the national economy, acting as an effective safeguard of the social welfare. An example is the possibility of extensive reuse of waste products. The Ministry of Environmental Protection and Water Economy has outlined the main directives for environmental protection measures up to 1980. With these directives as a starting point, concrete concepts for districts of industrial conurbation are created on the basis of socialist legislation for environmental conservation. In 1975, two-thirds of the investments in environmental protection were concentrated in districts of industrial conurbation which are assumed to be the most important areas for the energy industry.

3) Structure of the Optimization Model

i) Basic Structure

The aim of optimization is the minimization of social costs, limited only by essential restrictions. For that aim, a factor using costs which are obligatory for the whole energy industry is considered. Besides non-recurring and current costs, this factor contains the demand for surplus to increase the returns of profitable funds (investments and the increase of a circulating medium) and the social consumption. Both quantities are applicable to an average society and are derived from figures on the national economy. Social consumption means application of net income to the non-profit sphere for

- science, in so far as it is not directly integrated in the process of material production,
- public education,
- culture,
- public hygiene and sanitation,
- national defense, and,
- state administration.

The demand for increasing returns from profitable funds is expressed by the factor of accumulation q.

$$q = 1.065 \approx \text{constant in its development over time.}$$

It is a function of investments. The factor of consumption, q_k, is related to wages. It is considered to be a time-dependent quantity.

Year	1971-1975	1976-1980	1981-1985	1986-1990
q_k	1.7	1.9	2.1	2.4

Table 1: Values of the Factor of Consumption

In practical modeling the factor of costs is used in the form of cash-value.

$$AW_o = \sum_{j=-1}^{-d} I_j \cdot q^{-j} + \sum_{j=1}^{n} I_j\, q^{-j+1} + \sum_{j=1}^{n} U_j\, q^{-j+1}$$

$$- q^{-n} \sum_{j=1}^{n} (U_j) + \sum_{j=1}^{n} (\ell_j q_k + k_{m_j})\, q^{-j}$$

where

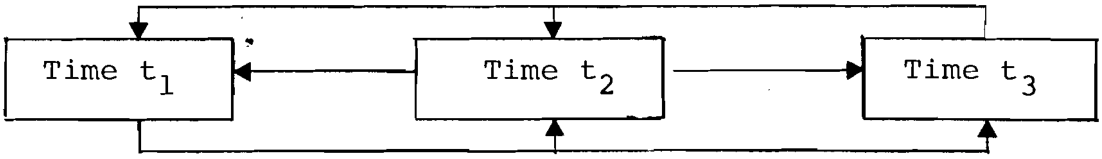
		Unit:
I	= investments	Marks
U	= circulating medium	Marks
ℓ	= wages	Marks/annum
k_m	= costs of materials	Marks/annum
q	= factor of accumulation	Marks/annum
q_k	= factor of consumption	Marks/Mark
n	= working life	years
d	= building time prior to the beginning of production	
j	= index for years.	

Besides minimization of costs, the following principles are to be considered:

1) Each cost which has already been included is not recalculated,

i.e. it is not necessary to take into account quantities related to funds, such as amortizations, profit, etc., for plants which already existed at the beginning of the period of consideration.

2) The working life of plants is only restricted by their physical working life. The calculation of optimization decides on the economic working life on the basis of normal wear.
3) No economic double counting is allowed, i.e. only those components of cost which are flowing into the system from outside in the form of investments, costs of materials for imported energy supplies, other raw materials and auxiliary agents, wages and outside aid, are considered. Factors related to the energy that is generated within the energy industry is not further calculated in the form of costs of energy supply.
4) In order to guarantee the comparability of all elements of cost, the structure of energy sources and plants which exist at the end of the period under consideration have their overall effectiveness taken into account.
5) The correct interconnection of several points in time within the period of consideration is extremely decisive. We therefore start with a real optimization of time periods which permits the mutual influence of all installations in a range exceeding the single time periods of the system. Here the principle of permanent forward and backward calculation is applied.



By this procedure it becomes necessary to build models in which the balances of material interconnection also occur over the total time period. In this way the balances of the single points in time are clearly emphasized.

Simultaneously it becomes possible to interrelate the technical/technological, material/technical, resource-conditioned and economic restrictions.

6) Each plant or resource is scheduled according to its efficiency, x, oriented towards time (installed capacity or agreed maximum delivery), and its temporally differentiated rate of utilization, y. The relations between these two factors are expressed by the condition

$$x - \Sigma y(t) \geqslant 0 \quad .$$

7) y-variables are introduced only for those temporal points and plants for which the expected rate of utilization and operation varies with time. In addition, there are capacitive values, x', used that are characterized by a constant or previously determined differential rate of utilization.

8) The registration is not done annually, but only in each n-th year. Recently, for instance, the following years were scheduled:
   1976, 1978, 1980, 1985, 1990
   whereby the reference year was considered to be 1975.

9) This gradation may lead to a distorted reflection of coefficients of economic influence. In order to limit this distortion a linear development of demand and elements of cost between time periods of several years was modeled.

This relatively simple description of the basic structure of models clearly shows that we start from a consistent consideration of periods of time. The isolated consideration of only one point in time leads to serious estimation errors.

4. The Model System

The strategic model system of the energy industry in the GDR is a hierarchical one. The initial point of all considerations are the models which are located at the central level. They consist of the Central Production Optimization Model and the Substitution Optimization model (ZPOM and SOM).

The Central Production Optimization Model represents a central model of the energy industry in the narrower sense. It includes plants of extraction, conversion and importing of energy sources. To this category belong all plants of the

coal industry,
gas industry,
electric energy industry,
primary refining of petroleum,
public heat supply,
important industrial power plants, and
heating plants,

independent of their subordination to a particular level of control. The load curve of the electric and gas systems is approximated by a step function. The total demand is either the whole country's demand or the demand sector's or the demand for energy sources from outside the energy industry. This model is used permanently for planning and research.

The Substitution Optimization Model also concentrates on the central level. It is comprised of energy-intensive processes that are to be decided at the central level (i.e. production of iron and steel, building materials such as cement, bricks, aluminum, copper, chlorine, plastic and elastic materials, the transport industry, etc.) as well as large scale energy production, the principal direction of which is still to be determined. Both these central models may be operated in a single and iterative way or in a mathematical coupling. Each branch of the energy industry which is represented in the central model has its own model. By means of these models it is possible to simulate the various plants and their seasonal behavior far more exactly. The aggregation is considerably lower. The disadvantage of these models exists in the impossibility of taking into consideration all variables influencing the energy industry. Therefore meaningful results can only be obtained if they are used within the model system or on the basis of the limitations calculated which are applicable to the whole energy industry (certain exceptions are permitted only in the case of special research).

The third decision component is considered to be the Optimization Models of Territorial Structure (TSM). These models optimize energy supply to be determined on a regional level. In this connection the most important points are the supplies to the population, communal economy and locally-managed industry. The models are connected with each other by a special coupling algorithm. The model system is operated as follows:

1) On the basis of calculations of central models, the submodels include assumptions about the highest and lowest limits of demand, and the possible supply of energy sources. In the same way, the specific costs of energy sources delivered from other spheres of industry, are included. Thus the central model (ZPOM) is withdrawn from the further process of calculation.
2) On this basis, the subdomains and territories may include any number of variables, but at least two.
3) The results of these investigations, together with the differentiated variables of the Substitution Optimization Model are introduced into the coupling algorithm in the form of variants. The coupling algorithm is also based on the principle of linear optimization and minimization of costs. The input of several variants is done complexly in a rigid material coupling with the value of the objective function. As each double counting must be avoided, the costs of energy sources which were delivered from other industries are again eliminated in advance. For each variant three possibilities exist:

1. It is used completely	Value = 1
2. It is not used	Value = 0
3. It is used partially	Value > 0, and < 1 .

It becomes evident that mixed variants may arise. In the case of mixed variants , the results are transmitted to subsystems for further processing. These conditions should prove whether such a mixture of variants is admissible. If it is admissible the calculation is continued as follows:

1) The optimum variable or combination of variables get the value 'zero' for all energy sources to be delivered. Simultaneously the subsystem gets the additional costs of sub optimum reference vectors of output derived from the coordination model. Thus, a counter proposal must contain such an economy that all losses arising in other subdomains can be absorbed by it.
2) The counter proposals are taken over into the coordination model, thereby not eliminating the former variables. For this reason the size of the model steadily increases with each iterative step.
3) The calculation is interrupted when a certain correspondence between the step n and (n + 1) is reached.

A special compensating block which can cover, take up and reverse deficiencies and excesses of several systems at each time period, leads to a high flexibilitiy, even under the conditions of a relatively rigid basic structure with several variants in the coupling algorithm.

The utilization of this model system is based on the principle of democratic centralism. This means on the one hand, that submodels are constructed by those who have the greatest knowledge of the subject, and on the other hand, that interests are subordinated to the whole. Depending on the number of hierarchical levels, the reaction time increases effectively. Therefore the model system is characterized by a structure which enables the system to be applied in various combinations, i.e. it is not necessary to use the whole system at once in every case.

Corresponding premises for submodels by the central model and the coordination model permit abundant scientific investigations. When applying the modeled results, however, it should be recognized that these results are considered to be initial and not final points of complex energy investigations implemented by specialists of several branches. The results of calculations must be fundamentally analyzed by groups of experts and must then be expanded substantially with regard to contents. It must not be forgotten that the advantage of models lies in the elaboration of essential connections. This is the reason that the work of experts must lead to an extension of the model content, which in turn results in new model calculations. We especially want to emphasize that the work with such economic/mathematical models is considered more effective, the more the models are integrated into the process of governing and planning.

In the GDR it would be possible to gather good experience on the basis of methods of long-term energy planning which are described in this context. The appropriate procedures were considered a valuable aid for the elaboration of strategies of energy development. The good results which were obtained within the five-year plans and which are based on the above methods, also argue for the quality gained in long-term planning.

In the future we shall steadily continue the course taken in the field of planning of the energy industry in the GDR. We expect particular success from the further extension of common planning with other socialist countries within the framework of the Council of Mutual Economic Aid which is considered to be one of the most important tasks of our future work.

B. Algorithms for the Coupling of Models of the Energy Sector

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1. Introduction

The energy sector of each country is a part of the national economic subsystems which have a direct and considerable influence on the growth rate of the national economy and the increase of the national income. Therefore it is a permanent objective to continually provide a rational basis for the provision of society with a demand-determined supply of energy sources. A tool for the proper achievement of this goal is the application of mathematical/economic models for optimization of the energy sector with consideration of national economic constraints. It is in the interest of society to include the largest possible system in the optimization models. According to the current level of our understanding, that kind of objective can be achieved only with mathematical/economic model systems which consider all essential economic, technological, and technical parameters, and to a limited degree, also political/economic influences.

2. Previous Developments in the Application of Mathematical/ Economic Models for Long-Term Planning

In the GDR, mathematical/economic models for mid- and long-term planning have been applied with success in the energy sector for many years. From this experience, it has been recognized that the optimization of economically important subprocesses can actually only be achieved through the minimization of costs in the entire national economy. However, in the use of mathematical/economic models, only limited possibilities exist to characterize the total national economy in the necessary depth and quality. Therefore an energy sector submodel was developed, taking into account the crucial national economic constraints. The energy sector was not built up as an administrative/technical unit. It includes all essential processes of energy supply and conversion, energy transport, and the industrial and non-industrial energy uses, as well as the total import and export of energy over a long time period.

In the initial stage of the application of the models it was not possible to include the energy sector comprehensively in one model. At this time, splitting energy use into industrial and non-industrial processes could not be achieved. Included in a central model, however, in one relatively strong aggregation (but sufficient for central national planning and decisions) were all essential facilities of primary petroleum processing, heat and electrical energy production, coal mining and coal processing, the production of city gas and the preparation of natural gas, as well as the importing of solid, liquid, and gaseous fuels. As an economic objective function, the minimization of social costs was used. The model brought together the following aspects:

- the development of demand as a function of time,
- the sequence of investments,
- the time-dependent occurrences of investment and plant expenses,
- the variable load-factor of the plants in successive periods of time, to the extent necessarv,
- the economic necessity for prematurely closing down existing plants,
- the change in the technical/economic indices as a function of time,
- the development of technology in successive time periods and the constant modernization of equipment according to the latest technological innovations,

- the economic/dynamic view of the selection of plants considering the mutual influence of plants available at different time periods; i.e. the influence of earlier plants on those built at a later time, and vice versa,
- an appropriately concise presentation and grouping of the primary energy production and energy conversion plants as well as the primary energy resources of the country,
- the interdependency between the plants of the energy sector,
- necessary economic restrictions.

The time period considered totalled 15 years from the end of the current five-year plan and was divided into multi-year sections of unequal length. As soon as this model had been found reliable in practice, models for the individual branches of the energy sector (e.g. coal mining, the gas sector, the electro-energy and heat sectors and the primary natural oil processing), were developed according to the same principle. A separate model was built to optimize that part of the energy demand in which a substitution of fuels is possible and which is important enough for an optimization. These models were used independently of each other for optimization of single branches. Although the results of the submodels gave deeper insights into the structure of the single branches, it was not possible to combine them in order to obtain balanced results representing the optimal solution for the energy sector as a whole. Therefore a system of models was developed for linking the already existing models, thus making them a tool for analyzing the whole energy sector.

3. Construction and Application of the Central Mathematical/Economic Model System of the Energy Sector of the GDR

For the construction of a model system it is assumed that the combination of the advantages of all the branch models leads to a super model, which in practice cannot be managed. A method which would allow coordination of the submodels of the branches is therefore searched for. A central coupling model system is being developed which, in its entirety as well as inside each single model, complies with the same demands; exactly like the central model of the energy sector. The basic assumption for the harmony of these single results is the uniformity of all submodels with respect to the type of model used, to the objective criterion including its concrete form of application, to the time period under consideration and its subdivision, as well as to the structure of the nomenclatures. In addition to this, it was decided to give increasing importance to the regional aspect. With this goal in mind, the construction of models of the complex regional energy supply for regional units of the country is necessitated. In these models all quantities that can be influenced on a regional basis are optimized. Results for subregions had to be obtained as soon as possible, with the personnel and experience available. Therefore the construction of the model system was planned to be done in two stages. The first stage contains 1) the modification of the individual branch models and the energy demand optimization model in such a way that they could be coupled, and 2) the creation of an appropriate coupling algorithm and the testing of this model system in the practical planning activity. In the second stage it is planned to elaborate step by step, complex regional models for political units of the country and selected cities and areas of industrial agglomeration, and seek to prove this by check calculations for selected cases. It was agreed that the step-wise designing of the single regional models already begins during the construction of the first stage and should be continued after completion. Currently, the primary stage appears in the first phase of its practical application, whereas for the second stage a larger part of the regional models has to be worked out yet.

The first stage of the central model system consists of four main parts. They are:

1) the central optimization model, which contains the entire energy sector in aggregated form,
2) the demand optimization model, which encompasses the substitution and optimization part of the energy demand,
3) the optimization part of the energy sector subsystems, energy production and energy conversion, and,
4) the coordination model for the direct coupling of the production optimization models of the various subsystems of the energy sector and of the demand optimization model, taking into consideration essential restrictions with respect to the total energy sector

The following strategy is thereby followed: in the first step, the energy demand of all economic sectors is calculated with the help of the demand optimization model and other research methods. The results of these calculations are produced in such a way that they can be, without contradiction, immediately introduced into the central optimization model as an essential part of the model. On this basis, the optimal energy supply and plant structure is determined by means of the central optimization model. Both models, when considered as a unit, represent an extended central optimization model. It is possible to reverse the order, i.e. that the central optimization model is first evaluated in order to define realistic constraints for the demand optimization model. In this connection one cannot speak of a primacy of the first step.

The first suggestions for the planning of the individual subsystems of the energy sector are deduced from the results of the optimization, and they are presented in the form of indices; each individual subsystem can then start with the optimization within the given limits. The results of these independent optimization calculations then flow into the central coordination model.

4. Coupling Algorithm for the Coordination of Submodels

Because of the large amount of labor and time that must be spent for the coordination of the submodels, it is necessary to carry out all formal calculation work for the balancing of the individual results and the selection of the optimal structure for the energy sector with the help of a suitable algorithm. Such a coupling algorithm must fulfil the following five basic conditions:

1) It must consistently represent the relevant conditions of the planning system in use and the general interdependency of all energy producing and energy consuming sectors.
2) It must be highly practical; in other words, the costs of labor and calculation time must remain within reasonable limits.
3) All variants appearing as intermediate or final solutions must, in principle, be technically and economically applicable.
4) The coupling algorithm must allow a variable application of the single models. This means it must be possible to use each single model either independently or as an integrated part of the model system, without further adjustments.
5) The coupling algorithm must guarantee the active cooperation of the planning experts.

A series of "decomposition processes" for the solution of large systems is known from the theory of linear optimization. Their mathematical validity has been proven at any rate. Their practical (applicability) use, however, is small to nil, particularly with regard to the above five basic conditions. For this reason a coupling algorithm for the practical control of the model system of the energy sector has been developed in the GDR. As previously noted, a preliminary balancing resulted from using the central optimization model to get data for the energy supply capacities. In this context, all necessary restrictions on the economy must be considered e.g. import facilities, investing capacities, the labor market, etc. Considering these limits, possible ranges of energy use are determined both for the regions and for large industrial consumers, and the costs for providing the amount of energy desired are deduced. These structures serve as limits for the application of regional models within the energy sector and for a demand model of the large industrial consumers, simultaneously preventing the appearance of unrealistic energy demand structures, either in the regions, or by the large consumers.

Using these models, primary optimized energy demand structures and primary energy supply input concepts are obtained within the established bounds. These structures, however, still need to be checked with the sectors of energy extraction. For this purpose the calculated energy demand structures are inserted into the central optimization model:

$$Z = \sum_{j,k,t} c_{jkt} x_{jkt} + \sum_{i,t} c_{it} i_{it} + \sum_{\mu} z^{B}_{\mu} p_{\mu} + \sum_{\kappa,\tau} z^{B}_{\kappa\tau} p_{\kappa\tau} \longrightarrow \text{Min}$$

$$\sum_{j,k} a_{ijkt} x_{jkt} + i_{it} + \sum_{\mu} b_{it\mu} p_{\mu} + \sum_{\kappa,\tau} b_{it\kappa\tau} p_{\kappa\tau} \geq \hat{b}_{it}$$

$$x_{jkt} \lesseqgtr X_{jkt}$$

$$i_{it} \lesseqgtr I_{it}$$

$$\sum_{\mu} p_{\mu} = 1$$

$$\sum_{\kappa,\tau} p_{\kappa\tau} = 1 \quad \text{(for each } \tau\text{)}$$

The interpretation of the variables is as follows:

Z-Value of the Objective Function (Total Cost)

c_{jkt}	specific social costs of the energy conversion plant j of the subsystem k in a year t,
c_{it}	specific social costs for the import of energy in a year t,
a_{ijkt}	specific coefficient of either the extraction or the input of the energy form i in the plant j of the subsystem k in a year t,
x_{jkt}	quantity processed in the energy conversion plant j of the subsystem k in a year t,
i_{it}	amount of energy supply i imported in a year t,
$Z^B_{\mu}, Z^B_{\kappa\tau}$	total social costs of the variant μ, which was calculated in the demand optimization model for the large industrial consumers, and of the variant κ, which was obtained in the model of the region τ, respectively,
$b_{it\mu}$ $b_{it\kappa\tau}$	demand for energy form i in a year t for the variant μ (large industrial consumers) and the variant κ of the region τ, respectively,
$\hat{b}_{it}$	energy demand which is not optimized,
$p_{\mu}, p_{\kappa\tau}$	weight factors ($0 \leq p \leq 1$),
x_{jkt}, I_{it}	limitation for the capacity of the conversion plants and the energy import, respectively.

To avoid double counting in handling both energy production and energy conversion and use at the same time, a given variant of energy demand must be associated only with the costs resulting from the direct use of the various energy forms. When costs for the energy production are used in the calculations, they must be eliminated from the total costs of the variants.

The calculations of this model provide an initial balanced and optimized energy supply and plant structure. However, since the central optimization model works with highly aggregated indices, it has to be checked with the various sectors of energy supply represented by detailed models. These models contain reference data deduced from the central model for the amount of energy to be produced by a given sector as well as for the costs associated with the energy input. In addition to this it is necessary that each sector calculates some other variants of energy supply that take into account the given economic restrictions, i.e. upper and lower bounds of capacities that can or have to be used are centrally determined. Within these limits, however, full freedom of choice is given. In this manner several variants of energy supply structures are created so that coordination with the energy demand structures of the fuel consumers is needed. For that purpose another central model is applied. As opposed to the models which have been described earlier it consists of vectors describing the output and input of the various forms of energy in the individual sectors. The model, called 'coordination model', has the following form:

$$Z = \sum_{\mu} z^{B}_{\mu} p_{\mu} + \sum_{k,\lambda} z^{E}_{k\lambda} \rho_{k\lambda} + \sum_{\kappa,\tau} z^{B}_{\kappa\tau} p_{\kappa\tau} + \sum_{i,t} c_{it} i_{it} \longrightarrow \text{Min}$$

$$\sum_{\mu} b_{it\mu} p_{\mu} + \sum_{k,\lambda} f_{ikt\lambda} \rho_{k\lambda} + \sum_{\kappa,\tau} b_{it\kappa\tau} p_{\kappa\tau} + i_{it} \geq \hat{b}_{it}$$

$$\sum_{\mu} q_{st\mu} p_{\mu} + \sum_{k,\lambda} q_{kst\lambda} \rho_{k\lambda} + \sum_{\kappa,\tau} q_{st\kappa\tau} p_{\kappa\tau} \lesseqgtr Q_{st}$$

$$\sum_{\mu} p_{\mu} = 1$$

$$\sum_{\lambda} \rho_{k\lambda} \leq 1 \text{ (for every } k\text{)}$$

$$\sum_{\kappa} p_{\kappa\tau} = 1 \text{ (for every } \tau\text{)}$$

$$i_{it} \lesseqgtr I_{it}$$

$Z^B_\mu, Z^B_{\kappa\tau}, Z^E_{k\lambda}$	Total social costs for the variants calculated in the optimization models of the subsystems k ($Z^E_{k\lambda}$), of the regions τ ($Z^B_{\kappa\tau}$), and in the demand optimization model for large-scale industrial consumers (Z^B_μ), respectively,
$b_{it\mu}, b_{it\kappa\tau}$	Demand for supply of energy form i in a year t for the variants calculated in the demand optimization model; or for the regions, respectively,
$f_{ikt\lambda}$	Variant λ of either the output or the input of the energy form i in a year t through the subsystem k,
$q_{st\mu}$, $q_{skt\lambda}$, $q_{st\kappa\tau}$	Extent to which our individual subsystem or region is restricted by the restraint s in year t with respect to the total energy sector or the economy as a whole,
Q_{st}	Limit for the restrictions,
p, ρ	Weight factors ($o \leq p, \rho \leq 1$),
c_{it}	Specific social costs for the import of energy, and
i_{it}	Energy import.

In order to avoid double counting, those cost elements have to be eliminated from the cost factor associated with a variant of a given sector, which are accounted for in other sectors. For each sector the solution of this vector model is balanced and optimized with respect to the total energy sector. The optimal variant may be a vector already calculated by our individual branch model or a combination of two or more of them. If such a "mixed variant" occurs, its technical and economical feasibility must be checked by planning experts.

Because of the high level of aggregation in the coordination model, a renewed application of the submodels of the sectors may be necessary, in order to get a more concrete and precise idea of the optimal variant of the central model. Complete submodels are used for this purpose. In order to avoid double calculations, one just has to remove the cost factors for the use of energy provided by other sectors. The limits for an individual model are composed of all variants of energy production and use which already have been calculated for the sector represented by the model. Here the optimal variants determined by the coordination model are also included. Contrary to the conventional practice of linear optimization models, these vectors are incorporated into the decision part of the optimization model. Factors that express the importance of a given variant for the optimum of the entire energy sector are estimated and used to weight the variables. The optimal variant obtained in the coordination process is the most effective with respect to the entire system, subjected to the conditions that must hold at this stage of the calculations. Therefore, it takes the value zero in the submodels. The use of the other variants results in a deviation from the optimum. The value assigned to a sub-optimal variant in the submodels therefore is its deviation from the optimal variant. The "reduced costs" which are obtained by the linear optimization as a dual solution, can be applied as values of the deviation.

$$Z_k = \sum_{j,\ell,t} c_{jk\ell t} x_{jk\ell t} + 0 \cdot \psi_k^* + \sum_{\lambda} r_{k\lambda} \psi_{k\lambda} \longrightarrow \text{Min}$$

$$\sum_{j,t} a_{ik\ell t} x_{jk\ell t} + f_{ikt}^* \psi_k^* + \sum_{\lambda} f_{ik\ell t} \psi_{k\lambda} \geq 0$$

$$x_{jk\ell t} \lesseqgtr X_{jk\ell t}$$

$$\psi_k^* + \sum_{\lambda} \psi_{k\lambda} = 1$$

where

$c_{jk\ell t}$	specific social costs of the energy conversion plant ℓ of the plant category j, of the subsystem k in a year t

$a_{ijk\ell t}$	specific coefficient of the outputs or the input of the energy form i in a year t of a certain plant and of category j in a subsystem k
$x_{jk\ell t}$	quantity processed by the plant ℓ in a year t
$f^*_{ikt}, f_{ikt\lambda}$	supply and demand of the energy source i in a year t by the subsystem k; * = optimal variant of the coordination model, λ suboptimal variable of the coordination model, f^*_{ikt} & $f_{ikt\lambda}$,
$r_{k\lambda}$	"reduced costs" of the coordination model for the variant λ of the subsystem k
$\psi^*_k, \psi_{k\lambda}$	weight factors

This technique allows the selection of that structure of a a sector which is more effective than the optimal structure chosen by the central model. This is indeed the case when the cost decrease in a specific sector compensates for the cost increase, with respect to the entire system, that arises from the application of a suboptimal variant.

A second advantage of this technique is that in cases where the optimal variant has been identified by the central model and cannot be realized technologically or economically in its formally calculated structure, there are always alternatives available, along with an indication of their excess economic costs relative to the cost of the optimal variant.

If in one or more individual sectors the process of optimization results in an improved structure of the output of and the demand for energy, the process of iterative approximation has to be combined with a renewed application of the coordination model. The optimal structure of the entire system is found when the results of the optimization for the individual branches are in agreement with the result of the coordination model. The process may be stopped when the deviation between the structure of the entire system and the structures of the individual branches is below a given tolerance parameter.

In practical applications, the number of iterative steps is low. In the calculations performed so far, the number of iterations was between 3 and 4. The fast convergence is due to the structure of the algorithm as well as to the careful balancing before the application of the model system.

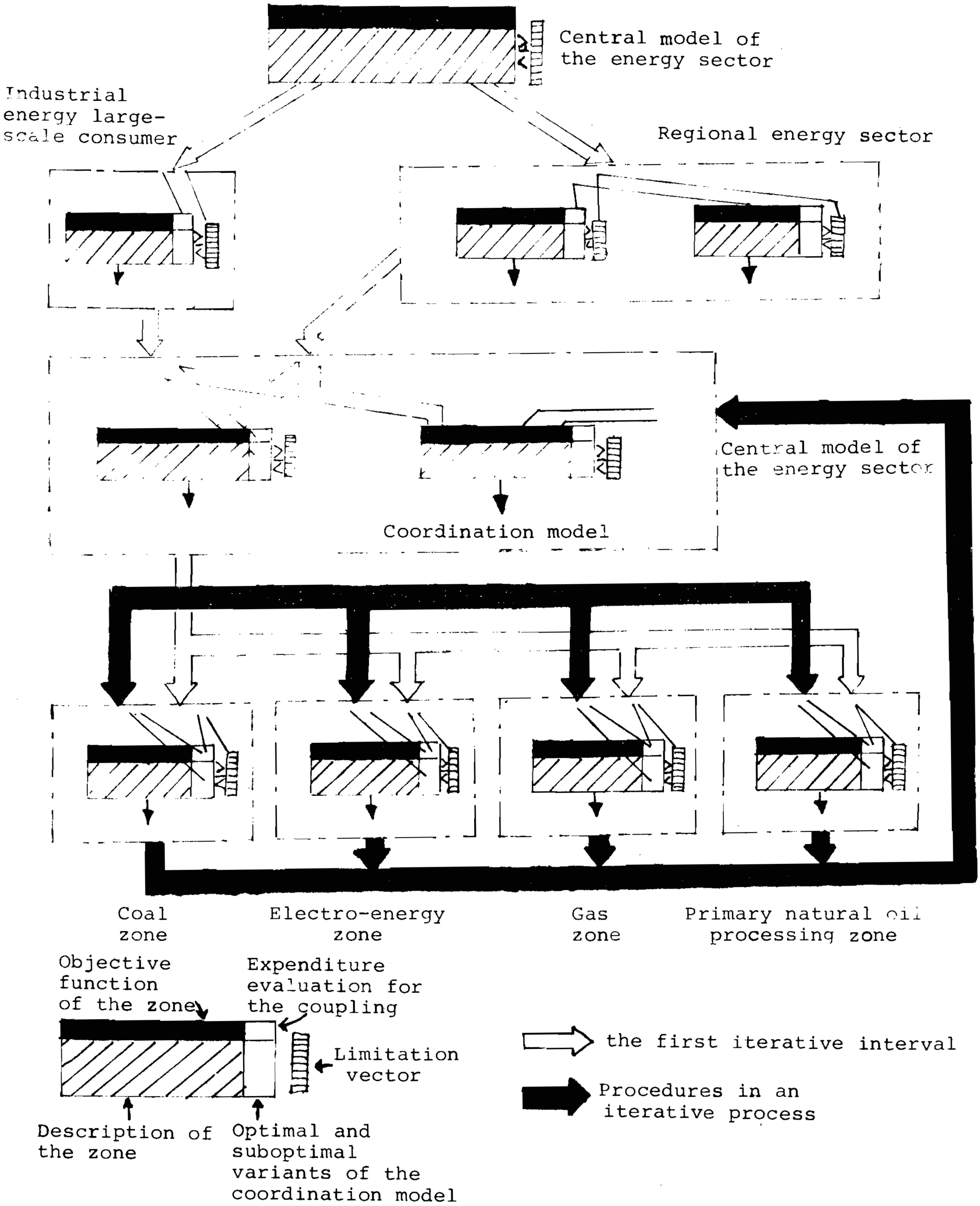
5. Application of the Model System and Problems

The description of the parts of the model system developed so far, and of the yet incomplete areas, have demonstrated that a stepwise procedure has to be followed, not only in developing such tools for preparing decisions, but also in their application. This is important from several viewpoints. No given tool used in the process of planning can automatically be generalized to make a practical algorithm, even if it is highly practical and flexible in itself. This sounds contradictory, but it is certainly true with respect to the application of the models. It takes several years of practical experience for those who run the models as well as for those who have to interpret the results, i.e. the decision makers in the government and the authorities leading the individual branches, to find the right way of dealing with mathematical/economical calculation procedures of this kind. And even this statement is valid only if the right, i.e. applicable level of aggregation, has been found. The main problem is the correct interpretation of the results of the models. One must be able to extract from the results the essential features of the real world, taking into consideration the various aggregations that have been made, to obtain the results and to use them for finding the right decision.

The application of models and model systems should by no means be understood in such a way that, with help of these modern tools, final plans can be produced by computers. Only by creative processing of the results by experts, can plans and other decision fundamentals be elaborated. These are, however, in every aspect superior to plans calculated in the conventional way, due to the higher degree of balance and optimality as well as to the governing role of the "objective function" which guarantees that subjective elements are eliminated in the planning process. Quite often teams of scientists or operations research groups are commissioned not only with the construction and application of the models, but also with the definition of the objective function and the interpretation of the results. This is only for the first steps. Efficient decision making is only accomplished when there is close cooperation between decision makers and modelers, and when there is a mutual understanding of the necessarily different ways of viewing the given problems. By merging the two viewpoints the new quality is created which is necessary in getting away from either the unreflected rejection or the glorification of the new technique; and ways can then be found for its effective use.

The fact that a model system is available, does not necessarily mean that one should refrain from the use of its submodels. On the contrary, an effective use of a model is only achieved when it is adapted for the solving of specific problems. Depending on the type of problem and its complexity, either the entire system, a subsystem, or an earlier version may be appropriate in finding a solution. Exaggerated use prevents, rather than promotes, successful utilization, as the optimization itself has to be done in an optimal way. Although the human role seems to be made distant with increasing rationalization of work preparation, of calculation stages of the evaluation process, which can only be done with use of a computer, still the creative capacity of humans increases through the possibility of people-machine-people dialogue. This is the case if people understand and shape this process such that they analyze, evaluate, and give directions at various intermediate stages, in other words, in a creative controlling manner. This is possible, but only when one has extensive experience. The simple and efficient coupling algorithm that has been developed in the GDR is especially suitable for this purpose. It provides a tool for controlling cooperative collaboration of all branches of the energy sector, which is based on the principle of democratic centralism, and for utilizing extensively the advantages of such collaboration. Previous experience shows that the coupling algorithm is suitable for coupling systems with quite different structures, if the models are adjusted in a consistent manner. From a mathematical-methodological point of view, we believe that it is possible to incorporate the energy sectors of several countries into one model system. The main difficulty in doing this lies in the fact that the economic conditions differ significantly in the individual countries. With the progress of economic integration of socialist countries, increasingly favorable conditions for such coupling will appear inside the RGW (COMECON). There is still enough time available for the construction and usage of such a hierarchial model system, since the availability of optimization models for the energy sector in the interested countries is a necessary condition. In future work on balancing and optimizing the energy sector, this problem should not remain unobserved.

A Schematic Diagram of the Central Mathematical/Economic Model System of the GDR Energy Sector



III. ENERGY/ENVIRONMENT MODELS AND THEIR RELATIONSHIP TO PLANNING IN THE RHÔNE-ALPES REGION

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A model is always a simplified representation of reality taken from a certain point of view which reflects the status and the interest of the modeler (or of the person in charge of it). Thus, one finds purely cognitive models, meant to improve one's knowledge of reality (physical, social cultural ...), as well as decision models which help a person or an institution make the best possible decision. Even in the same sphere of decision-making, the final decision varies according to the status, the functions, the temporal horizon, and point of view of the decision maker.

In dealing with energy matters, for example, one usually distinguishes between 1) the corporate models which help in choosing a sales strategy or a long-term investment strategy in a given market (coal, oil, natural gas, electricity...), and 2) the public planning models implemented by a governmental authority in order to identify the difficulties which could arise if the firm's strategies prove incompatible.

From one economy to another (United States, German Democratic Republic, France), the structure of decision making (in other words the totality of relations which connect centers of power) changes. A State may limit itself to a posteriori and indirect monitoring of the activity of firms, whereas elsewhere, the State actually determines the objectives to which the firms must adapt their programs. In this case, the scope of interaction between firms and the State can correspond to the limits of the studied region; in another case it can greatly exceed these boundaries.

These few considerations lead us to maintain that no evaluation of a model can be made (except an evaluation of their intrinsic coherence) without referring to the objectives and the resources of the authority in charge of the model. With reference to a given region (the state of Wisconsin, GDR, Rhône-Alpes region), the relevancy of a decision model increases as a function of the decision capability existing in the region.

How does the Rhône-Alpes region fit into the framework of the French economy and French institutions?

1. The Institutional Structure

Two aspects of the French economic and political organization are of importance for an understanding of the energy and environmental decisions in the Rhône-Alpes region.

First, for historical reasons, the entire French decision system is extremely centralized. This is true both for the State decision making apparatus which is centralized in high level administrative agencies (the ministries), geographically clustered in the capital, and also for the important firms whose power is also centralized within headquarters located in the capital. Government and corporate administrations (their overlapping will be discussed later) may be represented by bodies with greatly expanded heads and atrophied limbs which are reduced to executing orders coming from the top(1). For a long time, the Departments (created by Napoleon) formed the framework for executing orders. They were purposely small (about 90 in France) in order that they could not compete with the central authority. Recently, a shift has occurred: "Regions" consisting of several departments (from 4 to 10, depending on the specific case), have been created but they have not yet acquired true autonomy.

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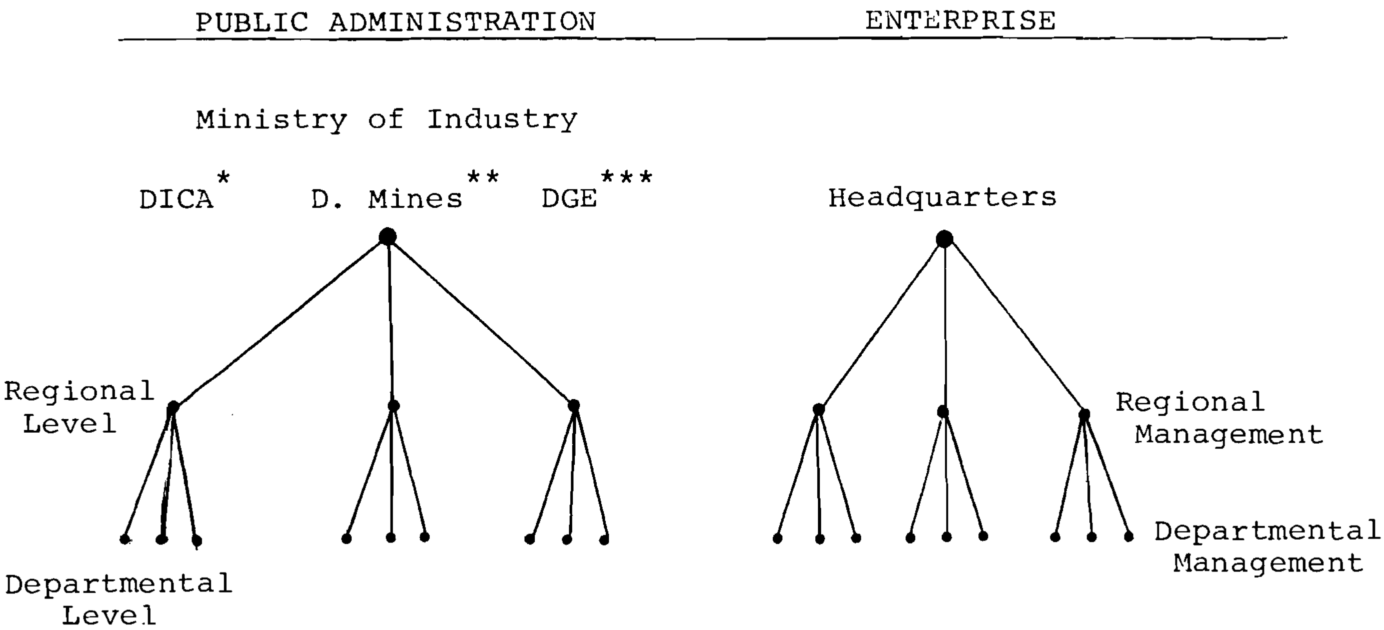
(1) If any difficulty arises on a given occasion, the department or region refers to its central agency which indicates how the obstacle may be overcome. If this is not sufficient, the central agency sends a high official who settles the problem on the spot.

In simplified terms, we shall thus consider the two following decision structures:



*Direction des Carburants

**Department of Mines

***Delegation Generale a l'Energie

In the realm of public administration and planning, monitoring and regulation are carried out only at the national level; in other words, they are uniform for the group of regions. The regional and departmental bodies collect information for the central agencies, promulgate the decisions of these agencies and supervise the application of the decisions.[2]

In the area of energy and environment, the central agencies do not have any unitary model available. They limit themselves to arbitration between the decisions taken by the firms which, as we will see further on, produce good national models.

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[2] This structure is so resourceful that it is capable of shaping all innovations to its needs. A recent study has pointed out, for example, that contrary to all expectation, the generalization of information processing in French enterprises is favorable to centralization. cf. Catherine Balle - The computer, a break in the reforms of structure of enterprises, <u>Le Monde</u> September 18, 1975.

The second important feature of French institutions is the status of corporations in the energy sector. The structure of this sector (e.g. the relations between firms) differs from that of other sectors of economic activity. The latter usually consist of a greater or lesser number of private French firms. Corporations of this type have practically disappeared from the energy sector to the extent that only two types of firms occur[3]:

- Branches of multinational firms which control about 50% of the French petroleum market;
- Public enterprises or mixed industry, either competing CFP and ELF-ERAP in the oil branch)[*] or monopolistic (EDF, CDF, GDF, CEA, CNR).[**]

Branches of multinational firms have a variable degree of autonomy, according to the structure and the strategy of the firm upon which they depend. At any rate, these firms never make decisions on their own, since the stakes are of some importance (large investment in refining or in transport, for example).

In the eyes of such firms, a region is at most a subgroup of consumers whose characteristics (quantity, density, growth rate) it is advisable to consider in a model representing the conditions of development of future sales. The results of such a model can influence the policies of the firm, for instance in the placing of investments.

Public enterprises or mixed industries enjoy a larger degree of power; however this power is far from complete because the public status of such firms makes them subordinate to the state authority. The amount of subordination varies, however, according to the extent to which the enterprise is

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[3] The emergence of nuclear energy tends, however, to change this situation. Pechiney-Ugine-Kuhlman, one of the largest French firms, is now being aided in taking control of a part of the fuel cycle.

[*] Compagnie Francaise des Petroles; ERF- Entreprise de Recherche et d'Applications Petrolieres, respectively.

[**] Electricite de France; Charbonnages de France; Gaz de France; Commissariat a l'Energie Atomique; Compagnie Nationale du Rhone, respectively.

a monopoly (the guardianship of the State is less constraining for the firms like CFP and ELF-ERAP which compete with the branches of the multinational oil companies) to the extent to which it can defray its investment expenses (EDF, which has become more than 50% self-financing, has acquired much more autonomy than CDF or GDF). No matter what their weight is in final decisions - especially those which concern new investments - all these firms resort to models in order to diminish the uncertainty in the evolution of their market, in the prices of their imported raw materials, and in the technologies which they adapt. But these models, as we shall see, are conceived both by and for the central agencies. Regional specifications are only taken into consideration in the form of exogeneous data and of constraints:

- probable evolution of the energy consumption
- the availability of sources of energy
- or, opportunities for siting and water cooling for the large installations.

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Before passing on to a short description of models conceived and used by the firms in the national plan, we would like to say a few words about the ties between the two decision making structures. The State government is of paramount importance because it is a legacy of the history of a nation dominated by a struggle between the Centre (the monarchy) and the provinces (the fuedal system). The structure of the firms closely approximates that of the central government for reasons easy to understand. Since the foreign oil firms first opened branches in France at the beginning of the century, they have tried to influence legislation which has not always been favorable to them; in order to do this, they have installed representatives as close as possible to the center of the State power. Later on, since the great wave of nationalization in 1974, rationalization has been synonymous for standardization and centralization. This was in reaction to the disintegration of the mechanism of production (especially electricity and gas), which resulted from undynamic and diffuse capitalism. The osmosis between government administration and energy firms has been made considerably easier and has been speeded up by another aspect of French centralization, namely the uniform production of managers in the 'Grand Ecoles' of engineers also concentrated in the Paris region. Through a well known and often studied phenomenon, the same personnel goes from the directorship of government agencies to that of public and sometimes private firms.

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2. The Models Used in the Rhone-Alpes Region

As has been stressed, economic and, in particular, energy activities in the Rhône-Alpes region do not constitute a self-contained economic system, since the institutional and economic structure of France is very centralized. Moreover, there are no energy models adapted particularly to the Rhône-Alpes region. The majority of the models which do exist, represent French activities in a centralized manner. We will, therefore, deal especially with models whose spatial area is the nation rather than the region.

A. Models of Decision Making

The majority of these models are very specific and are relevant to operational research or the simple administration of enterprises.

The Oil Branch Models

At the branch level, various oil companies have elaborated:[4]

- models which optimize the administration and the operation of a refinery, taking into account its technical characteristics, the quality of oil supplied to the refinery, and the production program imposed by company headquarters, and also taking into account the company's

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[4] See MAURIN, Linearly Applied Programming, Technip, 1967, 375 p.

market in the area of the refinery. In order to do this, the variable expenses (the buying of crude oil, utilities, various products) are minimized as given objectives of production; the specific characteristics of products are also taken into account, with the assistance of programming techniques;

- models of transport and distribution which minimize the transport expenses, as well as models of the availability of different oil products taking into account the siting of refineries, of departmental storage places, and of main areas of consumption. These models are most often regional and also use programming or various algorithms.

Much more general and global models exist, which attempt to optimize the strategy of oil companies by planning their investments in exploration, refining and distribution, and by optimizing their strategy of acquiring markets (fuels, light products...). Again it is necessary to remember that half of the French oil market is controlled by branches of multinational firms whose investment policy depends on the strategy of the group as a whole. Strategic models do not exist at the French level in these branches.

The Gas Branch Models

Except for the models which optimize the management of a gas pipeline, taking into account the possible extension of different regional markets and the availability of gas (national resources, import contracts), and the models for the management of reservoirs with underground storage, in order to regulate the point of demand, few models for gas have been developed in France by Gas de France. However it should be mentioned that different methodologies have been utilized in place of informal models, either to analyze the competitiveness of gas, or to help in choosing investments.

With the former methodology the markets for gas have been studied case by case, by considering the different domains where it is usable and/or used;[5] one determines an equivalent price

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[5] Some specific domains are tubular boilers, different types of drying, baking of burnt earth, etc.

for gas from the price of a competing fuel, taking into account the profit of utilization, costs of equipment and of exploitation of gas users. With the second methodology[6], "Gas de France" studies the profit of investment projects; with the help of a criterion, it determines from among a multitude of profitable operations (in other words those for which the rate of profit is superior to the rate imposed by public power), those which produce the best forecasted financial result. It is in effect necessary to cut down on less profitable projects because investment credits granted by public authorities are limited.

The Electricity Branch Models

This branch has been an object of particular attention on the part of the modelers: the first models of linear programming used in France were developed in 1954 by EDF for the purpose of choosing electrical investments. Since this time, the company's researchers are making progress in utilizing new computational techniques (non-linear programming, dynamic programming, the theory of optimal control, etc.). We would like to point out that very specific models exist - such as those for optimizing the nuclear fuel cycles[7], for optimizing the network of electricity transport, and for maximizing the reliability of this network[8], etc. But it is appropriate to dwell upon more general models, in particular on models for demand forecasting and for choosing among electricity investments.

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[6] cf. Toromanoff, The Choice of Investments at the Gas de France, Revue Francaise de l'Energie, 260, February, 1974.

[7] cf. Charpentier, Naudet, Paillot, Simulation Model of the Nuclear Fuel Cycle, Commissariat a l'Energie Atomique, France, 1973.

Model SEPTEN, Service des Etudes Nucleaires, Direction de l'equipment de l'EDF, France, 1972.

[8] J.C. Dodu, Probability Model for the Study of the Security of Supply from a Transport Network, Electricite de France, 1973.

The models for forecasting electricity demand used by EDF[9] are relatively simple and based upon extrapolation of past trends, using statistical relations of the simple or multiple regression type. These relations (generally logarithmic) associate the quantities of electrical energy at the global level (or at the level of highly aggregated sectors such as the residential, commercial, or industrial sector)[10] at time t:

$$\log C_t = a + b \cdot t$$

or with economic activity as represented by an operational economic index of the gross national product (Product National Brut or PNB) or industrial value added (Valeur Ajoutee Industrielle or VAI):

$$\log C_t = a + b \log PIB_t \quad .$$

Forecasters at the EDF have concluded that these models provide the best results and that all efforts to associate electricity consumption with other variables (such as the relative price of capital, of labor, or of fuels as compared with electricity in industry, or such as income and/or the number of households in the residential and commercial sector) prove to be unsatisfactory.[11] It is necessary to point out that this econometric approach assumes that the consumption of electricity is inelastic with respect to price, and that the market for electricity has developed in a relatively autonomous manner in a specific domain. The new commercial strategy of EDF and the great increase in the price of

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[9] D. Finon, Forecasting the Consumption of Energy and Electricity: The Methods Used in France, in C.J. Cicchetti and W.K. Foell, ed., Energy Systems Forecasting, Planning and Pricing; Proceedings of A French-American Conference, University of Wisconsin-Madison, February, 1975.

[10] Or even high or low consumptions.

[11] Y. Pioger, Forecasting Power Consumption and Models for Constructing Load Curves, in C.J. Cicchetti and W.K. Foell, ed., Energy Systems Forecasting, Planning and Pricing; Proceedings of a French-American Conference, University of Wisconsin-Madison, February, 1975.

petroleum products, however, cancels all compartmentalization between markets for different types of energy and makes these methods more open to criticism. At the present time it is necessary to confront econometric forecasts with the commercial objectives of a firm; further the forecasts must be supplemented by various scenarios for the future. One could never completely discard methods of extrapolation, but beyond a horizon of five years, such projections should be used with much caution.

In addition, a short to medium term forecasting model of the daily load curve is used to define the output power according to the hour, the day, the week and the month, by extrapolating various coefficients which characterize several parameters.[12]

Let us now consider the models for the choice of electricity investments. An important bibliography exists on this subject.[13] These models minimize in the long run (1975-2000) the actualized costs of electricity production over a long period of time, in accordance with given production objectives. These objectives are determined by projections of global electricity demand which are worked out (1) with the aid of the econometric models discussed above, and (2) by a representation of this demand by means of weekly load curves. The different types of equipment for electricity production, including hydroelectric equipment are explicitly taken into account and are characterized both by their capacity and by the services they are supposed to render, (in other words their functioning during the different hours of the load curve, taking into account

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[12] Y. Pioger, Forecasting Power Consumption and Models for Constructing Load Curves, in C.J. Cicchetti and W.K. Foell, ed., Energy Systems Forecasting, Planning and Pricing; Proceedings of a French-American Conference, University of Wisconsin-Madison, February, 1975.

[13] See for example: P. Masse and R. Gibrat, Application of Linear Programming to Investments in the Electric Power Industry, Management Science, 3, (1957).

F. Bessiere, Methods of Choosing Production Equipment at Electricite de France, European Economic Review, (Winter 1969).

F. Bessiere, Energy Systems Forecasting, Planning and Pricing; Proceedings of a French-American Conference, University of Wisconsin-Madison, February, 1975.

their availability). The risks associated with hydropower and hourly electricity consumption are taken into account with the help of probabilities established from past samples; these permit one to take into consideration possible failures of the production system.

The actual model[14] uses the theory of optimal control. The objective function of minimization is a function of cost, composed of three terms (investment, operating cost, cost of failure[15]). The control variables are the quantities of equipment to be installed year by year, and the constraints express an obligation to satisfy future demand as well as the forced (or limited) development of certain types of equipment. The algorithm has two parts: first, the control variables are determined and then the optimal management for equipment of given power is defined. The program allows one to obtain an optimal equipment plan at the national level, the duration of the economic life of equipment, the probability of failure, the marginal costs of production of a kWh (according to the hour, day, and month) and values in use. The marginal costs which have thus been determined serve to establish electricity tariffs. In order to do this, one adds to them the marginal costs of transport and distribution calculated elsewhere and a "toll" which permits the EDF to attain a budget equilibrium and even to possess an appreciable self-financing capacity.[16] The values of use determined by the model, aid in the comparison of individual hydro-electric projects with reference equipment (conventional thermic or nuclear), serving the same purpose, in order to study their profitability[17].

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[14] Called the "new national model of investment". c.f. D.Levi, D. Saumon, Description of the New National Model of Investment, Internal Memo of the EDF, May 1973.

[15] The cost of power-failure is a non-linear function increasing in relation to the duration and the amplitude of the power failure.

[16] P. Stasi, The Rational Use of Electricity: The Contribution of Tariffing, Symposium on the Rationalization of the Consumption of Electrical Energy, Varsovie, 1962.

C. Berthomeiu, Theory and Practice of Electricity Pricing in France, Energy Systems Forecasting, Planning, and Pricing; Proceedings of a French-American Conference, University of Wisconsin-Madison, February, 1975.

[17] This decentralized procedure is called the "Blue Note". M. Boiteux, F. Bessiere, The Use of Aggregate and Marginal Methods in Choosing Investments, in J.R. Nelson, Optimal Investment Decisions, Prentice Hall, 1962.

These models of investment choices are particularly complex to the extent that the system of French electricity production is a mixed hydropower system - conventional-thermal (or nuclear).[18] This necessitates a rather detailed representation of the management of various hydropower equipment (water flows, locks, reservoirs, pumps) during different hours of the year, taking into account the daily, weekly or seasonal carry-overs whcih they warrant. In the present model, a submodel simulates the management of the electrical capacity in such a manner that the diagram of the weekly (or monthly) load of the conventional thermal capacity is as flat as possible. It is necessary to stress that among the models of investment choices which succeeded one another, only the model "Investments 85" constructed in 1965,[18] was disaggregated into five regions; the Rhònes-Alpes region, together with the Mediterranean region - Cote d'Azur, constituted the Southwest region of this model. The Southwest region was linked with other regions by variables describing interregional exchanges. The objective was not to specify transport equipment, but rather to try to outline a preliminary scheme for the localization of production equipment, taking into consideration the location of hydropower resources and consumers.

It is necessary to specify that these investment models only deal with private costs and, in no case social costs such as the degradation of the environment arising from atmospheric or water pollution, or from land use. In other words not a single environmental constraint has explicitly been taken into account. From a practical point of view, for example, these models have never explicitly integrated the choice of siting for electricity installations since almost all the models have not been regionalized.[19] In France, where there

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[18] Utilizing non-linear programming.

[19] The regionalization included in the model "Investments 85" was not fine enough to permit this problem to be taken into consideration.

are few channels of water whose flow is sufficient to support, without risk,the installation of numerous sources of thermal pollution, the problems of cooling prevails over transport expenditures when choosing the siting of central thermal installations.

Consideration of environmental impacts, however, has not been excluded from the concerns of the EDF.[20] Ecological problems have been evaluated with reference to a group of factors from fields as varied as physics, medicine, biology or psychology. Some of the elements are purely qualitative or subjective and have been taken into account because of judgements or explicit or implicit choices made by alert citizens who are presumed to express the attitudes and the aspirations of the collectivity. The evaluation of the relative importance of ecological problems posed by different production installations, has been calculated using a single unit by means of "ecological points". Seven types of ecological problems have been catalogued[21]; then, for a given type of ecological problem, the present value of impacts brought about by different techniques has been calculated; and finally, using a comparison between the different types of impacts with the help of a function of implicit preference[22], the totality of values of impacts of different installations has been calculated in terms of "ecological points". Consequently, one can evaluate the ecological gain of each action undertaken to reduce

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[20] Harmful effects of radio nuclear origin, noise and oscillations of electrical or radioelectric origin, other harmful effects causing changes in the air, water, ground, etc.

[21] For instance, 600 Mw units in conventional thermal plants.

[22] This function of preference expresses the level of concern attached to each category of harmful effects and is based on subjective considerations (acceptable levels of change in the natural environment, quality of the atmosphere, etc.)

harmful effects to the environment. With this technique, one can also obtain an implicit evalution in monetary terms of an 'ecological point', an evaluation which will, however, remain more or less inexact. There is no room to dwell further upon this approach to environmental problems which, you will remember, is not directly related to the EDF's models of investment choices.

At the sectorial level, no global decision model exists which is designed to influence the decisions of public authorities or of organs close to those. This applies, too, to the regional energy system. Previously, a method of energy planning did exist and it was used within the framework of the IV and the V French Plan;[23] the method included a type of informal model which permitted one to determine how France could be supplied with energy at the lowest cost, taking into account the objective of having a reliable supply. But this method was abandoned in 1970 at the time of the conception of the V Plan, for the public authorities no longer had command over the energy system.

We would also like to mention the existence of a simulation model for the financing of the energy sector which permits one to forecast from 1970 to 1985 (or 1990) the medium- and long-term consequences of changes in energy policy (tariffs, taxes, investments, regulation)[24] for the financing, employment and annual investment needs and the budgets of enterprises in the energy sector.

B. The Cognitive Models

To our knowledge, very few efforts have been made in France to study the French energy system with the help of models, in order to better understand the system and to explore its future effectiveness.

One may take note, for example, of the scenario method;

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[23] 1961-1965 and 1966-1970.

[24] FINER's model constructed by D. Blain at the Ministry of Economics and Finances, No. 1972.

it permits one to reduce the complexity of the system studied through the selection of the most important factors, to trace different scenarios for the development of nuclear energy up to the year 2000.

At the Energy Institute of Grenoble, an optimization model for the energy sector[25] has been developed without any ties to the public authorities.[26] Its goal is to test the reaction of the French energy system to modification in its political and economic environment, e.g.

- price of oil
- cost of nuclear facilities
- development of certain technologies
- policy of preserving the environment
- policy of making the supply of energy secure or of limiting oil dependency, etc.

The model uses linear programming to reduce all the actualized costs of investment and exploitation which have accrued because of the need to satisfy energy demand; at the same time the model considers utilization expenses over the period 1975-2020. The activities in the energy sphere are approached in a centralized manner, France being considered as a whole.

The system is described by means of a graph in which the nodes represent economic operations (extraction, import, processing, transformation, transport, consumption) defined as all energy-related activities in the French territory. It integrates the consumptions of energy with possibilities for arbitrating between the different forms of final energy in the competitive domains of their thermal uses. In its current version, only SO_2 emissions have been taken into consideration from among all negative influences on the environment, but the method of formalization could easily be extended to other types of impact.

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[25] See D. Finon, The Energy Model - Optimization of the French Energy Sector Through Global Approach, Dissertation, Grenoble, March, 1975, 520p.

D. Finon, Optimization Models for the French Energy Sector Energy Policy, Vol. 2m No. 2, June 1974, 136-151.

[26] It does not, in other words, serve directly to help the sectorial decision makers.

The model chooses between the different processes for producing different types of energy on the basis of minimizing the cost, under the constraints of satisfying demand and under various political constraints (limitation of dependence on oil, possible acceleration of the nuclear program, limitation of the levels of emissions, etc.). The variables of the model are, in other words, the flows through the pathways of the figure during different years (variables of exploitation) and the equipment capacities to be created in the future (equipment variables). The different parts of the model are then composed of a subsystem of consumption and a subsystem of production.

The Subsystem of Consumption

Demand is partly endogenous to the model. In addition to the sector's own consumption, the consumptions to be satisfied are disaggregated into three groups of consumers (industry, transport, domestic furnaces), nine types of final energy (coke, coal, gas, electricity, motor fuels for the transport systems, napthalene for chemistry, domestic fuel, heavy sulfurreted fuel, and heavy weight fuel with a low sulfur content). One also distinguishes among two types of usages, namely, specific usages and the usages which may be substituted. The latter mainly occur in the domain of thermal usages[27] where there is competition between different forms of energy.

Suppose c is a group of consumers:

ϕ - a form of final energy

$x^{1}(\phi,c)$ - the flows of this form ϕ directed towards specific usages

$x^{11}(\phi,c)$ - flows directed towards thermal usages

$r(\phi,c)$ - the profit from utilizing ϕ in the machinery of the consumer

$D(\phi,c)$ - the specific energy needs of the consumer

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[27] One considers various domains in which the characteristics of the competition between types of energies are different (use of steam and ovens in industry, heating of individual homes, and collective heating in the residential sector).

U_c - the consumers' need for useful thermal energy

$T(\phi,c)$ - the initial capacity of the energy-using machinery of the consumer for thermal purposes

$X(\phi,c)$ - the capacity created between the starting date and the date under consideration

Constraints on satisfying the energy demand

specific needs: $x^{1}(\phi,c) > D(\phi,c)$ for all ϕ

substitutable needs: $\sum_{\phi} r(\phi,c) \cdot x^{11}(\phi,c) \geqslant U_c$

capacity constraints: $x^{11}(\phi,c) \leqslant T(\phi,c) + X(\phi,c)$

The objective function of this subsystem is a part of the objective function of the total system and includes the cost of the equipment utilized and the expense of purchasing energy.[28]

a) The Subsystem of Production

The model connects different subsystems of production (coal, gas, electricity, and oil). One can show with the network the interdependencies between operations and the ways of managing the equipment installations, i.e. contribution of electrical equipment to the various hourly positions of the load curve, taking into consideration the different types of crude oil and different degrees of distillation. In the new version used at the present time, the model integrates low enthalpy geothermics, solar energy for heating of buildings, and the recovery of the heat from power plants, etc.

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[28] We should stress the fact that the model integrates possibilities of choice between energy types at the level of final consumption, parallel to the concentrated decisions of the energy production system. The representation of phenomena of substitution between energy types has nothing to do with price elasticities of consumption, the use of which appears critical in every long-term model.

Optimization permits the realization of various types of arbitration:

- decisions between energy forms in the different competing domains,
- decisions between more or less capitalistic processes,
- decisions between types of energy to be imported and types of energy which should be locally produced,
- decisions between more or less polluting production and consumption process[29] .

It is thus possible to obtain for the years during the 1975-2020 period (taking into account the value of the different parameters):

- the balance of primary energy
- the global or disaggregated balance of final energy evaluation
- the supply of equipment for production and consumption
- the activity of the various plants
- the increase of investments necessary for the adaptation of the energy capacity
- the needs for currency necessary for import of fuels
- the total expenses from year to year (whether actualized or not)
- the emission of pollutants considered in the model

This type of model, which by no means can take the place of the decision makers, would permit an analysis of the rigidity of the energy structure, the competition between energy types in the various domains where competition exists,

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[29] The limitation of emissions is developed at the global level in France. Such a procedure may seem limited and even to be criticized, expecially as a single impact is considered. However, not everything should be rejected a priori; at the national level, one can fix thresholds of emissions or of waste materials which may not be exceeded, and which would be defined in such a way that the harmful effects observed by individuals would be at an acceptable level in the most polluted geographical sectors. (See on this subject, D. Finon, Evaluation of the Costs of an Environment Protection Policy on the French Energy System in OECD, Energy and Environment, Paris, 1974, 239-273).

and possibly their margin of operation.[30] This is in our opinion the ideal tool for obtaining some idea of the future of an energy type or new technology 15-25 years from now (for instance, solar energy, geothermics, hydrogen or recovering of heat from power plants).[31,32] In the future the model will be reviewed to study specifically these new energies and techniques; it will also be improved at the level of the representation of the arbitration of consumers by a disaggregation which is more driven by the type of usage and considered agents.[33]

In any case, let us stress that this type of model can be (and will be even more so in an improved version) a good instrument for analyzing the three fundamental elements of the

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[30] See the example of the utilization of the model on a variation of the investment cost of power plants.

[31] Others have a much more normative curve concept of this type of tool and would like to use it to calculate the optimal distribution between the various energies and to deduce optimal prices and tariffs (with the help of dual variables) which allow the guiding of the consumers' choice in the best way for the collectivity. We prefer to give a more prospective function to this type of tool.

[32] The model in its new version is actually used in a very pragmatic manner in the energy sector of nine countries of the EEC, with the help of a network (flow graph), general enough to be applied to each. The goal is to calculate at the same time the annual needs for investments and currency until 1985 and to trace various energy futures up to 2000-2020, taking into account the value of the parameters. One foresees the further study of the compatability of the local optimum with the global optimum of nine sectors which are integrated together.

[33] In connection with the research developed at the Institut Economique et Juridique de l'Energie by B. Chateau and B. Lapillonne on a prospective basis (by system analysis of the energy demand at the year 2000), this demand was studied from an analytical point of view in the consumer's section, taking into account present and future techniques.

energy policy:

- the energy economy
- the development of national resources
- the choice of the sources of import

with the aid of various criteria: the lowest cost for the collectivity (taking into account the financing problems), the least economic dependency on other countries, the reliability of supplies, and finally, the limit of ecological consequences[34].

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In summary, no specific models exist in the Rhône-Alpes Region, but there are models covering all the French activities in one branch or one sector. This is mainly due to the institutional and economic centralization of France.

Among the existing models, the most numerous ones are decision models covering one branch and, in this particular branch, well-specified methods. They utilize in general optimization techniques. At the global sectorial level, the only formalized model which exists serves a prospective goal without a real tie with the centers of public or private decision making.

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[34] The reduction of the foreign dependency, by the development of national resources and by energy economy, has strong limits resulting from the criterion of low cost.

APPENDIX

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

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