NESCOE
New England States Committee on Electricity

To: ISO New England
From: NESCOE
Date: April 13, 2018
Subject: Analysis to Enable Risk-Informed Judgments

ISO New England has made clear that fuel-security risks - which ISO New England has defined as the possibility that power plants will not have or be able to get the fuel they need to run, particularly in winter) - are the foremost challenge to a reliable power grid in New England. NESCOE appreciates ISO New England's initial efforts to study this issue and continues to evaluate the results of ISO New England's deterministic Operational Fuel Security Analysis (OFSA) as well as the results of subsequent analysis that ISO New England conducted at NESCOE's and stakeholders' request.

In Congressional testimony in January 2018, ISO New England explained an objective of the OFSA this way: "…to stimulate discussion with regional stakeholders and policymakers as to the degree of operational risk the region is willing to accept, and whether additional changes to the market design may be necessary to address the fuel security risks identified in the study." (p. 3) The OFSA appears to have achieved the purpose of illustrating a range of potential winter seasonal risks that could threaten New England's power system if fuel and, in turn, energy is constrained. The additional analysis ISO New England conducted in response to NESCOE's and stakeholders' requests shows markedly different outcomes based on changed assumptions, such as assuming states satisfy their clean energy laws.

While NESCOE recognizes ISO New England's preference to begin discussing solutions, these discussions must be informed by greater specificity about the problem to be solved. For example, does ISO New England assess the risk to power system reliability to be centered on the likelihood of losing an LNG terminal, having less dual-fuel units participating in the markets, losing a nuclear or other resource to retirement, or a combination of those or something else?

Further, ISO New England has identified a key question to be addressed: what level of fuel-security risk is New England willing to accept? States - and we believe all stakeholders - need more rigorous analysis of uncertainties and their likelihood to understand fully the risk reflected in the scenarios in order to develop cost-effective mitigation strategies and to prioritize potential approaches. An informed judgment requires information about the relationship between the asserted risks and proposed solutions and their associated costs, and an assessment of the benefits and trade-offs between various potential solution options.

To facilitate our thinking about the kind of analysis that would enable responsiveness to the question ISO New England has posed to New England states and stakeholders - what level of risk is the region willing to accept? - we sought independent guidance about analysis approaches well-suited to facilitate our thinking given the current New England circumstance. That third-party information is attached for your reference. To be clear, this guidance does not suggest that precise predictions are achievable. Nor does it indicate, and we do not suggest, that only one kind of analysis could enable better risk-informed judgements about the type or level of investment that makes operational and economic sense.

With this information as a reference point, we look forward to dialogue with ISO New England about the need, ability to conduct and the benefits of additional analysis ISO New England may be able to provide to help states and stakeholders make risk-informed judgments about the line between unacceptable and unacceptable risks. Following that, we look forward to discussing the range of means to mitigate unacceptable risks in a way that makes economic sense. If, on the other hand, ISO New England believes the OFSA or other information it possesses suffices to make cost-effective investment level decisions on behalf of consumers it would be helpful to better understand why that is.

Finally, we attach some suggested principles to help guide the discussion of risks and evaluation of potential solutions. These principles are intended to facilitate a shared understanding of how ISO New England will define identified risks and evaluate proposed solutions. NESCOE does not intend for this to be an exhaustive list of principles ISO New England could employ as part of the ongoing process and would welcome discussion with ISO New England and stakeholders on this list.

ATTACHMENT

Principles for Identifying Risks and Evaluating Solutions

1. The problem is fully and fairly analyzed and precisely defined;

2. A broad range of potential solutions are considered;

3. Consumer interests are the guiding factor in evaluating potential solutions; and

4. All potential solutions are illuminated by a cost-effectiveness analysis to enable assessment of whether the costs of proposed solutions have a reasonable relationship to asserted risks.

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Your ref: N/A
Our ref: LTR-RAM-18-46, Rev. 0

Date: April 12, 2018

Subject: Risk Assessment for Fuel-Security in Support of ISO-New England

Mr. Bentz,

Westinghouse is pleased to provide a proposal for scope of work that we can performed to support ISO-New England in your desire to better understand and address the potential fuel-security risks as the region transitions away from base load generation units and dual use power production facilities to a new mix of power sources with varying output and availability constraints. The attached proposal provides a structure framework for evaluating these issues, enabling decision makers at ISO-New England to have a risk-informed viewed of risks and benefits of alternative fuel-security management strategies with the intent to control unfavorable outcomes to an acceptable level.

Thank you for considering Westinghouse in helping your organization respond to such a timely and important issue.

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Proposed Scope Description for the Application of a Risk-Informed Assessment of ISO-New England Fuel-Security Scenarios for Use in the Development of Mitigation Strategies

The ISO-New England Fuel-Security study uses deterministic evaluations of potentially credible fuel availability scenarios to assess the region's ability to provide reliable power supply during the winter months. The study specifically considers the consequence of the scenarios involved without regard to the likelihood of the events postulated. The study concludes that most of the future power system scenarios would not result in adequate levels of fuel for the entire winter. Furthermore, most scenarios resulted in forced "brown-outs" and mandated load shedding. It was noted in closing that a key question that remains to be addressed is the "level of fuel-security risk" that the region's "policymakers and regulators are willing to tolerate".

Given that risks cannot always be reduced to zero, it is important that risk-significant alternatives be evaluated in a methodological manner. Many methods are available to establish a risk-informed approach to evaluating fuel-security. "Assessing Energy Security: An Overview of Commonly Used Methodologies," (Reference 1), provides a high-level introduction to the availability of various strategies including application of portfolio theory and traditional engineering reliability assessment. Risk-Informed decision making (RIDM) is routinely utilized in the United States nuclear industry to optimize plant resources and guarantee that nuclear plants in the United States are operated with an acceptable level of risk, where risk is measured by specific metrics and evaluated against acceptably low changes in those metrics (see for example, Reference 2). Typically, these metrics reflect frequency (or probability) of occurrence of an unfavorable outcome.

To fully understand the risk posed by the fuel-security scenarios and to establish mitigation strategies in a risk-informed approach, Westinghouse recommends that ISO-New England consider an expanded study using state-of the-art Event Tree and/or Bayesian Belief Network (BBN) (See Attachment A for brief description) approaches supported by a statistical assessment of potential winter challenges, key fuel availability parameters (e.g., plant retirements, implementation of alternate resources), resource make-up limitations (e.g., pipeline restraints) and knowledge of changing of resources. These approaches are similar to the engineering approaches identified in Reference 1 and may be applied within a limited scope or comprehensive framework. A limited scope approach would focus on placing the developed scenarios and consequences in perspective by quantifying and risk-ranking the bounding scenarios developed by ISO-New England.

Limited scope treatments discussed above provide partial detail of the "tails" or low probability fuel-security outcomes. While this process can quantify specific defined scenario risk, the limited scope approach does not systematically identify the spectrum of higher likelihood scenarios with significant, but potentially less severe, outcomes. To provide a more robust fuel-security risk assessment, a probabilistic model of resource availability should be developed based on anticipated weather hazards, and known resource changes, allocations, and limitations. Specific outcomes of this model would include:

1. Probability distribution of expected duration of "brown-outs".
2. Probability distribution of expected duration and extent and duration of load shedding.

This information can provide a direct assessment of fuel-security risk for various scenarios and would enable stakeholders to make a risk-informed judgement regarding securing delivery contracts and the need and extent of further operational or market design measures.

References

1. "Assessing Energy Security: An Overview of Commonly used Methodologies," Månsson, A., Johansson, B., Nilsson, L, Energy, Volume 73, 2014.
2. Regulatory Guide 1.174, "An Approach For Using Probabilistic Risk Assessment In Risk-Informed Decisions On Plant Specific Changes To The Licensing Basis" USNRC, May 11, 2011.

Attachment A

Event Tree

Event Tree Analysis (**ETA**) is a forward, bottom up, logical modeling technique for both success and failure that explores responses through a single initiating event and lays a path for assessing probabilities of the outcomes and overall system analysis. This analysis technique is used to analyze the effects of functioning or failed systems given that an event has occurred. ETA is a powerful tool that will identify all consequences of a system that have a probability of occurring after an initiating event that can be applied to a wide range of events. This Technique may be applied to a system early in the design process to identify potential issues that may arise rather than correcting the issues after they occur. With this forward logic process use of ETA as a tool in risk assessment can help to prevent negative outcomes from occurring by providing a risk assessor with the probability of occurrence. ETA uses a type of modeling technique called event tree which branches events from one single event using Boolean logic.

The overall goal of ETA is to determine the probability of possible negative outcomes that can cause harm and result from the chosen initiating event. It is necessary to use detailed information about a system to understand intermediate events, accident scenarios, and initiating events to construct the event tree diagram. The event tree begins with the initiating event where consequences of this event follow in a binary (success/failure) manner. Each event creates a path in which a series of successes or failures will occur where the overall probability of occurrence for that path can be calculated. The probabilities of failures for intermediate events can be calculated using fault tree analysis and the probability of success can be calculated from 1 = probability of success (ps) + probability of failure (pf). For example, in the equation 1 = (ps) + (pf) if we know that pf=.1 from fault tree analysis then through simple algebra we can solve for ps where ps = (1) - (pf) then we would have ps = (1) - (.1) and ps = .9.

The event tree diagram models all possible pathways from the initiating event. The initiating event starts at the left side as a horizontal line that branch vertically. The vertical branch is representative of the success/failure of the initiating event. At the end of the vertical branch a horizontal line is drawn on each, the top and the bottom representing the success or failure of the first event where a description (usually success or failure) is written with a tag that represents the path such as 1s where s is a success and 1 is the event number similarly with 1f where 1 is the event number and f denotes a failure. This process continues until the end state is reached. When the event tree diagram has reached the end state for all pathways the outcome probability equation is written.

Bayesian Belief Network (BBN)

A Bayesian network, Bayes network, belief network, Bayes(ian) model or probabilistic directed acyclic graphical model is a probabilistic graphical model (a type of statistical model) that represents a set of variables and their conditional dependencies via a directed acyclic graph (DAG). For example, a Bayesian network could represent the probabilistic relationships between diseases and symptoms. Given symptoms, the network can be used to compute the probabilities of the presence of various diseases.

Formally, Bayesian networks are DAGs whose nodes represent variables in the Bayesian sense: they may be observable quantities, latent variables, unknown parameters or hypotheses. Edges represent conditional dependencies; nodes that are not connected (there is no path from one of the variables to the other in the Bayesian network) represent variables that are conditionally independent of each other. Each node is associated with a probability function that takes, as input, a particular set of values for the node's parent variables, and gives (as output) the probability (or probability distribution, if applicable) of the variable represented by the node.

Efficient algorithms exist that perform inference and learning in Bayesian networks. Bayesian networks that model sequences of variables (e.g., speech signals or protein sequences) are called dynamic Bayesian networks. Generalizations of Bayesian networks that can represent and solve decision problems under uncertainty are called influence diagrams.

Introduction

Computer-based models are widely used in the energy sector to provide forecasts of the future to help inform decision-making, particularly to better appreciate the risk of future actions or inaction. A variety of approaches have been developed within the industry to do so, described below. It is helpful to remember, however, that while most approaches offer insight into possible outcomes based on certain initial assumptions, none will accurately predict the future. This fact does not diminish the usefulness of widely-used models and forecasts, but the reader should keep firmly in mind the impossibility of knowing the future with a degree of certainty, even when using the most sophisticated of modeling techniques available.

One recent example of an energy system forecast is ISO New England's (ISO-NE) *Operational Fuel Security Analysis* (OFSA), which "evaluated the level of operational risk posed to the power system by a wide range of potential fuel-mix scenarios. The study quantified the risk by calculating whether enough fuel would be available for the system to satisfy consumer electricity demand and to maintain power system reliability throughout an entire winter."[1] The OFSA analyzed 23 scenarios to test stress on the system, and concluded that "New England could be headed for significant levels of emergency actions, particularly during major fuel or resource outages."[2]

Reishus Consulting LLC has prepared, at the request of NESCOE, this brief memo that offers background and context on approaches to power system forecasting, including a high-level discussion of probabilistic versus deterministic modeling, and links to relevant literature for further reading.

Types of models used to forecast the future of energy systems

The following types of analyses, which vary somewhat by purpose and methodology, are typically used by utilities, grid operators, regulators, consultants and other stakeholders to predict energy-related outcomes.[3] These predictions are most frequently focused on the amount and type of capacity investments needed to serve future electricity demand or to estimate the future price of power, given certain initial assumptions such as the expected cost of new generation and availability of specific resources:

- Scenario analysis. Various forms of scenario planning have been widely used in the energy sector for many decades, as well as across other capital-intensive industries.[4]

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[1] ISO-NE, *Operational Fuel Security Analysis*, January 2018, p. 6. https://www.iso-ne.com/static-assets/documents/2018/01/20180117_operational_fuel-security_analysis.pdf.

[2] *Ibid.* p. 9.

[3] Excluded from this discussion are the highly technical, in-depth studies performed to monitor short-term power system reliability, such as circuit fault analyses and load (power) flow studies between specific points on a transmission grid, that RTOs and other transmission balancing authorities routinely conduct as part of their grid reliability responsibilities.

[4] McKinsey, *The use and abuse of scenarios,* November 2009. https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-use-and-abuse-of-scenarios.

Pioneered by Shell Oil in the early 1970s as a means of exploring different potential outcomes related to the global production and consumption of fossil energy, scenarios today are used to help answer many "what if" questions within the US power and natural gas sectors, such as "what would the power system look like in two decades if renewable generation targets were doubled?" Along with insights gained from testing the sensitivity of inputs within a scenario, many practitioners would argue that the major benefit of running scenarios is not to predict which future outcome is most likely but rather to consider the implications of how decisions made in the near-term may play out, for better or worse long-term, across strikingly different views of the future.[5] Scenarios are often used when companies or industries are facing disruptive challenges, to help identify signposts or early trends that may lead to radically different future outcomes.[6]

> Definition of Capacity Expansion: "Capacity expansion models simulate generation and transmission capacity investment, given assumptions about future electricity demand, fuel prices, technology cost and performance, and policy and regulation."
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> Definition of Production Cost: "Production cost models simulate operation of a specified power system over a relatively short period compared to Capacity Expansion Model (1-week to 1-year), but at higher temporal resolution (hours to 5-minutes) [to answer the question of] what is the least cost dispatch of a complex system of interconnected generators to reliably meet load in every hour of the day at every location?"
>
> Source: US DOE, *Power Sector Modeling 101*

- Integrated Resource Plans (IRPs), capacity expansion modeling and cost estimates. Vertically-integrated utilities have created IRPs as far back as the 1970s, to forecast supply, demand, and price within the utility's footprint, with a specific focus on predicting what new generation and/or transmission investments might be needed over the next 10-25 years to ensure resource adequacy. These planning exercises are typically conducted even in periods when a supply shortfall is not expected in the near-term, and some plans are updated periodically to incorporate speculative elements such as potential changes to supply technology cost, commodity fuel prices, and regulatory policy over the forecast period. Prior to the wave of state restructuring in early 2000s, most New England utilities routinely produced and updated IRPs within their footprint, often in conjunction with estimates of long-term avoided costs, for review and/or approval by their respective state regulatory commissions. Since the development of the wholesale power market in the 1990s, generation and transmission (G&T) modeling in restructured states has shifted in large part to regional transmission organizations (RTOs). Many utilities and agencies in

[5] Although there exists no universal definition, a significant difference between scenarios and sensitivities relates to the number of parameters that are adjusted in a given model run, with sensitivities typically used to test the impact of changes to a single variable, such as a high, low and base case around the expected price of natural gas price. Sensitivities are thus used as a means of bounding the uncertainty around a given input, but there are many examples in the literature in which sensitivities failed to adequately capture the wider range of actual outcomes. See for example, forecasted versus actual German energy prices noted in McKinsey, *From Scenario Planning to Stress Testing: The Next Step for Energy Companies,* February 2017. https://www.mckinsey.com/business-functions/risk/our-insights/from-scenario-planning-to-stress-testing-the-next-step-for-energy-companies.

[6] McKinsey, *Overcoming obstacles to effective scenario planning*, June 2015. https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/overcoming-obstacles-to-effective-scenario-planning.

restructured regions however still engage in planning and resource adequacy reviews, such as state efforts made to advance clean energy goals.[7] More recently, energy stakeholders and regulators are exploring a related approach called Integrated Distribution Planning, which examines alternative investments within the distribution-side system.[8]

- Regional System Plans (RSP). Like utility IRPs, RSPs routinely assess the long-term reliability and resource adequacy of the grid through capacity expansion modeling, albeit across an RTO's multi-state region. In New England, the region's grid modeling efforts have thus mostly shifted to ISO-NE, except for Vermont's utilities, which continue to produce their own IRPs. This state of play is similar in other restructured areas, where RTOs, such as PJM and the Midcontinent-ISO, provide the overall transmission planning for their regions, although within those RTOs there also remain some non-restructured utilities that produce independent resource plans.[9] As an example, here is a summary of ISO-NE's annual RSP process:

> The Regional System Plan (RSP) accounts for the addition of generating units and demand-response resources (i.e., resources made available when customers reduce their electricity consumption in response to reliability and price), potential resource retirements, and load growth, with due consideration of the system's economic performance and impact on system-wide air emissions. As is evident in the RSP, electrical problems and solutions can—and in many cases do—cross state and operating-company boundaries. As the Regional Transmission Organization, ISO New England leads the annual planning effort through an open stakeholder process. With input from the Planning Advisory Committee (PAC) and other stakeholders, and technical assistance from the transmission owners, the ISO analyzes and plans for the reliability and adequacy of the New England bulk power system as an integrated whole. This ensures that system modifications made to one part of the system, including newly interconnected generating units, will not have an adverse impact on another part of the system.[10]

- Network reliability reviews, risk and contingency planning, including single point of failure (SPOF) or of disruption (SPOD) analyses. The NERC, RTOs, utilities and others often produce risk assessments that focus on the potential impact of a single factor or contingency, such as the failure of the largest operating plant in the region, or the loss of a major gas storage facility, to assess how such one-off events may adversely affect the reliability of a power system. These reviews are typically modeled over shorter time periods than that considered by capacity expansion plans.

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[7] For example, the Massachusetts Department of Energy Resources is responsible for "ensuring the adequacy, security, diversity, and cost-effectiveness of the Commonwealth's energy supply to create a clean, affordable, and resilient energy future[…]" https://www.mass.gov/orgs/massachusetts-department-of-energy-resources

[8] ABB, *The new era of integrated resource planning in California and beyond,* 2017. https://library.e.abb.com/public/271d8b844b20410995c73e234d230413/New%20era%20of%20IRP_WP_Mar17.pdf

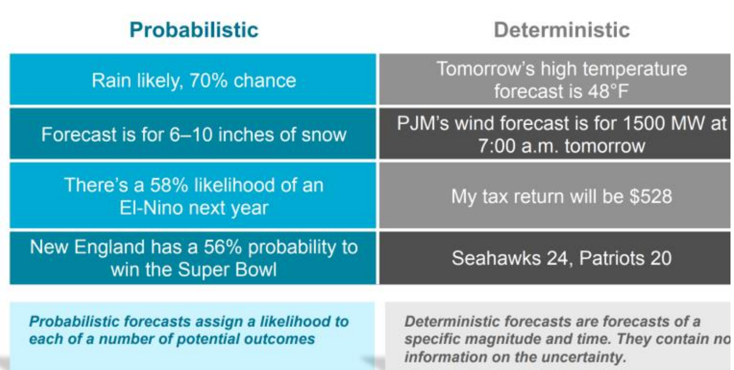
[9] For a more complete discussion, see the report by US DOE Lawrence Berkeley National Lab (LBNL), *The Future of Electricity Resource Planning,* September 2016, p 65- 70. https://emp.lbl.gov/sites/all/files/lbnl-1006269.pdf

[10] The ISO/RTO Council, *ISO/RTO Electric System Planning: Current Practices, Expansion Plans and Planning Issues*, 2006, see p. 50-52 for a fuller description of the RSP process. http://www.ercot.com/content/news/presentations/2006/IRC_PC_Planning_Report_Final_02_06_06.pdf

Deterministic versus Probabilistic Approach

A review of energy sector literature suggests that an important discussion has been underway in the power industry regarding how forecasts can be improved to better to capture risk, uncertainty and complexity in planning models, particularly for those used in forecasting capacity expansions. One facet of this discussion focuses on the difference between deterministic and probabilistic modeling. In many industries, both types of models are used in forecasting the future, although deterministic appears to more pervasive in energy modeling, based on this brief review of the literature.[11]

Deterministic models use specific assumptions, i.e. inputs, that are determined in advance, and then are run through computer models to estimate what effect those assumptions may have in the future, with the outcome typically expressed as a single point solution. For example, if one knew both the initial balance in a savings account and could predict with accuracy what the interest rate would be over a decade into the future, then one could also accurately predict what the balance of that account will be in ten years. Because deterministic models will result in solutions that depend on the specific assumptions provided as inputs, they often fail to adequately capture what degree of uncertainty is associated with the resulting forecast.



Probabilistic	Deterministic
Rain likely, 70% chance	Tomorrow's high temperature forecast is 48°F
Forecast is for 6–10 inches of snow	PJM's wind forecast is for 1500 MW at 7:00 a.m. tomorrow
There's a 58% likelihood of an El-Nino next year	My tax return will be $528
New England has a 56% probability to win the Super Bowl	Seahawks 24, Patriots 20
Probabilistic forecasts assign a likelihood to each of a number of potential outcomes	*Deterministic forecasts are forecasts of a specific magnitude and time. They contain no information on the uncertainty.*

Source: *Probabilistic Forecasting in Renewable Energy*, 2015

Probabilistic models typically run many simulations using inputs that are assigned a specific level of probability. Using the same example, above, one could assign a higher probability to what the forecaster expects to be the most likely interest rate in the future with less likely interest rates assigned lower probabilities; doing so will lead to a forecast that can typically express a range of possible outcomes for the account balance in year ten. Probabilistic modeling (also known as stochastic analysis) has not been historically used as often as the deterministic approach within the energy sector for medium- and long-term planning, as it has tended to both require more sophisticated and expensive data-intensive models, as well as necessitates making assumptions about the likelihood of various inputs that can be at best difficult to estimate or are highly

[11] Probabilistic modeling is more commonly used for very short-term reliability purposes, i.e. such as daily analyses related to calculating operating reserves. See discussion, e.g., in US DOE Quadrennial Energy Review, 2nd Installment, 2017. *Transforming the Nation's Electricity System.* https://www.energy.gov/policy/initiatives/quadrennial-energy-review-qer/quadrennial-energy-review-second-installment

speculative.[12] Thus, probabilistic models are not inherently more "accurate," but may provide insight that better captures the uncertainty of forecasting the future in a way that deterministic scenarios and sensitivities may not.

Examples of specific approaches to forecasting by energy sector participants

This section highlights the planning efforts of different organizations responsible for aspects of energy forecasting, and briefly describes their approach to further illuminate the discussion above.

ISO-NE, which is largely responsible for resource adequacy in the New England region, has produced many forecasts for use by stakeholders since its inception, including the annual ten-year outlook of the Capacity, Energy, Loads, and Transmission (CELT) forecast, the Regional System Plan (RSP), and various ad hoc studies, such as the recently released Operational Fuel Security Analysis. As noted in a recent review by the consultancy ICF, ISO-NE's primary models used in its planning forecasts include the Siemens PSS/E (power flow analysis), PowerGEM TARA (security assessment), and ABB/Ventyx GridView (production costing). These are all commercially-available forecasting models that are widely used in the power sector.

Notably, all seven RTOs, including ISO-NE, use deterministic models for their contingency analyses, although PJM uses an additional probabilistic layer for limited purposes.[13] Researchers at the US DOE's national labs, particularly NREL, as well as various consultancies such as ICF, the Analysis Group, and Brattle, have pushed the research on improvements in modeling and methodologies, especially as traditional aspects of the power system change, reflecting the growing additions of intermittent resources and behind-the-meter generation.

For example, efforts have been made in recent years to model the entire eastern and western US electric systems (interconnections), to assist stakeholders in analyzing and forecasting changes to power that are beyond the scope of individual RTOs and utilities. Cited in the bibliography below are the full reports of two such studies conducted by NREL: the 2016 Eastern Renewable Generation Integration Study (ERGIS) and the 2017 Western Wind and Solar Integration Study, Phase 2 (WWSIS-2). In each, the forecasters used models[14] that simulate operations of the power grid over small enough increments of time to capture the impact of adding significant wind and solar resources to the power system. Each relied on a scenario approach to answer a specific set of questions, such as what would be the impact on the operation of gas-fired plants when renewable resources were increased by different magnitudes in alternative scenarios. Unlike the ISO's recent OFSA, these large-scale modeling efforts were not designed solely to test fuel security risk.

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[12] Although not technically the same approach, some forecasters have used a deterministic planning model to run hundreds or in some cases thousands of sensitivities, and by combining them into a value-at-risk analysis, they strive to account for the risk and uncertainty of multiple factors and decisions into the future in the same way that probabilistic modeling achieves more directly.

[13] The ISO/RTO Council, *Ibid*.

[14] The WWSIS-2 and ERGIS used the commercially-available PLEXOS software, while also making use of an NREL-developed tool called Regional Energy Deployment System (ReEDS).

North America's reliability organization, NERC, has produced many examples of large scale contingency analyses, consistent with its mission of monitoring and ensuring reliability of the power systems operating in the US & Canada. These studies are focused mainly on shorter-term network reliability rather than longer term expansions, often making use of tools such as power flow studies. NERC has also produced risk assessments that identify when additional studies may be necessary. For example, a recent report from NERC[15] on the potential reliability impact of natural gas disruptions was widely cited in the trade and popular press this past winter. It surveyed utilities in forty regions in the US where natural gas dependency could contribute to power reliability risks. The report itself offered several recommendations to power system operators and planners regarding possible additional actions to mitigate risk and reduce reliability concerns associated with gas disruptions, including adding natural gas system contingencies to power system planning frameworks.

Many vertically-integrated utilities continue to routinely conduct IRPs or scenario analyses, often in conjunction with the periodic review of their plans by the respective state commission. The LBNL report *The Future of Electricity Resource Planning* in 2016 profiled the approach of ten utilities, including two power planning systems in the US that used probabilistic (stochastic) analysis to estimate uncertainty in their planning forecasts, TVA and Pacificorp.[16] The researchers urged regulators to encourage wider adoption of risk analyses by planners using the best-available modeling techniques, while acknowledging the challenge of simulating the disruptive changes ongoing in the power system. Many other utilities continue to use deterministic approaches to assess their future options. A survey of generation-owning utilities in the 2000s showed that at least a handful of utilities incorporated risk into their IRP planning efforts by running a massive number of sensitivities, as a proxy for probabilistic modeling.[17]

Notably, between 2011-2015, the United Kingdom's energy regulator, Ofgem, examined the risk of a winter capacity shortfall three years in the future by annually running a forecast model that mixed probabilistic and deterministic methodologies to test scenarios and related sensitivities that could result in blackouts. After proposing this methodology at the start of the process, Ofgem requested comments from stakeholders,[18] who generally agreed with the proposed approach,[19] and it remained in use for the next several annual risk assessments. The forecasts included both probabilistic variables for certain short-run inputs such as wind speed and forced outages, and deterministic measures for other longer-term inputs such as plant retirements. Ofgem affirmatively noted that the scenario approach, which incorporate both types of variables,

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[15] NERC, *Potential Bulk Power System Impacts Due to Severe Disruptions on the Natural Gas System*, November 2017. https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SPOD_11142017_Final.pdf

[16] LBNL, *Ibid*., p. 57.

[17] *Survey of Utility Resource Planning and Procurement Practices for Application to Long-Term Procurement Planning in California*, 2008. www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=10960

[18] The United Kingdom Office of Gas and Electricity Markets (Ofgem), *Electricity Capacity Assessment: Measuring and modelling the risk of supply shortfalls*, 2011 https://www.ofgem.gov.uk/ofgem-publications/40421/capacityassessmentconsultationdocument.pdf

[19] Of the eleven respondents to Ofgem's initial request for comment on its methodology, nine supported the mixed approach, one preferred a fully probabilistic model, and one preferred that no probabilistic elements be used. See Ofgem February 2013 report, *Electricity Capacity Assessment 2013: decision on methodology.* https://www.ofgem.gov.uk/publications-and-updates/electricity-capacity-assessment-2013-decision-methodology

plus the application of a wide range of sensitivities, would together provide a reasonable basis for assessing the risk of energy demand exceeding supply in the nation's power system. The forecasting effort shifted from Ofgem to the UK's system operator, National Grid, once the capacity market was in place in 2016. The electricity capacity and related forecasts produced annually by National Grid since then appears to continue to use a mix of variables (probabilistic and deterministic) along with a large set of scenarios and sensitivities to test stress on the system in the winter three years out.[20]

Links to these studies as well as additional analyses and reports are included in the bibliography below for further reading.

For Further Reading

General resources on power system models and forecasting:

- A good starting point for the lay reader is a slide deck from the US Department of Energy that briefly describes different power system models and offers some commentary on their appropriate use. US DOE, *Power Sector Modeling 101* (presentation), 2016. https://www.energy.gov/sites/prod/files/2016/02/f30/EPSA_Power_Sector_Modeling_FINAL_021816_0.pdf
- For a slightly more technical but still high-level discussion of how resource planning works, see *Production Cost Model Fundamentals,* undated Midwest ISO presentation. http://home.eng.iastate.edu/~jdm/ee590-Old/ProductionCostModleFundamentals_EE590.pdf
- Also helpful is Synapse Energy's 2016 presentation on energy modeling tools, albeit in the context of the now defunct Clean Power Plan. http://www.synapse-energy.com/sites/default/files/Guide-to-Modeling-Tools-Clean-Power-Plan-Other-Analyses.pdf
- For a broader discussion of the underlying principles of future forecasting, see this Harvard Business Review article, *Living in the Futures*, May 2013 https://hbr.org/2013/05/living-in-the-futures
- For a general discussion of planning approaches for both short- and long-term periods, see US DOE Quadrennial Energy Review, 2nd Installment, 2017. *Transforming the Nation's Electricity System.* https://www.energy.gov/policy/initiatives/quadrennial-energy-review-qer/quadrennial-energy-review-second-installment
- From the US DOE Pacific Northwest National Lab, a thorough list of energy forecasting models with brief descriptions of key features, identification of major studies making use of specific models, and links to model documentation sites, *North American Modeling Compendium and Analysis*, 2016. https://www.energy.gov/sites/prod/files/2017/01/f34/North%20America%20Modeling%20Compendium%20and%20Analysis.pdf

[20] National Grid EMR Electricity Capacity Report, 2015. https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/Electricity%20Capacity%20Report%202015.pdf

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- McKinsey, *The use and abuse of scenarios,* November 2009 https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-use-and-abuse-of-scenarios
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- Analysis Group, *Electricity Markets, Reliability and the Evolving U.S. Power System*, June 2017. http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/ag_markets_reliability_final_june_2017.pdf
- Brattle Group, *Reviving Integrated Resource Planning for Electric Utilities: New Challenges and Innovative Approaches*, 2008. http://files.brattle.com/files/6665_energy_newsletter_2008_no_1_-_irp.pdf
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- For some historical perspective, see an early discussion of utility planning by Sandia Labs, circa 1997. https://www.osti.gov/servlets/purl/522766

Sources that specifically address approaches to risk and uncertainty, including probabilistic versus deterministic forecasting:

- Eric Grimit, *Probabilistic Forecasting in Renewable Energy,* 2015, (presentation) https://www.ametsoc.org/cwwce/index.cfm/committees/renewable-energy-committee/meeting-minutes/september-24-2015/probabilistic-forecasting-in-renewable-energy/
- Excerpt from AIMMS Modeling guidebook, 2014, describing the methodology used to model power system expansion, including a brief description of stochastic modeling. https://download.aimms.com/aimms/download/manuals/*AIMMS3OM*_PowerSystemExpansion.pdf

For examples of specific energy forecasts, see:

- ISO-NE*, Fuel Security Analysis*, January 2018, https://www.iso-ne.com/static-assets/documents/2018/01/20180117_operational_fuel-security_analysis.pdf
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- For a discussion of the scenario-based methodology that the Australian Electricity Market Operator uses in its supply and demand forecasting, see http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2017/2017-NEM-ESOO-Methodology.pdf and http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan/NTNDP-database
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