Tradeoff Analysis for Electric Power Planning in New England: A Methodology for Dealing with Uncertain Futures

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1. Introduction

With regulatory and utility policy-making set through the use of issue-specific forums, options can often be dismissed before they are evaluated as part of a broader based strategy. We propose a new forum which incorporates a multi-attribute trade-off analysis techniques for integrated resource planning designed to bring diverse interests together to discuss long-term, multiple option, multiple issue strategies.

New England is not unlike other areas in the United States in terms of the issues facing its electric utilities. The fuel price shocks of the seventies, and cascading impacts of PURPA and other legislative actions have affected the utilities' supply decisions and consumers' demand response. Environmental concerns and consumer challenges to the electric utilities' decisions have served to broaden the debate on how utilities will meet future demand for electricity.

While the inclusion of consumer and environmental representatives in the planning process has been constructive and ensures that a wide variety of alternatives get a fair hearing, the discussions regarding electric power options often become adversarial. This has led to entrenchment by groups over philosophical and semantic differences, diverting discussions away from the evaluation of complementary supply and demand options. What has been missing from this forum has been an integrative framework for evaluating options against different future uncertainties.

Unlike other regions, New England has no indigenous energy resources; it is situated at the end of fuel supply pipelines and transportation routes. The surplus of generating capacity of the early 1980's has ended, and the recent track record for adding capacity to the region, whether a utility financed nuclear power plant or non-utility generating unit, is poor. The licensing of power plants, additional natural gas pipelines, transmission lines, and now access to cooling water, all contribute to the uncertainty associated with long-range planning and the provision of electric service.

This reliance on outside sources of primary energy requires that New England's utilities make the best possible use of *all* supply and demand-side options. Creating an environment where alternatives can be evaluated on an equal footing is the necessary first step in ensuring the supply of reliable, efficient electricity to the region.

Because of environmental and safety concerns associated with nuclear and coal-fired power plants, supply-side discussions have focused almost exclusively on natural gas-fired technologies as the fuel-of-choice for independent power producers, cogenerators and utilities. The question of whether there will be sufficient natural gas for both traditional uses and electric power generation is becoming a major concern. In addition, the reliability of electricity supplies for both the short and long term has become a prominent issue.

Integrated Resource Planning requires, by its nature, a multi-objective multi-player analytic framework. The framework presented in this paper focuses on the development of trade-offs between attributes whose inherent value is dependent on the perspective of the individual player. The methodology accepts the reality that there is no optimum solution, in that the future is essentially unknowable. For this reason the framework is based on the comparative analysis of multiple scenarios concerning alternative futures. As will be discussed below a scenario is defined as a combination of technological options [over which the decision-maker has control] and uncertainties [beyond the control of the decision-maker].

2. The Open-Decision/Open-Planning Environment

The past decade and a half has seen a marked shift in the way society procures its electricity. The environmental problems of the late sixties, early seventies, and again in the eighties have altered the way in which utilities as well as heavy industries assess the operation of their facilities. The debate over actions by utilities, government and society-at-large to alleviate these effects has been widespread as solutions to such complex international and long-term problems are evaluated. The major changes in the way electric power decisions have been made can be summarized as follows:

- Increased regulatory oversight and direct participation in the electric power industry due, in part, to increased pressure from consumer and environmental groups over changing electricity costs, environmental quality, and nuclear safety.
- Increased participation of non-utility organizations in the provision of electricity supply and conservation services.
- Increased uncertainty in the growth of electricity demand and the costs (fuel and construction) of supplying electricity.

The shift away from utility exclusive decision-making to increased regulatory oversight and control has led to what we call an "Open-Decision Environment". Unfortunately, the structure of the industry and regulatory agencies in which decisions are made does not coincide with either the general operation of the electric power system, nor the environmental effects associated with that operation. The need for regional based, long-range planning to develop effective strategies for meeting electric service needs is becoming more apparent as inter-regional disputes arise for the provision of electricity and fuel supplies.

The effectiveness of environmental and consumer interests in using the regulatory process to air their concerns has also acerbated the development of coordinated long-range strategies. The incremental decision-making, generated by the need to make regulatory challenges, prohibits integrated strategies from being developed as single-option strategies are proposed, challenged, accepted or rejected.

The focus on the approval or rejection of one option at a time leads to fragmented long-run strategies, and ultimately to unacceptable levels (cost, reliability, environmental impact, etc.) of electric service. For effective long-term strategies to emerge, it is necessary that a multiple issue, multiple option framework be developed.

To help develop such an "Open-Planning Environment" the MIT Energy Laboratory has recently finished the initial phase of an Integrated Resource Planning project which incorporates both the complexity of electric power issues and options with the wide range of organizations participating in the open-decision environment.

As illustrated in Figure 1, the goal of the project is to provide a forum where representatives from different groups may meet and discuss issues related to their own as well as others' concerns; and, with the assistance of an analysis team, discuss those issues with better information and understanding than would be available in a less structured open-decision environment. The organization of the project is to let the interested groups define the issues they feel are important, and then let a mutually acceptable research team, in this case MIT, evaluate the issues using an Integrated Resource Planning technique designed to identify the trade-offs between different long term strategies.

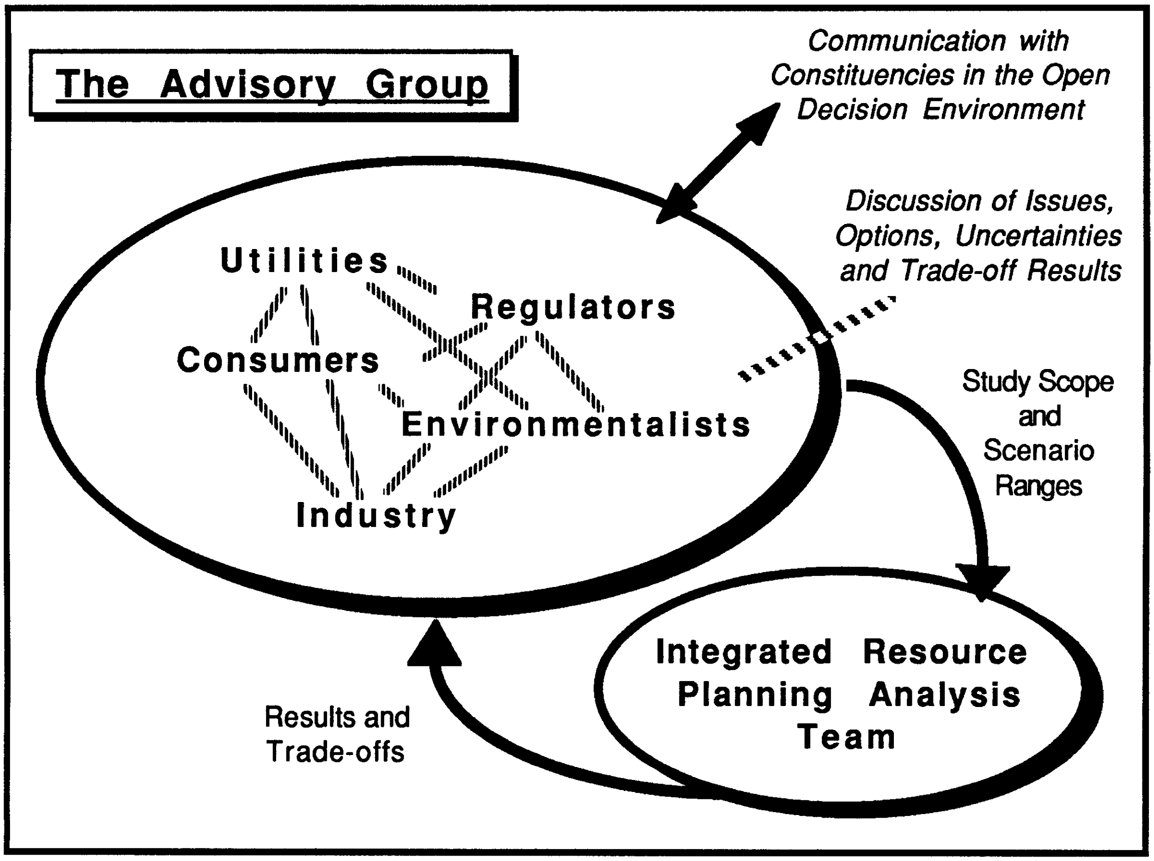


Figure 1: Structure of the M.I.T. Integrated Resource Planning Project

The ultimate goal of such a forum, or forums, is to serve as an adjunct to regulatory agencies in evaluating broader policy issues. In order to obtain this a forum must perform the following functions:

- provide a multiple issue forum for communication between disparate groups within the open decision environment.
- allow groups to identify central issues and explore solutions that touch upon all the participant's interests.
- provide the open-decision environment with a place not only to identify problems, but to evaluate the different policy options, and to formulate general policy actions.
- enhance the ability of individual concerns to promote more complete solutions by providing them with additional technical and planning resources they might otherwise not have. Since the forum is

not a decision-making body, no group loses its opportunities to have issues addressed in the public arena.

- help educate the public on how to interpret complex issues evaluated using integrated resource planning and other techniques.

The following sections describe the Integrated Resource Planning technique designed to support the advisory group's information needs, and the results of an initial study of New England's electric power options incorporating the multi-attribute trade-off analysis technique.

3. Integrated Resource Planning for the Open Decision Environment

The Integrated Resource Planning (IRP) framework used in conjunction with the advisory group focuses on the identification of issues, and then based on the issues considered most important defines a set of scenarios which evaluate how different options and uncertainties affect those issues. The issues identification and evaluation process is effectively an informational/educational tool rather than a internalized decision-making tool. Designed as an iterative evaluation/learning tool the general process flows as follows:

- *Issues/Attribute Identification* - The advisory group identifies issues and major factors concerning those issues. With this issues in mind the analysis team develops a set of measures, called attributes with which these issues can be evaluated.

- *Scenario Development* - A set of options available to decision-makers, and a separate set of uncertainties reflecting the possible 'environment' the electric power industry might face are defined and combined into multiple scenarios

- *Scenario Analysis* - Scenarios are analyzed and the attributes associated with each are tabulated for further analysis

- *Trade-Off Analysis* - Results for all the scenario runs are compared for the attributes considered to identify robust and vulnerable options for the issues and uncertainties identified.

> Poor options and irrelevant uncertainties can be eliminated from further evaluation.

There are three primary advantages to performing the analysis in this manner. First, the research effort focuses on the issues the open-decision environment considers the most important. Second, the massive uncertainties associated with future supply and demand of electricity and related issues are dealt with explicitly. Finally, the method focuses directly on the trade-offs between attributes whose inherent value is dependent on the perspective of the individual participant in the open-decision environment. Looking at the trade-offs between attributes, rather than searching for a way to calculate a single common value side-steps the issue associated with determining, for instance, the monetary value of system externalities. The incorporation of uncertainties, and the role of multi-attribute trade-off analysis will be briefly discussed in more detail.

3.1 Incorporating Uncertainties

Southern California Edison recently focused on the importance uncertainty plays within the planning process. After reviewing the events that had invalidated each and every one of their forecasts, Southern California Edison determined, "it is futile to tie future plans too rigidly to a single projection or forecast, no matter how sophisticated the forecasting technique." (1988, p.132) By incorporating the role of uncertainty into the analysis technique they conclude that the emphasis of the planning process changes "from forecasting accuracy to responsiveness to change." (1988, p.147)

The Integrated Resource Planning method presented here incorporated uncertainty into the analysis two ways. First, through the use of multiple scenarios, where sets of uncertainties change reflecting different possible combinations of future events. Second, uncertainty is inserted into the description of the uncertainty itself. In this manner both short and long-term variability is introduced into the analysis.

Figure 2 shows the difference between short and long-term uncertainties. Displayed are the year-to-year annual growth rates for peak loads presented in the Electric Council of New England's (ECNE) 1987 Statistical Tables. Shown are actual or historical rates, and the ECNE forecast. Historical differences are highly variable due to weather and energy-economy interaction reflective of a complex world. Actual growth between 1970 and 1987 averaged 3.2% with a standard deviation of 4.5 percentage points. The forecast rates' (1988-2004) average is 1.9% with a standard deviation of only 0.4.

While the flat load growth rate reflected in the ECNE report is a good representation of how the region's utilities expect load to grow over the long term it is not a good basis for modeling load growth which, as demonstrated, has relatively high short-term variability. Therefore when modeling uncertainties it may be necessary to re-introduce the short-term variability associated with the actual behavior of load growth, fuel price changes, and other factors affecting system decision-making, operation and performance.

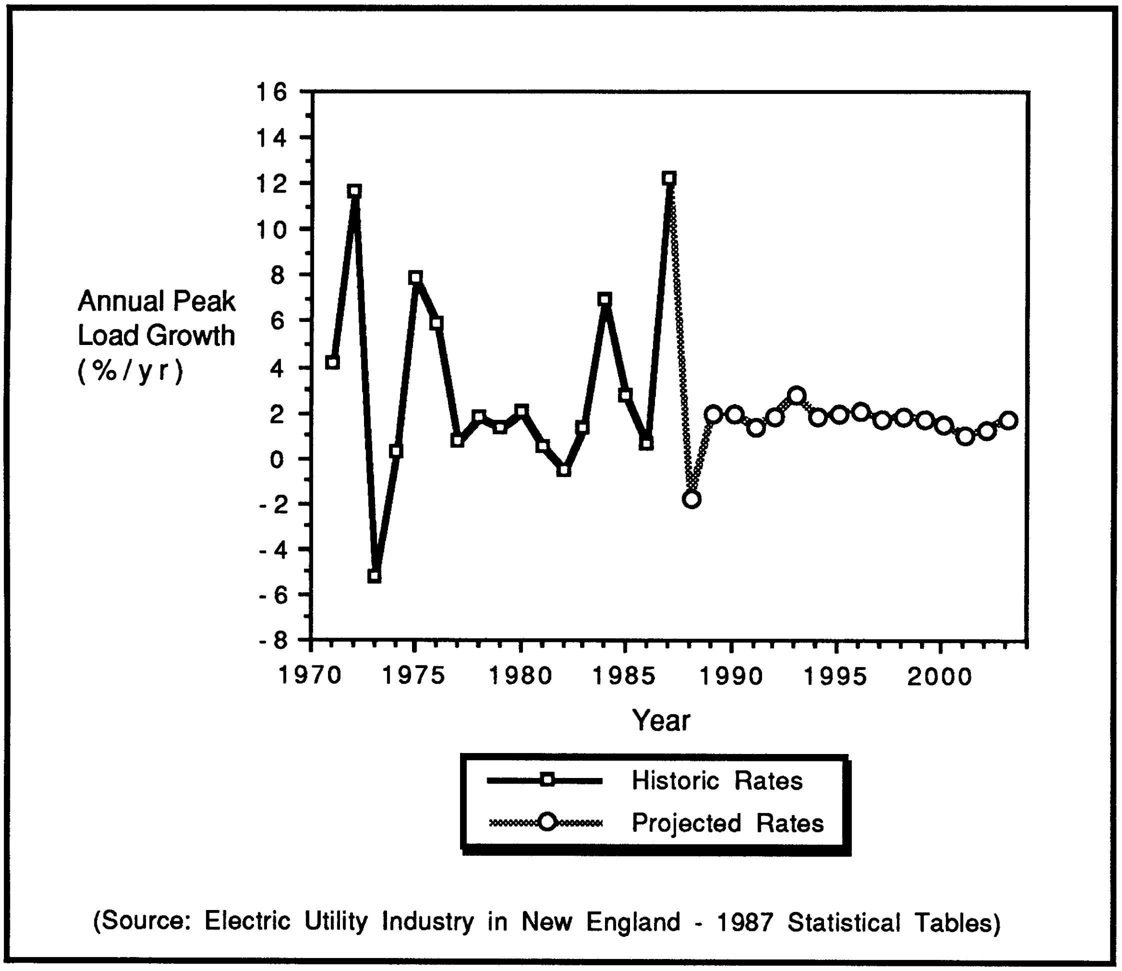


Figure 2: Actual and Projected Peak Load Growth Rates (1970-2003)

Figure 3 shows the four peak load trajectories used in the 1989 New England study described later. Long-term trends were chosen, based on existing forecasts, and hypothetical occurrences, then year to year rates were changed to reflect the weather-economy effects present in recorded peak growth. An example of the change used in modifying the NEPOOL forecast is given in the lower of the two graphs in Figure 3.

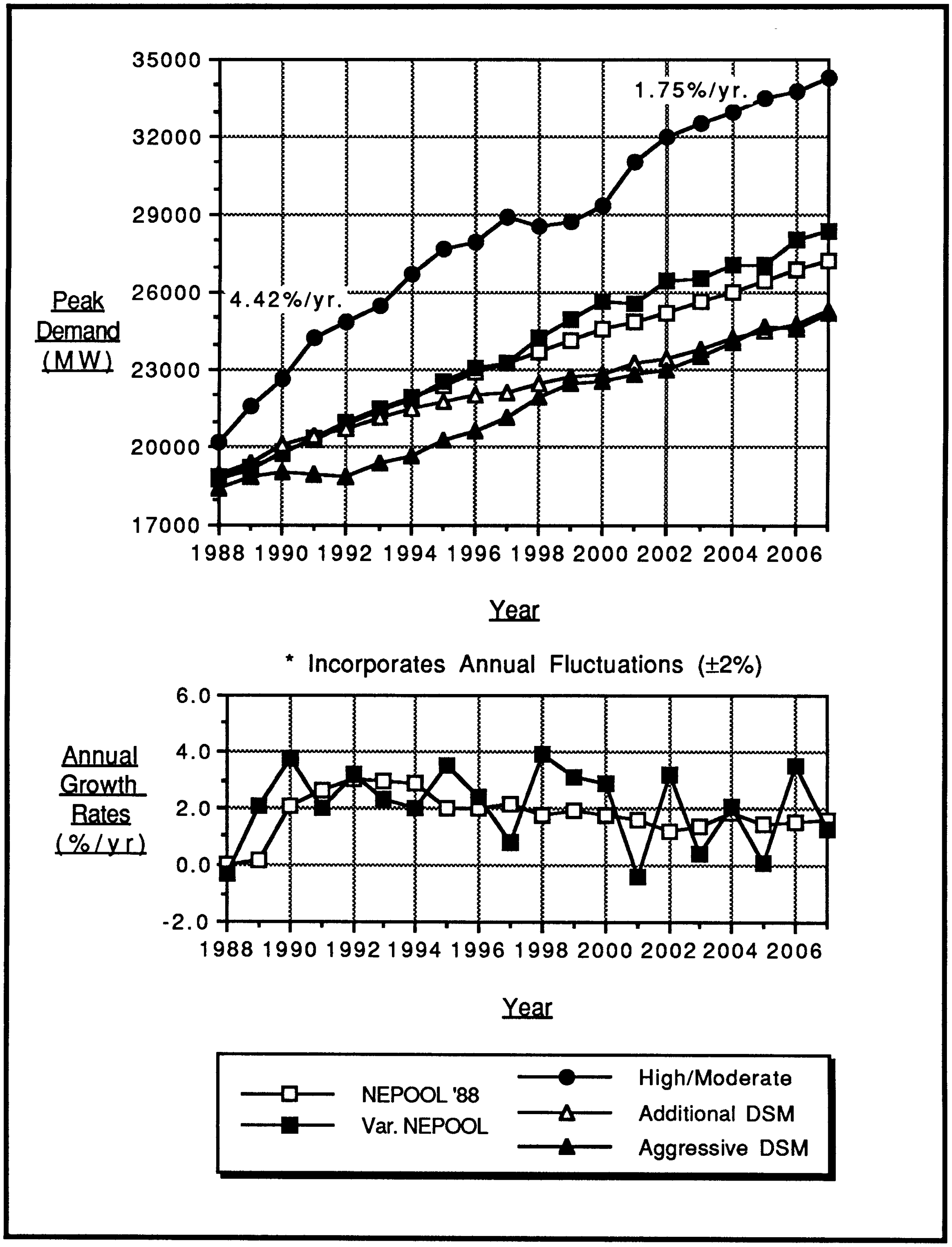


Figure 3: Load Growth Uncertainties for New England Study

3.3 Multi-Attribute Trade-Off Analysis

Figure 4 shows the general method for developing a trade-off curve. The graph on the left shows how for two attributes (A1 and A2), for which lower values are desirable (for example, cost and environmental emissions), a trade-off curve can be developed. In the left-hand figure, each scenario is represented by an 'x'. Each of these scenarios share the same uncertainty set, so in this instance we compare options sets, or strategies, directly. Any strategy which has less desirable (in this case greater) attribute values than those of *any* other single strategy is considered dominated and assigned to the "Dominated Set". In this instance 'd' is the only dominated strategy.

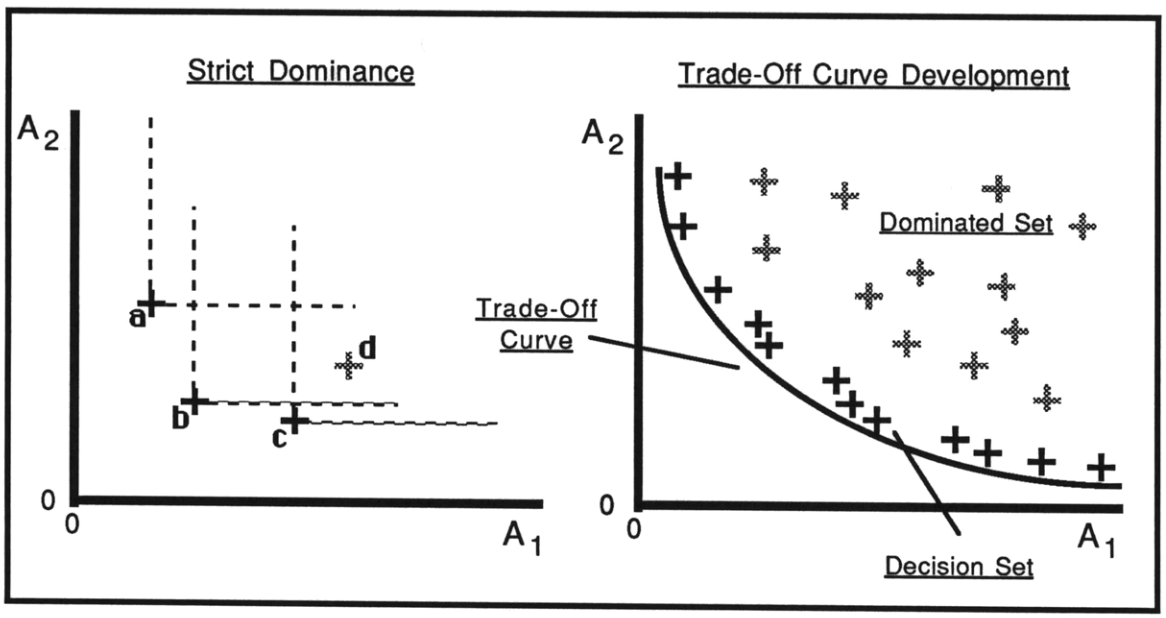


Figure 4: Development of Trade-Off Curves

If the graph displays a large number of option sets, such as the one on the right, then a trade-off curve, and "Decision Set" of non-dominated strategies can be developed. "Robust" strategies are those that occur in the decision set across most of the uncertainties being considered. The right hand graph displays evaluation of option sets under strict dominance, where the

the value of the attributes is certain. For less accurate measures, bandwidths around attribute values may be used, a technique called significant dominance, (Schweppe and Merrill, 1987).

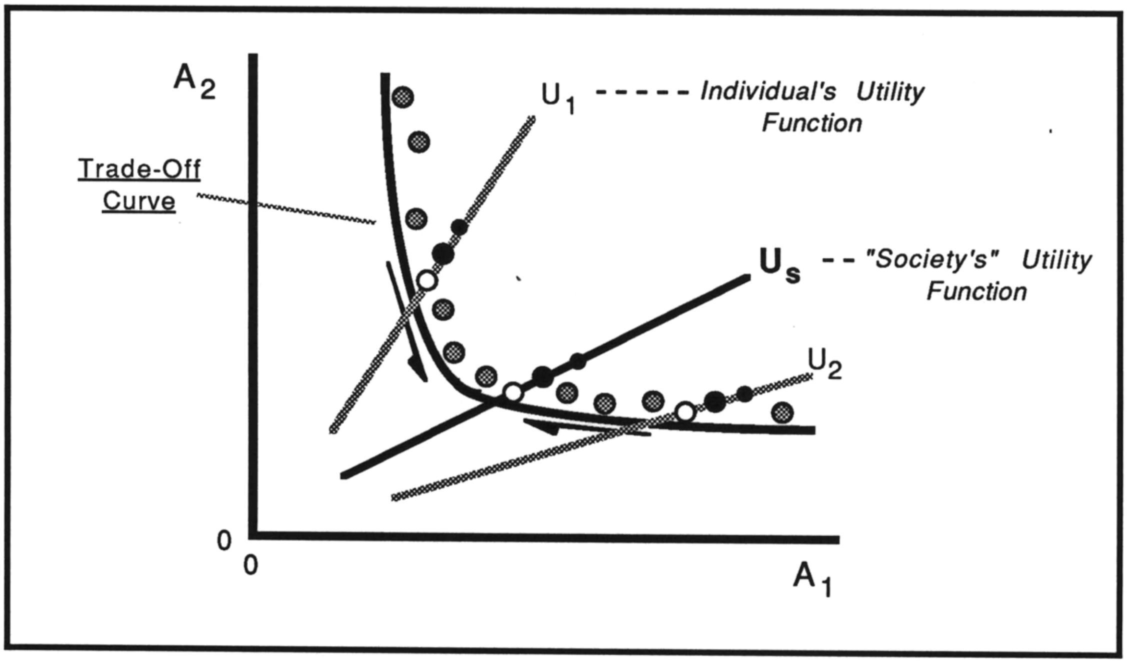


Figure 5: Trade-Off vs. Multi-Utility Optimization Techniques

Employing analysis techniques that attempt to internalize this constantly changing structure, such as multiple-utility, or multi-objective techniques has disadvantages. Figure 5 attempts to represent the inherent differences between an optimizing multi-utility method and the multi-attribute trade-off technique. Using optimization techniques, solutions for a specific set of uncertainties are determined subject to the constraints of the utility function. Examples of these exclusive solutions are indicated by the white circles in Figure 5. In contrast, by using trade-off analysis, decision sets for each set of uncertainties are determined, and a trade-off curve or surface is obtained of the most efficient, non-dominated options. While multi-utility optimization yields a single "best" strategy, it provides little information of the trade-offs between itself and the results of another optimized run with different weights.

The two most important aspects associated with multi-attribute trade-off analysis is that it educates the participant of the trade-offs choosing one strategy over another for a range of attributes and uncertainties, and allows discussions among members of the open-decision environment to focus on the robust strategies in the decisions sets, having eliminated the inferior, dominated strategies.

4. The New England Study

In 1988, the MIT analysis team, with the help of an advisory group of utility executives and planners, regulators and industrial customers performed the initial phase on a more comprehensive research effort employing the multi-attribute trade-off analysis technique. A description of the study follows.

4.1 Issues and Attributes

From discussions with the advisory group two main issues gained prominence, the reliability of electricity supplies, and factors associated with increased use of natural gas as a fuel for electric power generation. Cost of electric service and environmental impacts associated with different supply strategies were also considered important in assessing the performance of any one strategy designed to deal with natural gas usage and reliability.

Figure 6 shows how the analysis team, acting on the advisory group's recommendations, structured the scenario description and analysis portion of the study. Reliability issues were described by attributes derived from the operating procedures of the New England Power Pool (NEPOOL). The general system performance is captured by the secondary attributes listed. Also listed are the options and uncertainties directly associated with reliability issues.

Reliability

Associated Attributes

Primary Attributes

Total No. of Hours in OP-4: Action 3 (Σ Hrs.)
(No. of Hours in Capacity Deficit Situation)

Total No. of Hours in OP-4: Action 5 (Σ Hrs.)
(No. of Hours All Interupptible Customers Called)

Ratio of OP-4: Action 5 to Action 3
(Severity of Capacity Deficits)

Secondary Attributes

Social Cost of Electricity (¢/kWh)

Cumulative SO2 Emissions (Σ Millions of Tons)

Relavant Options

Primary Options

Target Reserve Margins (20%, 25% Target Reserve Margins)

Replacement of Old Capacity (No Replacement, Replacement)

Secondary Options

Generation Mix (Gas Dependent, Diversified)

Predominant Uncertainties

Load Growth Trajectories

Fuel Price Trajectories

Natural Gas Dependency

Associated Attributes

Primary Attributes

Percent of Desired Gas Usage Unmet (% Mcf-Total)
(% fuel switching due to unavialability of natural gas)

Secondary Attributes

Social Cost of Electricity (¢/kWh)

Cumulative SO2 Emissions (Σ Millions of Tons)

Relavant Options

Primary Options

Generation Mix (Gas Dependent, Diversified)

Predominant Uncertainties

Natural Gas Availability

Load Growth Trajectories

Figure 6: Overview of 1988 New England Study

The issue of natural gas dependency focused on the vulnerability of the region to overinvestment in natural gas fueled generating capacity, particularly with respect to the availability of natural gas. The primary attribute associated with this issue is the amount of forced fuel switching, by substituting gas with No.2 fuel oil, when natural gas is unavailable. Secondary attributes associated with system performance were the same as for reliability. Of central concern was the uncertainty associated with the introduction of new pipeline supplies into the region.

4.2 Options

The multi-attribute trade-off analysis technique was used to evaluate the relative impacts of an overlapping pair of capacity expansion strategies involving natural gas-fired generation. These options were evaluated for a set of uncertainties affecting the delivery of electric power to the New England Region over a period of twenty years, starting in 1988. The options considered for the study were the target generation mix of new capacity over the period, and the target reserve margin for New England.

Two new-capacity generation mixes were defined. The Gas-Dependent Strategy consisted of three natural gas-fired technology options described in Figure 7. The other generation mix option, the Diversified Strategy incorporates base-load coal into the mix along with the natural gas options. In order to simulate realistic operating conditions in New England, both the Combined-Cycle and Combustion Turbine plants were modelled as dual-fuel plants required to burn No.2 fuel oil during the four winter months. Heat rates adapted from the EPRI Technology Assessment Guide were used for both these plant types. Because packaged steam boilers were assumed to be used as cogenerators their heat rates were adjusted to reflect only the marginal contribution to electric generation.

	Combined Cycle	Combustion Turbine	Cogenerator-Steam Boiler	Fluidized Bed Combuster
Fuel				
Type(s)	Nat. Gas/Oil2	Nat. Gas/Oil 2	Natural Gas	Coal
(mo.-Nat. Gas)	8	8	12	-
Size				
(MW)	250	50	30	500
Lead Times				
(Yrs.-Build)	4	3	3	10
(Yrs.-Cancel)	1	1	1	5
Heat Rate				
(Btu/kWh)	8150	11000	*6000*	9710
Efficiency				
(%)	41.88%	31.03%	*56.88%*	35.15%
Capital Cost				
(1987-$/kW)	$591	$339	$958	$1,406
Target Capacity Mix-New Capacity				
Gas Dependent				
(MW-%)	70%	20%	10%	0%
Diversified				
(MW-%)	25%	15%	10%	50%

Figure 7: Description of Supply Options

Existing capacity in the base year, 1987, was taken from NEPOOL's CELT Report (NEPOOL, 1988). Capacity additions in the short term were taken from the CELT report, and served to constrain all supply-side options in the first three years of the study period.

4.3 Uncertainties

The two capacity-expansion strategies were combined with four sets of uncertainties as shown in Figure 8. Briefly these were: (1) Load Growth Uncertainty (four paths), (2) Fuel Price Escalation (four sets), (3) Natural Gas Availability (two ceilings), and (4) Capacity Expansion Constraints (existence or non-existence of a hypothetical fuel-use act).

Figure 3, above, shows the four load growth trajectories used in the study. Each path reflects a different combination of uncertainties about electricity growth in the region, including the availability of conservation and load management. The first trajectory, Variable NEPOOL, is a modification of the load growth projection in the CELT report, altered so that cumulative load growth is similar, but load growth from year to year was less predictable. The second trajectory, High/Moderate, assumes that recent rapid growth in electricity demand continues for several years and then levels off. The effect on the supply-side is to give the region undercapacity in the short-term and overcapacity in the long-term. The third and fourth load growth trajectories were again based on the CELT report's projection. In each case an additional 2000 MW of conservation was added to the conservation already in the report. The third trajectory, Aggressive Demand-Side Management incorporates 2000MW of additional conservation in the first few years of the study. The fourth trajectory, Additional Demand-Side Management, adds the conservation over ten years in the middle of the study period. For both the demand-side management load growth trajectories, the cost of the demand-side management was external to the analysis, and therefore the slower load growth can also be viewed as the result of an economic downturn.

Four fuel price escalation schedules were used in the analysis. The first, Low/Coupled, assumes that there is no fuel price escalation over inflation, which is assumed to be a constant four percent per year for the entire study period. The second, Low/Uncoupled, assumes that coal and nuclear fuel prices track with inflation, but natural gas and fuel oil prices escalate at an additional 1.5% per year. The third, Medium/Coupled assumes that all fuels escalate at 3% above inflation. The fourth, High/Uncoupled, has coal and nuclear track with inflation, but natural gas and fuel oil escalate at 4.5% above inflation. By choosing these significantly different fuel price trajectories, the vulnerability of choosing one fuel technology over another can be modeled.

Components for Scenario Formulation

Options (Choices or actions available to decision-makers)

Generation Technologies and Technology Mix
- Gas-Dependent Strategy
- Diversified Strategy

Target Reserve Margin
- Maintain 20% Reserve Margin
- Increase to 25% Reserve Margin

Replacement of Old Capacity
- Do not retire old capacity
- Replace old capacity with new technologies

Uncertainties (Effects or events that cannot be controlled)

Load Growth Trajectories
- Variable NEPOOL
- High/Moderate Growth
- Additional Demand-Side Management
- Aggressive Demand-Side Management

Fuel Price Trajectories
- Medium/Coupled
- High/Uncoupled
- Low/Coupled
- Low/Uncoupled

Natural Gas Availability
- Base Case
- Base plus Additions Case

Capacity Constraints
- No Regulatory Constraints
- Hypothetical Fuel-Use Act

Figure 8: Options and Uncertainties for New England Study

The third set of uncertainties examines the quantity of natural gas available for electric power generation. Figure 9, shows the natural gas ceilings used in the study. Here existing and additional supplies of natural gas into New England are hypothesized. From these total capacities non-electric demand for natural gas is subtracted causing the downward slope in the amount of natural gas available for electric power generation. When that ceiling for natural gas use in power generation is reached, forced fuel switching to more expensive No.2 fuel oil occurs. Two different ceilings were used. The first, called the Base Case takes existing natural gas capacity and adds to it most of the new gas supplies submitted in response to FERC's Fall 1987 "Open Season" for proposals. The second ceiling, called Additions, is the Base Case with two additional increases in capacity in the latter part of the study period.

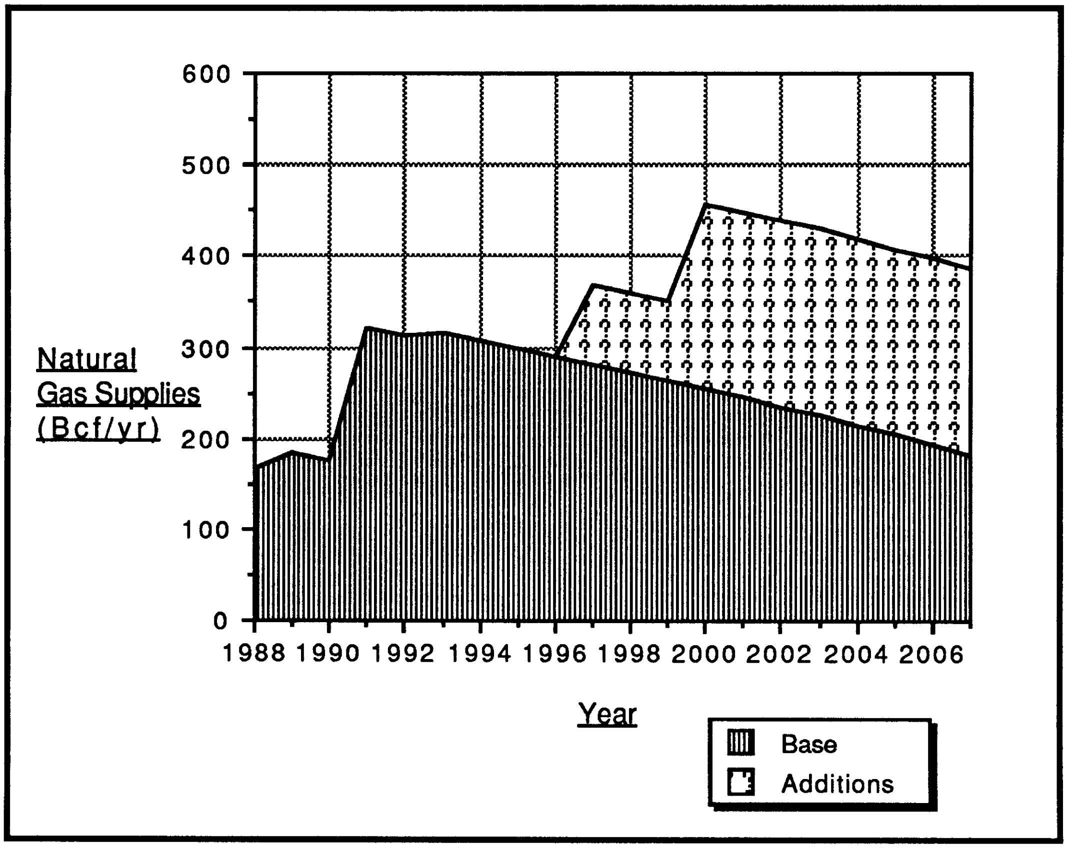


Figure 9: Natural Gas Supplies Available for Electricity Generation

The last uncertainty deals with the cost of unanticipated regulatory requirements. Here a hypothetical fuel use act, beginning in the fifth year of the study, limits the amount of gas/oil fired generation that can come on line in any year. The resulting affect is that the utilities' ability to add capacity in the short-term is limited. In addition, the utilities are forced to commit coal plants to meet long-term expected load.

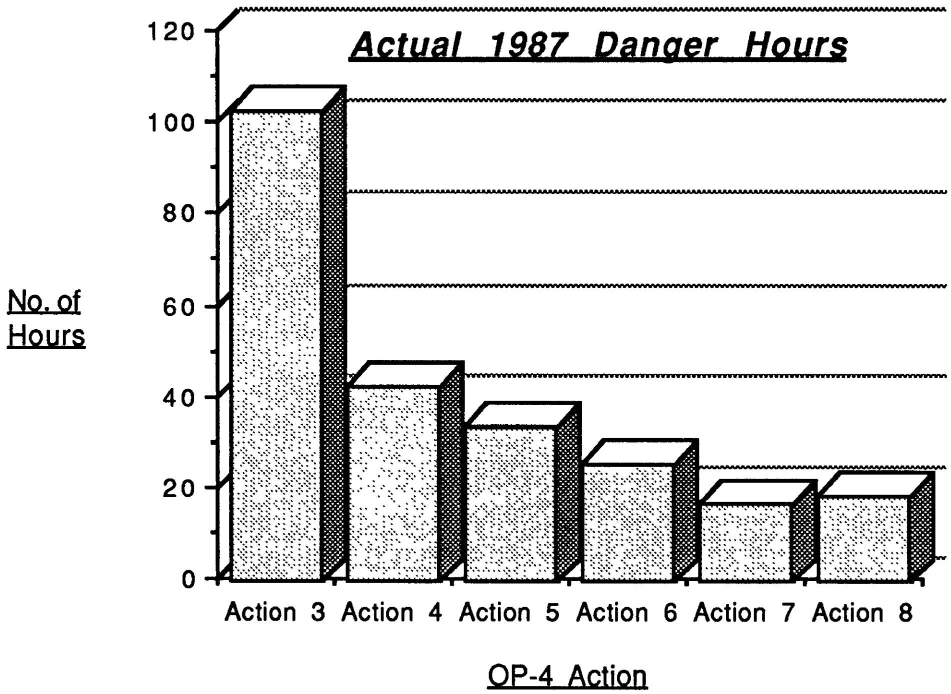
5. New England Study Results

Study results come from the evaluation of attributes obtained from the a total of 264 scenario analyses. Results are broken down into two main areas, reliabilility of electricity supplies and dependency on natural gas as described in Figure 6 above.

5.1 Reliability Results

As a preliminary step in evaluating reliability issues the analysis team had to develop a new reliability measure. When working in conjunction with the open-decision environment the ability to communicate technical information to a non-technical audience becomes important. Since traditional measures of reliability, such as unmet energy and loss of load probability are not easily communicated to a lay audience. The analysis team developed a reliability attribute based on NEPOOL's Operating Procedure 4 (OP-4), used in the event of a capacity shortfall.

Figure 10 gives a brief description of the Action levels within OP-4. OP-4 is applied after all the region's generating capacity is in use. Also shown is the number of hours NEPOOL was in any one action during 1987. Using the analysis team's computer analysis method the distribution of unmet energy could be calculated and assigned to the different OP-4 action levels. Called "Danger Hours", this measure effectively showed not only the amount of unmet energy but its distribution, allowing the utilities, industrial customers and regulators to estimate a given strategy's reliance on interruptible rates, voltage reductions and public appeals for conservation.



Action 3:	• Purchase Emergency Capacity • 30-minute Interruptible Loads
Action 4:	• NEPOOL Facility Loads • Maximum Contracted Customer Generation • 10-minute Interruptible Loads
Action 5:	• 10-minute Interruptible Reserve Loads
Action 6:	• 5% Voltage Reduction (Slow, >10 min.)
Action 7:	• < 10 minute Interruptible Loads • 5% Voltage Reduction (Quick, <10 min.)
Action 8:	• Uncontracted Customer Generation • Appeals to Industrial/Commercial Customers • Radio/TV Appeals to Residential Customers

Figure 10: NEPOOL's Operating Procedure 4

In all cases, increasing the target reserve margin from 20 to 25% improved system reliability, as measured by a decrease in danger hours. On average the total number of hours that the system was in OP-4 Action 3 or above decreased 51%, with a range of between 9 and 72%. The maximum increase in the unit cost of electricity by adding the new capacity was 1.3%, with an average increase of 0.2%. In addition to the increase in reliability, sulfur dioxide (SO_2) emissions decreased by an average of 3.8%, even with the increase in capacity. The maximum decrease was 6.3%, with a minimum of 0.9%.

The decrease in danger hours, and SO_2 emissions without a substantial increase in the cost of electricity indicated that the improved technology embodied in the new capacity was substituted for older, dirtier, and less efficient capacity. Therefore there are significant gains to be made through upgrading of old generating technology capacity in New England.

Several advisory group members suggested that since the aging capacity probably had higher than normal forced outage rates that some reliability and emissions improvements might be attained by maintaining the 20% reserve margin, but replacing old capacity (40 years or more) with new generating capacity.

Figure 11 shows the trade-offs for cost and reliability for the total range of options applied to the Variable NEPOOL load growth uncertainty with Medium/Coupled fuel prices, Base-case natural gas availability and no Fuel-Use Act. The axes show the percent change in the two attributes versus a base case of a Gas-Dependent strategy with a 20% reserve margin and no replacement of old capacity. This case was considered by the analysis team to be the most closely resemble the present trend in supply-side policies.

The base case is compared with combinations of changes in technology choice (gas-dependent vs. diversified), reserve margin (20 vs. 25%), and replacement of old capacity. Increases in reserve margin were obtained two ways for these scenarios. The standard increase in the reserve margin was obtained by building up to the 25% margin using the target mix of generating technologies. An additional method was added where the 20% margin was met with the technology mix, and the difference between 20 and 25% was met with the addition of combustion gas turbines as peaking units.

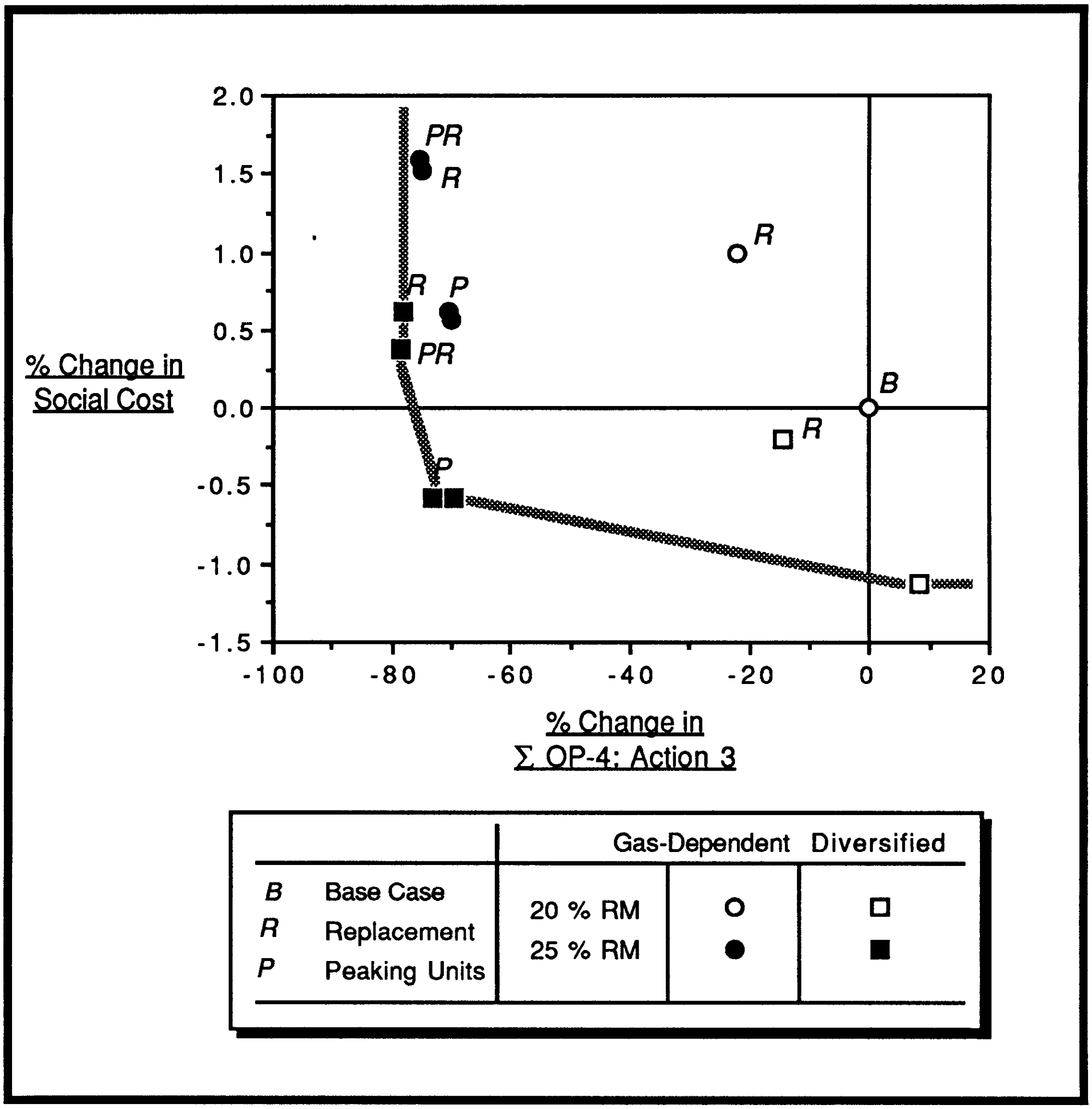


Figure 11: Cost vs. Reliability Trade-Off — Variable NEPOOL

As can be seen in Figure 11, considering cost and reliability alone for this one set of uncertainties, the base case, and in fact, all except one of the gas-dependent strategies can be assigned to the dominated set. Both options where a combination of the diversified strategy and a 25% reserve margin are used appear to offer the best performance. These results however can change markedly with differences in fuel prices.

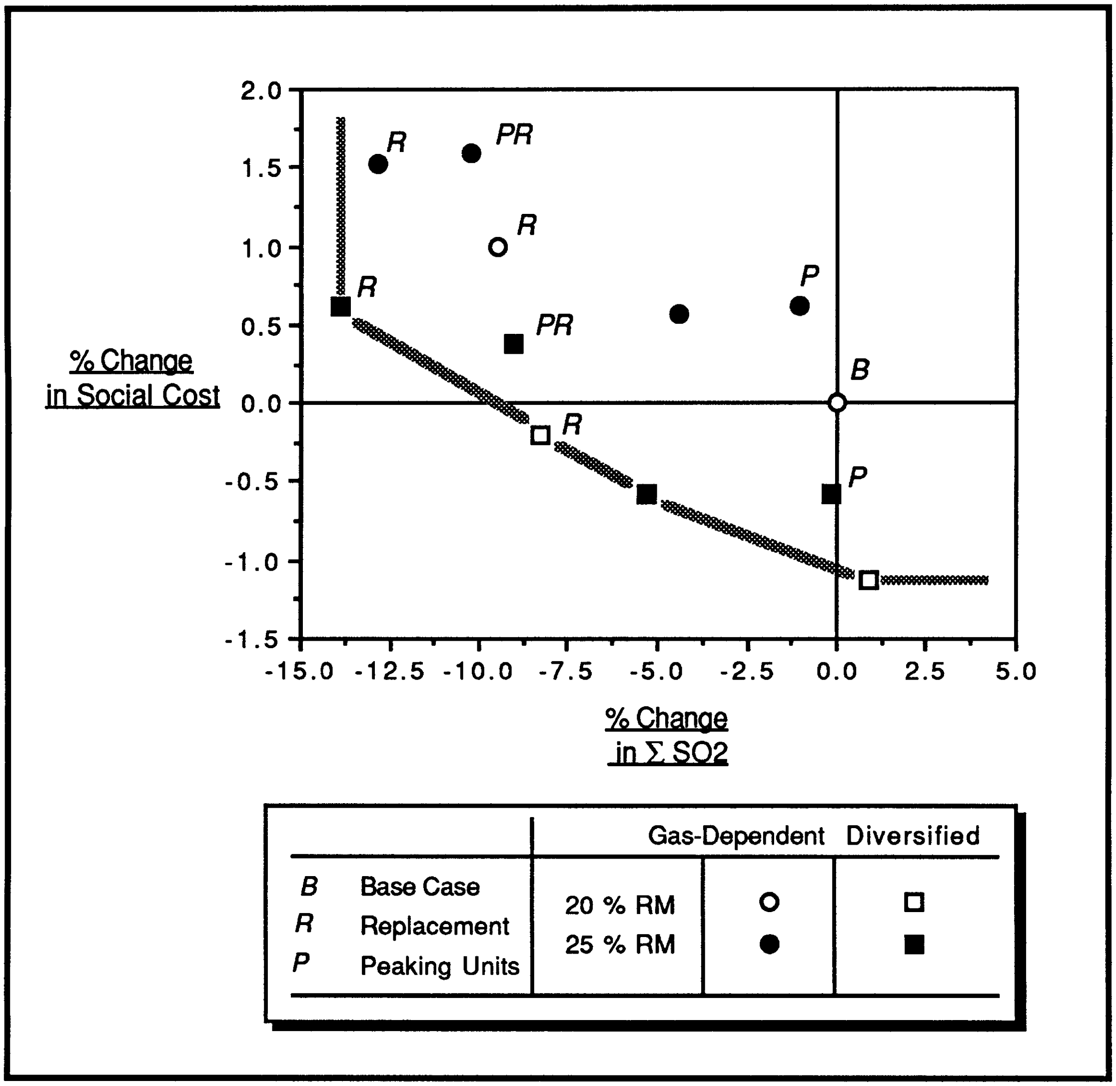


Figure 12: Cost vs. Sulfur Dioxide Emissions Trade-Offs — Var. NEPOOL

Figure 12 shows the same options, but this time comparing cost versus sulfur dioxide emissions. As can be seen the shape of the trade-off curve has changed and the replacement options have moved towards the curve. Also noticeable is the fact that all the gas-dependent options appear to have shifted upwards away from the diversified strategies. This indicates that for the medium/coupled fuel price uncertainty, while SO_2 emissions appear equivalent, the higher cost of gas and oil make the gas-dependent strategies more vulnerable.

The results of the trade-off analysis of reliability issues indicate that gains can be obtained in both reliability of electricity supplies and reduction of sulfur dioxide through the introduction of new generating technologies into the region's supply mix. Also, fuel price vulnerability can be lessened through diversification of fuel technologies.

5.2 Natural Gas Results

The technique for evaluating reliability results can be used to assess the costs associated with natural gas use. However, because of the way the effects of a natural gas deficiency were modelled, many of the trends are fixed. When there was insufficient natural gas available No. 2 Oil (Oil 2) was used instead. Oil 2 has more impurities than natural gas, and for all the fuel price uncertainties modelled, Oil 2 costs more than natural gas. Therefore whenever the gas-cap is reached there is both a cost and emissions penalty associated with the forced fuel switching. The issue therefore focuses on two questions: Does the availability of natural gas become a constraint, and if so, how severe is the shortfall?

Even with the optimistic timing of pipeline additions, as modeled by the Base-Case natural gas supply curve, only 14 of 136 scenarios did not experience any forced fuel switching. Furthermore, those seven were all cases where a regulatory constraint prohibited the region from adding above a certain cap, gas/oil fired technologies. For the Additions gas supply constraint, 88 of 128 scenarios did not require forced fuel switching.

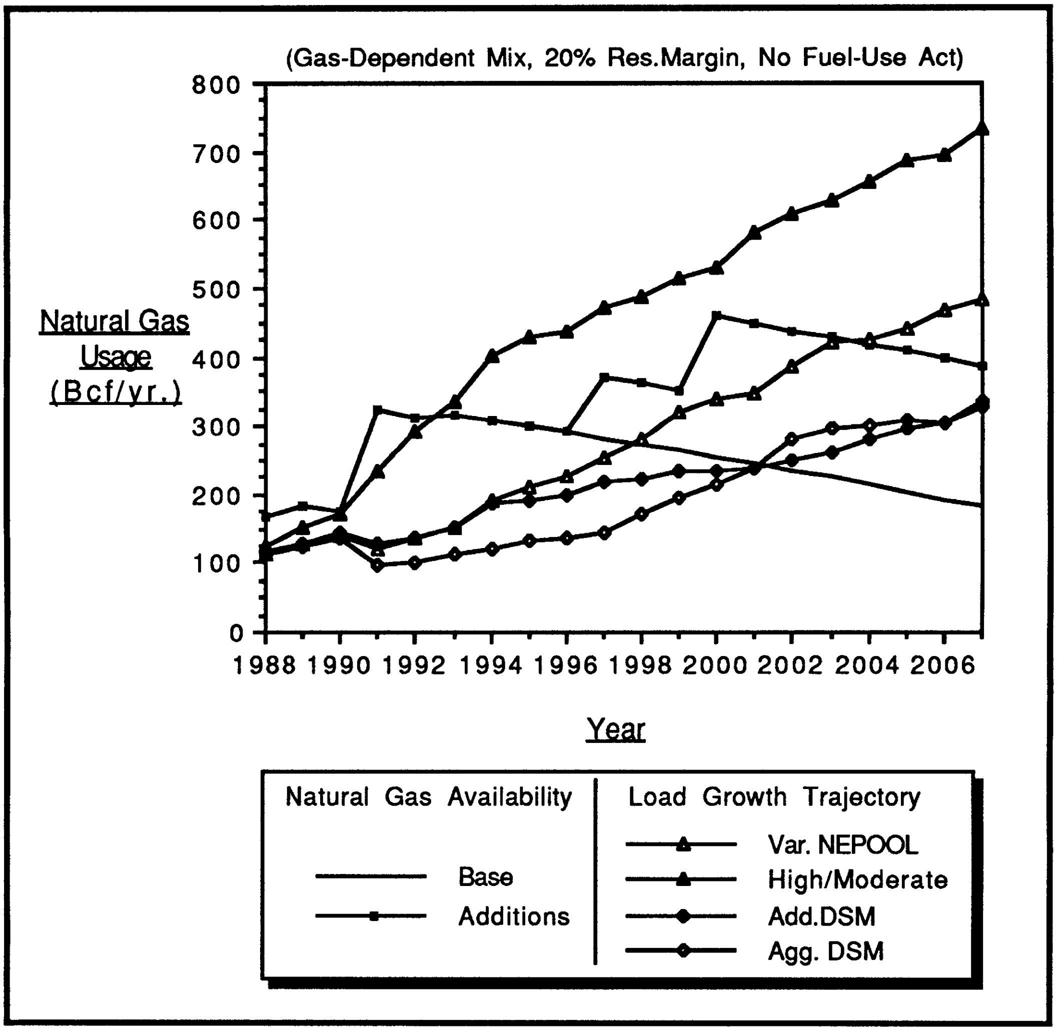


Figure 13: Unconstrained Demand for Natural Gas - Gas-Dependent Strategies

Figure 13 shows a plot of the unconstrained demand for natural gas for the selected gas-dependent strategy Var. NEPOOL scenarios. Whenever one of the lines crosses the gas availability lines, forced fuel switching occurs in proportion to the distance the demand line rise above the supply line. In this instance all four scenarios have insufficient natural gas for the base case, and the Var. NEPOOL and High/Moderate fall short even with the additional supplies. Recall from the description of the supply technologies that the larger gas/oil units already burn natural gas only eight months of the year.

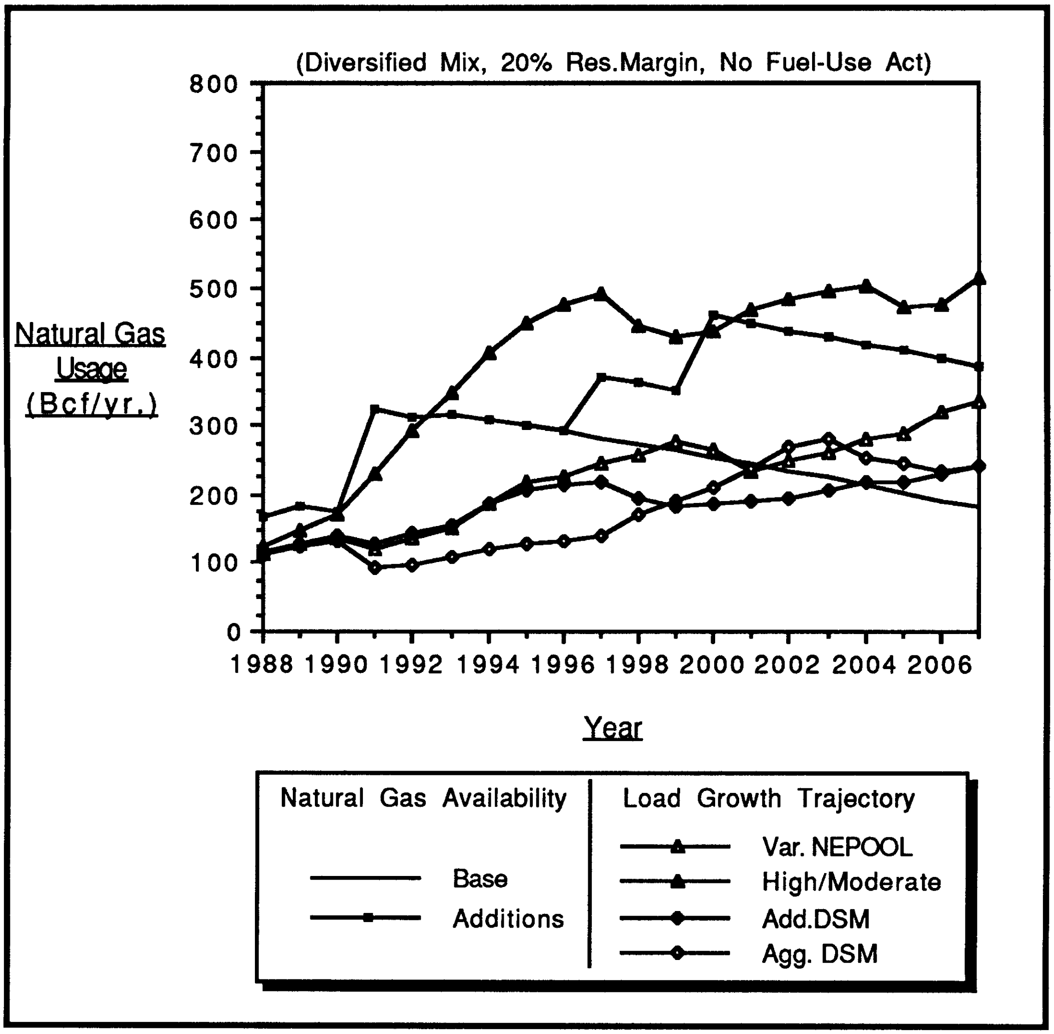


Figure 14: Unconstrained Demand for Natural Gas - Diversified Strategies

Figure 14 is similar to Figure 13 in all respects except that the natural gas demand curves are shown for diversified rather than gas-dependent technology mixes. Even here Base gas supplies are not sufficient to prevent forced fuel switching for all four load growth uncertainties, however, only the High/Moderate load growth experiences a shortage with the Additions supply.

Results of the natural gas analysis focus on the need for additional natural gas supplies beyond the Base-case pipeline additions around the year 2000, independent of the load growth considered. If the region wishes to take advantage of gas-burning technologies, or if recent trends in load growth continue, both timely installation of proposed supplies, and future supplies will be required.

In comparing Figures 13 and 14, notice that the first ten years for both the gas-dependent and diversified strategies are nearly identical. This emphasizes the effect of lead times in planning for new generating capacity. Clean-coal plants were assumed to have a combined licensing/construction time of ten years. Therefore, deciding to add additional coal-fired generation today, does not accrue any benefits in the region with respect to reduced fuel price vulnerability or dependence on natural gas until the late 1990's.

6. Conclusion

The use of a multi-attribute trade-off analysis technique as a vehicle to provide information to a diverse group of electric industry interests can play a beneficial role for developing long-range strategies for the electric power sector. The advisory group/analysis team structure presented here allows different groups to evaluate multiple issues simultaneously, incorporating the range of supply and demand options, and future uncertainties characteristic of complex systems.

The initial phase of such an Integrated Resource Planning project for New England electric power industry has identified that:

- Significant gains in the areas of reliability and environmental emissions can be made by the introduction of new generating technologies.
- The recent emphasis on natural gas fired technologies should be matched by an effort to ensure adequate supplies of gas, and other effort to guard against fuel related vulnerabilities.

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