NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Probabilistic Planning for Tail Risks

PAWG White Paper

March 2024

RELIABILITY | RESILIENCE | SECURITY




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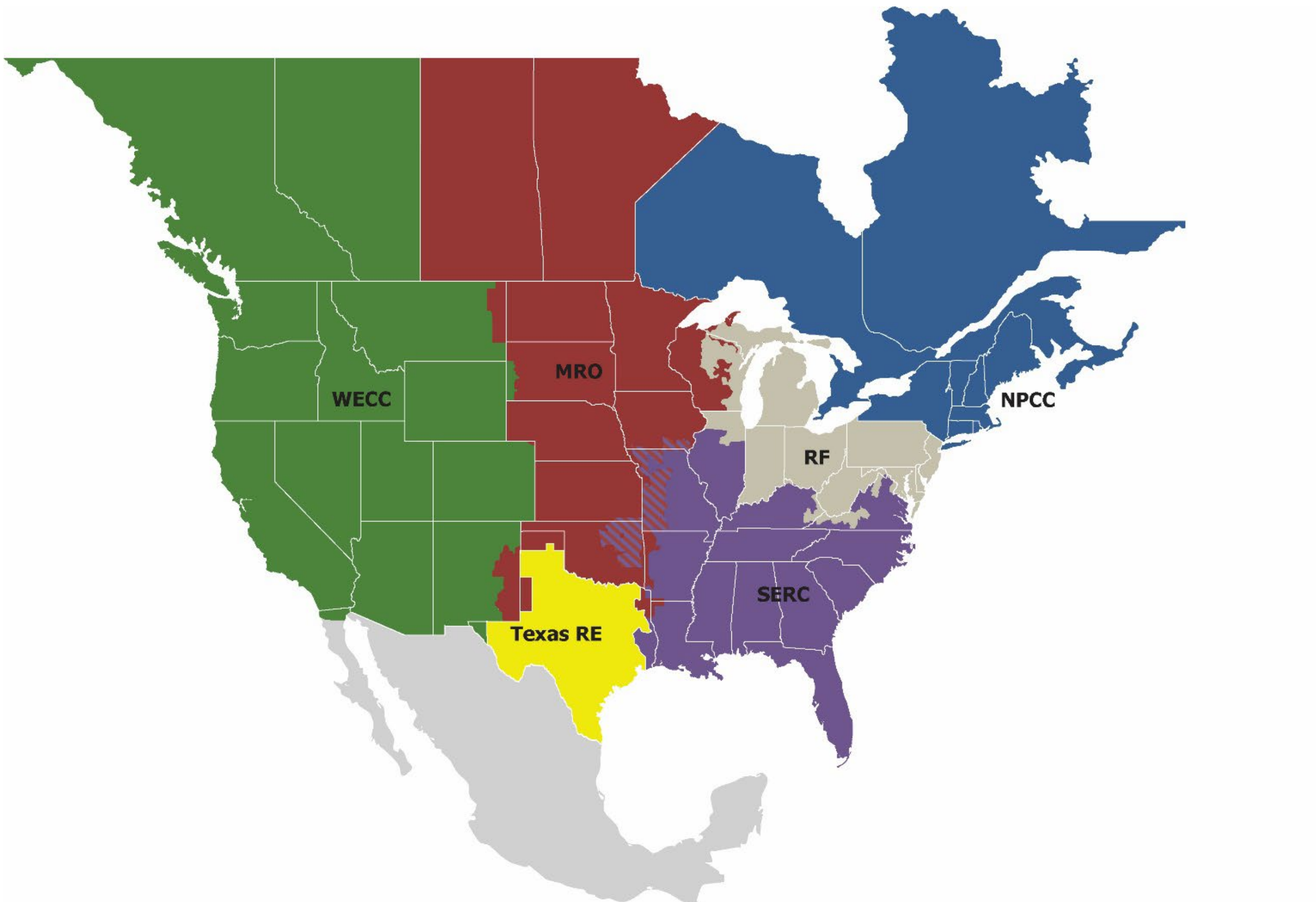
Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of NERC and the six Regional Entities, is a highly reliable, resilient, and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security
Because nearly 400 million citizens in North America are counting on us

The North American BPS is made up of six Regional Entities as shown on the map and in the corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one Regional Entity while associated Transmission Owners/Operators participate in another.



MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

Statement of Purpose

The purpose of this white paper, Probabilistic Planning for Tail Risk, is to investigate the operational risks from low-probability/high-impact future weather extreme conditions. Understanding the impacts of risks will prompt discussions about how best to prepare for them. As described in this white paper, operational planning responses can be in the form of increased generation and transmission capacity to bolster reserve margins, identification of resources with common-mode vulnerabilities, and energy sources that can offset deficits or provide resilience in the event of an extreme event.

Recognizing that the BPS cannot totally withstand all potential events, an adequate level of reliability[1] must be provided so that the system can be reliably operated even with degradation in the quality of service. Furthermore, the system must have the ability to rebound or recover when repairs are made, or system conditions are alleviated. The *Reliability Issues Steering Committee* (RISC) *Report on Resilience*[2] provides guidance on how resilience fits into NERC's activities and how additional activities might further support resilience of the grid. The RISC report underscores NERC's longstanding focus on aspects of resilience and emphasis on re-examining the issue in the face of a changing resource mix.

The NERC Probabilistic Analysis Working Group (PAWG) attempts to address these concerns through best practices gathered from published literature and users of the probabilistic tools in the electric power industry. The main concern for both planners and operators is to develop a system with an adequate level of reliability as spelled out in NERC's Standards. Their common objective is to maintain reliability, resilience, and security of the system at satisfactory levels and plan to avoid widespread outages during extreme high-impact, low-probability events that could occur in real-time operations.

The white paper covers the full implementation of a probabilistic study on extreme weather events and includes the following components:

- Assessment or study setup for extreme weather or events, including key assumptions.
- Development and enhancement of study models.
- Simulation or study techniques regarding extreme weather.
- Reporting of probabilistic indices on extreme weather.
- Recommended steps for the Reliability and Security Technical Committee (RSTC) or other NERC entities regarding probabilistic assessments (ProbA) and the related reporting of these extreme weather risks.

[1] https://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/Informational_Filing_Definition_Adequate_Level_Reliability_20130510.pdf

[2] Report on Resilience, NERC, November 8, 2018

Chapter 1: Key Findings and Recommendations

With the electric industry transforming its resource mix, rapid changes are being made in the way the BPS is planned and operated. Driving this transformation is a changing resource mix, with increased penetration of renewable energy resources such as wind and solar coupled with frequent extreme weather events. Models focused on tail risks could be used to address the risks imposed on the BPS. Typically, these risks are characterized by their low probability, but potentially with high-impact disruptions. Tail risks are sometimes so difficult to quantify that they seem unlikely, although we know this is not always the case.

The white paper's key findings and recommendations focused on improving modeling of tail risks in planning studies are summarized below:

Key Findings

- Exploring best practices and modeling approaches for tail risks such as extreme weather events by industry in probabilistic resource adequacy planning processes has attracted renewed attention in power systems engineering in recent years.
- Probabilistic methods can often reflect underlying uncertainties better than deterministic methods, and they can also support and enhance more efficient BPS planning and operation.
- Uncertainty of variable energy resources (VER) is likely to be the dominant source of tail risk in the future.
- The addition of a wider range of scenarios will provide the natural framework in which to analyze the variable output from renewable sources during extreme weather events when determining system impact and resource interconnection studies.
- Scenario analysis for focused time-limited duration analysis is warranted as modeling must consider weather risk with a limited duration and the scope of the outages is not easily determined from historical data.
- Expected unserved energy (EUE) could be the most useful metric in understanding and comparing the severity of the degraded tail risk state.
- Probabilistic planning needs to continually evolve to properly account for the increasing frequency and impacts of extreme natural events deviating from historical trends, coupled with the anticipated increase of weather-dependent resources connecting to the BPS.

Recommendations

- Develop a catalogue of tail risk scenarios that can be applied to many Regional Entities that consider a wide range of risks.
- Use the catalogue as a checklist to identify potential risks and suggest the need for additional study years or advise the industry of targeted "useful" sensitivities to underscore the risk.
- Analyses should include a risk perspective across relatively wide footprints because of the uncertainty of resources and the interconnected nature of the power grid.
- Encourage commercial software vendors to adopt a front-end, pre-processing model that could translate temperatures to fuel availability and augment existing tools to allow fuel limitations to be represented.
- Modeling should consider weather risk that could have a limited duration while the scope of the outages is unclear from historical data, thereby making scenario analysis for a focused time-limited duration analysis warranted.

Chapter 2: Tail Risk Study Background

Leveraging the National Infrastructure Advisory Council (NIAC) framework and the NERC adequate level of reliability, the RISC created the model depicted in **Figure 2.1** that illustrates and enables measurement of system performance or resilience and provides an understanding of the elements needed to support the reliable operation of the BPS. Measuring the profile represented in this model provides relative characteristics of system performance, identifies areas where improvements may be desired post-event, and measures the success of system improvements. The key areas that lend themselves for measurement include robustness, amplitude, degradation, recovery, and recovery state.

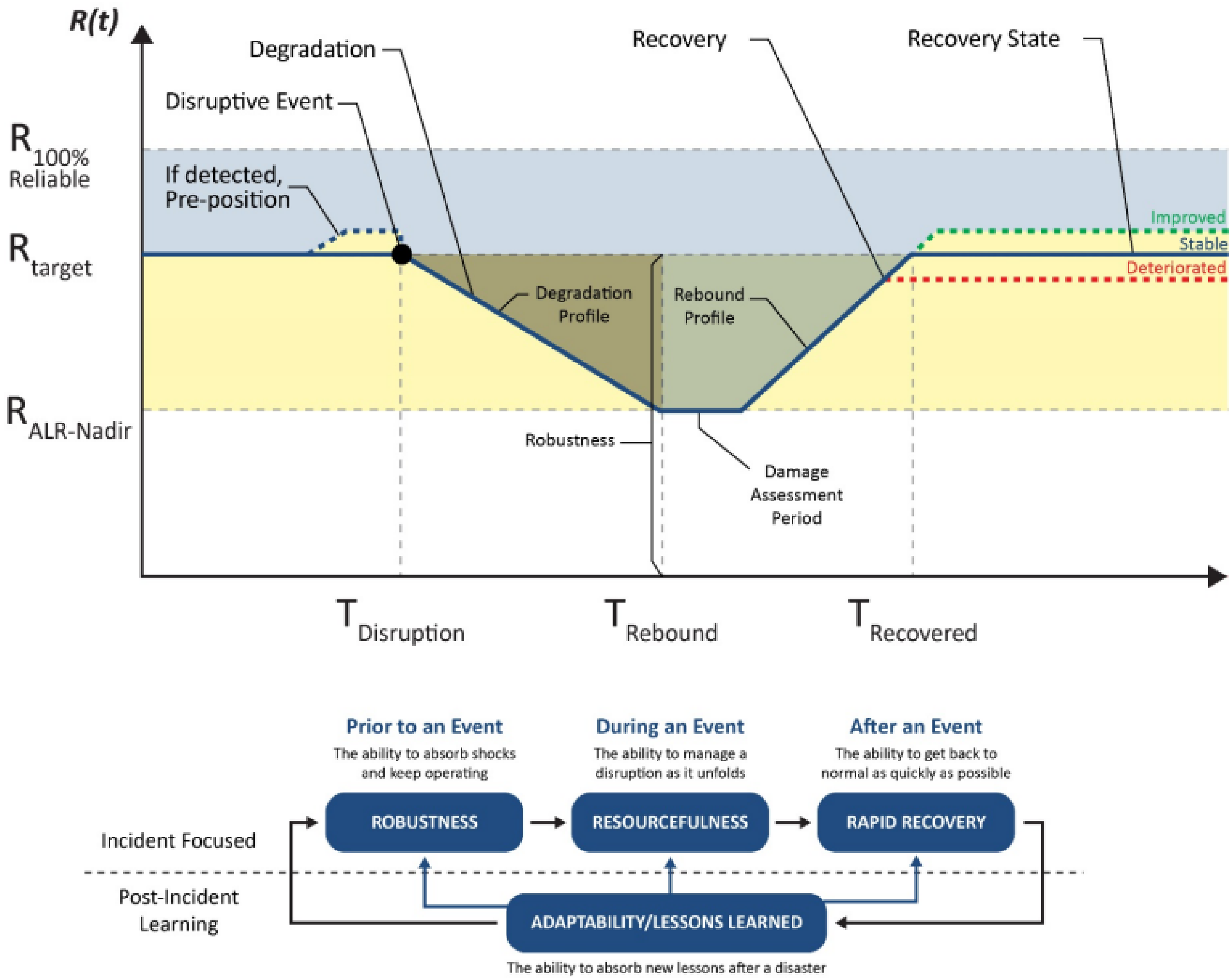


Figure 2.1: RISC Model for Reliable Operation of the BPS

Probabilistic Indices

In the electrical power industry, risk is evaluated by using a loss of load metric over a duration of time based on the probability of not meeting all customer demand, resulting in unserved energy. Probabilistic metrics describe the probability that a period will have unserved energy due to insufficient resources to meet demand during that period. This evaluation method is referred to as a loss of load probability (LOLP). The summation of the LOLP over a specific time, such as a year, will provide an expected value of the number of occurrences of loss of load events. This summation is referred to as a loss of load expectation (LOLE) over a specified period. The LOLE is typically for the most severe conditions in a day; historically, the highest contributions to LOLP and LOLE occurred during the annual peaks. A related metric that is frequently used is the expected number of hours that a deficiency will occur (e.g., loss of load hours (LOLH)) over a specific time, such as a year. Neither the LOLE nor the LOLH metrics provide information about the amount of unserved energy in the loss of load events. Because the cumulative amount[3] of this unserved energy is a useful metric, the EUE metric is frequently reported for completeness.

To develop these reliability metrics, a set of assumptions about the system to be evaluated must be developed. Using a framework that evaluates these probabilities in an organized manner quantifies if there are sufficient resources and transmission to meet system demand.[4] The results can be developed for the entire system or for portions that are constrained or bounded by transmission limitations.

While reliability models are already designed to address tail risks and investigate infrequent risks to reliable operation of the electric grid, concern is growing that some risks may become amplified by changing weather patterns that are underrepresented by assumptions used in current models. Further, these risks may not be random in nature as weather patterns cannot be assumed to be random. Additionally, supply resources are increasingly turning toward sources of energy that are a product of weather conditions (e.g., wind and solar energy) that have significant variability, common modes of production, and lulls that add to system risks. Furthermore, with increased electrification of the economy, supply disruptions due to weather conditions can be amplified.

The set of underlying assumptions for a probabilistic study can be modified to investigate specific tail risks and studied to determine the consequences of a specific conditional probability scenario. This can be done either individually or in combination with other factors. This paper proposes ways to plan the bulk system while recognizing tail risks.

Definition of Tail Risks and Extreme Weather

Tail risks are characterized by the risk imposed on a system because of their low-probability but high-impact disruptions. As the electric system becomes influenced by weather for both demand and supply, weather-related risks become critical factors that affect reliability. Furthermore, these weather-related risks are not random, and mitigating them is challenging since weather patterns may become more difficult to predict as the patterns change. Climate models may be needed to put boundaries around scenarios useful in the probabilistic analysis of future systems.

Currently, the supply uncertainty associated with solar, wind, and hydro-based VERs is reasonably well understood and accommodated in planning studies. The supply risks associated with the VERs are embedded in the historical output of solar, wind, and hydro generation. Given the availability of real and synthetic data that covers most of North America,[5] the data to evaluate some amounts of reliability impacts is available. However, a more complete range of possible weather-related risks is not available.

While the historical data provides a great deal of information about the reliability contribution of these VERs, the variability due to extreme weather is likely underrepresented. The greatest supply risk associated with these technologies is prolonged widespread hydro droughts, long periods of low wind output (e.g., “wind droughts”), high wind cut-outs, or very low ambient temperatures and solar soiling (e.g., dust, snow, smoke, smog, extreme clouds). Such reductions in VER energy would result in the drawdown of stored energy from dispatchable resources that would be needed during lulls in the production of VER energy. A drawdown in available energy may be associated with local resources but may also affect stored energy in neighboring and even more distant regions.

[3] The term “expected” here is used in the description of anticipated value of a random variable rather than a future prediction of the disruption.
[4] This is one of the roles of the Resource Planner and Transmission Planner, respectively.
[5] National Renewable Energy Laboratory (NREL) synthetic data sets in their toolkits.

Historically, the stored energy was readily available in the form of coal in coal-piles, natural gas in pipelines and geologic storage reservoirs, oil and liquefied natural gas in tanks, rods in nuclear plants, and water in hydro reservoirs. In the future, batteries will be added to the system, but the amount of energy (expressed in MWh equivalent) is expected to be much smaller than the more traditional sources of stored fossil and hydro energy. Consequently, the state of charge of batteries can be depleted relatively quickly compared to stored energy fueling legacy fossil energy resources. Depletion of stored energy resources is a key concern that makes the analysis of tail risks critical.

Recent Extreme Weather Events

Recent NERC Event Analysis reports and FERC-NERC inquiries have demonstrated the impact that some extreme weather events have had on the reliability of the bulk system. There are a few documents of note:

- Joint FERC-NERC inquiry on the December 2022 winter storm Elliott[6]
- Joint FERC-NERC inquiry on the February 2021 ERCOT events (cold weather related)[7]
- Hurricane[8] Harvey
- Hurricane Irma[9]
- Joint FERC-NERC report on the 2018 South Central Cold Weather Event[10]
- January 2014 Polar Vortex[11]

Analysis of Changing Weather Patterns

Weather, particularly changing extremes and the range of variability, is a key factor that affects resource (i.e., energy) availability, demand patterns, and related reliability concerns. Extreme weather events in Texas and California have made it apparent that multi-day or longer energy deficiencies have serious consequences for residents of the affected areas and the economy. Energy unavailability events are well documented, highlighting the importance of conducting comprehensive energy reliability assessments that cover a wide range of operating conditions, including low-probability, high-impact reliability risks (tail risks) related to extreme weather.

For instance, the Electric Power Research Institute (EPRI), in collaboration with ISO New England and other interested parties, is conducting *The Operational Impacts of Extreme Weather Events*[12] project, a probabilistic energy availability case study for the New England area under extreme weather events. The study seeks to develop a framework to assess operational energy-security risks associated with extreme weather events to enhance awareness of regional energy shortfall risk over the study horizon and prompt preparation.

Augmenting NERC PAWG Probabilistic Assessments

The PAWG has members whose companies are at work implementing the specific recommendations of the various NERC studies and reports. These companies are envisioned to modify their own planning processes in ways that are ongoing. While most of these efforts are weather related, there can be future ways and methods to probabilistically plan for extreme risks.

Time will tell if any of these efforts will emphasize tail risk over reworking the "normal" ProbAs that each organization performs as part of the NERC Long-Term Reliability Assessment and their own reports. The PAWG will continue to

[6] https://www.ferc.gov/news-events/news/ferc-nerc-release-final-report-lessons-winter-storm-elliott
[7] Joint FERC-NERC inquiry on the February 2021 ERCOT events
[8] Hurricane Harvey
[9] Hurricane Irma
[10] Joint FERC-NERC report on the 2018 South Central Cold Weather Event
[11] January 2014 Polar Vortex
[12] Operational Impacts of Extreme Weather Events Key Project

share the efforts and successes and determine if future work at the NERC PAWG is needed to provide best practice to augment the material here.

Classification of Tail Risks by Planning Response

There are three general classifications of tail risks based on the resource adequacy planning response. All three classifications can be analyzed by using simulations and are suitable for developing quantitative reliability indices. However, the type of planning response that may be appropriate to address the risk is different for each of the three classifications. Some tail risks, such as cyber security, widespread forest fires, and grid stability issues, are outside the realm of probabilistic analysis and not addressed here.

Technology-Agnostic Resource Adequacy Response

Generally, technology-agnostic resources have root causes of unavailability that are random and independent compared to the rest of the resource fleet. For this class of risk, the most appropriate planning response is to increase or decrease the number of resources available to serve demand for energy from customers. This supply is described as technology agnostic because one type of resource is reasonably interchangeable with another resource even though there may be a quantifiable capacity "equivalence rate" between different types of technologies.

The planning response to a tail risk associated with high loads driven by weather would be to install more supply resources to decrease the probability of a shortage when the high loads occur. With the rising concern that weather will encompass more extremes than observed in the past, quantifying the magnitude of the resulting additional loads is important to understanding reliability impacts and how an increase in available resources would affect reliability.

Because these conditions are driven by an identified need for additional supply, a salient feature of weather-driven extreme loads is that curtailment may have detrimental impacts on the customers. Because these episodes are not likely to be frequent, customers may not develop suitable or sufficient alternatives that would enable them to forgo essential heating or cooling services. In other words, because these events are infrequent, targeted demand reductions with market mechanisms or backup technologies (e.g., large ice-chests, gasoline-powered generators, or kerosene heaters) may not be available or sufficient.[13]

If an extreme weather event has a low probability to occur, its effect on expected load distributions would be diluted even if it had a high-impact outcome. Because the impacts are not detected, the additional supply resources indicated by the resource adequacy analysis may not be sufficient to satisfy the demands of that extreme weather event if it were to occur.

Given that the reliability criterion is non-zero, the risk of insufficient resources is an acceptable outcome. One planning response to the tail risk caused by the low probability of extreme weather is to make the desired reliability criterion more stringent and therefore to require additional resources. Because there is a risk of insufficient resources, strategic management of such a resulting loss of load occurrence must be a consideration.

During extreme weather, the effects of heating or cooling equipment running at full output may saturate demand and limit any additional increases in demand because everything is running. Alternatively, these effects may drive the aggregate demand higher based on the addition of climate-conditioning equipment—such as a spare electric space heater—operating with a high coincidence factor or the equipment's operating characteristics themselves, such as heat pumps that switch to resistance heating at low temperatures. Care should be taken to understand the load behavior under these harsh conditions.

[13] Developing a technology solution for curtailing weather-driven loads during a once-in-a-decade extreme weather-driven event may be possible but difficult. Technology solutions, such as energy efficiency, reduce weather-driven load volatility in all hours but would not have a supplemental dispatchable component during an extreme weather event.

Technology Vulnerability Resource Adequacy Response

A secondary class of tail risk is characterized by resources that have a specific vulnerability commonly shared with other similar resources; this shared vulnerability could threaten reliability if the resource type is widespread. Examples of a technologically vulnerable resource would be wind generation during a widespread wind lull or storage resources after an extended period when stored energy is drawn down. For this class of risk, the planning response would be to recognize and limit the dependence on the resource type with the identified vulnerability. A related planning response would be to decrease the equivalence rate of the vulnerable resource type (e.g., more nameplate capacity to get the same reliability equivalent as another type of capacity). Various methods have been developed to quantify an equivalence rate between different types of capacity. This equivalence is frequently expressed as an equivalent load carrying capability (ELCC).[14]

The vulnerability is generally caused by a disruption of the primary source of energy used in electricity production or because of a common-mode condition. An example would be the decreased capability of natural gas turbine technologies associated with higher ambient temperatures. Another example of such a vulnerability is the decreasing equivalence rate of wind and solar resources as their penetration increases. This decreasing equivalence occurs because widespread wind lulls and/or widespread cloud cover reduces the primary energy source for the wind and solar resources as a class and the reductions can no longer be described as random and independent.

Another example of a technologically vulnerable resource is a fleet of natural gas resources[15] that do not have dual-fuel capability. Such resources may be subject to simultaneous primary energy source disruptions due to pipeline ruptures, fuel supply difficulties due to freeze-in of natural gas wells, competition for limited fuel supplies, or other mechanisms that preclude acquisition of sufficient fuel. These vulnerabilities could render the resources unable to provide their expected resource adequacy services. The planning response to this could include requiring or incentivizing dual-fuel capability to reduce the natural gas supply risk.

Restoration-Focused Resource Adequacy Response

The third class of tail risk is characterized as one where the most likely planning response would be to focus on resilience, enhanced restoration procedures, and equipment placement rather than implementing a resource adequacy solution where more supply resources are added. The need for this class of response is explicitly recognized because of a non-zero reliability criterion where events go beyond the capabilities of the available resources, suggesting the need for operating with a degraded system.

Examples of this class of risks could include recovery from a severe weather event, such as a hurricane, derecho, tornado, or ice storm. In these latter examples, the key problem is not the loss of supply resources, but rather an inability to move energy from where it is available to where it is needed. A planning solution that called for the installation of more resources to increase reserve margins would most likely be ineffective, as the ability of the additional resources to provide the power and move it to where it is needed depends upon the path of the storm and transmission lines that would have been taken out of service by the weather event.

A planning response for this tail risk might be to develop criteria for customer outage restoration times depending on severity. While it is quite reasonable to expect that some severe weather events could be made less impactful by the judicious location of emergency or backup generators, this is not generally referred to as a resource adequacy issue. Additional transmission to more distant areas would increase the footprint where additional support might be sought.

To address disruptive common-mode events that are not yet fully reflected in resource adequacy, the industry can build on the conceptual framework for developing resilience metrics. Resource adequacy may contribute to supply

[14] Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning, March 2011
[15] BERC SPOD Document

resilience, while a broader resilience framework considers how to absorb, manage, recover, and learn from disruptive events.

Probabilistic Framework

Fundamental to the analysis of tail risks is an analysis of the underlying probabilistic distributions of loads and resources. The following figures provide a conceptual illustration of the distributions that are central to this analysis and how they interact in a resource adequacy analysis. The impact of tail risks will be discussed at a conceptual level.

The primary distribution used in resource adequacy analyses is a probabilistic representation of the loads to be served. Figure 2.2 shows that the 8,760 hourly loads in this example have a central tendency to be between 10,000 and 16,000 MW. The highest load in the distribution is 25,868 MW corresponding to a summer peak day that is, broadly speaking, typical. A tail risk due to extreme weather would increase the peak loads in the direction shown by the red arrow. To be reliable, the probability of having insufficient resources to meet this summer peak load should be zero or a small value. In this example, a small amount of unserved load will be used for illustration.

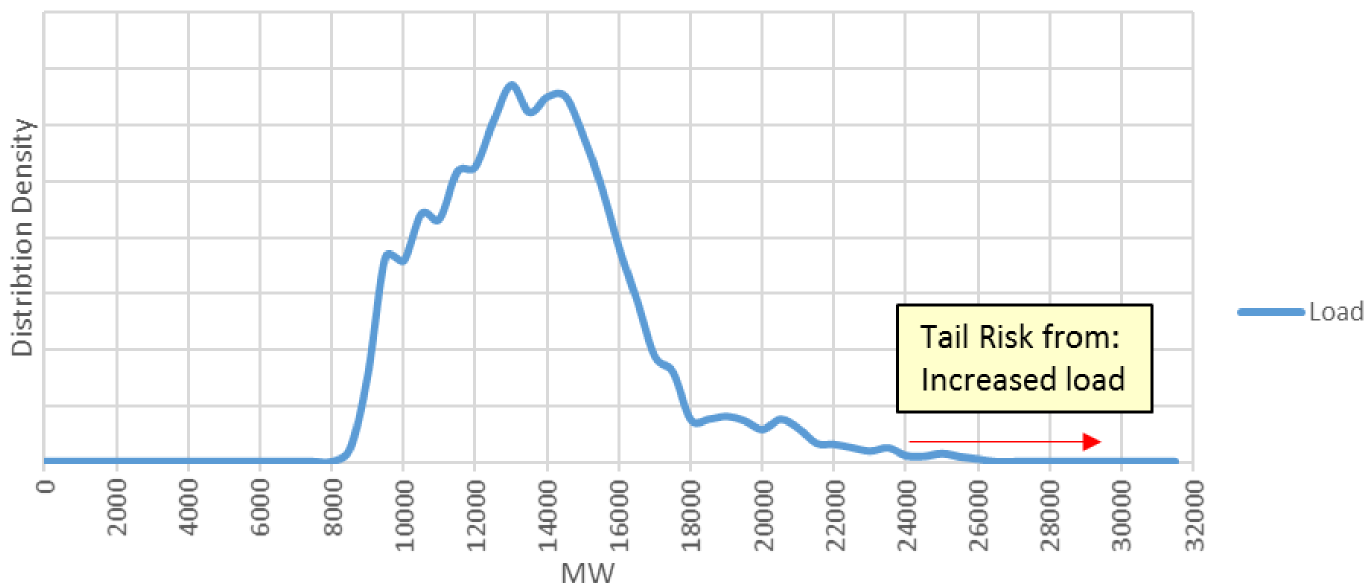


Figure 2.2: Illustrative Distribution of all 8,760 Hourly Loads

Figure 2.3 shows a conceptual distribution of available dispatchable resources. This distribution suggests that there are approximately 32,000 MW of available resources. Because of outages, the amount of capacity available to serve loads is always less than the maximum amount. In this example, the probability of having less than 25,000 MW is shown to be small. If there were common-mode vulnerabilities, the distribution would expand to the left as shown by the red arrow.

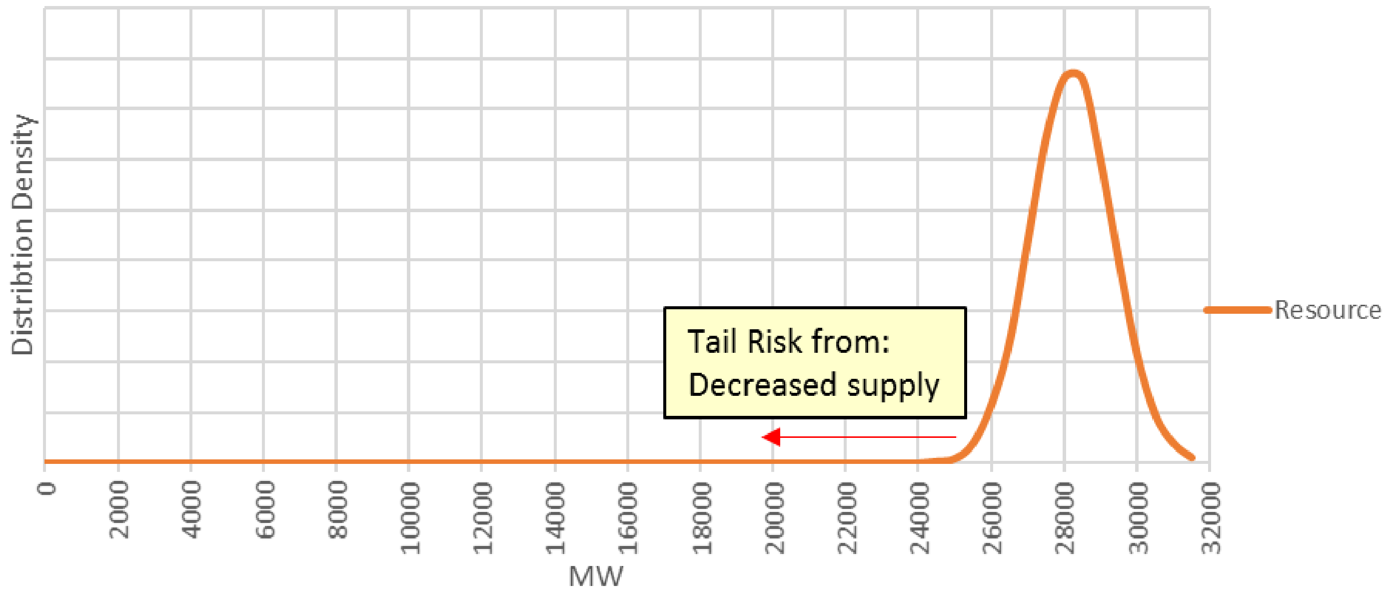


Figure 2.3: Illustrative Distribution of Available Resources

Figure 2.4 shows these two distributions superimposed on the same axes. This shows that the peak load is close to the minimum amount of capacity of the aggregate resources.

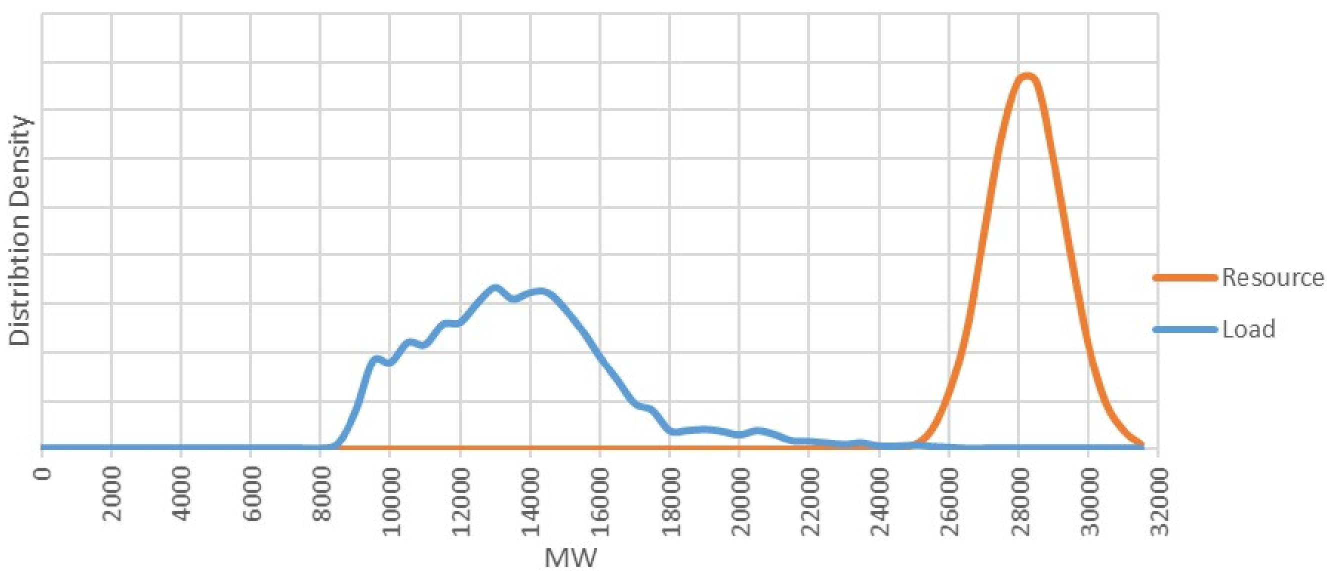


Figure 2.4: Conceptual Illustration of Loads vs. Available Resources

Figure 2.5 shows the actual margin between one Monte-Carlo replication of the resource distribution versus the load distribution.[16] Typically, the amount of available resources exceeds load by 8,000 to 20,000 MW. However, there are a few hours when the margin is close to zero or negative. In the case of a negative margin, the system had a non-zero probability of losing load.

[16] The margin was calculated by first creating a distribution representing the available capacity for all 8,760 hours. This distribution was based on a mean of 27,000 MW, a standard deviation of 1,200 MW, and a random number for each hour. The corresponding load in the associated hour was then subtracted from the available resource in order to get the margin in a specific hour. While not a rigorous probabilistic analysis, this approach is appropriate for illustrative purposes.

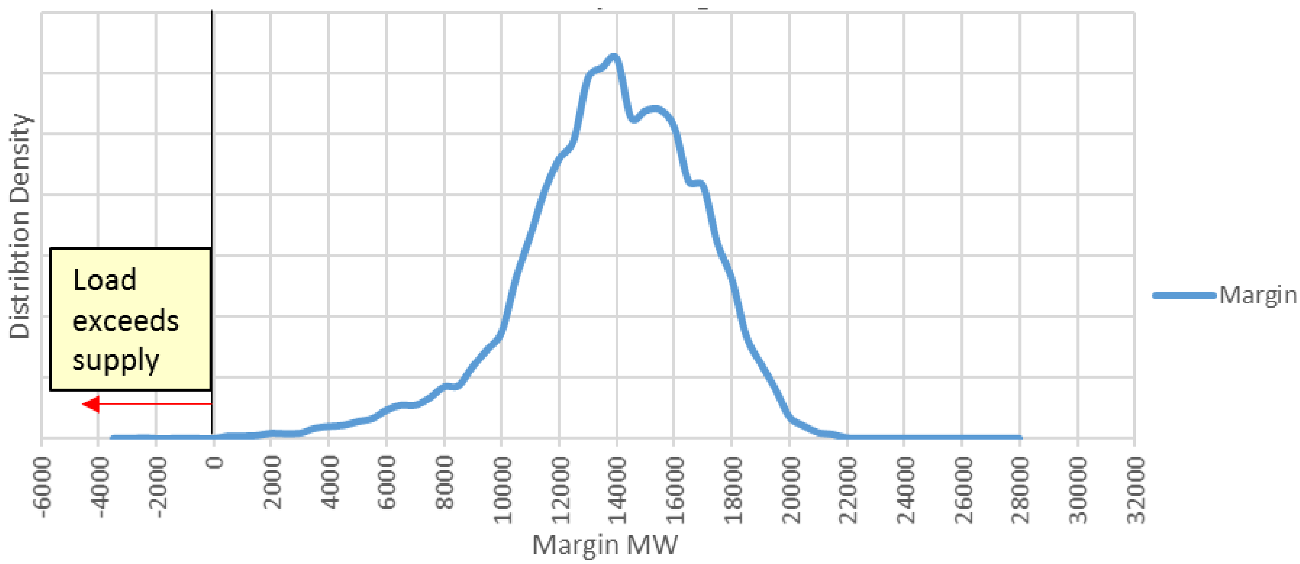


Figure 2.5: Conceptual Margin Between Loads and Resources

Figure 2.6 shows a revised margin distribution based on the addition of wind and solar resources. To illustrate a comparable loss of load magnitude, the amount of dispatchable resources was reduced.[17] Typically, the amount of available resources exceeds the load by a wider range of 4,000 to 28,000 MW, suggesting that the dispatchable resources were available but not typically needed to serve loads. Because of the assumed reduction in the amount of dispatchable resources (compared to those assumed in **Figure 2.3**), a few hours remain during which the margin is close to zero or negative, similar to **Figure 2.5**.

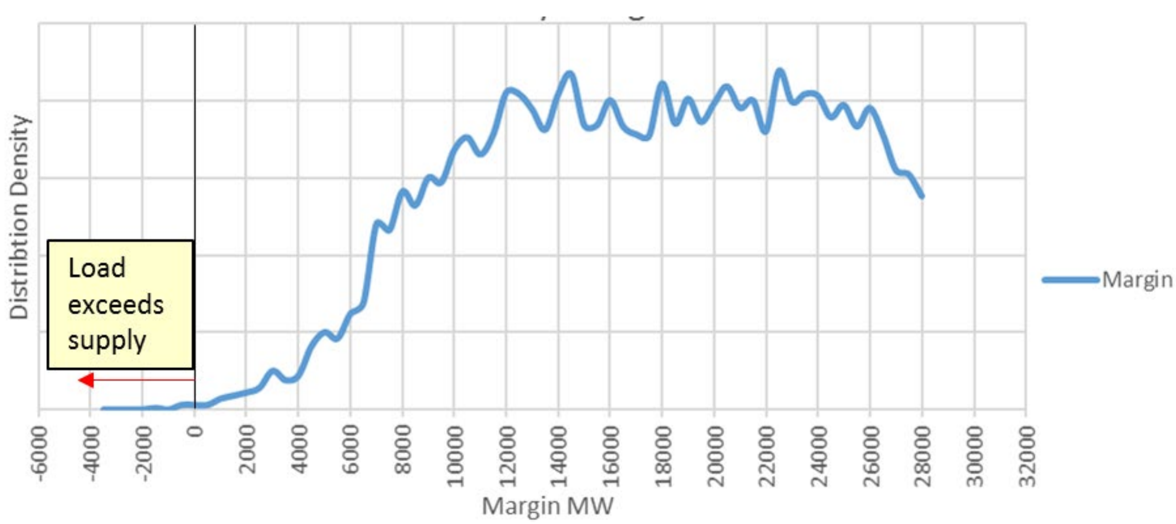


Figure 2.6: Conceptual Margin Between Loads and Mix with Wind, Solar, and Fewer Dispatchable Resources

The red arrow in **Figure 2.7** illustrates the tail risk affecting resource adequacy as discussed in this white paper; it could be due to either higher loads or resources with greater unavailability.

[17] The mean of the distribution representing the available capacity for all 8,760 hours was reduced from 27,000 MW to 18,500 with the same standard deviation of 1,200 MW.

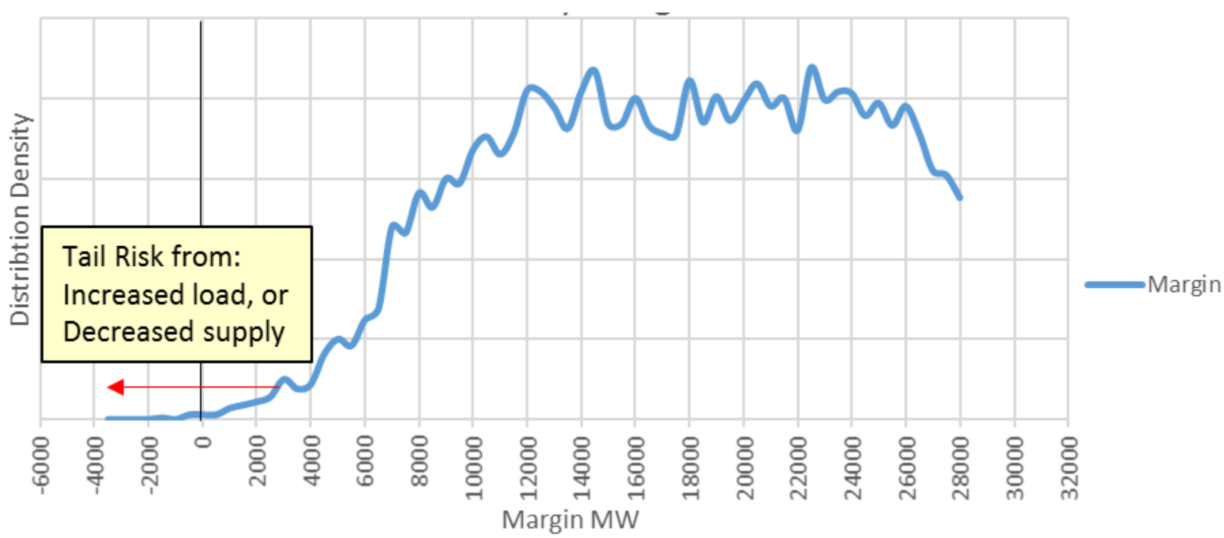


Figure 2.7: Additional Tail Risk from Increased Loads and/or Decreased Supply

Assumptions for Probabilistic Study of Tail Risks

There are several broad classes of factors that affect reliability because of tail risks. At a high level, two of these factors are the magnitude of the loads in comparison to the availability of supply and factors where supply can be a function of weather-related phenomena.

Risk of Extreme Loads

Reliability studies have methods that incorporate a range of loads based on observations developed from historical weather datasets. To some extent, forecast loads may reflect high values because the forecasting process typically incorporates normal variations based on observations spanning several decades that will surely include some hot- and cold-weather outliers. Even if the risk of extreme weather is expected to increase over time, the likelihood of that weather being far outside the outliers experienced in the historical record is low. Some climate models suggest[18] that there may be more frequent occurrences of the outlier values with only modest increases in their magnitudes. A review of 2020 California and 2021 ERCOT outages suggests that, while extreme hot or cold temperatures contributed to those reliability events, they were not outside of the historical record. Consequently, a focus on extreme temperature excursions may provide an incomplete assessment of the reliability landscape, and other factors need to be investigated.

California 2020

The August 2020 load-shedding events in California were not caused by "extreme" heat solely from temperatures in California as shown in the graph below. The rest of the western United States also experienced high temperatures at the same time, and this reduced available support from other areas throughout the Interconnection. **Figure 2.8** shows that the temperatures in both September 2020 and July 2006 were higher than mid-August 2020 when the outages occurred.[19]

[18] EPRI Report presentations with ISO New England

[19] Root Cause Analysis; Mid-August 2020 Extreme Heat Wave, California ISO, January 13, 2021

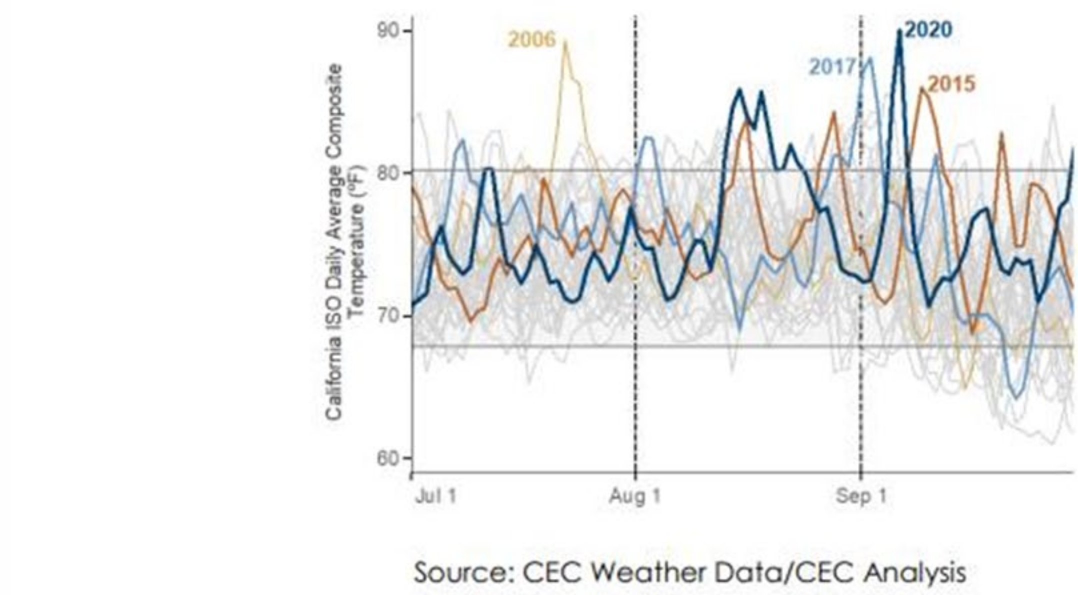


Figure 2.8: Summer California Temperatures 1985–2020

ERCOT 2021

In ERCOT, the temperature during the February 2021 cold snap was not an extreme weather event compared to past historical events. **Figure 2.9**[20] shows that the 2021 daily average temperatures tended to be the second or third coldest during the seven-day window shown. This suggests that factors other than extreme weather had a significant role in the reliability event. Specifically, resource challenges occurred due to a sensitivity to weather conditions, which did not manifest itself during previous events. In addition to the freezing of mechanical components in power plants and unavailability due to the natural gas freeze-in that will be discussed later, another significant factor was the simultaneous outage of wind resources, with a large part of those outages caused by icing.

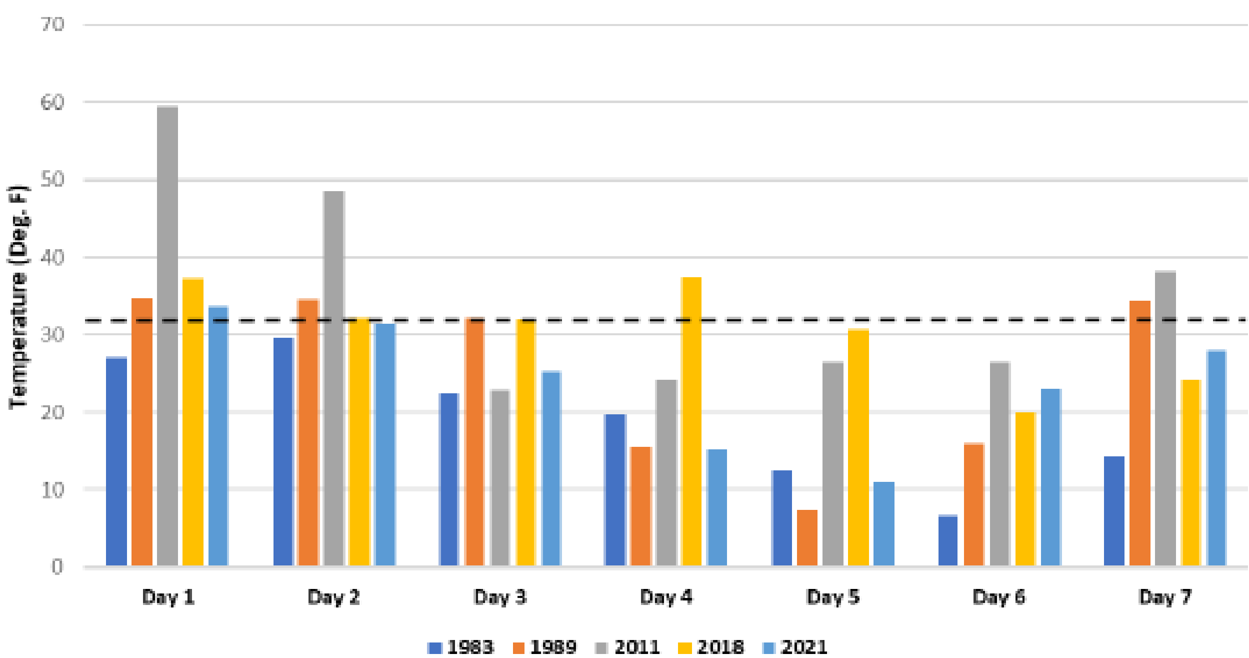


Figure 2.9: ERCOT Cold-Snap Temperatures

[20] February 2021 Cold Weather Outages in Texas and the South Central United States, pdf page 247/316

Evolving Resource Mixes Reduce Fuel Diversity

As electricity resources evolve to lower carbon-intensity portfolios, the diversity of fuels supplying generating resources is shrinking. The increased penetration of wind and solar resources is reducing the energy from fossil resources, especially coal, oil, and natural gas generators. This is a trend that affects all Regional Entities. As an example, **Figure 2.10** shows the retirement of coal-fired and other dispatchable resources projected in the next decade[21] in the NERC footprint; the non-coal resources that could retire may have had dual-fuel capability. This will decrease fuel diversity that amplifies the reliance on dependable transportation of natural gas to generators during times of system stress.

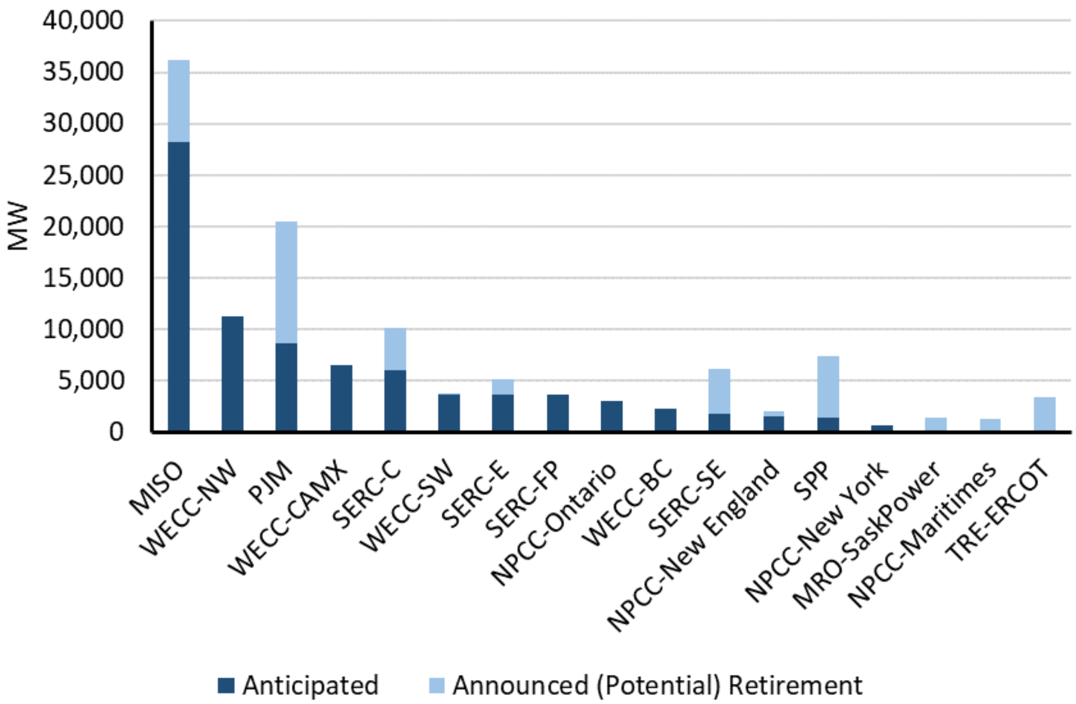


Figure 2.10: Projected Retiring Nuclear and Fossil Generation Capacity 2023–2033: NERC LTRA

Changing Weather Sensitivity of Load

The sensitivity of electricity loads to weather may be increasing as national and state policies promote electrification to increase overall energy efficiency and reduce carbon emissions from customer demand. This increased sensitivity can also be a source of increased risk. For example, increased heating electrification can result in an increased load sensitivity to cold weather that would be greater than experienced previously for a comparable temperature. The historical sensitivity to temperature would be used to develop load volatility for the forecast years. The compounded risk of both greater electrification heating loads and a potential increase in sensitivity to colder temperatures could create loads that exceed forecasts.

Load Forecast Uncertainty Multipliers

There is no standard industry practice for addressing the future load volatility in reliability models. In developing load distributions for use in reliability studies, the tail risks associated with uncertain weather are represented by load forecast uncertainty multipliers. Reliability models, such as the GE MARS Model, use a combination of load-scaling multipliers and associated probabilities to reflect higher-than-expected loads at a relatively low probability.

[21] https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2023.pdf

Increased Competition for Natural Gas

State policies are orientated toward promoting electrification to reduce carbon emissions. Because liquid fuels such as heating oil and propane are more expensive than natural gas, electrification of heating systems using these fuels would typically provide greater economic benefits. Additionally, oil has a higher carbon footprint than natural gas for heating and would be the preferred target for electrification. Consequently, the demand for natural gas heating during cold snaps is likely to remain robust. Natural gas infrastructure expansion has been lagging the increased demand from the power sector. If a lull in wind and solar energy production occurs, natural gas may not be available in sufficient quantities for the power sector, and this would place increased demand on oil and coal generation with locally stored fuels. This would also increase the use and drawdown of other forms of dispatchable stored energy such as hydroelectric and batteries.

Resource Unavailability

Typically, probabilistic reliability analyses have reflected the unavailability of generating resources as random and independent events. The statistics underlying the unavailability are typically related to mechanical problems that affect only one generator without affecting other generators. While anecdotal evidence suggests the possibility of common-mode events among dispatchable resources, it has been difficult to establish quantifiable statistical relationships to include in forward-looking reliability studies. Generally, it has been relatively straightforward to develop estimates of resource availability due to random and independent events that can then be compared to loads. However, weather-driven factors can cause common-mode failures.

Temperature Sensitivities

One of the exceptions to assumptions about random and independent generator unavailability is related to temperature dependencies. The effect of ambient temperatures on mechanical availability is typically reflected by derating generators seasonally (e.g., summer vs. winter ratings). Combustion turbines are sensitive to air density, which reduces the rating with higher temperatures because less air can be brought in to support combustion. On the other hand, the air is denser with colder temperatures and generators can ingest more air and, therefore, operate at higher outputs. Similarly, PV panels have decreased capability deratings during periods of high ambient temperatures.

Additionally, the typical seasonal profile of hydro energy limitations can also be reflected in seasonal or monthly ratings. These risk attributes have been addressed for many years in reliability analyses by using well-established protocols.

Effects of Freezing on Resource Unavailability

Mechanical unavailability due to freezing has been a recognized root cause of degraded system operations. The severity and consequences of freezing get worse with decreasing temperatures and have caused the industry to work together to address this common-mode vulnerability. However, addressing this risk vector has proven to be difficult, elaborated on here:

- Both the 2011 and 2018 Reports identified certain equipment that more frequently contributed to generating unit outages, including frozen sensing lines, frozen transmitters, frozen valves, frozen water lines, and wind turbine icing. The Event was no different—generation freezing issues were the number one cause of the Event, and the same frequently-seen frozen components reappear. Given the repeated appearance of certain equipment in causing generating unit outages during cold weather events, NERC recommends in its Reliability Guideline that entities responsible for generating units “identify and prioritize critical components, systems and other areas of vulnerability.” NERC further explains in its Reliability Guideline that “this includes critical instrumentation or equipment that has the potential to … initiate an automatic unit trip impact unit start-up[,] …initiate automatic unit runback schemes or cause partial outages.”[22]

[22] The February 2021 Cold Weather Outages in Texas and the South Central United States, https://ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and , p 186/316

The effect of cold temperatures on resource unavailability affects many areas, including those located in northern climates where such conditions are expected. MISO's review of the event included these key takeaways:

- Key Takeaways: … extreme weather events cause even greater negative impacts on generation performance because of issues like unexpected weather-related generator outages or fuel delivery challenges. Winterization to protect generation and fuel supplies from extreme weather can mitigate this risk but MISO and its members must assess and establish certain criteria. For instance, to what extreme temperature must generators be prepared to operate, how does MISO ensure consistency amongst similarly situated generations, and whose role it is to establish and verify such requirements? … Further, fuel availability varies over time, and how and who should ensure fuel availability must be considered in reliability planning. Furthermore, if fuel assurance is required, how do we do so in the most cost-effective manner (e.g., annual firm fuel when the generator may only be needed a few times a year)?[23]

Figure 2.11 shows the sudden rise in resource unavailability at the onset of the cold snap at about February 15. Natural gas resources showed a large increase in unavailability while coal resources showed a relatively smaller increase. Increased wind resource unavailability preceded the cold snap and remained elevated until after the cold weather dissipated.

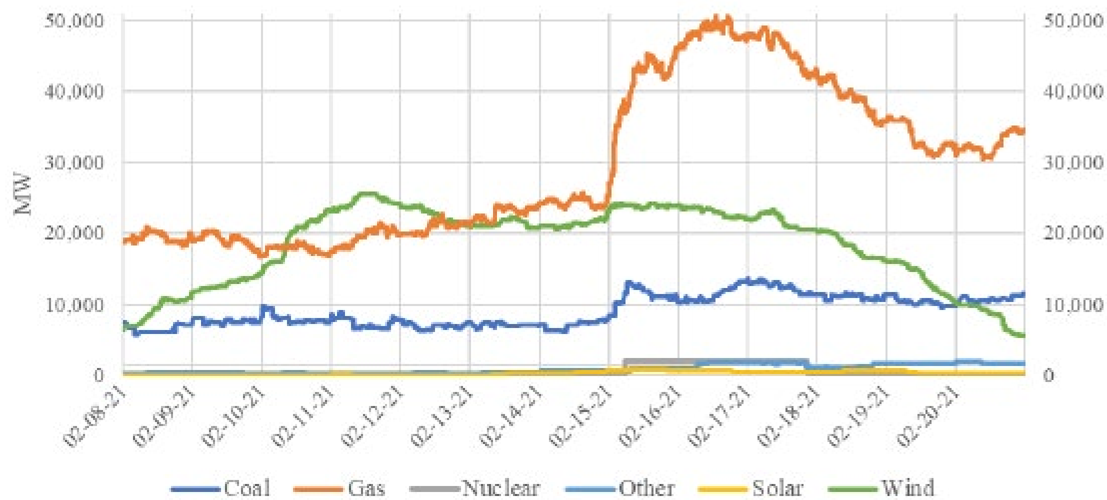


Figure 2.11: ERCOT Cold-Snap Unavailability by Energy Source

Cold Weather and Natural Gas Supply

One of the dominant risk factors that affects large footprints is the reduction in natural gas supplies during cold snaps due to lost production because of supply freeze-in. Freeze-ins are a relatively frequent and recurring problem in natural gas production and processing facilities that have caused considerable supply issues, but this is outside of the scope of current electric system reliability models.[24] The development of techniques to quantify this risk as an integral part of a reliability framework may be an appropriate next step in the evolution of probabilistic analysis.

It is important to account for this fuel supply aspect of resource unavailability. For example, if forced outage statistics for resources affected by cold-weather-related fuel supply were to be increased to reflect this unavailability without explicitly representing the root cause of the reduction from freeze-ins, then it is possible that a solution of adding more resources with the same vulnerability might be identified and pursued. However, because the root cause of the outage was not addressed, the reliability improvement from adding resources with the same vulnerability might prove elusive. Namely, the system condition that impacts existing resources would have the same effect on the

[23] The February Arctic Event / February 14 - 18, 2021 / Event Details, Lessons Learned and Implications for MISO's Reliability Imperative, https://cdn.misoenergy.org/2021%20Arctic%20Event%20Report554429.pdf, p 7/54

[24] Natural Gas Dependence Document (see Chapter 5—Methods for Analyzing Natural Gas Demand and Infrastructure for Electric Power Needs)

availability of added resources. Solutions that explore other fuel types, technologies, or increased reach of transfers may have the desired impact.

ERCOT 2021

One of the key themes related to the February 2021 cold snap in the central United States was the available supply of natural gas for electricity generation.[25] This reduction in supply was mentioned in the above reports and is shown in **Figure 2.12**. The key freeze-in issues are summarized here:

- Generating unit outages and natural gas fuel supply and delivery were inextricably linked in the Event. Fuel issues, at 31.4 percent, were the second largest cause of unplanned outages, derates and failures to start during the Event. Eighty-seven percent of the fuel issues involved natural gas fuel supply issues and 13 percent involved issues with other fuels (such as coal or fuel oil). Natural gas fuel supply issues alone caused 27.3 percent of the generating unit outages. Natural gas fuel supply issues include declines in natural gas production, the terms and conditions of natural gas commodity and transportation contracts, low pipeline pressure and other issues. During the Event, unplanned outages of natural gas wellheads due to freeze-related issues, loss of power and facility shut-ins to prevent imminent freezing issues, and unplanned outages of gathering and processing facilities decreased the natural gas available for supply and transportation to many natural gas-fired generating units in Texas and the South Central United States.[26]

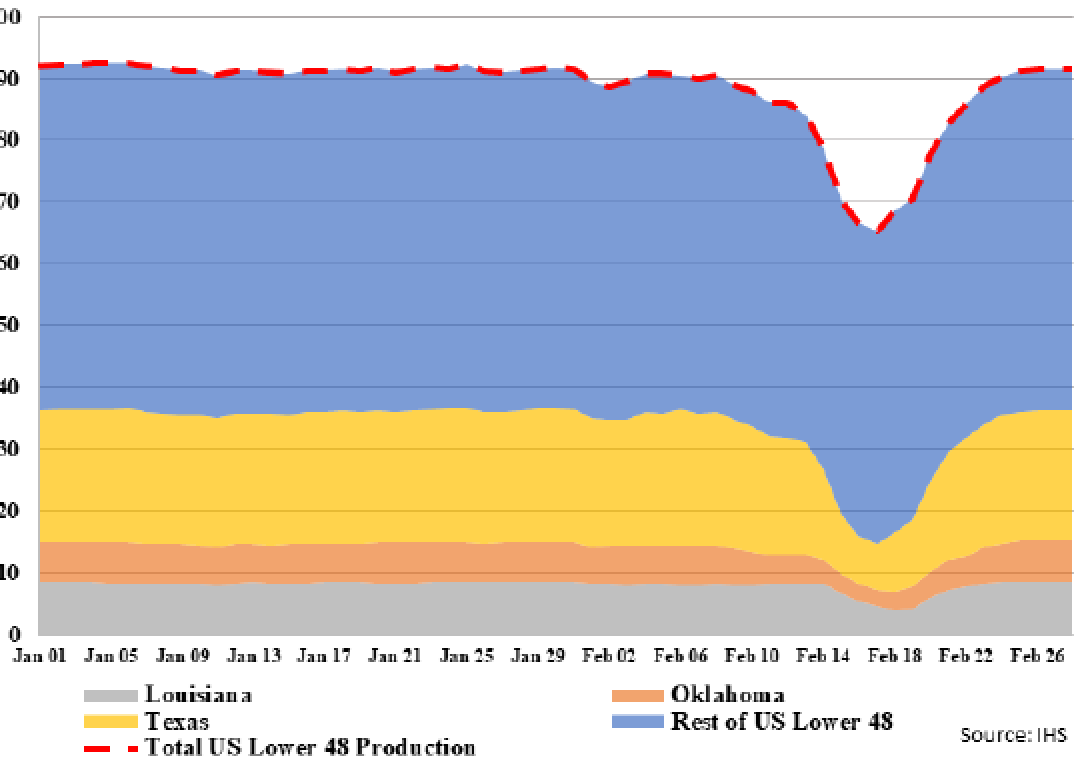


Figure 2.12: 2021 Natural Gas Freeze-In

ERCOT 2011

A cold snap in ERCOT during February 2011 created challenging conditions for electricity generators. The reduction in available natural gas supply, shown in **Figure 2.13**, was identified as a significant root cause, as described below:

- Both the San Juan Basin in northern New Mexico and the Permian Basin in west Texas and southeastern New Mexico tend to experience production declines with low temperatures, and the February [2011] event was no exception. The declines in these basins, together with the large increases in demand, were almost

[25] 1 Bcf of natural gas per day is sufficient to supply approximately 6,000 MW of efficient natural gas combined-cycle capacity for 24 hours.

[26] [FERC_ NERC(2021) at 163]

exclusively responsible for the gas curtailments in Texas, New Mexico and Arizona This weather event was so extreme that production freeze-offs were experienced not only in the San Juan and Permian Basins, but throughout Texas and as far south as the Gulf Coast.[27]

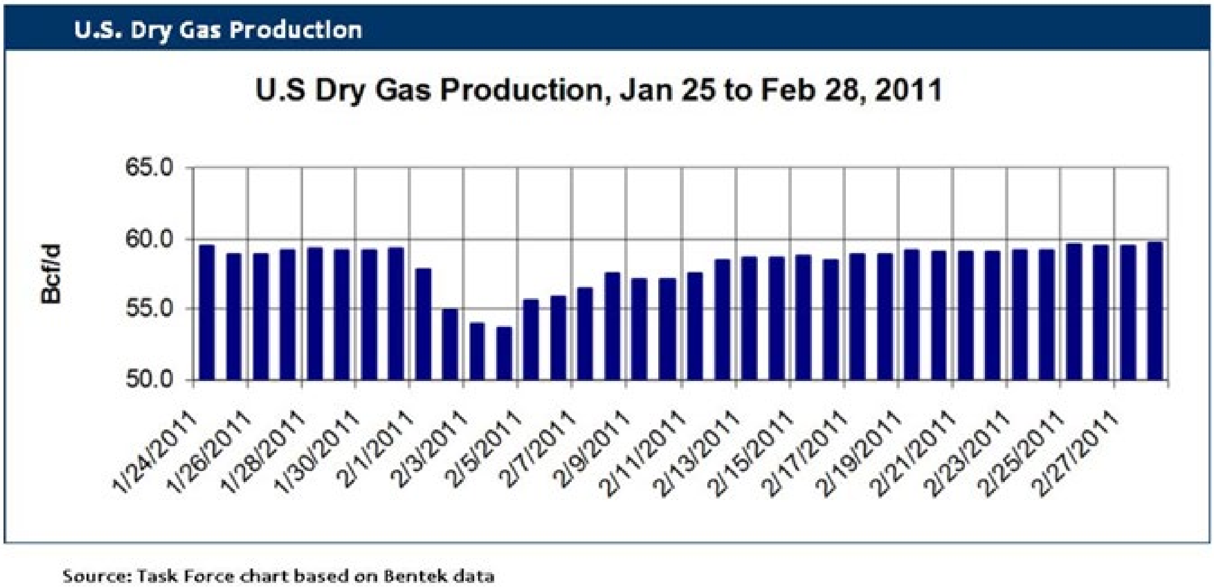


Figure 2.13: 2011 Natural Gas Freeze-In

Continuing the theme of natural gas unavailability, this tail risk was also identified as a concern in SPP, as noted below:

- The unavailability of generation, driven mostly by lack of fuel, was the largest contributing factor to the severity of the winter weather event's impacts, which was exacerbated by record wintertime energy consumption and a rapid reduction of energy imports. (Note: Up to approximately 59,000 MW of generating name plate capacity in SPP was unavailable to meet demand during the week of the event.) When generation was most needed on Feb. 16, about 30,000 MW of generating capacity was unavailable due to forced outages. The largest single cause of these forced generation outages was attributed to fuel-supply issues, causing nearly 47% of the outages and affecting over 13,000 MW of gas generation.[28]

Figure 2.13 shows the unavailability of natural gas increasing through the event with the sharpest increase beginning on February 14. Wind unavailability preceded the rise in natural gas unavailability and remained elevated throughout the event. **Figure 2.13** and **Figure 2.14** show the contribution of natural gas unavailability to the total amount of unavailable supply.

It is important to note that the electric industry does not have the ability, nor should it have the responsibility, to ensure a reliable, resilient and affordable natural gas supply. It is incumbent upon the natural gas industry to make the changes necessary to improve the supply of natural gas during extreme weather events. It is imperative that regulators understand the limitations of the electric industry in improving natural gas supply. Any new requirements

[27] Reference: Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1–5, 2011: Causes and Recommendations, Staffs of the Federal Energy Regulatory Commission and the North American Electric Reliability Corporation, August 2011, p114
FERC Outages and Curtailments Paper

[28] A Comprehensive Review of Southwest Power Pool's Response to the February 2021 Winter Storm Analysis and Recommendations, Southwest Power Pool, July 19, 2021: SPP Comprehensive Review

to improve natural gas supply need to be imposed upon the gas industry and not the electric industry if this situation is to be improved.[29]

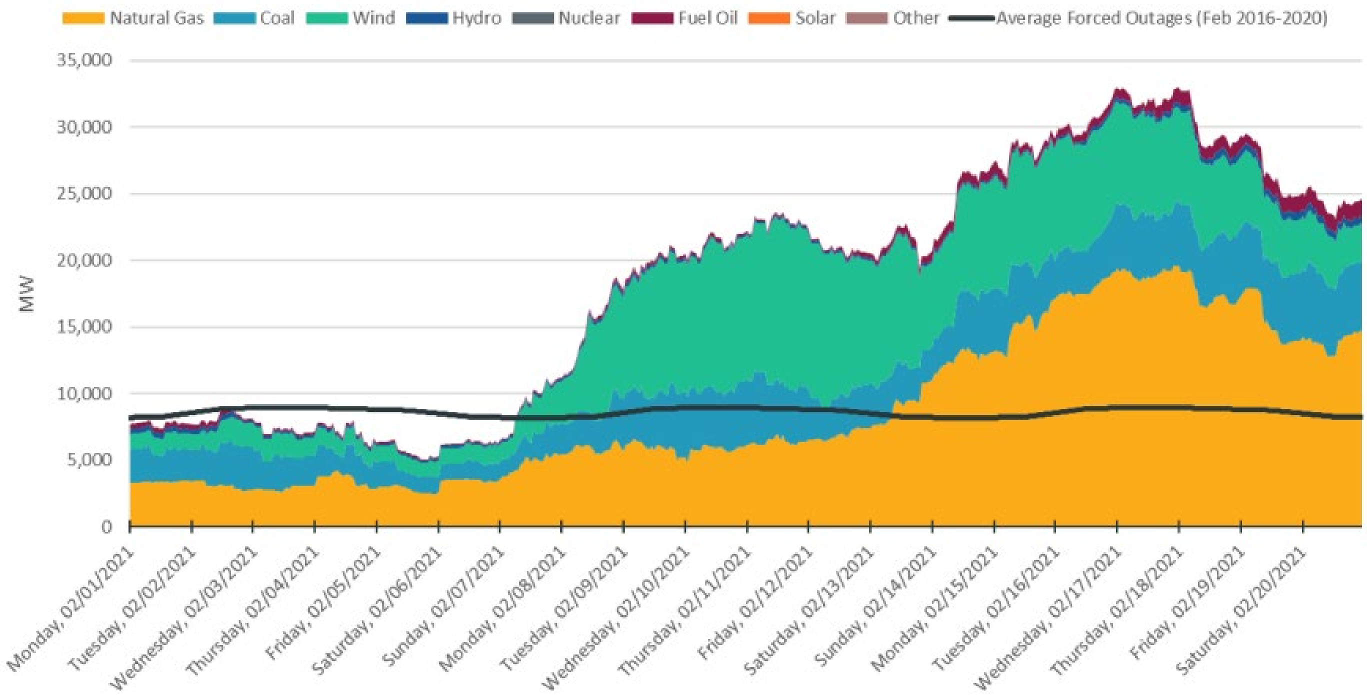


Figure 2.14: Unavailability by Source of Energy

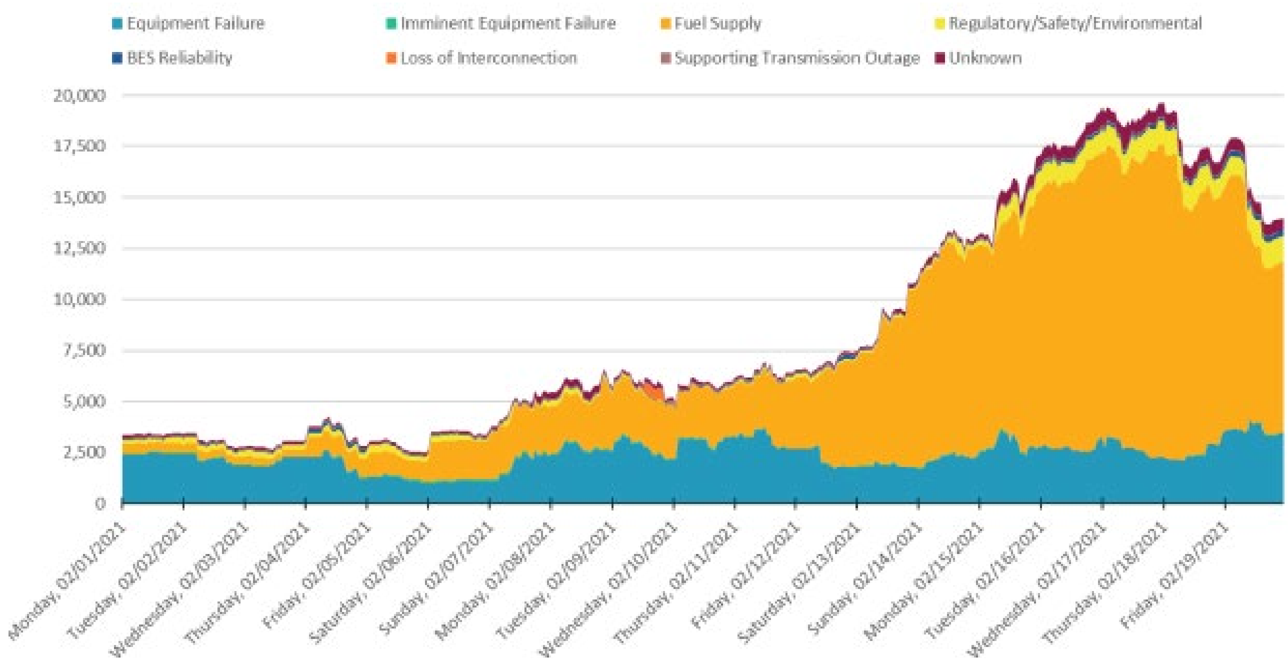


Figure 2.15: Unavailability of Natural Gas Generation Outages

[29] A Comprehensive Review of Southwest Power Pool's Response to the February 2021 Winter Storm Analysis and Recommendations, Southwest Power Pool, July 19, 2021: SPP Comprehensive Review

Variable Energy Resources

The desire to decarbonize the power sector, coupled with declining capital costs, has resulted in the deployment of large amounts of wind and solar resources. These VERs are dependent upon weather conditions and exhibit a high degree of correlation over a relatively large footprint. Additionally, the timing and amount of energy available from wind and solar resources is not well correlated with customer demands. With increased penetration of these resources and their displacing dispatchable resources, the risk of mismatch between when the energy is available and when the energy is needed by customers increases.

In the event of wind lulls or periods of decreased solar energy production, additional sources of energy need to be dispatched to maintain a reliable system. Because of the large footprint that will be subjected to similar weather conditions, the risk of widespread lulls that lead to simultaneous decreases in output requires the amount of installed dispatchable resources to remain relatively constant or decrease only slightly. Further, transmission options should be considered that can bring in energy resources when they are needed from areas that have excess energy available. Because of the uncertainty in weather and the relatively weak correlation to load, uncertainty of VER output is likely to be the dominant source of tail risk in the future. Because of this uncertainty and the interconnected nature of the power grid, analyses should include a risk perspective across relatively wide footprints.

Interconnection Support and Tie Benefits

In reliability studies that have been dominated by dispatchable resources, the interconnection support that can be obtained from neighboring regions has frequently been included. This support has the theoretical underpinning that arises from both the load diversity across a large footprint as well as the random and independent outages of dispatchable resources. With these two assumptions, there is a significant probability that the neighboring system would have surplus resources that could be used to assist when needed.

These load diversity and independent random outage assumptions are reasonable for a weather-driven system in which weather primarily affects the loads across neighboring areas.

However, as renewable resources among all the interconnected neighboring systems increasingly become weather dominated, the assumption that a neighboring system will have surplus resources to supply may become more tenuous. Weather-dominated conditions over a large footprint can lead to wide-area wind or solar lulls that could inhibit the ability to provide mutual assistance.

Energy Storage

The lulls associated with the reduced output from VERs amplify the uncertainty associated with energy availability. Because reliability models have traditionally been focused on random independent outages of dispatchable resources, the chronological aspects of energy availability did not play a prominent role in most reliability modeling.[30] A justification for this was that many of the energy limitations could be managed through better dispatch of the relatively smaller population of energy-limited storage resources given the available dispatchable resources.

For example, low-hydro conditions could be reflected by lower seasonal ratings, reflecting decreased reservoir heads as well as limited dispatch flexibility. Low-hydro reservoir storage due to droughts or limited energy in pumped storage reservoirs or batteries could be managed by dispatching their limited energy at the hours of greatest need.

However, as the risk of wind and solar lulls materialize in a simulation and potentially transform into wind and solar droughts, the amount of energy needed to be withdrawn from storage increases. The longer the lulls continue, the more energy needs to be withdrawn. Assuming the energy storage facilities are limited in size and need to recharge, they could become depleted, possibly resulting in a deficit of available resources. Therefore, as the amount of storage

[30] While reliability models have attempted to reflect chronological needs by using parameters, such as mean-time-to repair, the influence of this type of parameter over many Monte-Carlo replications was usually lost in the average's summary statistics.

increases and displaces fossil-fuel-based dispatchable resources with access to large inventories of stored energy, the energy drawdown and replenishment may create a significant risk vector. Such limitations would need to be represented better in reliability models. Energy storage is currently an active area of development by reliability model vendors.[31]

The risks associated with these energy issues are difficult to reflect because the inter-temporal aspects are typically outside the scope of reliability studies. Reliability studies evaluate the risk of loads plus a minimum amount of reserve exceeding available resources due to random and independent mechanical unavailability. In the case of energy storage, the decisions to withdraw stored energy to serve load, retain the stored energy for future contingency events, or replenish the state of charge of the stored energy have not been a core function of a reliability simulation model. Representation of the weather-driven severity, duration, and geographic footprint of stored energy drawdown needs to be based on realistic assessments of past weather and reflect possible future trends.

Location of Critical Loads

The locations of critical loads for hospitals and schools are important for managing systems in a degraded state. However, another aspect that has caused concern is the location of electricity-driven natural gas compressor station loads as noted below:

Interruption of Critical Load

During the load-shed events, there were concerns from TOPs that natural gas compressor station loads may be curtailed, exacerbating the fuel shortage issue and causing a need for additional load shed. There are additional concerns that these critical loads do not have adequate backup plans to continue operating in the event of a loss of interconnection to the grid such as gas fired compression. Reliance upon the electric grid to power compressors will lead to interruptions in service due to other forced outages not initiated by the TOP.[32]

Contingency and Robustness

Unlike wind droughts and weather-driven load excursions that can be alleviated by having more resources, some tail risks may not be avoidable. These risks can be in the form of hurricanes, tornadoes, earthquakes, and/or fires; these risks cannot be directly mitigated by having more installed resources. Risks like these require different remedies, such as workable restoration procedures or the positioning of restoration tools, labor, and equipment.

Other tail risks that can create unreliability, such as the loss of long lead-time replacement components (e.g., power transformers), can be addressed probabilistically but are outside the scope of a resource adequacy analysis.

Reliability Criterion

The reliability criterion that has traditionally been used for resource adequacy is 1-day-in-10 years for interruption of firm load due to insufficient resources. This criterion was developed to address unavailability due to random and independent outages of traditional dispatchable resources. In practice, this criteria risk has rarely been encountered and outages have mostly been due to other factors such as storms and fuel delivery problems that are outside the scope of traditional reliability models.

However, with an increased emphasis on VERs whose output is dominated by weather patterns that can extend over a very wide footprint, it is likely that the wind and solar lulls may become more constraining and interruption of firm load due to insufficient resources may increase. Addressing this form of resource unavailability for high penetrations of these resources is an emerging concern.

[31] See NERC Battery Storage Report.

[32] SPP Winter Storm Document p 57/109

This white paper has touched on several potential reliability criteria that could be used. For example, EUE is one of the metrics that can capture the amount of energy that could not be served due to insufficient resources to serve the loads. The concept of applying a more stringent criterion to compensate for additional tail risk was also discussed. Regardless of which metric is selected as the reliability criterion of choice, they all have the same general characteristic: when the system is adequate the risks are relatively small and when the system risks increase the metrics increase rapidly. The threshold when a criterion indicates that risks have risen and actions need to be taken depends in part on what is included in the underlying risk analysis. Every additional risk factor that is considered in a resource adequacy analysis raises the resulting metric. The benefit of discussing tail risk is that it crystalizes the awareness that risks are looming in the future.

Independence of Risk Factors

Scheduled maintenance outages are not included in resource adequacy analyses even though they can have a significant impact. For example, resources could be scheduled out for maintenance and then unseasonable weather could occur. With climate change, weather patterns could emerge and very early summer weather, very late summer weather, very early winter polar vortices, or very late polar vortices could arrive and create challenging operating conditions. Tail risk could, therefore, occur when those events occur with significant amounts of resources on scheduled maintenance.

Chapter 3: Simulation-Based Approaches for Extreme Weather

This chapter will discuss the approaches to setting up a study regarding "tail" events that are typically related to extreme or unusual weather. The process used to investigate tail risks is like that used to investigate other emerging risks to the electric grid. The ProbA analyses undertaken by the PAWG embodies the current best practices and modeling approaches to analyzing risks by collectively discussing risks, sparking discussions about what might occur that is not explicitly analyzed in the base ProbA cases, and having PAWG members select issues that appear to be relevant to their system.

These results are then peer reviewed by other PAWG members. By this method, trends that begin to emerge in one area can be shared and inspire other analyses to enhance probabilistic resource adequacy planning processes.

Because tail risks are typically related to time-limited windows of varying durations, incorporating the results into an annual analysis may result in the significant masking of the effect being evaluated. Consequently, tail risks are probably best represented as scenarios of time-limited windows. However, if the tail risk occurs at a time that coincides with a critical period of need, such as hot or cold weather, and there are not any common-mode failures driving the analysis, it may be appropriate to reflect the tail risk in an annual assessment. For example, if hot summer weather is expected to be increasing in magnitude, then incorporating the risk into an annual reliability analysis that would increase installed reserves could be appropriate.

Additionally, care should be taken to understand the risk factors that are being evaluated. Causal analysis of statistics may indicate a statistical relationship between a condition and a statistic, such as EFOR. Without a clear understanding of the underlying root cause of the statistical relationship, erroneous conclusions may be inferred, and inappropriate remedies suggested. For example, in the event a statistic shows an increase in EFOR with cold temperatures, adding more resources with the same vulnerability may not produce the desired improvement because the additional resources also may not be properly insulated and winterized.

Fuel Risks Related to Severe Cold Weather

As illustrated in the previous chapter, tail risks come in many different forms and are generally correlated to weather-related events. For example, freezing conditions may inhibit fuel processing such as well-head natural gas production and extraction of fuel from storage and/or generate problems related to combustion at the burner tip.

In addition to fuel supply issues, fuel delivery systems may be inadequate for simultaneous delivery of fuel to electric power generators. Typically, this is discussed and characterized as a pipeline limitation; however, delivery of fuel oils via truck can create a significant bottleneck during a prolonged cold snap when fuel inventories at home and commercial, industrial, and electric generators are depleted and require timely refills.

Natural gas infrastructure is a common carrier that supplies natural gas energy for a wide range of customers from residential customers to electric generators. This infrastructure has traditionally been built and funded by natural gas distribution companies that consequently have priority rights to the transportation services provided by the pipelines. These priority customers generally have sufficient unused pipeline capacity to enable electric generators to use their transportation resources on an as-available basis. While some electric generators may have affiliates that provide firm supplies and transportation, this is not a widespread practice. Thus, natural gas may become unavailable due to the competing demand of other parties with higher contractual priorities. Because FERC regulations require unused natural gas pipeline capacity to be released to other customers when not needed, only firm contracts by electric generators that result in enhancements to natural gas pipeline and supply infrastructure will improve the robustness of natural gas supply to those electric generators.

Modeling Recommendations

To analyze these risks, existing tools need to be augmented to represent fuel limitations. This can be done via scenario analysis in which specific amounts of vulnerable resources are removed from service. Using a national fuel model that simulates fuel supply, demand, storage, and pipelines may be one way forward. A wide-footprint model of this complexity might be needed to predict fuel limitations because of the potential effects of temperature on natural gas availability. In addition to temperatures, winter precipitation may also inhibit adequate fuel replenishment. A front-end, pre-processing model that could translate temperatures to fuel availability would be ideal. Additionally, a scenario model that would progress through time to capture the depletion of energy reserves would be helpful.

Moderate Cold Weather-Related Risks

Severe weather is not the only cold-weather risk that may occur. Moderate cold weather-related risks in the form of ice storms are emerging due to their effects on the wind generators. Icing of wind generating resources was identified as a cause of significant unavailability in the February 2021 event in the South-Central United States. While there is a significant interest in extreme temperature events, the impacts of ice storms are much more difficult to forecast.

Modeling Recommendations

Because the effect of this type of weather risk would have a limited duration and the scope of the outages is not easily determinable from historical data, scenario analysis for a focused time-limited duration analysis would be warranted.

Severe Cold Weather-Related Non-Fuel Risks

Severe periods of cold can also result in increases in electric demands. With the emphasis on electrification of natural gas, oil, and resistance electric heating systems to energy-efficient electric heat pumps, these periods can result in significant additional loads while fuel supply issues may emerge.

Modeling Recommendations

The increase in loads can be analyzed via scenario analysis. Incorporating a cold-weather event in an annual analysis would lead to the effect being diluted. Consequently, a focused, time-limited duration analysis would be warranted.

Severe Hot Weather-Related Risks

Severe periods of hot weather can also result in increases in electricity demand. Unlike the severe cold-weather risks, natural gas demand during these hot-weather events would only be constrained during pipeline-maintenance conditions. However, hot-weather events pose risks for stored energy resources such as hydro reservoirs, pumped storage reservoirs, and other sources of energy storage such as batteries.

Modeling Recommendations

This can be analyzed via scenario analysis. A front-end, pre-processing model that could translate temperatures to a scenario model that would progress through time to capture the depletion of energy reserves would be helpful. Incorporating a hot-weather event in an annual analysis would lead to the effect being diluted. Consequently, a focused, time-limited duration analysis would be warranted.

Scheduled Maintenance of Unexpected Weather

Scheduled maintenance outages are a difficult problem for reliability analyses because of the many management decisions that affect the timing and duration of these outages. Because of the long lead times for scheduling maintenance and securing the appropriate skill sets and repair/refurbishment resources, these schedules are frequently inflexible. If either cold or hot weather occurs when a significant number of resources are out of service for maintenance, reliability could be at risk.

Modeling Recommendations

This can be analyzed via scenario analysis. A front-end, pre-processing model that could estimate known or expected scheduled maintenance would be able to provide insights. Consequently, a focused, time-limited duration analysis would be warranted.

Chapter 4: Interpretation of Probabilistic Indices for Extreme Weather

The NERC PAWG performs a ProbA[33] to supplement the annual deterministic NERC Long-Term Reliability Assessment (LTRA) analysis. The ProbA calculates monthly EUE and LOLH indices for 2 years of the 10-year LTRA outlook. Complete details and underlying assumptions of the ProbA Base Case analysis are included in the published LTRA reports. The ProbA analysis contains two studies that consist of a Base Case and a Sensitivity Case. The two differ in that the Base Case contains assumptions under normal operating conditions while the Sensitivity Case characterizes "what-if" probabilistic analysis terms.

Tail risks, such as those discussed in this white paper, are similar in construction and interpretation to the Sensitivity Cases, but a tail risk analysis studies something different. Tail risk analysis is intended to include additional risk factors to reveal the reliability implications across all hours with probabilistic methods. In many cases, time-limited windows focus on specific periods of a year where a risk or vulnerability might occur. The PAWG believes this approach to be of higher value than standardizing a Sensitivity Case study to capture the varied and complex reliability risks across Reliability Coordinators. Planning engineers use both expected outcomes as well as scenario cases.

While extreme weather scenarios represent an analysis into potential reliability risk factors, there is no guarantee or indication that these scenarios are indicative of future occurrences. However, these results are used to inform system planners and operators about potential emerging reliability risks. The PAWG recommends considering these tail risks in future probabilistic resource adequacy studies to develop further guidance for future work activities, when key points and takeaways are called out.

Reliability Metrics for Tail Risks

With the growing penetration of VERs in comparison to traditional base-load resources, either as load reducers or as supply, hourly variations in load and supply will become less predictable. Time series models that more accurately reflect the behavior of stochastic processes, such as the variations in wind speed and solar variations as well as assessment of the contributions and limitations of energy storage, may become more prevalent in probabilistic assessments. This change in modeling may, in turn, result in metrics like LOLH and EUE, which capture hourly variations in system conditions, becoming increasingly meaningful for measuring the reliability of the system. LOLH and EUE provide insight to the impact of energy-limited resources on a system's reliability, particularly in systems with growing penetration of such resources.

EUE, along with the value of load loss, can be used to perform the following actions:

- Monetize the cost of load loss to justify, prioritize, or rank transmission or other capital projects.
- Form the basis of a reference reserve margin to determine capacity credits for VERs.
- Quantify the impacts of extreme weather, common-mode failures, etc.

The focus of this section is three-fold: it surveys the electric sector's existing and future use of probabilistic studies to investigate BPS risks to reliability, it tracks evolving emerging trends, and it identifies applications for the electric sector to use known reliability metrics to assess emerging issues.

While many of the traditional probabilistic reliability metrics are useful for analyzing tail risks,[34] EUE may be the most relevant metric for understanding and comparing the severity of degraded-state tail risk events. Simulations should proceed until the system is restored at the end of the extreme weather event, so load can be lost, recovered, and

[33] Probabilistic Adequacy and Measures Technical Reference Report Final, July, 2018
[34] EPRI RA for a Decarbonized Future 2022 white paper

lost again depending on if the chosen extreme weather is expected to last significantly long (e.g., heat wave, downing of power lines over water like in the New Orleans event).

Description of Output

While the output of studies using methods in **Chapter 2:** will produce probabilistic indices, it may not be appropriate to compare the observed risk sensitivity to the ProbA base cases or another annualized metric.

Because these are tail risks, the metrics are conditional probabilities associated with a low relative probability. This conditional probability can be interpreted as the assumption that an extreme weather event is coming. Therefore, the resulting reliability indices do not reflect the actual expected probability that "extreme weather could occur and result in the risk of operating in a degraded state." Rather, it is the impact given the extreme weather occurred.

Operating in a Degraded State

Normal long-term resource adequacy plans include allowances for load and capacity relief via "emergency operating procedures." Because tail risks manifest themselves as reliability events when compounding events become so severe or pervasive that they overwhelm the reserve and contingency plans embodied in "traditional" resource adequacy plans, it may become appropriate to develop quantifiable "long-term emergency recovery procedures." Including such recovery procedures and reporting on their potential implementation can quantify a system's resilience against the identified tail risk.

Due to the infrequent and uncertain nature of whether an extreme event will occur, the appropriate planning may not be to install additional supply resources; it could be to react with a methodical and planned response while operating in a degraded state that minimizes the impact across the affected area without unnecessarily inflicting undue hardship on a limited subset of customers. This would depend on the type of load not served and the length of time that the load would not be served.

The addition of weather-related risks might necessitate the formal recognition of responses and development of emergency operating procedures to address these additional risks. For example, consider a customer with an electric heat pump for heating in the winter: they are concerned about a widespread ice storm outage that would be coupled with "normal" cold and result in days or weeks of outages such that their heat pump could not warm their home. Greater penetrations of heat pumps in the Northeast could lead to an auxiliary "emergency electrical distribution system recovery arm of fire-departments," or something similar, being added to the emergency operations. NERC encourages resource planners to develop such strategies in discussions with Transmission Planners and Planning Coordinators to plan for future-year operators to operate the system in potential emergency conditions.

Interpretation of Probabilistic Studies to Assess Tail Risk

Previous NERC assessments showed the need to support probability-based resource adequacy assessment due to a changing resource mix with significant increases in energy-limited resources, changes in off-peak demand, and other factors that can influence resource adequacy. As a result, NERC is incorporating more probabilistic approaches into its assessments, including the development of this report. The NERC PAWG examined the use of probabilistic studies for assessing emerging reliability issues.

NERC's goals, outlined in the operating plan,[35] include identifying, assessing, and prioritizing emerging risks to reliability by using probabilistic approaches to develop resource adequacy measures that reflect variability and overall reliability characteristics of the resources and composite loads, including non-peak system conditions. NERC's intent is to perform the following actions:

[35] https://www.nerc.com/comm/RISC/Related%20Files%20DL/ERO-Reliability-_Risk_Priorities-Report_Board_Accepted_February_2018.pdf

- Educate policymakers, regulators, and industry on the relationship of on-peak deterministic reliability indicators (e.g., reserve margin) to 8,760 hourly probabilistic reliability indicators (e.g., LOLH).
- Develop a catalogue of tail risk scenarios that can be applied to many areas that consider a wide range of risks.
- Create a catalogue of scenarios that builds in regional, and climate-model driven extreme events.
- Develop a screening tool to identify potential risks and suggest the need for additional study years or ad-hoc regional assessments.
- Work in tandem with LTRA annual results.
- Develop a collective understanding of existing applications of probabilistic techniques used for reliability assessments and planning studies.
- Identify commonalities to inform industry on the applications of probabilistic reliability metrics.
- Provide guidance on the development of probabilistic methods for ensuring resource adequacy and reliability to allow better risk-informed decisions for planners and policymakers in the face of increasing uncertainty of supply and demands on the BPS.