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Electric Power Resource Planning under Uncertainty: Critical Review and Best Practices

Prepared By:

Adam Borison
aborison@brg-expert.com
510.285.3282

Berkeley Research Group | 2200 Powell Street, Suite 1200 | Emeryville, CA | 94608

Abstract

Electric power in North America is a massive industry, and making long-term investment decisions in that industry—typically called resource planning—is critically important. The many uncertainties in the electric power environment make planning difficult. This paper is designed to help address this difficulty by providing a critical review of the major approaches to resource planning under uncertainty and recommendations for best practices.

Introduction

Electric power is a major part of the North American economy. The industry's current asset base—generation, transmission, and distribution—is valued at over $1 trillion.[1] The industry's annual revenue is more than $400 billion,[2] and its annual capital expenditure is expected to reach nearly $100 billion in 2014.[3]

Electric power is not only a massive business, but it is also typically considered a critical keystone of our economic and social welfare, even beyond its size. As summarized in a Carnegie Mellon report on climate change, "Nearly every aspect of productive activity and daily life in a modern economy depends on electricity."[4] The Federal Energy Regulatory Commission referred to the importance of electricity in the economy as "staggering."[5]

Given electric power's significance to our welfare, making long-term decisions about investments in this industry—typically referred to as resource planning—is important. With the ebb and flow of regulation, deregulation, and reregulation in the power industry over the years, the parties responsible for resource planning have evolved. The parties currently involved—and the approaches they use—vary widely. In some jurisdictions, a tightly orchestrated "traditional" integrated resource-planning process uses proscribed procedures led by a single government agency; in other jurisdictions, resource planning involves a complex mix of federal, state, and local government agencies, and unregulated and regulated companies, using a variety of formal and ad hoc procedures. A recent report by Synapse Energy Economics provides a good review of formal integrated resource planning and describes key elements of a quality resource plan.[6]

Planning—making long-term decisions—is made more difficult by uncertainty. Resource planning is no exception, and the electric power environment is full of uncertainties, including scientific and technological developments, electricity and commodity prices, economic and financial conditions, and cultural and social forces.

The primary purpose of this document is to help stakeholders in the resource-planning process be better producers and consumers of planning under uncertainty. These stakeholders include the executives, managers, and analysts of power companies (and their consultants) that produce resource plans; the federal, state, and local authorities that oversee, review, and approve these plans; and the power customers and other individuals that feel the impact of these plans, economically or otherwise. We provide a critical review of the major approaches to resource planning under uncertainty, including pros/cons and examples (using publicly available documents). Based on this review, we provide recommendations for best practices. We also provide resources for further study, if desired.

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[1] NERC *Fast Facts*, August 2013.

[2] EIA *Electric Power Annual*, December 2013.

[3] Geoffrey Buswick, *Standard and Poor's Rating Services*, July 29, 2014.

[4] Carnegie Mellon University, *The US Electric Power Sector and Climate Change Mitigation*, June 2005.

[5] FERC, *Grid* 2030, July 2003.

[6] Synapse Energy Economics, *A Brief Survey of Integrated Resource Planning Rules and Requirements*, April 28, 2011.

The Uncertainty Context

The importance of uncertainty—and potential change—in the power industry is cited commonly by industry participants:

- "Recent technological and economic changes are expected to challenge and transform the electric utility industry…. falling costs of distributed generation and other distributed energy resources (DER); an enhanced focus on development of new DER technologies; increasing customer, regulatory, and political interest in demand-side management technologies (DSM); government programs to incentivize selected technologies; the declining price of natural gas; slowing economic growth trends; and rising electricity prices in certain areas of the country… these factors are potential 'game changers.'"[7]

- "… utility participants are ranking virtually all issues with higher levels of concern. In some cases, chronic issues are becoming more severe. In others, changes in the business context, including a lingering recession, regulatory policy uncertainty and dramatic changes in commodity fuels markets, are exacerbating the effects of age-old concerns."[8]

- "The electric supply industry is entering a period of extraordinary change, given emerging regulations and technologies, and economic uncertainties."[9]

- "The future of the United States electric utility industry is fraught with regulatory, economic and competitive uncertainty, and that trend will continue for the foreseeable future."[10]

Some argue that the level of uncertainty in the electric power industry is bigger than ever. For example, one industry observer stated in 2012, "The U.S. utility industry has entered what may be the most uncertain, complex and risky period in its history."[11] Similar observations have been made repeatedly going back decades. In a 1983 article on coal generation, the authors refer specifically and dramatically to the then-current "era of unprecedented uncertainty."[12] Perhaps it is most accurate to say that there is and has been considerable uncertainty in the power industry for years, and the nature—but not necessarily the magnitude—of the current uncertainty is unprecedented.

Uncertainty makes planning difficult, and planning mistakes are costly. Building too much can waste billions of dollars better used elsewhere. Building too little can increase costs and risks. Choosing the wrong technology can lead to not only economic damage, but also environmental and social damage. Even building the right asset at the wrong time or in the wrong place can have a considerable downside.

Given the costs of such mistakes, planners should take special care to capture uncertainty appropriately and effectively in planning. It is important to make decisions that are realistic about both what is known and not known about the future. The point of view that true wisdom is "knowing what (or even that) you do not know" extends back to Plato and Socrates.[13]

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[7] Peter Kind, *Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business*, Energy Infrastructure Advocates (for Edison Electric Institute), January 2013.

[8] Black and Veatch, *Strategic Directions in the U.S. Electric Industry*, 2013.

[9] Rodney Frame, Edward Kahn, John Landon, and Virginia Perry-Failor, *What's Keeping Electric Utility Executives Awake at Night?*, Analysis Group, 2011.

[10] EUCG, *'The Certainty of Uncertainty' Dominates Electric Utility Leader Discussions at EUCG's Fall Workshop*, 2011.

[11] Ron Binz et al., *Practicing Risk-Aware Electricity Regulation: What Every State Regulator Needs to Know*, Ceres, April 2012.

[12] A.C. Cagnetta et al., *Coal-Fired Unit Size Selection…Is Bigger Better?*, American Power Conference, April 1983.

[13] Plato, *The Apology*.

Increasingly, stakeholders in the resource-planning process—companies, citizens and particularly regulators—understand this. Regulators are encouraging, and even demanding, better resource planning under uncertainty, and are providing more guidelines for incorporating uncertainty in that planning.

In some jurisdictions, regulators provide limited advice on the quality and quantity of uncertainty analysis they would like to see. For example, the British Columbia Utilities Commission makes a modest request regarding treatment of demand uncertainty: "More than one forecast would generally be required in order to reflect uncertainty about the future: probabilities or qualitative statements may be used to indicate that one forecast is considered more likely than others."[14]

In other jurisdictions, regulators provide clear and extensive guidance on the form and purpose of uncertainty analysis. For example, the Colorado Public Utilities Commission directs: "The utility shall propose a range of possible future scenarios and input sensitivities for the purpose of testing the robustness of the alternate plans under various parameters."[15]

In a few cases, regulators put uncertainty at the center of the resource-planning process. Consider the planning criteria in Oregon: "In an integrated resource plan, an energy utility must: (1) evaluate resources on a consistent and comparable basis; (2) consider risk and uncertainty; (3) aim to select a portfolio of resources with the best combination of expected costs and associated risks and uncertainties for the utility and its customers; and (4) create a plan that is consistent with the long-run public interest as expressed in Oregon and federal energy policies."[16]

Partly in response to these demands and encouragements, many power companies prominently mention uncertainty in external documents as an issue that makes planning a challenge and must be analyzed carefully:

- The 2007 Nova Scotia Power Integrated Resource Plan (IRP) makes uncertainty an important part of the planning process. It states that the key goal of the planning process is "to meet customer needs and environmental obligations during a period of substantial uncertainty." The word *uncertainty* appears more than 15 times in the document.[17]

- The 2011 Puget Sound Energy IRP makes uncertainty even more central, stating that it is the primary issue underlying formal planning: "Integrated resource plans are a means of examining the potential outcomes over time of different resource decisions within a matrix of varying assumptions and risk scenarios."[18]

- The 2012 BC Hydro IRP has an entire chapter on its risk framework that "sets out the analytical framework … used to compare resource alternatives, addressing multiple objectives, attributes and uncertainties."[19] The 2013 BC Hydro IRP uses the word *uncertainty* more than 300 times and includes an appendix specifically on quantifying uncertainty.[20]

- The 2012 Arizona Public Service IRP states: "Environmental impacts, technological uncertainties, financial sustainability, and other risks have in recent years assumed a larger role. This broader spectrum of considerations … has forged a terrain of uncertainty that not only demands flexibility in the formulation of a resource plan but also vigilance in its execution."[21]

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[14] British Columbia Utilities Commission, *Resource Planning Guidelines*, December 2003.

[15] State of Colorado Secretary of State, Code of Colorado Regulations, 2014.

[16] Public Utility Commission of Oregon, *Investigation into Integrated Resource Planning*, 2007.

[17] Nova Scotia Power, Inc., *Integrated Resource Plan (IRP) Report*, July 2007.

[18] Puget Sound Energy, *2011 Integrated Resource Plan*, May 30, 2011.

[19] BC Hydro, *2012 Integrated Resource Plan*, Chapter 5: "Resource Planning Risk Framework," 2012.

[20] BC Hydro, *2013 Integrated Resource Plan*, November 2013.

[21] Arizona Public Service, *2012 Integrated Resource Plan*, March 2012.

- Xcel Energy's 2010 Upper Midwest IRP states: "Uncertainty surrounding the impacts of new technology, federal energy policy, and the pace and extent of economic recovery has compelled us to build a new level of flexibility into our future plans."[22]
- Tacoma Power's 2010 IRP states that the goal of resource planning is to "determine the combination of new resources that impose the least cost and the least risk."[23]

Despite this substantial and increasing attention paid to uncertainty, resource planning is still frequently conducted as if there were no uncertainty or as if uncertainty were limited to specific, generally familiar, data-heavy areas such as stream flows or commodity prices. Even when planning extensively reflects uncertainty, it is not always done well. Both uncertainty analysis and uncertainty communication can be poor. It is hard to do right, and the quality and quantity of uncertainty treatment varies widely.

At a high level, there are really four major, distinct approaches for incorporating uncertainty in resource planning:

- Scenario planning
- Sensitivity analysis
- Probabilistic analysis
- Option analysis

Each approach is described below, followed by a discussion of best practices based on these approaches.

Scenario Planning

The simplest and most common form of uncertainty analysis is *scenario planning*. It has a long and diverse history. Harvard Business School provides a simple description: "… in a scenario planning exercise first conduct research to understand the major forces that might move the world in different directions….then map out a small number of possible alternative futures (called "scenarios"), craft narratives to describe these scenarios, and develop options for their organization for managing within these future worlds."[24]

Scenario planning typically involves a handful of "equally plausible" and "self-consistent" alternative futures. Most practitioners feel that having a manageable number of scenarios (three to five, certainly less than ten) is essential. Typically, each scenario is described in depth, has an underlying theme (e.g., high penetration of efficiency and renewables), and is associated with a memorable name (e.g., green revolution). Qualitative plausibility is emphasized over quantitative probability.

Most practitioners feel that assigning probabilities violates the underlying philosophy of scenario planning. When considering the performance of alternative plans in these scenarios, impacts are sometimes quantified or expressed in qualitative terms such as "large" or "small."

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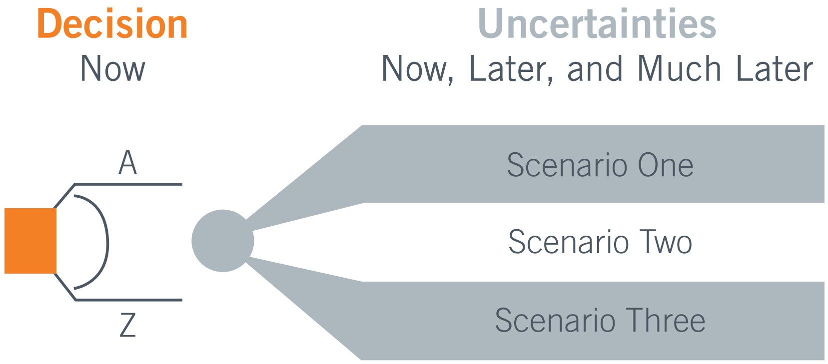
[22] Xcel Energy, *Application for Resource Plan Approval 2011–2025*, August 2010.

[23] Tacoma Power/Tahoma Public Utilities, *2010 Integrated Resource Plan*, August 2010.

[24] David Garvin and Lynne Levesque, *A Note on Scenario Planning*, Harvard Business School, July 2006.

Figure 1 illustrates the scenario planning worldview of the resource-planning problem in simple graphic form. The orange decision node to the left indicates that a choice must be made among several alternative resource plans, indicated in this figure by A to Z. The gray uncertainty node indicates that, once this plan is chosen and as time progresses, it will face one of a handful of alternative futures or scenarios. Each scenario incorporates multiple individual uncertainties over multiple time periods. This figure contains three scenarios. As is the standard in scenario planning, no probabilities are assigned.

Figure 1. Scenario Planning Worldview



Scenario planning is popular because it has important strengths:

- Perhaps most importantly, it is relatively easy to do and to explain. It is highly inclusive and participatory, lends itself to group activity, and requires little if any special training.
- It is helpful for generating and clarifying alternatives and objectives, particularly as participants work to craft plans that are well suited to different scenarios.
- It can be helpful for identifying uncertainties, particularly as participants brainstorm regarding what could happen—both good and bad.
- It can be helpful for generating insights into impacts of alternatives, particularly as participants consider how a plan crafted with one scenario in mind will perform in another scenario.

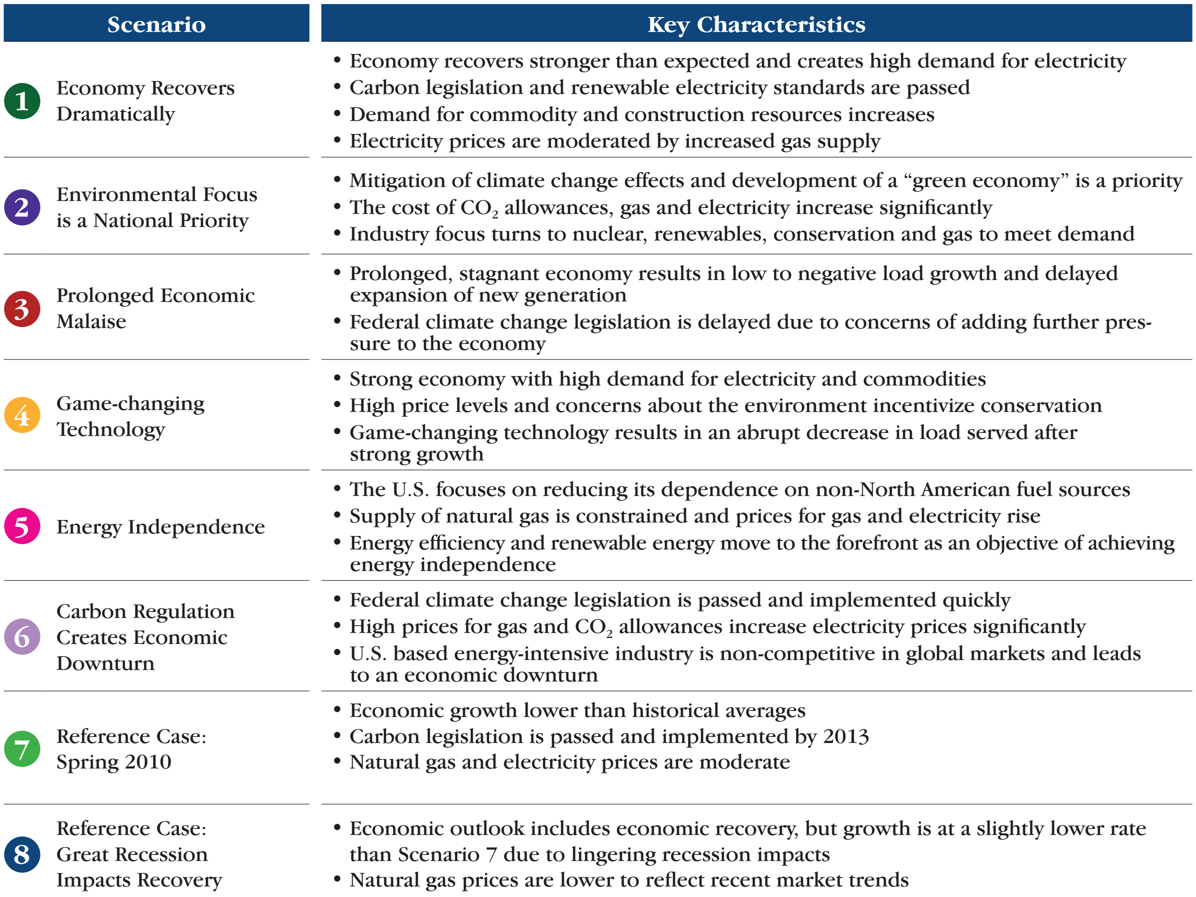
Scenario planning also has important weaknesses:

- Perhaps most importantly, it lacks analytic rigor. For example, it relies on terms such as "plausible," which do not have clear and precise meanings, and generally does not demand clarity and precision from participants. As such, it really is a creative exercise rather than an analytic one, designed to expand rather than narrow.
- It lacks comprehensiveness. The set of scenarios developed may only cover a relatively small fraction of potential futures. For example, unlikely but important events that don't fit neatly into a particular scenario may be missed or downplayed.
- It ignores the role of learning and flexibility. Scenarios are typically fixed going forward in time. Little attention is paid to dynamics—shifting from one scenario to another, and as a result from one plan to another.
- It does not lend itself to comparing plans and choosing the best one—providing little information for ranking alternatives. Some may view this characteristic as a strength, and this may be a significant contributor to its popularity among practitioners. More so than analytically rigorous approaches, scenario planning provides them with a great deal of leeway in drawing conclusions and recommendations.

McKinsey provides a more extensive summary of the positives and negatives of scenario planning.[25]

Scenario planning is popular in electric power resource planning. The Tennessee Valley Authority's (TVA) most recent (2011) integrated resource plan provides a good example of the application of scenario planning. TVA identified eight scenarios (two reference scenarios and six others), each with a memorable name, theme, and list of key characteristics.[26] As Figure 2 indicates, each scenario involves the combination of individual factors such as economic growth, regulation, and commodity prices.

Figure 2. Scenarios from TVA's 2011 IRP



Scenario	Key Characteristics
1 Economy Recovers Dramatically	• Economy recovers stronger than expected and creates high demand for electricity • Carbon legislation and renewable electricity standards are passed • Demand for commodity and construction resources increases • Electricity prices are moderated by increased gas supply
2 Environmental Focus is a National Priority	• Mitigation of climate change effects and development of a "green economy" is a priority • The cost of CO_2 allowances, gas and electricity increase significantly • Industry focus turns to nuclear, renewables, conservation and gas to meet demand
3 Prolonged Economic Malaise	• Prolonged, stagnant economy results in low to negative load growth and delayed expansion of new generation • Federal climate change legislation is delayed due to concerns of adding further pressure to the economy
4 Game-changing Technology	• Strong economy with high demand for electricity and commodities • High price levels and concerns about the environment incentivize conservation • Game-changing technology results in an abrupt decrease in load served after strong growth
5 Energy Independence	• The U.S. focuses on reducing its dependence on non-North American fuel sources • Supply of natural gas is constrained and prices for gas and electricity rise • Energy efficiency and renewable energy move to the forefront as an objective of achieving energy independence
6 Carbon Regulation Creates Economic Downturn	• Federal climate change legislation is passed and implemented quickly • High prices for gas and CO_2 allowances increase electricity prices significantly • U.S. based energy-intensive industry is non-competitive in global markets and leads to an economic downturn
7 Reference Case: Spring 2010	• Economic growth lower than historical averages • Carbon legislation is passed and implemented by 2013 • Natural gas and electricity prices are moderate
8 Reference Case: Great Recession Impacts Recovery	• Economic outlook includes economic recovery, but growth is at a slightly lower rate than Scenario 7 due to lingering recession impacts • Natural gas prices are lower to reflect recent market trends

Five major alternative resource plans or strategies were evaluated quantitatively in these scenarios. The results of this evaluation are shown in Figure 3.

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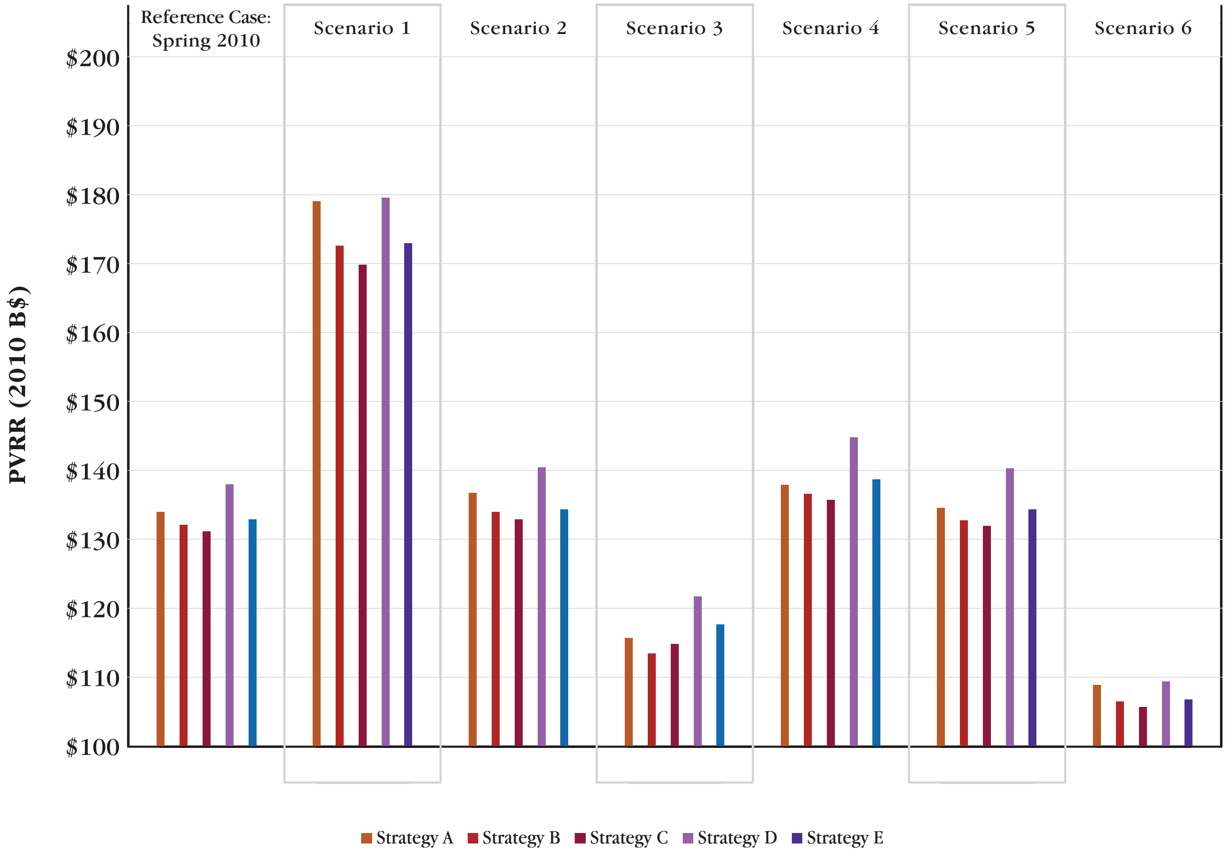
[25] Charles Rodburgh, "The Use and Abuse of Scenarios," *McKinsey Quarterly*, November 2009.

[26] Tennessee Valley Authority, *Integrated Resource Plan: TVA's Environmental & Energy Future*, March 2011.

Figure 3. TVA Evaluation of Alternative Strategies by Scenario



This example illustrates some key strengths and weaknesses of scenario planning. The scenarios are useful communicating to diverse stakeholders the range of possible futures and the factors that drive those futures. These scenarios help all participants expand their thinking and venture "outside the box." Given that many strategies perform similarly on an economic basis, the evaluation also may inspire thinking about non-economic objectives.

On the other hand, the evaluation of plans across these scenarios provides only modest help in ranking plans and choosing the best one. For example, it shows that Strategy D in Figure 3 performs relatively poorly and is unlikely to be the best choice, but provides little guidance on the choice among the other alternatives—largely because there is no formal weighting of the scenarios through probabilities. In addition, the evaluation pays little attention to individual uncertainties that may be relatively implausible but potentially significant.

All approaches, including fairly simple ones, have pitfalls in practice. The most important pitfall for scenario planning is trying to make it something that it is not. It is a creative, broadening, and participatory exercise best suited for generating ideas and gaining support. It is not an analytic, focused, and expert exercise well suited to evaluating and selecting alternatives. When attempts are made to use it in this latter mode, it can fall well short, and the quality of the resulting conclusions and recommendations may suffer.

Sensitivity Analysis

Scenario planning is a simple, aggregate form of uncertainty analysis. As noted above, it is primarily a creative rather than analytic exercise, designed to broaden rather than narrow. *Sensitivity analysis* can be viewed as a further step down the analytic path. It is a simple, disaggregated form of uncertainty analysis that focuses on individual assumptions rather than entire futures. And it is designed specifically to narrow and focus planning.

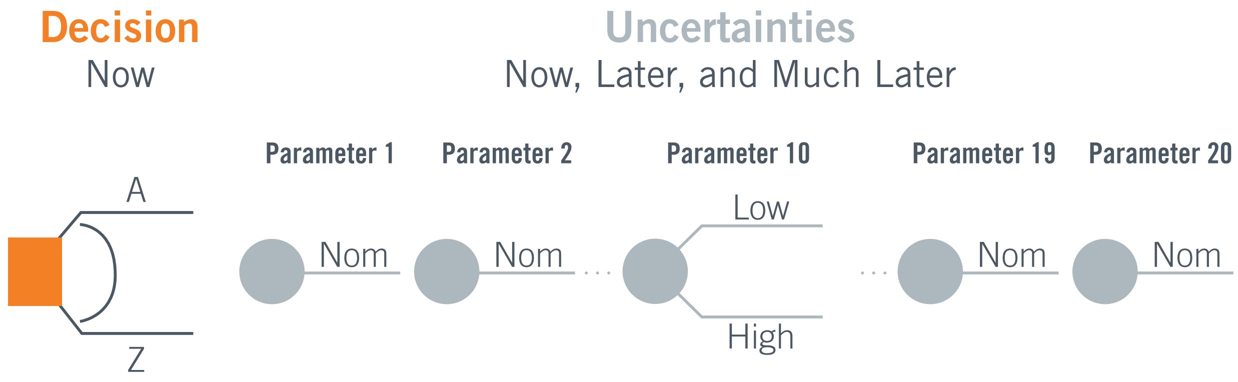
In sensitivity analysis, the impact of varying individual assumptions is evaluated without formal probabilities. Professor Alfred Rappaport provides an intuitive description of the motivation behind sensitivity analysis:

> In the face of uncertainty, the most recurring questions are of the form "What if…? ...The "what if" question may be viewed as the introduction to sensitivity analysis. In its mathematical sense, sensitivity analysis is a study to determine how possible changes or errors in parameter values affect model outputs.[27]

As with scenario planning, there are many flavors of sensitivity analysis. In common practice, a list of major assumptions is made (e.g., load growth), and a parameter is associated with each such assumption (e.g., 1.5 percent annual). Then, the parameter associated with each assumption is varied over an "equally plausible" range from low (e.g., 0.5 percent) to high (e.g., 3.5 percent), and the impact on alternative plans is evaluated. Most documents provide a list of these individual assumptions (e.g., load growth, gas price, CO2 regulation) along with the baseline and sensitivity values. In most documents, the impact of varying the individual assumptions is expressed quantitatively. In a few cases, the impact is expressed qualitatively using terms such as "large" or "small." Based on sensitivity analysis, conclusions can be drawn about which assumptions are most significant—from an uncertainty perspective. Conclusions are also sometimes drawn informally about which alternatives deserve in-depth consideration because they are robust—relatively insensitive to assumptions—and which alternatives deserve to be rejected because they are too risky—too sensitive to assumptions.

Figure 4 illustrates the sensitivity analysis worldview of the resource-planning problem in graphic form. As with scenario planning, a decision must be made among alternative resource plans. Again, this is illustrated with a decision node and alternative plans A through Z. Unlike in scenario planning, each plan performs in set of many futures—not just a handful. In each future, one assumption or parameter varies at a time from its baseline or nominal setting. In the figure, the parameters are noted as 1 through 20, and sensitivity analysis is conducted on parameter 10. Parameter 10 is varied from its low to its high value; all other parameters remain at their nominal values. As is typical, there is no formal weight or probability on each outcome. In practice, sensitivity analysis would be conducted on all 20 parameters.

Figure 4. Sensitivity Analysis Worldview



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[27] Alfred Rappaport, "Sensitivity Analysis in Decision Making," *The Accounting Review*, July 1967, 441–456.

Sensitivity analysis has a variety of strengths:

- Perhaps most importantly, it is relatively easy to do and explain, particularly because it is generally conducted without requiring participants to grapple with formal probabilities. Because it focuses on individual assumptions, it typically is more of a "solo" than a "group" activity—which can sometimes be easier.
- More so than scenario planning, sensitivity analysis can be comprehensive. In many ways, that is the intention—to examine the significance of all important assumptions. Generally, there is no arbitrary limit on the number of individual assumptions that can be examined, allowing for evaluation of a full range of issues. This stands in contrast to scenario planning, with its emphasis on only a handful of scenarios.
- It is helpful for prioritizing the effort devoted to evaluating uncertainties. Highly-sensitive inputs can be studied in detail, and less-sensitive inputs can be treated less thoroughly.
- Like scenario planning, it can be helpful for generating insights into impacts and creating new alternatives as one moves from "what if" to "why."

Sensitivity analysis also has a variety of weaknesses:

- Like scenario planning, it can suffer from a lack of analytic rigor, such as the use of terms like "low" and "high" that do not have clear and precise definitions. Some forms of sensitivity analysis are more rigorous; for example, some define "low" precisely at the 10th percentile and "high" precisely as the 90th percentile.
- By its very nature, sensitivity analysis is a "first-order" activity. It ignores cross effects, correlations, and interactions among uncertainties. First-order analysis is a well-accepted approximation, but an approximation nevertheless.
- Like scenario planning, it ignores the role of learning and flexibility. There are typically no dynamics in sensitivity analysis.
- Like scenario planning, it does not lend itself well to comparing plans and choosing the best one. Instead, as noted above, it is helpful for identifying the most important individual assumptions.

Sensitivity analysis is popular in resource planning. The most recent Nebraska Public Power District (NPPD) IRP provides a good example of the application of sensitivity analysis.[28] NPPD examined the impact of 10 individual factors on nearly 20 resource plan alternatives. Figure 5 displays what is often called a tornado diagram, which shows this sensitivity analysis for one resource plan—H13. As indicated in the figure, the economics of this plan are affected heavily by uncertainty in load and only slightly by uncertainty in capacity prices. It is important to note that this sensitivity analysis, like others, does not indicate whether an individual factor is important; it indicates whether *uncertainty* in that factor is important.

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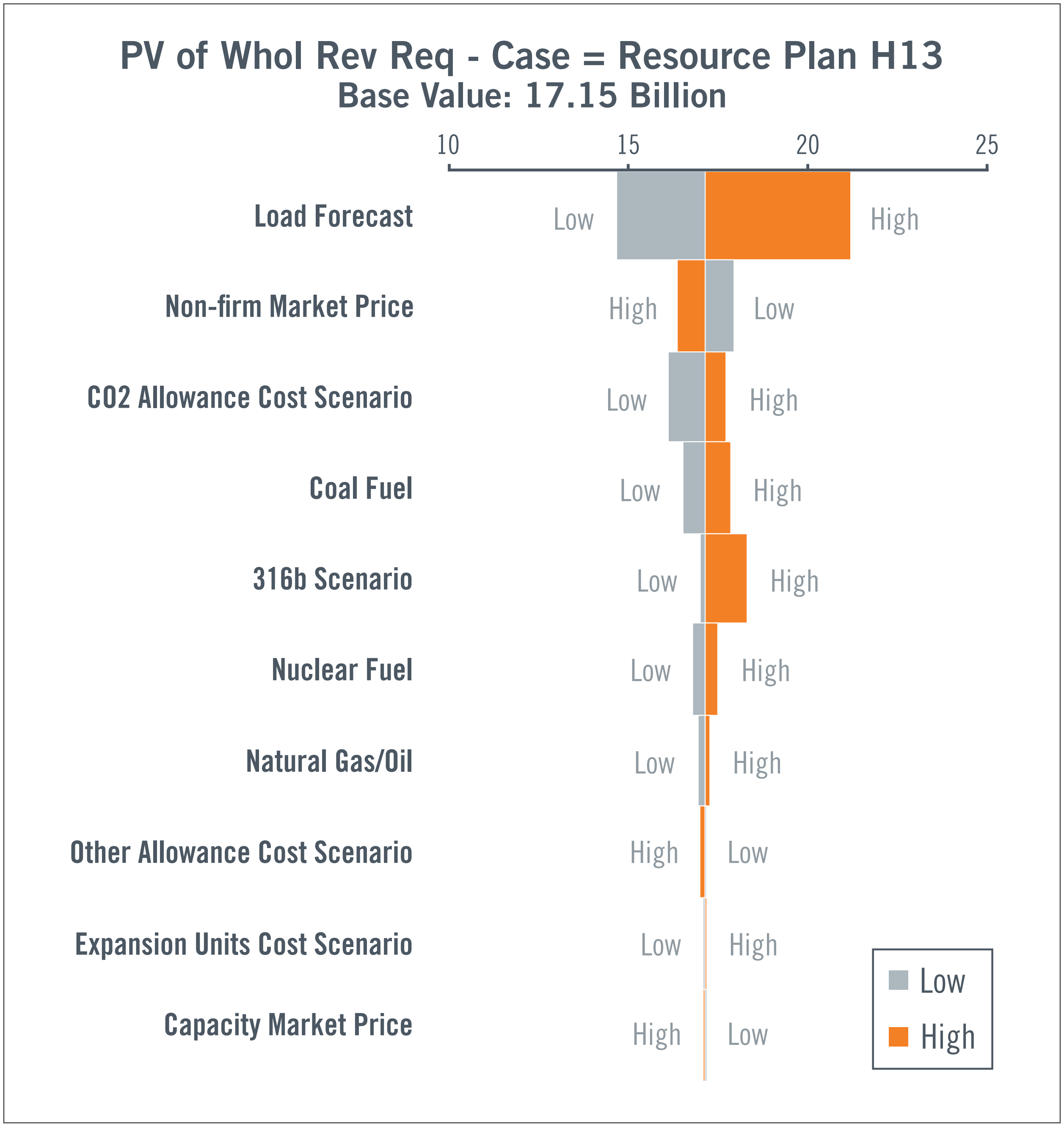
[28] Nebraska Public Power District, *2013 Integrated Resource Plan*, 2013.

Figure 5. NPPD Sensitivity Analysis



NPPD looked at which uncertainties were most important for each resource plan (i.e., those that show up at the top of each tornado diagram). This information is displayed in Figure 6. As the figure indicates, the load forecast plays a major role in all plans, and other factors (e.g., nuclear fuel) play a major role for a subset of plans.

Figure 6. Most Important Uncertain Factors

RP	#1	#2	#3	#4	#5
L01	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
L02	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
L03	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
L04	Load Forecast	Natural Gas/Oil	CO2 Allowance Cost Scenario	Coal Fuel	316b Scenario
L05	Load Forecast	Natural Gas/Oil	316b Scenario	CO2 Allowance Cost Scenario	Coal Fuel
L06	Load Forecast	Natural Gas/Oil	Nuclear Fuel	316b Scenario	Coal Fuel
L07	Load Forecast	Natural Gas/Oil	Nuclear Fuel	316b Scenario	Coal Fuel
L08	Load Forecast	Natural Gas/Oil	Nuclear Fuel	316b Scenario	Expansion Units Cost Scenario
L09	Load Forecast	Natural Gas/Oil	Nuclear Fuel	Expansion Units Cost Scenario	316b Scenario
S10	Load Forecast	Natural Gas/Oil	CO2 Allowance Cost Scenario	Non-firm Market Price	Nuclear Fuel
S11	Load Forecast	Non-firm Market Price	316b Scenario	Coal Fuel	Nuclear Fuel
L12	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
M03_LW	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
H03_LW	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
H03_MW	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
H03_HW	Load Forecast	Non-firm Market Price	CO2 Allowance Cost Scenario	Coal Fuel	316b Scenario
H03_HWxEPU	Load Forecast	CO2 Allowance Cost Scenario	Non-firm Market Price	Coal Fuel	316b Scenario
H13	Load Forecast	Non-firm Market Price	CO2 Allowance Cost Scenario	Coal Fuel	316b Scenario
H14	Load Forecast	Non-firm Market Price	CO2 Allowance Cost Scenario	Coal Fuel	316b Scenario

This example illustrates some key strengths and weaknesses of sensitivity analysis. The analysis is wide ranging and covers a broad set of economic, market, regulatory, and technological factors. It is well suited for determining which uncertainties affect which plans, and therefore for prioritizing planning efforts. It is hard to argue for in-depth uncertainty treatment for an uncertainty with minimal impact on the alternatives. At the same time, sensitivity analysis is perhaps too "disaggregated." Each factor is examined independently in isolation, and common drivers that could shift multiple factors at a time are ignored. Finally, it provides little guidance on ranking plans and choosing the best one.

The biggest pitfall with sensitivity analysis in practice is not treating the analysis with sufficient care. In many cases, sensitivity analysis is only performed on a few easily quantified variables, perhaps where there is a great deal of historical data. Load growth is a good example of such a variable, and many IRPs include sensitivity analysis on load growth. However, sensitivity analysis is often not performed on the full range of potentially important variables—typically because there is little available data and they are difficult to quantify. In addition, where sensitivity analysis is performed, inappropriate ranges are often chosen. Sensitivity analysis should not be conducted simply by varying each input factor by ±25 percent, for example. It is critical that the range used for each variable accurately reflect what is known (or not) about that variable, and that these ranges reflect comparable ranges of uncertainty. Some well-understood variables may vary by percentages; other poorly understood variables may vary by orders of magnitude. When not treated with sufficient care, the results of sensitivity analysis can be misleading, and important uncertainties can be ignored.

Probabilistic Analysis

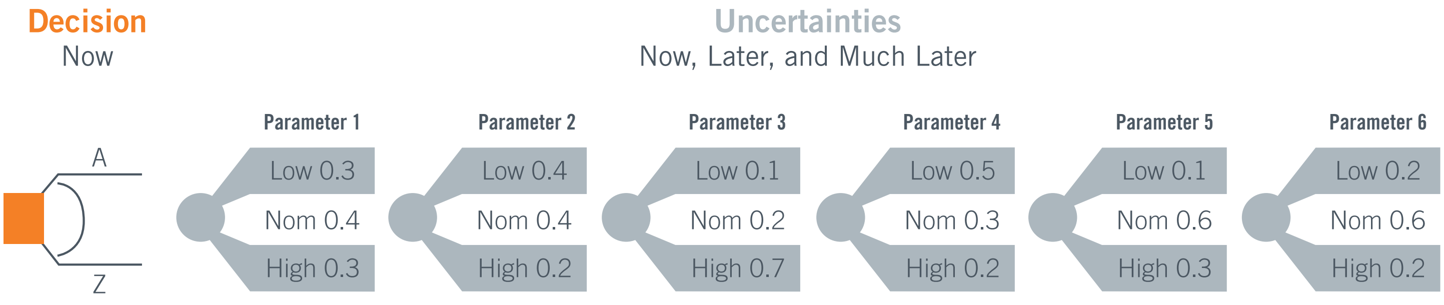
Scenario planning is a simple creative process that helps participants gain understanding and expand thinking. But in truth, it helps little with the choice among alternative plans. *Sensitivity analysis* is a simple analytic process that helps participants prioritize uncertainties. But it also helps little with the choice among alternative plans. *Probabilistic analysis*, on the other hand, is a moderately sophisticated analytic process that focuses directly on providing information that can be used to rank and select alternative plans.

In probabilistic analysis, probabilities are assigned to combinations of uncertain outcomes (aka scenarios) based on their individual likelihoods and their relationships. The impact of each plan is evaluated quantitatively in each scenario based on economic impact or other metrics, and across all scenarios using the scenario probabilities. Cross-scenario measures include entire probability distributions and summary statistics such as mean and variance.

Probabilistic analysis can be conducted in various ways at varying levels of detail. Uncertainties can be treated as independent or correlated. Probabilities can be treated as discrete (using decision trees) or continuous (using Monte Carlo simulation). The preferred variation may depend on the nature of the resource-planning problem, on available tools, or on the background and preferences of the participants. Because it is directly designed to support decision making, probabilistic analysis is both more difficult and more powerful than scenario planning and sensitivity analysis.

Figure 7 illustrates the probabilistic worldview of the resource-planning problem in graphic form. As with scenario planning and sensitivity analysis, a decision must be made among alternative plans. Again, this is indicated by a decision node with alternatives A to Z. Then, each plan performs over a range of potential futures. Each future represents a combination of the outcomes of many individual factors and has a combined or joint probability. In this figure, there are six individual factors (parameters 1 through 6), each with three outcomes. The tree is shown in schematic or compact form. When fully expanded, there are 729 scenarios (3 × 3 × 3 × 3 × 3 × 3), each with a joint probability. Of course, the probabilities in this figure are arbitrary.

Figure 7. Probabilistic Analysis Worldview



Probabilistic analysis has several strengths:

- Perhaps most importantly, it is designed and directly useful for comparing alternatives and choosing the best one. This contrasts with scenario planning and sensitivity analysis, which help only indirectly in the effort.
- Also importantly, it is based on specific, well-established logical principles and empirical evidence. Practitioners can draw upon extensive academic and business resources as guidance.
- When appropriately applied, probabilistic analysis can be comprehensive. It can be designed to cover a full range of issues.
- In addition to its direct help choosing among alternatives, it can be helpful—like other approaches—for generating insights into impacts, particularly when participants probe the "why" behind specific results.

Probabilistic analysis also has several weaknesses:

- Most significantly, it is moderately difficult to do and explain (well). It involves concepts and techniques that may not be familiar to many, such as the assignment of probabilities to events where there is little if any historical data. Consequently, it is not fully participatory and typically requires experts with special training. It also requires participants to be explicit and specific about issues often easier left vague and general. Of course, this requirement may also be viewed as a strength.
- It typically involves the development and use of a (potentially less accurate and credible) high-level model of the electric power system. Probabilistic analysis may require the evaluation of thousands (if not more) of individual cases. It is usually impractical to run this many cases with the usual highly detailed, operation-focused engineering/economic models (like PROMOD).
- It is also moderately resource intensive, which can be a significant issue in some contexts. The term "moderately" is accurate—with advances in hardware, software, communications, and the like, probabilistic analysis is not as difficult as it once was.
- Although it puts a great deal of emphasis on uncertainty, most probabilistic analysis is weak in dynamics. Like scenario planning and uncertainty analysis, it ignores or downplays the roles of learning and flexibility.

Despite its strengths, or perhaps because of its weaknesses, probabilistic analysis is only modestly popular in resource planning. The recent IRP from Puget Sound Energy (PSE) provides a good example of the application of probabilistic analysis. Figure 8 shows how PSE uses probabilistic analysis to compare the performance of four resource plans.[29] The probabilistic approach provides key statistics on each plan. For example, it shows the median value and the 50 percent confidence interval. These results are based on Monte Carlo simulation with 1,000 samples of numerous uncertain inputs.

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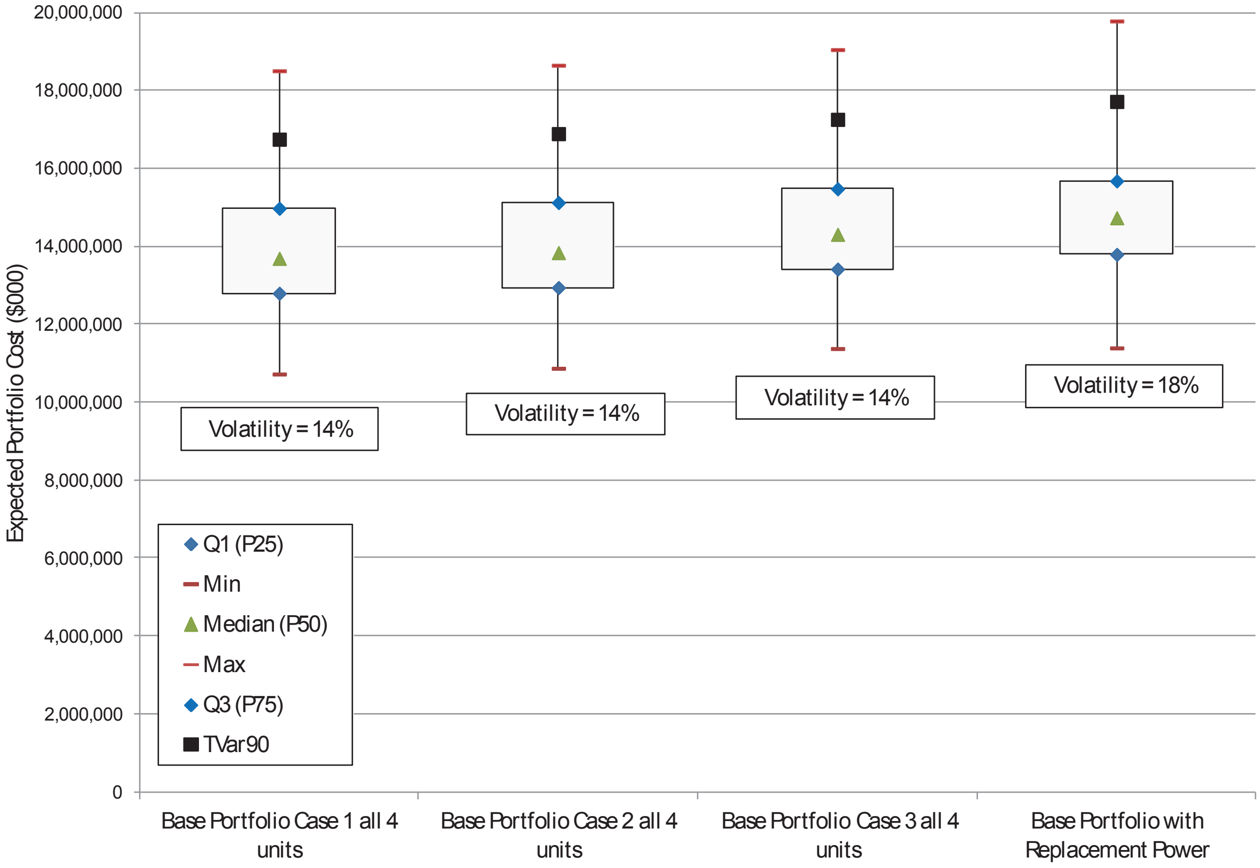
[29] Puget Sound Energy, *2013 Integrated Resource Plan*, 2013.

Figure 8. Probabilistic Analysis from PSE IRP



This example illustrates some key strengths and weaknesses of probabilistic analysis. Unlike scenario planning and sensitivity analysis, probabilistic analysis allows one to summarize and compare very compactly the performance of alternative resource plans across a wide range of futures. The example clearly illustrates that the base portfolio has a lower median cost and lower "risk"—as measured by the 50 percent confidence interval—than the other alternatives, although the numbers are close. The example shows that participants must be comfortable with the philosophy and language of statistics, also unlike scenario planning and sensitivity analysis.

The biggest pitfall with probabilistic analysis in practice is leaving it solely to analysts, which can be tempting given the complexities and difficulties. Probabilistic analysis is designed for evaluating alternatives and selecting the best one, which is arguably the central and most important activity in the resource-planning process. If this role is left solely to analysts, the results may be disappointing. Either the results will be intuitive and therefore obvious ("We already knew that"), or counterintuitive and therefore rejected ("That can't be right"). This disappointment can be avoided if non-analytic stakeholders—those providing data, reviewing results, and responsible for recommendations—are an active part of the analytic effort. Under these conditions, intuitive results will be viewed positively as confirming the wisdom of the participants and the process, and counterintuitive results will be viewed positively as an opportunity to review and rethink.

Option Analysis

Option analysis is a highly sophisticated and increasingly popular form of uncertainty analysis that adds learning and flexibility to probabilistic analysis. In option analysis, uncertainties are not treated as fixed or static. Instead, they evolve over time with learning; they are dynamic. Along with dynamic uncertainties, option analysis opens up the possibility of dynamic decisions. Decisions need not be treated as fixed—"do it now" or "all or none" alternatives—based solely on what you know now. Instead, decisions can be broken into stages over time—"start the first phase only"—providing flexibility to incorporate learning—"cancel if things don't go well." This is more reflective of the reality of management. It helps match the analysis to the real world.

The term "option" is taken largely from finance. A financial option is a derivative financial investment made now (an option on IBM stock) that provides the right, but not the obligation, to make a future underlying financial investment (the IBM stock). This concept has been extended to non-financial or real investments under the banner "real options" or "real-option valuation" (see Triantis & Borison, 2001,[30] for further information). A real option is a non-financial investment (acquire land) that allows but does not require one to make future investments (build plant).

Option analysis has a variety of approaches, particularly given the close connection to finance. Approaches range from the Nobel Prize–winning Black–Scholes model from finance to decision trees and Monte Carlo simulation from engineering. For real—as opposed to financial—options, decision trees and Monte Carlo simulation are typically used. See Borison (2005)[31] for a critical review of option analysis approaches.

Figure 9 illustrates the option worldview of the resource-planning problem. This figure has two notable differences from earlier figures. First, unlike the other forms of uncertainty analysis, the choice of resource plan is not viewed as a "now or never" initial decision. Instead, it is broken up into decisions now, later, and much later, reflected in three—not one—decision nodes. The alternatives in the first node are indicated as A through Z, although they may not be the same as in other approaches. In practice, initial decisions are typically just the first phase of a long-term plan. The alternatives in the second node are indicated by AA through ZZ, and in the third node by AAA to ZZZ. In practice, the alternatives available in the future are of course dependent on the choices made today. For example, one cannot choose to complete a power plant in phase two unless one has started it in phase one.

Second, the uncertainties in the environment are no longer static. Probabilities are assigned to current uncertainties, but the probabilities assigned to future uncertainties vary depending on what is learned in the interim. Decisions made later can take advantage of learning that occurs between now and later. The probabilities for uncertainties later and much later are not shown in the diagram because they, of course, depend on what is learned between now and then.

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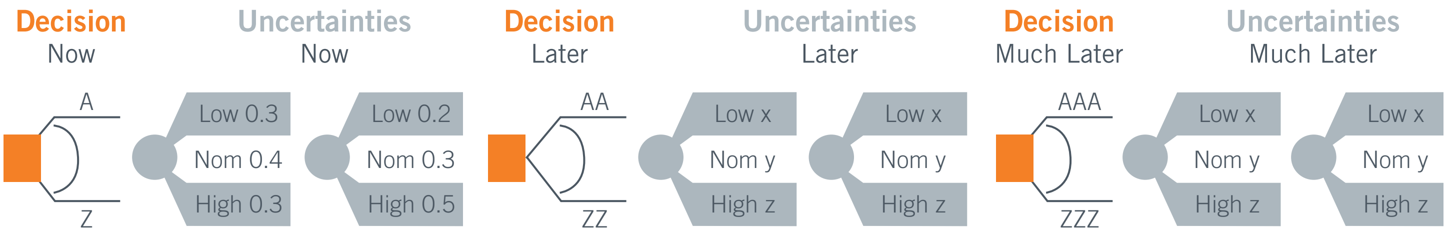
[30] Alex Triantis and Adam Borison, "Real Options: State of the Practice," *Journal of Applied Corporate Finance*, Summer 2001.

[31] Adam Borison, "Real Options Analysis: Where are the Emperor's Clothes?," *Journal of Applied Corporate Finance*, Spring 2005.

Figure 9. Option Analysis Worldview



Option analysis has several important strengths:

- Perhaps most importantly, and unlike other forms of analysis, it is based explicitly on a realistic, dynamic view of the planning environment with learning and flexibility. Participants of all types and levels in the resource-planning process typically strive to be attentive enough to learn and adapt appropriately; option analysis is the only approach that attempts to capture this.
- Like probabilistic analysis, it is well suited for comparing plans—both fixed and dynamic—and choosing the best one, including those that involve changing over time. In addition, unlike other approaches, it provides guidance on the management "roadmap" associated with the chosen plan.
- Like probabilistic analysis, it can be comprehensive and cover a wide range of issues.
- Like probabilistic analysis, it is rigorous, axiomatic, and proven.

Option analysis has two major weaknesses:

- As the most sophisticated approach, it is difficult to do and explain (well). As a result, it is not as fully participatory as other approaches. While the concepts may be intuitive (learning and flexibility), the tools often are not. Option analysis often involves a new and more subtle view of both data and modeling.
- It can be resource intensive, which can be a major issue in some contexts.

In the resource-planning context, option *thinking* is becoming increasingly popular. By "option thinking," we mean devoting attention to, and discussing which plans are likely to take the greatest advantage of, learning and flexibility. However, formal option *analysis* is still relatively uncommon. Manitoba Hydro's recent NFAT (Needs for and Alternatives to) provides a good example of the application of option analysis to resource planning.[32] Figure 10 shows the structure of this analysis using graphics similar to our earlier figures. In this figure, the initial resource decision is which "pathway" to embark on. A pathway is an initial direction, but not a precise plan. After the pathway is chosen, there is learning about energy prices; uncertainty about near-term energy prices is resolved. After this learning, there is a second resource decision: which specific plan to choose consistent with the pathway chosen initially. After the second decision, the plan is faced with a range of potential futures involving energy prices, economic indicators, and capital costs.

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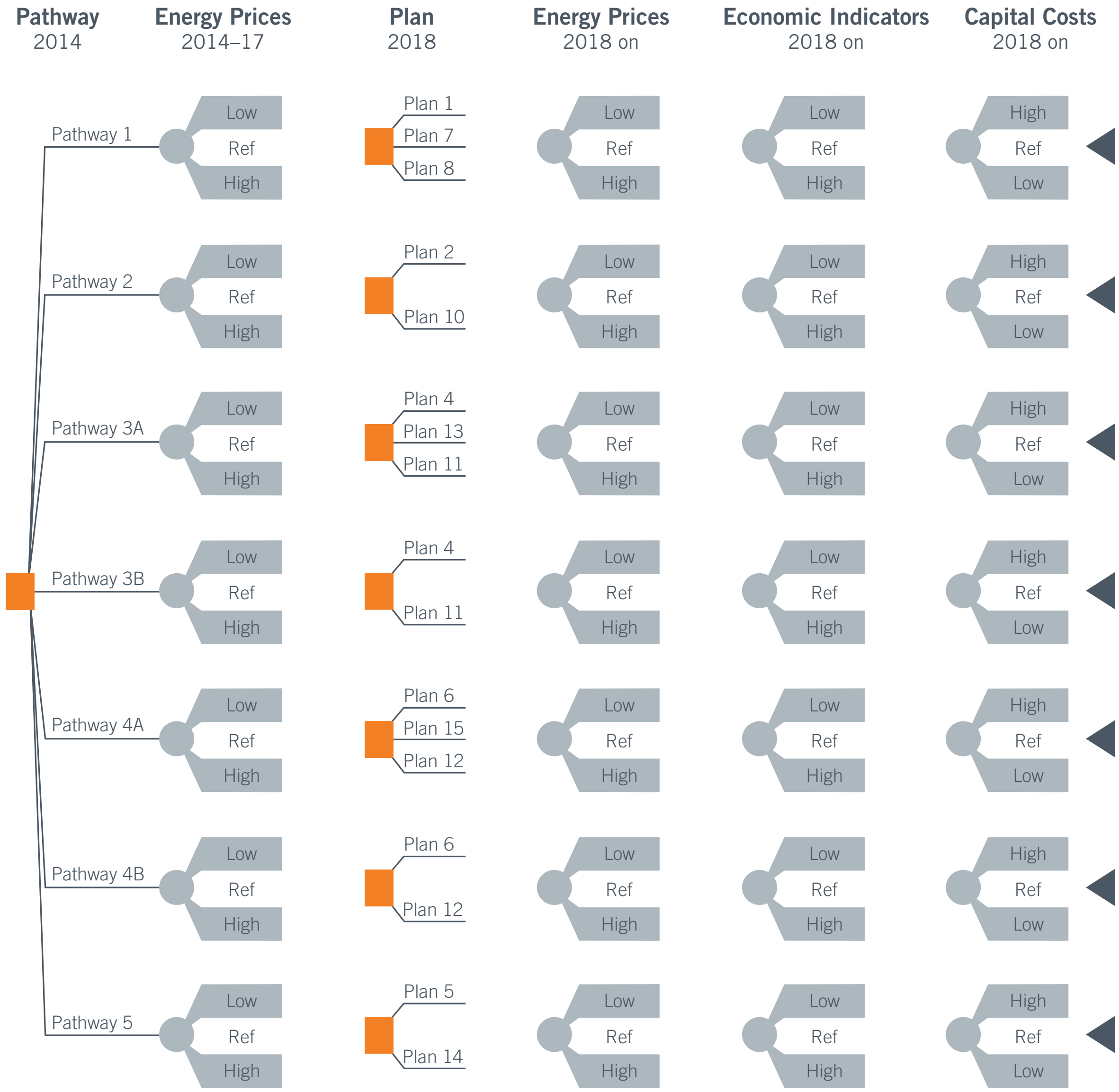
[32] Manitoba Hydro, *Needs for and Alternatives To*, August 2013.

Figure 10. Manitoba Hydro's Option Analysis Structure



The results of this option analysis are shown in Figure 11, which provides statistics for each of the major initial "pathway" choices, including the 10th percentile, 90th percentile, and expected value. Manitoba Hydro's conclusion was that: "…with learning and flexibility… the expected value is improved by \$41M (from \$1085M to \$1126M) and the 10th percentile risk is improved by \$412M (from −\$1429M to −\$1017M). Optionality results in both a moderate increase in expected value and a large decrease in risk."

Figure 11. Manitoba Hydro Option Analysis Results

Millions of 2014 NPV dollars	Pathway						
	1	2	3A	3B	4A	4B	5
	Gas/?	K22/?	K19/250/? Prot. C26	K19/250/? Prot. C31	K19/750/? Prot. C26	K19/750/? Prot. C31	K19/750/? WPS Sale & Inv.
10th Percentile -"Risk"	-1193	-1347	-1269	-990	-1526	-1250	-1017
90th Percentile - "Reward"	1956	2325	2805	2669	3126	2770	3276
Expected Value	455	562	878	957	869	919	1126

This example illustrates the strengths and weaknesses of option analysis. It provides information directly for comparing both fixed and flexible resource plans based on a more realistic view of how those plans will actually be managed or implemented. It also shows the added value provided by flexibility, something other approaches cannot provide. However, it is clear from the example that this approach is considerably more involved, and perhaps more difficult to understand and communicate, than other approaches. It asks participants to think not just about uncertainty, but also about how that uncertainty changes over time, and how one should respond to changes.

The biggest pitfall with option analysis in practice is actually not practicing it. The concepts underlying option analysis are intuitive. We all understand learning and adapting. And stakeholders—including managers and regulators—often resonate with these concepts. They expect to see resource planning include this perspective. Yet resource planners can be intimidated by the analytic effort and, sometimes, by the analytic jargon and tools. This is unfortunate, because while option analysis is more complex than other approaches, it can be conducted manageably and understandably. Without option analysis, a critical element of resource planning may be missed.

Best Practices

As discussed above, there are four major approaches to uncertainty analysis in resource planning. Figure 12 summarizes the strengths and weaknesses of these approaches based on informed, but subjective, judgment. Each approach is evaluated on six criteria:

- Ease of use: How easy is it to conduct the analysis? Are extraordinary measures required?
- Ease of communication: How easy is it to communicate the analysis? Can it be explained?
- Rigor: How much is the analysis based on solid principles and experience? Can it be defended?
- Comprehensiveness: How thorough is the analysis? Are major elements missing?
- Usefulness for insight: How helpful is it for generating insights? Will it produce “aha’s”?
- Usefulness for decision making: How helpful is it for choosing among alternative plans?

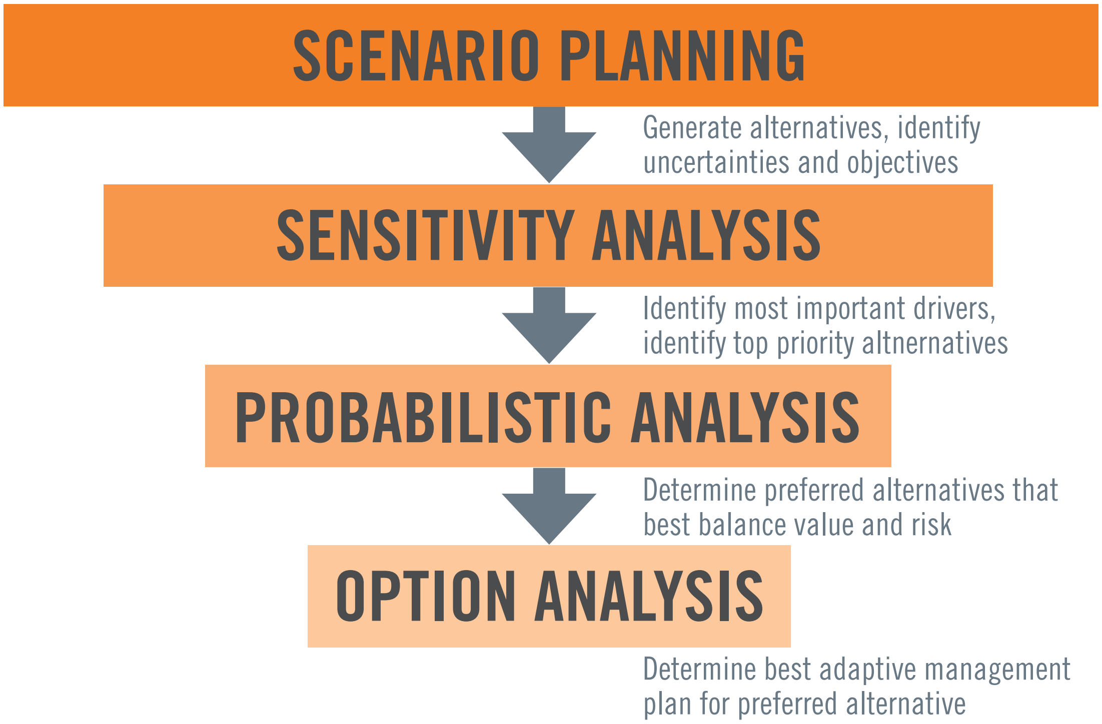
Figure 12. Resource Planning: Strengths and Weaknesses

Approach	Ease of Use	Ease of Communication	Rigor	Comprehensiveness	Usefulness for Insight	Usefulness for Decision-Making
Scenario Planning	Excellent	Good	Fair	Poor	Good	Poor
Sensitivity Analysis	Good	Good	Fair	Good	Good	Fair
Probabilistic Analysis	Fair	Fair	Good	Good	Good	Good
Option Analysis	Poor	Fair	Good	Excellent	Fair	Excellent

As the figure shows, no approach is dominant. Each has pluses and minuses. No one approach excels in all dimensions.

Fortunately, best practice does not require one to choose a single approach and suffer its limitations. Instead, we suggest that best practice is to follow a *logical progression* through these approaches in a specific order. This is best but not common practice. Figure 13 illustrates this progression.

Figure 13. Resource Planning under Uncertainty Best Practice



Best practice begins with *scenario planning*, or something similar. It is important that the first step be a creative, participatory activity that helps achieve consensus among a range of stakeholders on the "frame" of the resource-planning problem—the objectives, uncertainties, and alternatives. It is widely recognized that careful attention to framing is essential for addressing the right problem, involving the right participants, identifying the right solution, and implementing it right away. As noted earlier, scenario planning is a creative, expansive activity that can help greatly with framing. It should be used as such.

Once scenario planning has helped establish the right frame, *sensitivity analysis* is a useful second step. Scenario planning is a creative activity that often includes a wide range of participants with different perspectives, backgrounds, training, and the like. It has a broadening effect—more alternatives, more issues, more impacts. On the other hand, sensitivity analysis is an analytic activity involving technical experts. It has a narrowing effect that helps focus on the most relevant uncertainties and eliminate alternatives that perform poorly when exposed to a range of futures. In a world of limited resources, it is essential to focus time and effort where it matters. Sensitivity analysis should be used to do so.

Scenario planning and sensitivity analysis are important—but they are only preliminary steps, in that they generally provide only limited guidance on the core resource-planning question: what is the best alternative? On the other hand, *probabilistic analysis* is an expert analytic activity specifically designed for comparing alternatives and identifying the best one. Once the preliminary steps are complete, probabilistic analysis should be used to address this core issue directly.

In some contexts, probabilistic analysis may be the final step. Plans have been compared rigorously across a range of futures, and the best plan has been identified. Learning and adapting are not central. However, in many contexts, the ability to learn and adapt is critical to both the choice of plan and the actions taken over time to implement that plan. In these cases, *option analysis* should be the final step to determine the best flexible or adaptive strategy.

Following this progression of approaches in resource planning requires considerable effort. But it generates considerable benefits in the quality of the resulting plan and the buy-in of that plan with stakeholders. Given the "staggering importance" of the power industry, these benefits are worth obtaining.

About the Author

Adam Borison

Dr. Adam Borison is an internationally recognized consultant, academic, and entrepreneur. He specializes in the application of advanced analytic methods to strategy, valuation, and risk assessment in power and fuels. Dr. Borison has led numerous engagements in investment strategy, corporate mergers and acquisitions, environmental resources management (ERM), project planning and evaluation, product design and research and development, capital allocation, government policy and regulation, and litigation/arbitration. He has broad experience across a range of geographies, technologies, and applications.

Most recently, Dr. Borison advised on pipeline gas/power business strategy in the Midwest United States, supported utility resource planning efforts involving tens of billions in dollars of generation and transmission facilities in Canada, and helped develop renewable energy policy and regulation in the Caribbean. He has also worked on dozens of capability-building engagements for clients involving data development, model transfer, results review, training and coaching. Dr. Borison has submitted expert testimony in arbitration, litigation, and regulation settings extending from the Gulf of Mexico to Kurdistan.

Dr. Borison has served on the visiting faculty at Stanford University, U.C. Berkeley, and the University of Cambridge, teaching courses both specifically in the energy business and generally in management methods. Most recently, he co-taught a renewable energy project development course at Stanford. Dr. Borison is widely known as an expert in management science and operations research, especially decision/risk analysis, real options, and other forms of uncertainty analysis. He has authored several articles on the application of analytic methods in leading publications such as *The Electricity Journal*, *Public Utilities Fortnightly*, *Sloan Management Review*, *California Management Review*, and the *Journal of Applied Corporate Finance*. Dr. Borison led the original development team for DPL, a leading decision and risk analysis software package now in its eighth release. He also co-founded Agni Energy, an India-focused bioenergy company.

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