INCORPORATING UNCERTAINTY INTO ELECTRIC UTILITY LONG-TERM PLANNING AND DECISION MAKING*

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ABSTRACT

This paper discusses uncertainty as it affects the planning and acquisition of demand and supply resources by electric utilities. The basic elements of uncertainty and definitions of key terms are given to illustrate diverse types of uncertainties associated with different resources and with the utility's external environment. Various analytical methods employed by utilities to treat uncertainty are discussed. A suggestion is offered on ways to enhance analysis of uncertainty by focusing more on the decision making process (and therefore less on the simulation of utility operations and finances). Finally, an example is presented that shows how a particular resource (programs aimed at improving energy efficiency of new buildings in this case) can affect other uncertainties that affect utility decisions.

Substantial progress has been made during the past few years in development and application of analytical methods to explicitly incorporate uncertainty into long-term planning. However, much remains to be done in collecting and interpreting data on the uncertainties associated with different resources and the utility's external environment and in using this information to assist decision makers in utilities and in regulatory commissions.

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INTRODUCTION

> Uncertainty today is not just an occasional, temporary deviation from a reasonable predictability; it is a basic structural feature of the business environment. The methods used to think about and plan for the future must be made appropriate to a changed business environment.

This statement (Wack 1985), which refers to business in general, certainly applies to electric utilities. During the past 15 years, the environment in which utilities operate has changed dramatically. The costs to construct and operate traditional central-station power plants have increased dramatically, natural gas and oil prices increased sharply during the 1970s and then decreased suddenly in 1986, load growth has slowed substantially, environmental-protection requirements have increased, non-utility sources of supply have emerged, the use of conservation and load management programs as "resources" has become important, and the concerns of state regulatory commissions have changed.

Because of all these changes and because the future will likely bring further changes, uncertainty is a critical element of utility analysis, planning, and decision making. New phrases such as uncertainty, risk, diversity, flexibility, resource portfolios, and hedging are frequently discussed. Unfortunately, appropriate methods to define and value these terms have not yet been developed. And utilities and their commissions have generally not agreed on how to balance risk against cost, how risk-averse utility decisions should be, and how the extra costs (i.e., the insurance premium) of a diverse and flexible mix of resources should be shared between customers and shareholders.

According to the dictionary (World Book 1983), uncertainty means "not known with certainty; in doubt. Not sure. Likely to change ... ." Risk means "a chance of harm or loss; danger. ... the amount of possible loss." Thus, uncertainty refers to lack of knowledge about future events, and risk refers to the consequences of this uncertainty. For example, utilities are uncertain about future natural-gas prices and therefore face risks of higher electricity prices and lower earnings if gas prices increase faster than anticipated.

Because of the risks associated with various uncertainties, utilities often consider a diverse ("different; completely unlike") mix of resources to meet future loads. They diversify ("give variety to; vary") and choose flexible ("easily adapted to various conditions") resources to hedge their decisions ("to bet on both sides in order to reduce one's possible losses").

This paper discusses several issues that utilities face as they grapple with resource decisions for an uncertain future:

The elements of uncertainty and the ways that utilities currently incorporate uncertainty into their models and analyses,

A key limitation in current modeling approaches and a new modeling framework that might provide information more useful to decision makers,

An example that shows how different kinds of resources can interact with various types of uncertainties.

Although this paper covers diverse topics, it is not a definitive, comprehensive treatise on uncertainty. Rather, this is the first output from a multiyear project at the Oak Ridge National Laboratory sponsored by the Least-Cost Utility Planning Program of the U.S. Department of Energy.

KEY ELEMENTS OF UNCERTAINTY

The most important element of uncertainty is agreement on and definition of the decisions that a utility has to make and how they are affected by future uncertain outcomes. Although the emphasis on decisions seems obvious, some utility plans contain page after page of analysis with no relationship to decisions that the utility might face during the next few years. For example, detailed analysis of a decision that might be made in 1996 (e.g., to begin construction of a new coal-fired power plant) is irrelevant in 1988. Similarly, careful review of the amount of conservation resources in a utility's service area is less important than analysis of the timing of conservation programs for a utility that currently has surplus energy and capacity.

To deal with uncertainty effectively, it is helpful to divide the uncertainties into two categories, external and internal factors.* External factors are those largely outside the control of the utility, such as inflation rates, regional economic growth, and the prices of fossil fuels. Internal factors are those at least partly under the influence of the utility such as construction schedules, operation and maintenance costs, plant availability, public opinion on various energy options, and participation in conservation and load-management programs. Although participation in conservation programs also depends strongly on customer interest, such

*In reality, these uncertainties fall along a continuum. The two categories are helpful in thinking about possible utility actions to manage uncertainty. Uncertainties also differ in degree; for example, the future price of natural gas is more uncertain than the future price of coal.

interest can be affected by the amount and types of marketing efforts undertaken by the utility.

Uncertainty can be handled in various ways (Quade 1975). Decisions might be deferred until additional information is available. For example, initiation of new demand-side management programs might be delayed until the regulatory commission announces new rules on cost recovery.

The utility might purchase additional information to reduce its uncertainty about key factors. In anticipation of a decision to build combustion turbines, a utility could hire expert consultants to develop improved forecasts of future trends in natural gas prices.

Or a utility might sell the risks associated with uncertainty to another party better able to manage the risk. Rather than purchasing natural gas for its combustion turbines from the local distribution company at prevailing prices, the utility might sign a long-term contract with a gas producer or pipeline with a predetermined price schedule. Similarly, a utility could negotiate performance contracts with energy-service companies to purchase the savings associated with energy-efficiency improvements. Finally, a utility could acquire flexible resources with short leadtimes, small unit size, and/or diverse fuel sources.

TYPICAL APPROACHES TO TREATMENT OF UNCERTAINTY

Traditionally (i.e., during the 1950s and 1960s), utilities did not explicitly consider uncertainties in analysis of future resource acquisitions (Fig. 1). At that time, the key questions facing utility planners were when to construct the next central-station power plant, what fuel to use in the plant, and where to build it. Single forecasts of future load growth, fossil-fuel prices, inflation and the other factors that affected the cost of constructing and operating power plants were developed. These forecasts were then used to assess the relative costs of different types and sizes of plants.

During the past few years both internal and external sources of uncertainty have become increasingly recognized. Utilities have begun to use at least three different methods to treat uncertainty: sensitivity analysis, scenario analysis, and portfolio analysis.

In sensitivity analysis (Fig. 2), the utility first develops a "preferred" mix of resources under baseline assumptions about exogenous factors. The utility then tests this preferred mix against uncertainties associated with key factors. Potomac Electric Power Company (1987) tested alternative plans against different assumptions about changes in oil and gas prices, coal prices, fuel types, construction costs, demand forecasts, power-plant outage rates and heat rates, inflation, capital costs, and other factors. Typically, utility revenue requirements and average electricity prices are the primary factors for which the uncertain variables are tested. The results of such sensitivity analysis show how "robust" a plan is to possible future changes in the utility's external environment. These analyses also help identify the risks associated with this plan.

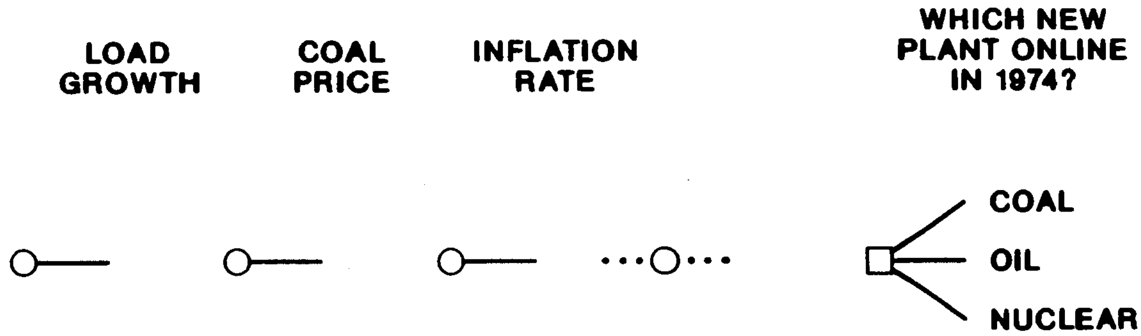

Fig. 1. Traditional utility planning. The focus was on a few supply resources (large central-station power plants) and point forecasts of exogenous factors. Boxes are decision nodes, circles are uncertainty nodes, and ellipses imply other uncertain factors such as future oil and gas prices, and regulatory changes.

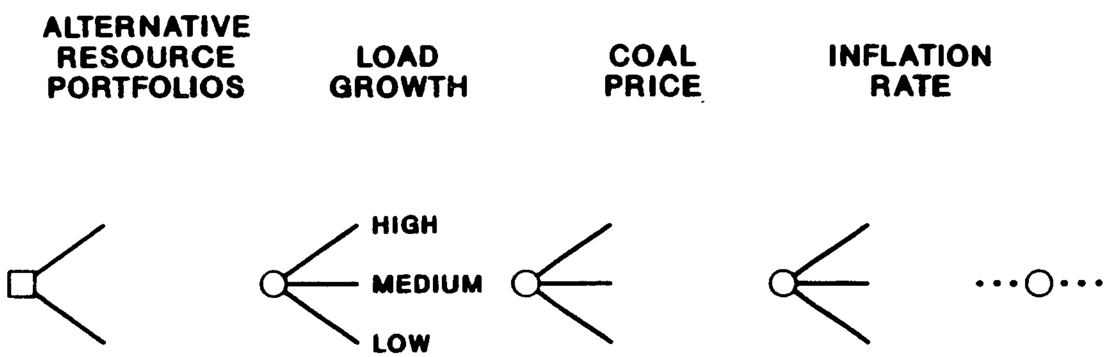

Fig. 2. Sensitivity analysis assesses the effects of several uncertain exogenous factors on predetermined resource mixes. Portfolio analysis is similar to sensitivity analysis.

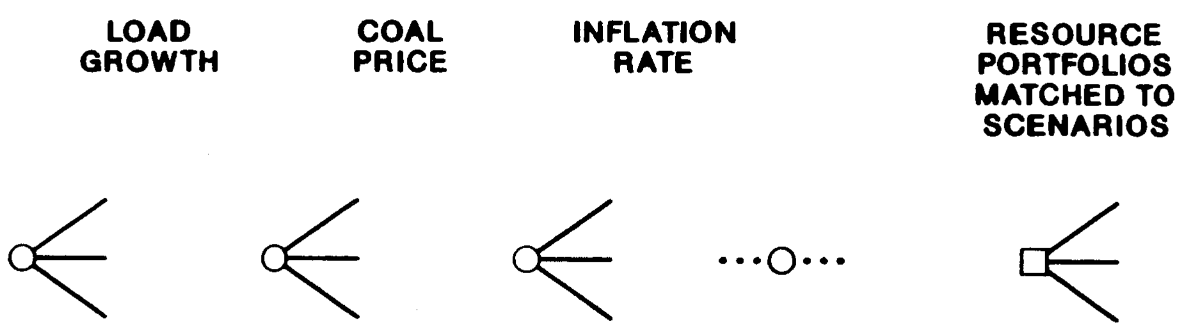

Fig. 3. Scenario analysis, in some ways the reverse of sensitivity analysis, involves the specification of several alternative futures. Resource mixes are then matched to each scenario.

Scenario analysis (Fig. 3) is, in some ways, the opposite of sensitivity analysis. In sensitivity analysis, all the resource-acquisition decisions are made at the beginning of the analysis period, and the effects of uncertainties on these decisions are then examined. In scenario analysis, the process is reversed, and the utility identifies preferred resource mixes for different sets of assumptions about the future.

The utility planners first develop alternative views of the future. Southern California Edison (1988) developed 12 scenarios with different levels of economic growth, fuel prices, industrial bypass, environmental concerns, and electrification, and loss of some of their generating plants. A different mix of resources is developed to match the conditions specified in each scenario. The utility's decisions for each scenario are then examined to identify common and disparate elements. The utility can implement the common elements, confident that these actions will prove valuable regardless of how future events unfold. The actions that are attractive for only some scenarios require additional analysis and/or flexible implementation so that these decisions can be modified as external conditions change from those in the utility's reference forecast.

Thus, scenario analysis helps to identify utility actions appropriate for different future conditions. It expands thinking about the range of alternative futures and appropriate responses to possible changes (Wack 1985).

Such analysis may identify a resource mix that is not "least cost" under any scenario but is second or third best under most futures, providing a hedge against various uncertainties. This approach is what the New England Electric System (1986) calls a "balanced" plan, one that balances additional cost against reduced risk to achieve reasonable and stable costs under a variety of assumptions. In essence, this approach emphasizes diversity among resources.

Finally, portfolio analysis involves specification of a few possible corporate objectives and selection of resource mixes matched to each objective. Because the objectives may be incompatible with each other, different resource portfolios will be optimal for each objective. These resource-mix portfolios are then tested against key uncertain variables as in sensitivity analysis. For example, Northeast Utilities (1985) examined resource portfolios to meet the following objectives:

Minimize dependence on oil,

Attain the lowest practicable electricity cost over the long run,

Plan projects to smooth out construction expenditures over time,

Emphasize conservation and load management measures,

Emphasize life extension and repowering of existing Northeast Utilities fossil steam plants,

Use small generation alternatives such as renewable resources, cogeneration plants, and small power production facilities.

The Michigan Electricity Options Study, conducted by the Michigan Department of Commerce (1987), developed four resource portfolios that emphasized: broad options, central station power, small diversified resources, and resources that minimized pollution.

Other methods are also employed by utilities, including decision analysis (with explicit assignment of probabilities to future events) and risk-tradeoff methods. In practice, utilities often use several of these methods to analyze multiple alternatives and many uncertainties with different outcomes and consequences. The ways that these methods are used depend on many factors including human resources (staff time, academic backgrounds, and experience), data, and the organization's corporate culture.

Although sensitivity, scenario, and portfolio analyses can provide valuable insights concerning resource alternatives, all three approaches suffer from a critical failing. As typically applied, these approaches use a computer model that simulates the operation of the utility (load growth, demand-side programs, production costing, capacity expansion, financial analysis, and rate setting) for 20- to 30-years. Because all the model inputs are specified before the model is run, all the utility's decisions are made at one time for the full simulation period. In sensitivity and portfolio analyses, decisions are all made before uncertainties are resolved. In scenario analyses, decisions are made after uncertainties are resolved. Thus, these approaches do not permit incremental decision making and they are therefore inconsistent with actual decision making.

NEED FOR A NEW MODELING APPROACH TO ASSIST DECISION MAKING

The foregoing suggests that a new modeling paradigm is needed, one that focuses more on the utility's decision process and less on the simulation details. This new approach would emphasize the inputs important to decision making, the accuracy of these inputs, the effects of frequent (e.g., annual) decision making, and the effects of permitting decisions to be modified.

For example, a typical application of an integrated planning model might involve the construction of a 250-MW coal-fired power plant. Inputs to the model specify that construction begins in 1991 and the plant comes online in 1999. This application provides no opportunity to revise the initial (1991) decision to begin construction and treats that decision as irrevocable. In reality, the utility could cancel or stretch out construction of the plant if coal prices rise rapidly, if acid-rain legislation increases the costs of pollution reduction at the plant or if loads grow more slowly than expected.

The Northwest Power Planning Council's (1986) option-and-build strategy is a pioneering first step that permits dynamic adjustment. The Council treats resource-acquisition decisions in two stages. The first involves purchase of an "option" to construct. For a typical supply project, this phase involves site selection, development of applications for construction permits and other licenses, environmental analyses, and engineering studies. The second ("build") stage involves construction of the facility.

The Council recommends this approach because the first stage is relatively inexpensive and saves several years of the construction cycle. If the situation changes while the resource is being optioned, it can be abandoned with little loss. The option stage provides insurance to the utility and its customers against the need for additional resources to fill the gap between growing demand and existing supply.*

The demand-side analogy to the option-and-build process involves implementation of small pilot programs, followed by systemwide implementation of fullscale programs. Systemwide programs are operated only if the need exists for these demand-side resources and if the results from the pilot programs are promising.

An approach proposed by ORNL extends the Council's two-stage process with an operational game (Hirst 1988a). The key features of the new approach (Fig. 4) are its provision for incremental decision making, its requirement that users interact with the model, and its explicit treatment of uncertainty.

The first element of this approach is a Futures submodel, which computes values of the exogenous factors year by year. This part of the model calculates internally consistent values of inflation rates, local and regional

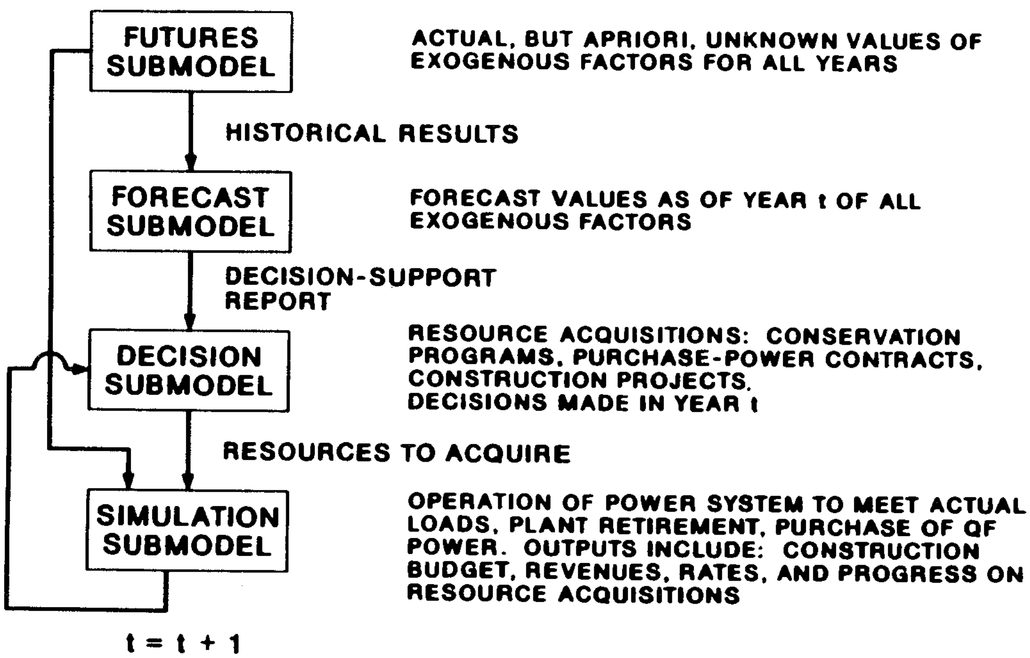

Fig. 4. Schematic of proposed modeling framework to analyze uncertainty in utility long-term resource planning.

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*Several commissions (e.g., Nevada, Wisconsin, and Washington) require their utilities to prepare long-term resource plans every two years. Periodic revision and review of plans encourage incremental decision making.

economic growth, and fossil-fuel prices for the analysis period. Before analysis begins, these factors are determined on the basis of simple underlying models plus a random component. More important than the structure that determines these factors is the fact that the values of these factors are unknown to the analyst (the individual acting as the utility decision maker).

The second element is a Forecast submodel, which estimates future values of the exogenous variables based only on historical values from the Futures submodel. For example, the Forecast submodel in the year 1994 would estimate future values (e.g., through the year 2010) of natural gas prices using values from the Futures submodel for natural gas price and other factors from 1980 through 1993.

The third and most important element is the Decision submodel. Here the user interacts with data and forecasts to make decisions about future resource acquisitions. "Historical" results from the simulation model (on the load/resource balance, electricity prices, and construction of new resources) are combined with forecasts to help the analyst decide among alternative resources. Because the Decision submodel is entered every year of the analysis, past decisions can be modified. Thus, construction projects can be accelerated, continued as planned, slowed down, mothballed, or cancelled. Contrast these choices with the once-and-for-all decision to construct a resource in the typical simulation model.

The final element simulates the annual operation and finances of the utility. This process is based on data from the Futures submodel and decisions made in the Decision submodel. This element could use an existing simulation model, such as MIDAS (Temple, Barker & Sloane 1987) or LMSTM (Decision Focus, Inc. 1984).

The proposed interactive model can be used in several ways, primarily to help utility staff gain experience in making decisions under uncertainty:

Identify the effects of forecast errors on decisions and on the effectiveness of decisions;

Explore differences in decision making among utility planners, utility executives, and state regulatory commissions;

Observe how decision making improves with practice;

Identify the benefits of flexible resources with short leadtimes and small unit sizes;

Develop decision rules for an expert system based on how people use the model.

EFFECTS OF CONSERVATION RESOURCES ON LOAD-GROWTH UNCERTAINTY

Resources differ in construction time, unit size, cost, and performance. In addition, resources can affect other uncertainties about the utility's system. For example, conservation programs aimed at improving energy-efficiency in new buildings affect load-growth uncertainties.

Proponents of conservation programs claim that the small size and short leadtime of such programs make them attractive in terms of reducing the adverse effects of uncertainty. Watson (1986) and Cavanagh (1986) noted that programs aimed at improving energy-efficiency in new buildings reduce uncertainty about future load growth. Ford and Geinzer (1988) analyzed the effects of new-construction performance standards on the Pacific Northwest electric system. They found that standards reduce uncertainty about future loads, although the value of that uncertainty reduction is small relative to the electric system's total cost.

To further investigate the effects of such programs on uncertainty, a spreadsheet model was developed to examine efficiency standards and rebates aimed at improving energy-efficiency in new buildings (Hirst 1988b). The effects of these programs on uncertainties related to economic growth and to consumer behavior are examined below.

The investigation began with the multiple forecasts that utilities often prepare as they develop their long-term resource plans. Typically, high and low forecasts are prepared in addition to a baseline forecast. Much of the difference among these forecasts is caused by different assumptions about economic growth in the utility's service area (Tennessee Valley Authority 1987). Economic growth implies creation of new businesses and expansion of existing ones, which in turn require construction of new factories, commercial buildings, and homes. Thus, for any forecast year, the estimated loads will vary, partly because of differences in new construction during both that year and prior years.

Programs aimed at improving electricity efficiency in new buildings will, all else being equal, reduce the loads associated with this new construction. The hypothetical programs tested here begin in 1990, run for the full 30-year forecast, and improve efficiency enough to cut electricity use by 20% relative to what would have occurred without the programs (Fig. 5). As expected, the programs reduce electricity use in both the high and low load-growth cases.

These programs do more than save electricity. They reduce electricity use more when loads grow rapidly and reduce electricity use less when loads grow slowly (Fig. 6). When the economy grows rapidly, there is substantial new construction, which increases the potential for saving electricity in new buildings; therefore, programs aimed at improving energy efficiency in new buildings reduce uncertainty about economic growth. This effect increases over time, as more and more new buildings enter the stock.

The reduction in mean load caused by these efficiency programs is expected. But the standards and rebates have very different effects on the uncertainty associated with consumer behavior because of their differing effects on efficiency levels in individual buildings (Table I).

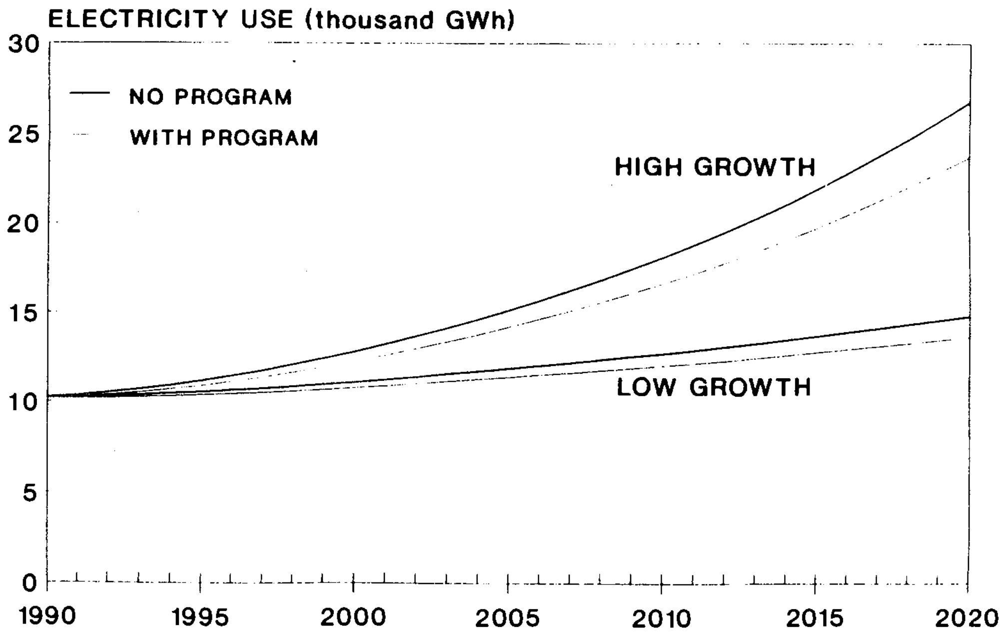

Fig. 5. High and low economic-growth forecasts with and without programs that cut electricity use in new buildings by 20%.

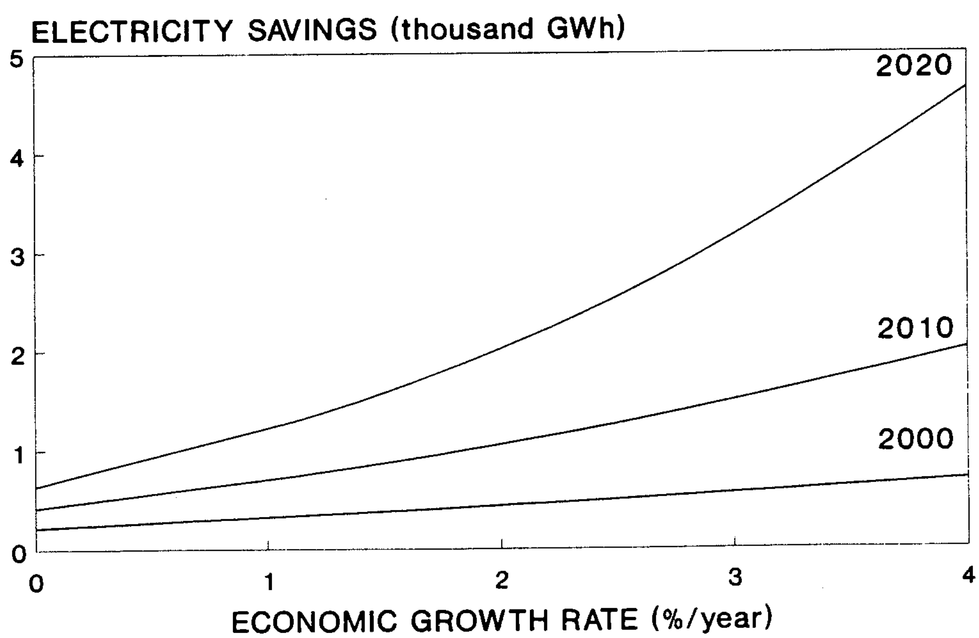

Fig. 6. Electricity savings produced by programs that cut electricity use in new buildings by 20% (Fig. 5) as a function of economic growth rate. The curves for the years 2000, 2010, and 2020 all show that program savings increase with economic and load growth.

Table I. Consumer response to efficiency standards and rebates in terms of annual electricity use in new buildings (kWh/building).

Program	Mean use	Standard deviation
Baseline (no program)	6600	1400
Efficiency standards		
6 kWh/ft^2 maximum	6200	1200
5 kWh/ft^2 maximum	5700	1100
4 kWh/ft^2 maximum	5100	1000
Rebates		
\$1000, 5 kWh/ft^2 maximum	5800	1400
\$2000, 5 kWh/ft^2 maximum	5000	1100
\$1000, 4 kWh/ft^2 maximum	6000	1600
\$2000, 4 kWh/ft^2 maximum	5400	1600

Source: Hirst (1988b).

The model's forecast of future loads with no efficiency-improvement program in place (baseline) assumes that efficiency levels in new buildings depend partly on consumer discount rates, with high-income customers having lower discount rates (and therefore more efficient buildings) than low-income customers. The standard forces the least efficient buildings to just meet the standard. In doing so, it compresses the distribution of electricity-use levels by shifting buildings from the high end of the scale towards the center. As the standard becomes stricter, the standard deviation of the distribution of electricity use declines.

The rebate, on the other hand, is accepted only by builders and building owners who had initially intended to construct buildings with efficiency levels near or better than the minimum required for the rebate. The rebate increases the efficiency of buildings that would have been at least modestly efficient to begin with. Thus, the rebate spreads the distribution of electricity-use levels by pulling buildings from the center of the distribution to the low end of the scale.

This example shows that different resources can affect uncertainty about different factors. Both standards and rebates reduce uncertainty about the effects of economic growth on load growth. The two programs, however, have opposite effects on the load-growth uncertainties associated with consumer behavior, as reflected by consumer decisions on energy-efficiency in new buildings.

SUMMARY

The importance of uncertainty was highlighted at a recent conference on Least-Cost Utility Planning. Commissioner Wiel (1988, Nevada Public Service Commission), in his closing remarks, identified development of improved methods to incorporate uncertainty into utility planning and decision making as a critical issue facing utilities and their regulators.

Utilities have made substantial progress during the past few years in development and use of sophisticated analytical methods that allow for various uncertainties. Much of this analysis involves repeated application of the utility's simulation models to explore different uncertainties and their effects on resource selection and on outcomes (e.g., revenue requirements, rates, and construction budgets).

However, more work is required to translate these computer results (and the judgment of planners) into forms that will be useful to utility executives and that can reduce controversies in the regulatory arena. In particular, analysis needs to focus explicitly on the decision-making processes within utilities and regulatory commissions (and less on the operational and financial details of simulation models). Also, although treatment of all resources in a consistent fashion is an important goal of integrated resource planning, it is essential to recognize differences among resources in conducting uncertainty analyses. Finally, additional data are needed to characterize the uncertainties associated with the construction costs, lead times, and operating performances of different demand and supply resources.

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