Introducing CRA AdequacyX

CRA’s resource adequacy model

October 2024

CRA AdequacyX is an artificial intelligence resource adequacy model that enables utilities to assess the risk associated with generator resource mix

Executive summary

CRA AdequacyX is an artificial intelligence driven resource adequacy model. The model uses artificial intelligence and synthetic data to simulate *future* conditions on the grid, such as changing load shapes and generator unit reliability. It also captures correlated events like high load coupled with wide-scale outages during cold weather events. By simulating future conditions, our model can correctly capture the capacity contribution of different generating technologies and identify reliability risks that would be missed by models that only simulate historical conditions. Equipped with our state-of-the-art quantitative tools and market expertise, CRA is uniquely equipped to support utilities and grid operators in developing their long-term plans and evaluating difficult trade-offs between affordability, reliability, and cleanliness.

Introduction

The power grid is undergoing a period of rapid transformation. Many thermal generators are retiring due to challenging market conditions and decarbonization policy goals, with only some of this capacity being replaced, primarily with variable and energy limited resources.[1] At the same time, energy demand is rising, driven by electrification and new demand, like data centers.[2] New technologies, such as electric vehicles, electric heating, and data centers, are shifting the times of day and seasons when peak electricity demand occurs. These changes are bringing new challenges for maintaining resource adequacy.[3] Recent extreme weather events have demonstrated the increasing difficulty of maintaining resource adequacy. During Winter Storms Elliot and Uri, 5,400 MW and 20,000 MW of load were shed, respectively.[4] These events highlighted the need to understand the correlation between load demand, generator availability, and the behavior of new technologies, like heat pumps, which may increase electricity demand disproportionately during these periods of stress.

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1 See, for example, https://www.pjm.com/-/media/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx

2 Rogers, Jack, “U.S Data Center Demand Will Double by 2030,” Globest, January 11, 2024, https://www.globest.com/2024/01/11/u-s-data-center-demand-will-double-by-2030/?slreturn=20240604-40110.

3 “2023 Long-Term Reliability Assessment,” NERC, December 2023, https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2023.pdf.

4 “FERC, NERC Release Final Report on Lessons from Winter Storm Elliot,” FERC, November 7, 2023, https://www.ferc.gov/news-events/news/ferc-nerc-release-final-report-lessons-winter-storm-elliott.

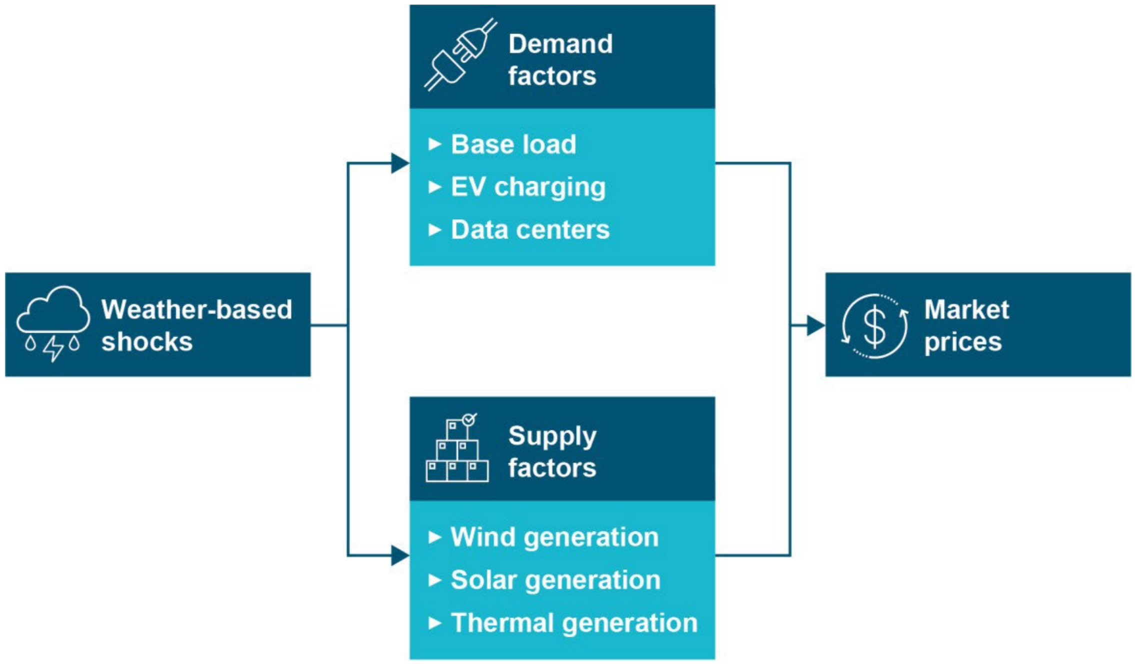
To support our clients in tackling these emerging resource adequacy challenges, CRA has developed CRA AdequacyX an AI-driven, Monte-Carlo based loss of load model. Using this model, CRA can support clients in evaluating the reliability risks of a proposed resource mix by identifying the likelihood, times, and durations of loss of load events.[5] CRA can also evaluate the capacity contribution of different resources and quantify the reserve margin needed to meet the reliability targets for a system. CRA has leveraged this modeling tool, along with quantitative and market expertise, to support clients in identifying resource adequacy challenges, evaluating strategic decisions and policies in light of resource adequacy, and communicating risks to a wide range of stakeholders.

Tool development and methodology

CRA AdequacyX employs Monte Carlo simulations, a mathematical technique that predicts the distribution of possible outcomes of an uncertain event. AdequacyX simulates a wide range of possible outcomes for load demand, wind/solar generation, generator availability, electricity prices, and natural gas prices. Each of these outcomes is driven by underlying weather conditions. In this manner, AdequacyX captures correlations between the outcomes. The overall modeling structure is demonstrated in Figure 1. For example, very cold weather conditions may result in high load demand, unusually high generator outages, and elevated market prices. Very hot conditions may result in very high load demand, modest de-rates of thermal and generators, reduced wind generation, and high commodity prices. Failing to capture these correlations mischaracterizes risks, particularly for cold weather events. During both Winter Storms Uri and Elliot, the net load was unusually high, but the grid stress was further exacerbated by high natural gas prices and unusually high unplanned generator outages. It was the combination of these factors that led to the need to shed load, rather than a single factor.

5 For utilities which operate in a larger ISO/RTO market, CRA can also evaluate the likelihood of “forced market exposure” by performing pseudo-loss of load studies by assuming the utility operates as an island.

Figure 1. CRA AdequacyX modeling structure



CRA AdequacyX evaluates a proposed generator portfolio's *adequacy* to meet demand at all hours of the year and *resiliency* under extreme events. An example of such an assessment is shown in Figure 2. In this example simulating a utility in the upper Midwest operating under islanded grid conditions,[6] we utilized CRA AdequacyX to evaluate the potential for unserved energy[7] of a client's existing generator resource mix. To provide further context, the amount of expected unserved energy was normalized by the expected load demand to evaluate the portion of energy needs likely to go unmet. The normalized expected unserved energy of the base resource portfolio is shown in Figure 2. The resource mix had periods of high risk of unserved energy during summer evening hours and moderate risk during winter morning and evening hours. The utility deemed these risks as unacceptably high.

CRA worked with this client to identify additional generating resources to cover energy needs during these risky hours. We then completed the risk assessment, including the additional generating resources in the portfolio. The normalized expected unserved energy is shown in Figure 3. The addition of these resources substantially reduced risk across all hours and returned the portfolio to an acceptable risk condition. Using this analysis, we were able to support the client in identifying periods of unacceptable risk and justifying the need for additional generating resources.

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6 Assuming the utility must act as its own balancing authority, without obtaining energy or capacity from the wider market. In reality, utilities will operate economically and purchase from the wider market when it is cost-optimal to do so.

7 The amount of electricity demand which cannot be served due to insufficient generating capacity within a power system. See https://nerc.com/comm/pc/pawg%20dl/proba%20technical%20guideline%20document_08082014.pdf

Figure 2. Normalized expected unserved energy of the status quo resource mix

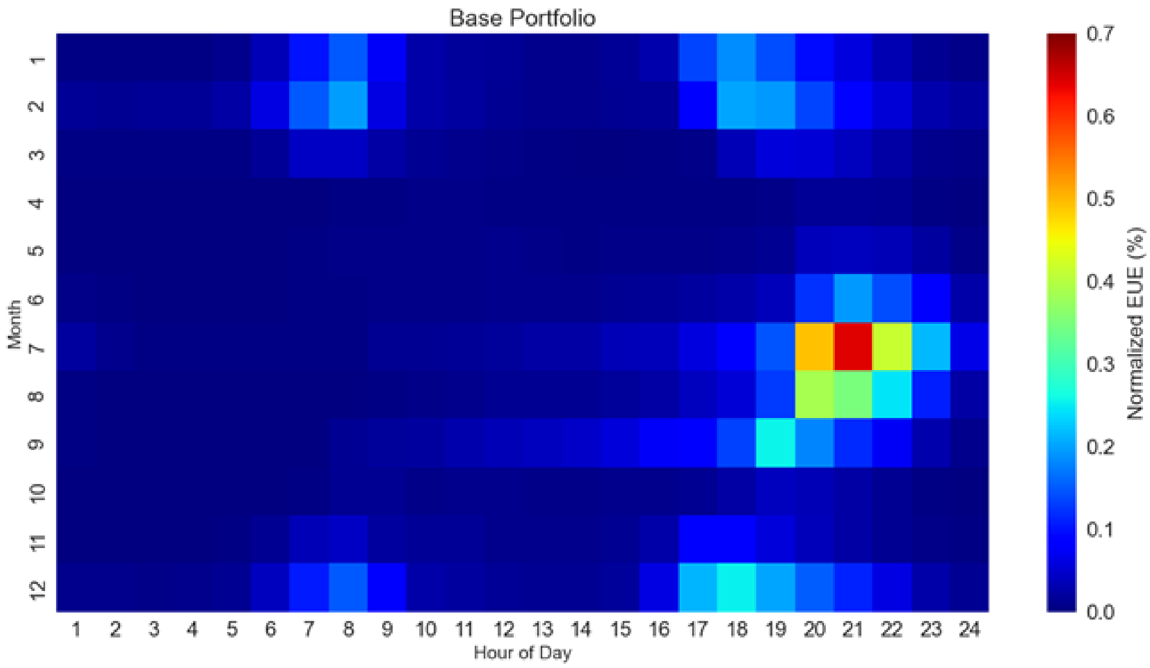
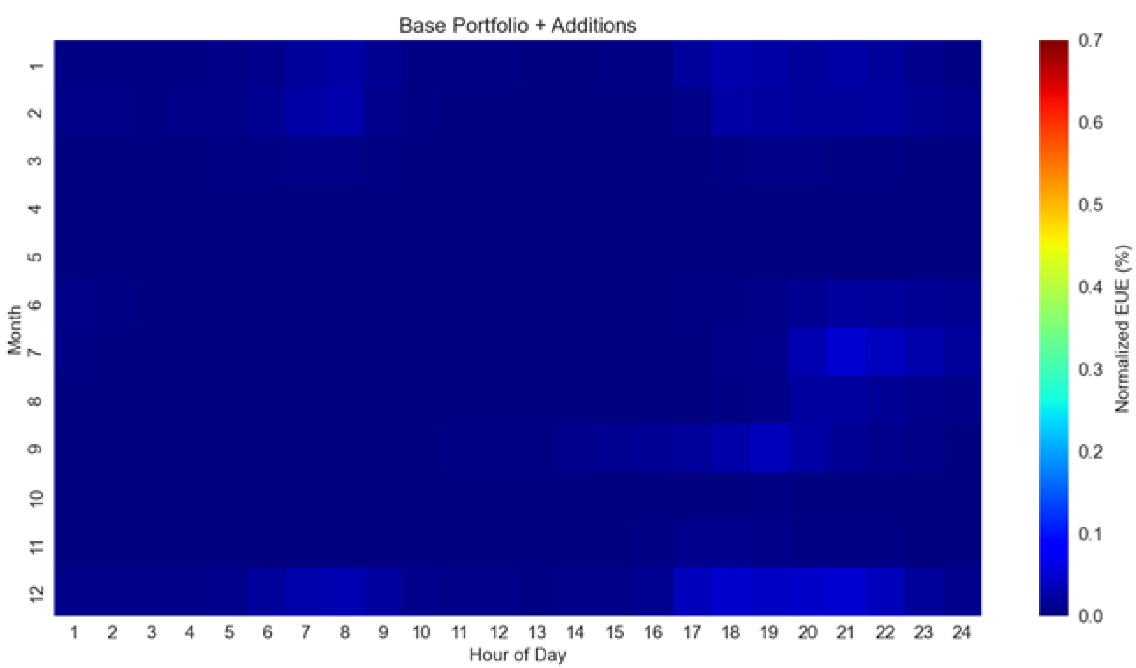


Figure 3. Normalized expected unserved energy of the alternative resource mix



Simulating cold weather outages

Recent winter weather events have demonstrated the need to understand the likelihood of cold weather causing generator unit outages. During extreme cold, generators have been more likely to experience mechanical and electrical issues, frozen equipment, and fuel supply issues.[8] CRA AdequacyX is able to simulate this increased likelihood of unplanned generator outages during cold weather, in addition to outages that occur randomly throughout the year.

To examine the impact of cold weather outages, we simulated the loss of load expectation for a utility operating in the American Southeast at varying levels of cold-weather outages for gas- and coal-based resources. These outages were meant to simulate freezing, loss of fuel supply, or other disruptions. While we did not consider the highest ranges of cold weather outages in this system to be likely, they were included in this study as a stress test to illustrate the impact of losing key elements in the natural gas system due to freezing. As shown in Figure 4, the likelihood of cold weather outages has a substantial, non-linear impact on the resource adequacy of portfolios, as measured by the loss of load expectation (LOLE).[9] We found the grid's resource mix to be sufficient to meet the "1-Day-in-10-Years" planning target at low levels of cold weather outages. However, the LOLE values quickly exceeded the planning targets as the level of cold weather outages increased. Even if a modest degree of cold weather outages was assumed in this system, additional generating resources would be required to meet the system's reliability targets. CRA utilized this study to highlight the benefit of winterizing units[10] and improving fuel security. For this system, even a modest decrease in the cold weather outage rate can substantially improve the resource adequacy of a system and decrease the planning reserve margin[11] needs.

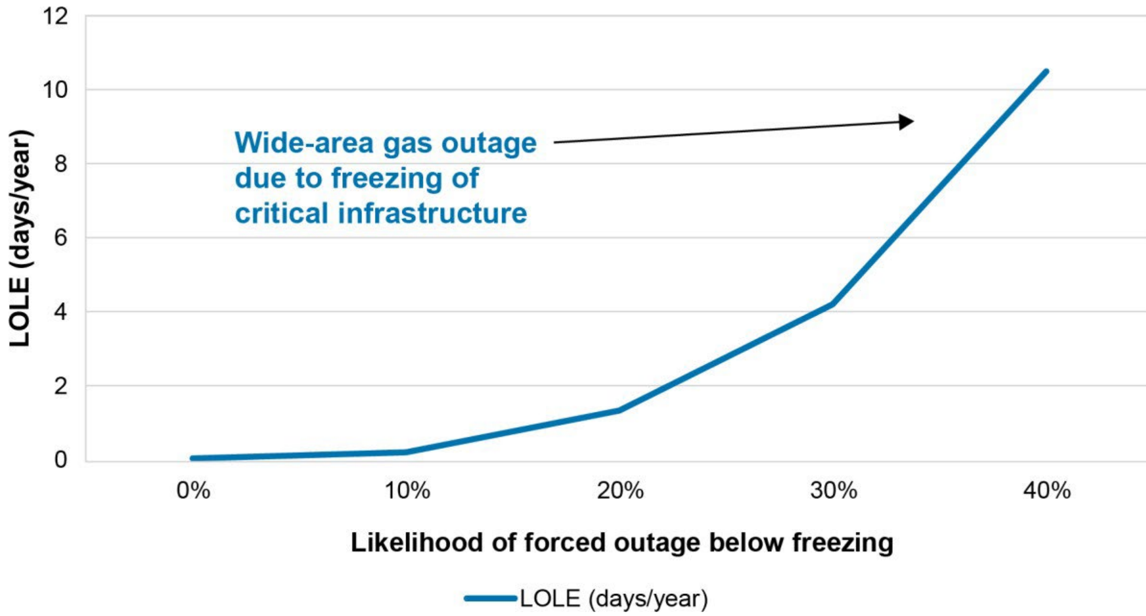
[8] Hale, Jack, "Joint inquiry finds same 3 causes driving US generator outages in extreme cold," S&P Global, June 15, 2023, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/joint-inquiry-finds-same-3-causes-driving-us-generator-outages-in-extreme-cold-76195520.

[9] The expected number of days per year for which the available generation capacity is insufficient to serve the daily peak demand. This shortfall can be of any magnitude and for any duration. See https://nerc.com/comm/pc/pawg%20dl/proba%20technical%20guideline%20document_08082014.pdf

[10] Winterization efforts improve the generator's resilience to cold weather conditions. These efforts can include improving fuel security, employing heat tracing, burying pipes, employing cold weather barriers etc. https://www.ferc.gov/sites/default/files/202007/OutagesandCurtailmentsDuringtheSouthwestColdWeatherEventofFebruary1-5-2011.pdf

[11] Reserve margins indicate the excess capacity needed to accommodate forecasting errors, unplanned outages, and other sources of uncertainty while meeting the reliability targets of the system. https://www.nerc.com/pa/RAPA/ri/Pages/PlanningReserveMargin.aspx#:~:text=Planning%20reserve%20margin%20is%20designed,a%20relative%20indication%20of%20adequacy.

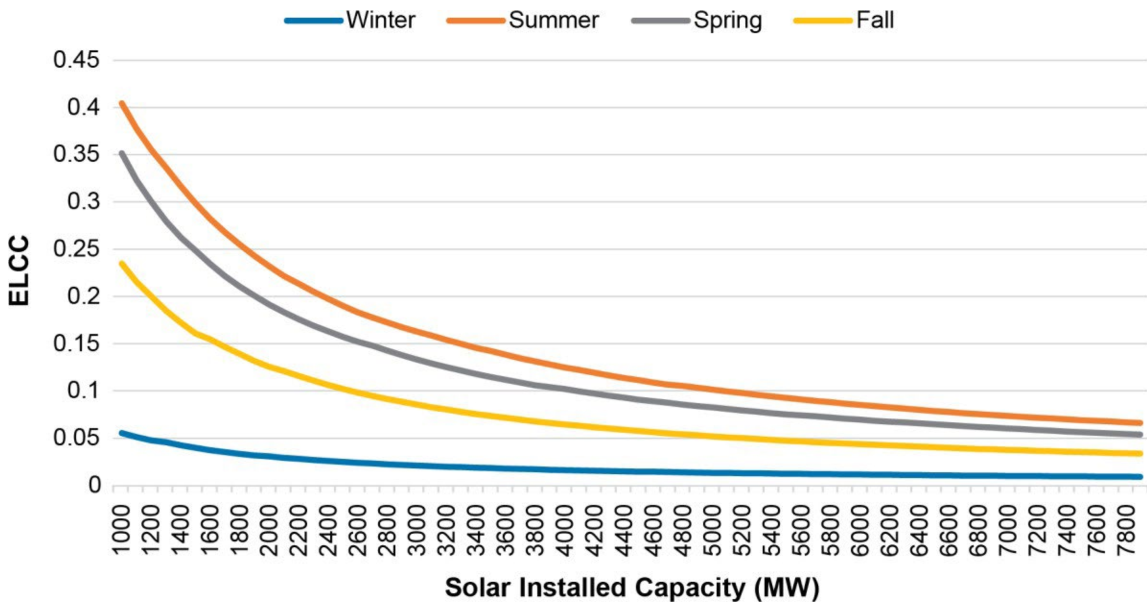
Figure 4: Impact of cold weather outages on resource adequacy



Computing planning Reserve Margins and effective load carrying capabilities

CRA AdequacyX can be used to evaluate the capacity contribution of different technologies by calculating the effective load carrying capabilities (ELCCs) of each, as well as the planning reserve margin (PRM) needed to meet a desired reliability target. An example of ELCC curves for solar resources is shown in Figure 5. This figure represents the capacity contribution for a synthetic island utility based in the upper Midwest. For this utility, standalone solar makes a minimal contribution during winter months. During the remaining months, solar resources initially had a high capacity contribution, but quickly declined. Based on these results, CRA was able to highlight the need for storage resources to fully harness solar energy for meeting capacity needs and quantify the synergies between solar and storage technologies.

Figure 5. Average effective load carrying capability of solar generation at varying levels of installed capacity



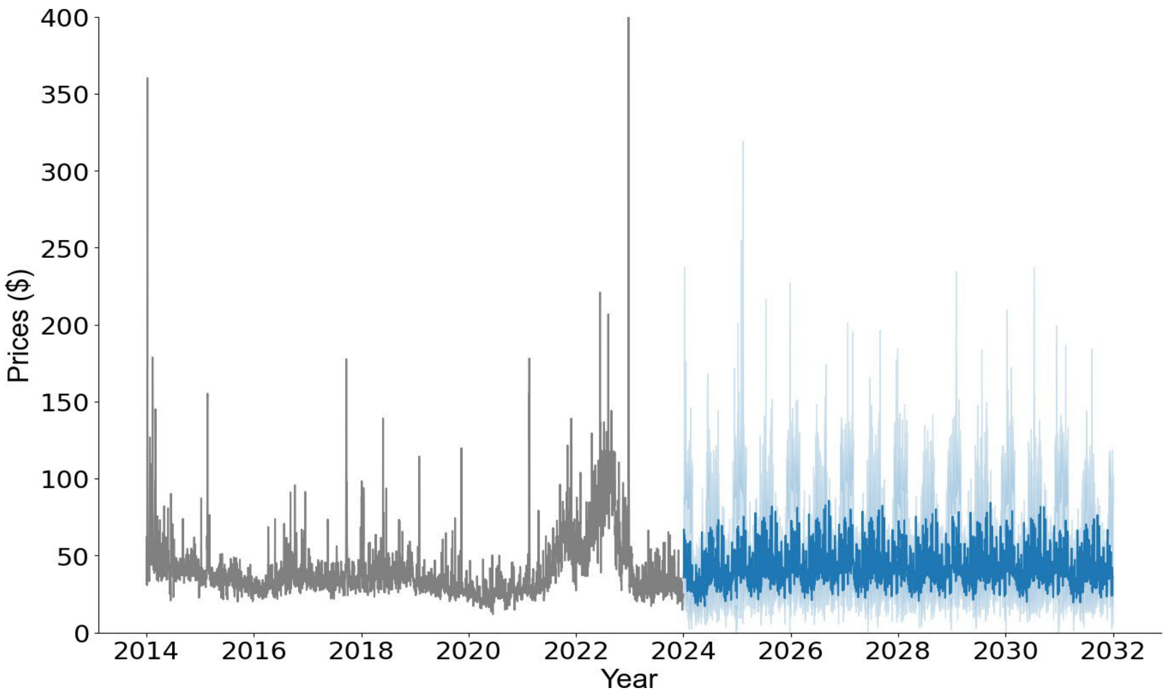
Evaluating market exposure and commodity price risk

Many utilities operate within a broader ISO/RTO market and are not their own balancing authorities. They do not need to obtain sufficient capacity to meet their own adequacy needs (i.e., plan their system as an island to meet "1-Day-in-10-Year" targets). Instead, they benefit from pooling the risks and responsibilities of meeting capacity needs. These utilities operate economically, buying and selling on the market when it is cost-optimal to do so. However, to meet the customer expectations for affordable and reliable power, these utilities must still contribute their share of capacity to the system and protect themselves from unacceptably high exposure to atypical commodity prices. For example, a utility may experience periods when it is forced to purchase power from the market during times of very high electricity prices, driving up the marginal cost of operation. Utilities must find the right balance between native capacity build and market exposure to best protect their customers from high prices, while providing highly reliable power.

CRA has utilized AdequacyX to support both utility and large load customers by evaluating the resource adequacy and cost exposure risks within a broader market context in several ways. CRA has evaluated the portfolios of such utilities by performing island loss of load studies and identifying periods of pseudo-loss of load when the utility is forced to rely on the market. CRA can apply loss of load style metrics to evaluate the likelihood and magnitude of these events, and qualitatively evaluate whether these stress periods align with market-wide stress periods.

CRA has enhanced traditional loss of load modeling techniques to analyze the price impacts associated with market exposure. We have leveraged our internal market modeling capabilities to generate future probabilistic views of electricity prices.[12] An example of CRA's probabilistic iterations on electricity prices in MISO Zone 6 is shown in Figure 6. This figure captures the long-term, seasonal, and daily trends of electricity prices, as well as the substantial uncertainty in exact pricing and the short, sharp price spikes. CRA employs machine learning to adjust these market prices to capture the net load conditions. In this manner, the simulation of market price correctly captures the impact of a utility's net load to price, and implicitly simulates other price drivers (like generator outages, net load of other market entities, trading, congestion, etc.). Using these net load correlated price simulations, CRA supports clients understanding of the potential cost of the market exposure for a proposed resource mix during forced market exposure events.

Figure 6. Illustrative example of Monte Carlo samples for electricity price



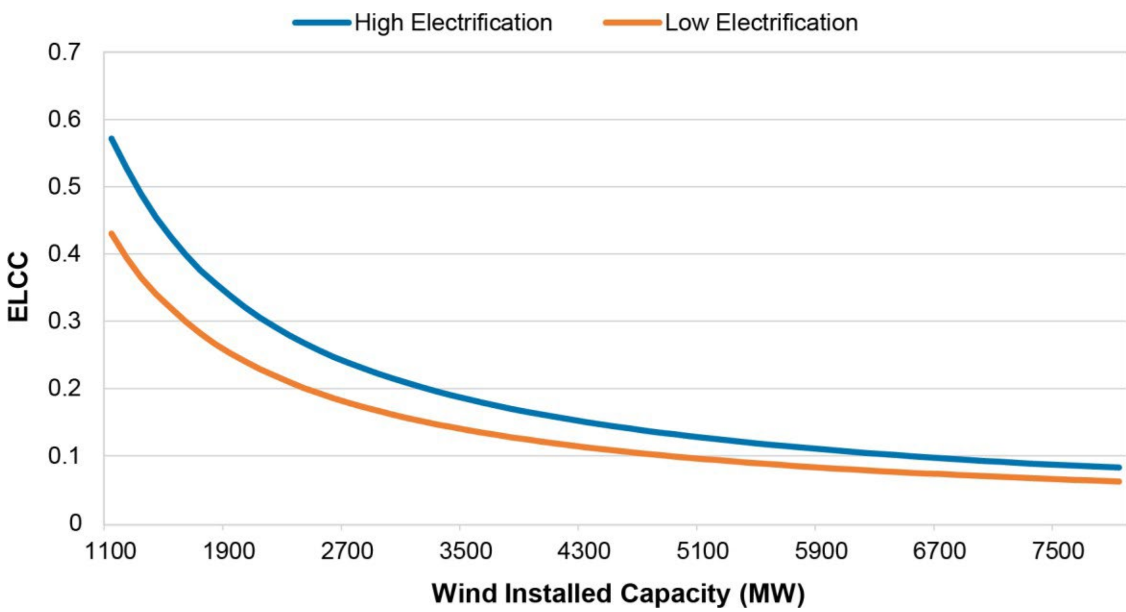
CRA has further evaluated commodity price risk by simulating cost-optimal generator unit commitment and economic dispatch decisions based on simulated net load, generator availability, and commodity price conditions using its power systems modeling tool, Aurora. From these simulations, CRA can evaluate the spread of possible marginal generating costs and assist clients in quantifying and communicating the cost risk exposure for a proposed portfolio of generators.

12 CRA's MOSEP model is used to generate probabilistic forward views on commodity prices using a mean-reverting regime-switching time series model. Commodity prices have been found to exhibit a mean-reverting behavior. The regime-switching feature of the model allows for simulation of price spikes by modeling different price regimes (e.g., normal price regime, spike price regime). The simulated switching between regimes is facilitated by a transition matrix. Given the current regime, the transition matrix specifies the probabilities of staying in the current regime or moving to a different regime. The probabilities are estimated based on historical data. For references, see the following paper, on which MOSEP is based - Higgs, H. & Worthington, A. "Stochastic price modelling of high volatility, mean-reverting, spike-prone commodities: The Australian wholesale electricity market." Energy Economics, 2008.

The importance of future looking data

CRA's AdequacyX uses artificial intelligence to generate future looking data. This is critical since load shapes are under a substantial evolution, driven by new technologies, like behind-the-meter solar generators and heat pumps, that alter hourly and monthly electrical demand patterns. Electric vehicles will also increase load demand, and their impact on the load will be driven by the incentives and tariff structures used to reward charging during periods of low net load and/or cost. Using AdequacyX, CRA analysed the impact of capacity accreditation under different electrification scenarios. These are shown in Figure 7. Under a high electrification scenario, load is disproportionately added during winter mornings, winter evenings, and periods of cold temperatures. These coincide with periods of stronger wind. Consequently, wind capacity accreditation will be higher if high electrification occurs. Without accounting for changing load shapes, ELCC models cannot capture this synergistic relationship between wind generation and electrification.

Figure 7. Winter capacity accreditation of wind



Similarly, the forced outage rate of generators will be affected by efforts to winterize units or secure firm gas contracts to prevent cold-weather outages. For example, many utilities have opted to pursue firm gas contracts to improve fuel security during cold weather events. Failing to account for the future state of the grid will underestimate the reliability of a proposed resource mix and overestimate the reserve margin needs.

Benefits and impact

CRA brings extensive experience in statistical, fundamental market modeling, investor due diligence, and integrated resource planning. CRA has deployed the AdequacyX tool to aid utilities, developers, investors, and ISOs across both North America and Europe. The tool has been instrumental in evaluating areas such as reliability planning, resource capacity valuation, and weather/climate resilience, among other topics.

Applications of CRA’s AdequacyX model are categorized as follows: (i) Risk assessment, (ii) Intervention identification, (iii) Benefit assessment, or (iv) Evaluating capacity accreditation and planning reserve margins.

Reliability risk assessment: CRA's AdequacyX evaluates the resource adequacy of a proposed resource mix. This includes identifying the likelihood, duration, and magnitude of loss of load events (or forced market exposure events for utilities without their own balancing authority). The tool also assesses and scores the resource adequacy of the proposed generator portfolio using popular risk metrics and estimates the potential costs of loss of load or forced market exposure events.

Commodity risk assessment: Using its suite of stochastic and market modeling tools including AdequacyX, CRA can evaluate an array of potential net load, generator outage, and commodity price paths. This can allow clients to understand their tail risk exposure to unusual market prices, find the right balance of resources, and evaluate the optimal trade between building native capacity and market reliance.

Intervention identification: For portfolios facing high reliability risks, AdequacyX results are used to identify potential interventions. These interventions may include enhancing existing generating capacity, integrating energy-limited resources like storage, or increasing firm generating capacity.

Benefit assessment: AdequacyX compares the resource adequacy implications of various interventions by simulating the system with and without the proposed interventions. This helps identify the intervention with the best benefit-to-cost ratio. Potential interventions include firming fuel supplies, adding generating capacity, or expanding transmission.

Evaluating capacity accreditation and planning reserve margins: CRA leverages AdequacyX to provide and quantify the capacity accreditation (i.e., ELCC values) or planning reserve margin needs. CRA can provide an alternative view to existing ELCC or PRM values, or evaluate these values under multiple futures (i.e., low versus high EV growth, etc). CRA also supports investors and operators in evaluating the risks from changing capacity accreditation/ planning reserve margins or non-performance penalties.

Challenges and future enhancements

In this *Insights,* we introduced CRA’s proprietary loss of load model–CRA AdequacyX—and discussed quantitative approaches to evaluating the resource adequacy and commodity price exposure for a proposed portfolio resource mix. Our findings highlight the importance of simulating *future* load conditions and correlated events. Without accounting for changing load shapes, changes in cold weather outages, and other system changes, models may miss synergies between technologies or provide an inaccurate view of the resource adequacy of the system.

CRA is committed to further growing its modeling capabilities. Across the industry, a critical area of growth in loss of load modeling is the simulation of climate change and rare events. Developing models is inherently challenging due to the limited data available on system performance during atypical conditions. CRA will continue to enhance its modeling approaches to better capture these changing weather conditions and rare events.

About CRA's Energy Practice

Charles River Associates is a leading global consulting firm that offers strategic, economic, and financial expertise to major corporations and other businesses around the world. CRA's Energy Practice provides services to a wide range of industry clients, including utilities, ISOs, RTOs, large customers, and investors. The Energy Practice has offices in Boston, New York City, Washington DC, Toronto, London, Houston, Los Angeles, Salt Lake City, Dusseldorf, and Munich. Learn more at **www.crai.com/energy**.

To learn more about how CRA is leveraging these tools to help utilities, ISOs, large load customers, and investors, visit: **https://www.crai.com/industries/energy/adequacyx/.**

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