RESOURCE ADEQUACY FOR A CLEAN ENERGY GRID

TECHNICAL ANALYSIS

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This memo answers questions on resource adequacy with high renewable energy penetration.

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This memo answers questions on resource adequacy for a clean energy future. Our analysis is based on reviewing and participating many region-wide and utility-specific resource adequacy modeling exercises. In summary, we conclude:

1. As the resource mix changes and decarbonizes, so do the system needs for reliability. The proliferation of variable renewable energy, energy storage, flexible load, and fossil retirements are altering the way resource adequacy analysis needs to be conducted and the way it is translated to procurement decisions and capacity accreditation.
2. Conventional resource adequacy metrics (LOLE, LOLH, LOLP) only count the number or probability of shortfall events. They provide little or no information on the size, frequency duration, and timing of the shortfalls. With increased variable renewable energy and energy limited resources, this information is critical to ensure the right resources are selected for the reliability needs.
3. Modeling tools must also adapt. Sequential Monte Carlo analysis – which chronologically evaluates each hour of the year across many years of weather data (wind, solar, load) – is necessary.
4. Peak reliability risk is no longer isolated to peak load hours. In the near-term, risk is shifting to net-load peak but will eventually shift to multi-day periods of low solar and wind output, often occurring in the winter.
5. Capacity accreditation is increasingly complex due to saturation effects (decreasing capacity credit at increasing penetrations) and portfolio effects (changes to individual resource capacity credit due to changes in the underlying resource mix). As a result, ELCC may be sufficient for near-term resource accreditation, but has limitations for long-term planning.
6. If ELCC is used as the methodology, it should be applied consistently across resource types. This includes accounting for potential fuel supply disruptions, ambient derates, and increased outage rates during extreme weather.

7. Transmission is an important mitigation for resource adequacy, allowing for geographic diversity in weather, load, and renewable resource availability. Increased transmission should be evaluated as a capacity resource to meet reliability needs.

Resource Adequacy Need Determination

1. How are resource adequacy needs determined?

Underpinning any capacity accreditation mechanism — whether it be a mandatory capacity market auction in Northeast ISOs or integrated resource planning for vertically integrated utilities — is technical resource adequacy analysis and modeling.

Resource adequacy (RA) analysis utilizes modeling conducted to measure whether the system has enough resources to serve load under a wide range of potential future system conditions. RA analysis considers potential variations in system load, fluctuations in weather and corresponding availability of variable renewable energy (VRE) resources like wind and solar, and planned and unplanned generator outages. By utilizing statistical techniques, the analysis measures the probability, or expectation, that the system has insufficient resources (i.e., capacity) to meet load.

When evaluated across many simulated years of various weather and generator outages, the count of days that experienced some level of capacity shortfall is summarized as the Loss of Load Expectation (LOLE). The LOLE metric is commonly utilized as a resource adequacy criterion (e.g., a 1-day-in-10-years LOLE requirement) in many jurisdictions across North America.[1]

It is important to clarify that resource adequacy analysis simply measures the risk of a power system not meeting load. It can quantify the likelihood of shortfall events and the magnitude of those events, but it does not, by itself, determine the amount or characteristics of required resources. To determine requirements, the resource adequacy analysis – which is measured in a probability of not having enough resources to serve load - must be translated into capacity needs. In many jurisdictions this is done via the planning reserve margin (PRM), which quantifies the amount of surplus capacity (MW) relative to peak load that is required to meet a 1 day in 10 LOLE target, is the metric used to determine total system need. Because different resources have different operating characteristics and availability, estimated contributions to the PRM from each resource need to be determined. We call contributions accreditation metrics, often measured as their "capacity value."

In many regions, a planned reserve margin around 15 percent has been deemed to be sufficient to achieve the desired probability of meeting load under conditions of long-lasting and sudden generator outages and interannual variation in peak load, given a typical resource mix of coal, gas, nuclear, and hydro. In regulated vertically integrated utility systems, the PRM is used for integrated resource planning and procurement. In deregulated ISOs and RTOs with capacity markets, it determines the amount of capacity required via an administrative demand curve.

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1 Additional information on resource adequacy metrics is provided in Question 3.

Because not all resources have the same expected performance during shortfall events, different resources are accounted for differently. In these cases, a resource is accredited a certain amount of "firm capacity" that counts towards the planning reserve margin. For example, fossil fuel-fired generators may be counted as "unforced capacity" (UCAP) that discounts the firm capacity of the resource by the generator's forced outage rate (unplanned outages). For variable renewable resources, the generators are often discounted based on their availability during likely shortfall events.[2]

As a result, the resource adequacy analysis, which measures system risk, is translated to system needs via the planning reserve margin (in most jurisdictions), and resource accreditation. The tight coupling of resource adequacy, PRM, and resource accreditation is an important underpinning of most resource adequacy regimes.

However, as the resource mix is changing, so are the system needs and reliability. The proliferation of variable renewable energy, energy storage, flexible load, and fossil retirements are altering the way resource adequacy analysis needs to be conducted and its translation to resource adequacy needs and accreditation.

2. How are system needs shifting, and what does that mean for resource adequacy?

Historically, resource adequacy analysis was relatively straightforward. The traditional resource mix was composed predominantly of large, nuclear, coal, and natural gas generators without significant fuel constraints. As a result, the reliability of the system was largely dependent on the planned maintenance and unplanned forced outages. The resulting system's reliability risk was almost always concentrated in a few peak load days and hours of the year. Because the resource availability of fossil-fired units were assumed to fluctuate randomly (due to forced outages), the analysis assumed that if there were enough resources to serve peak load conditions, there would also be sufficient resources the rest of the year.

The changing resource mix is changing the way resource adequacy needs to be evaluated. For instance, wind and solar resource availability is not as much a function of maintenance and outages (which is not a concern due to the modular nature of the resources), but rather a function of the underlying weather conditions. In addition, the availability of energy storage resources depends on their ability to charge during low load or high renewable hours and the duration of potential shortfall events. The same can be said for load flexibility and demand response. In a high renewable system, the periods of risk may no longer be the typical peak load conditions but may become more aligned with resource availability and the underlying weather conditions.

Numerous studies show that very high levels of renewable penetration can be achieved reliably and consistent with electricity rates at or close to current levels. When aggregated over large geographic areas, a significant share of wind and solar capacity can be relied on to meet resource adequacy needs. However, the consensus of modeling efforts suggests that relying on wind, solar, and short duration storage to meet 100% of resource adequacy needs is not economic due to their declining capacity value at higher penetrations.

2 Additional information on accreditation methods is provided in Question 10.

Plots of wind and solar output over time reveal the very large contributions of those resources, and the occasional use of firm backup resources. Across many studies, it tends to be the existing gas fleet that operates at reduced levels but stays available for those rare instances. In the future, "clean firm" sources may be needed to fully decarbonize. The figure below shows wind in green and solar in red, complementing each other, and storage in orange covering ramps and shoulder times. The gray area shows how the existing gas fleet can be used as a dispatchable source of stand-by power to fill remaining gaps. However, the compensation schemes may need to change in order to ensure backup capacity is available when needed.

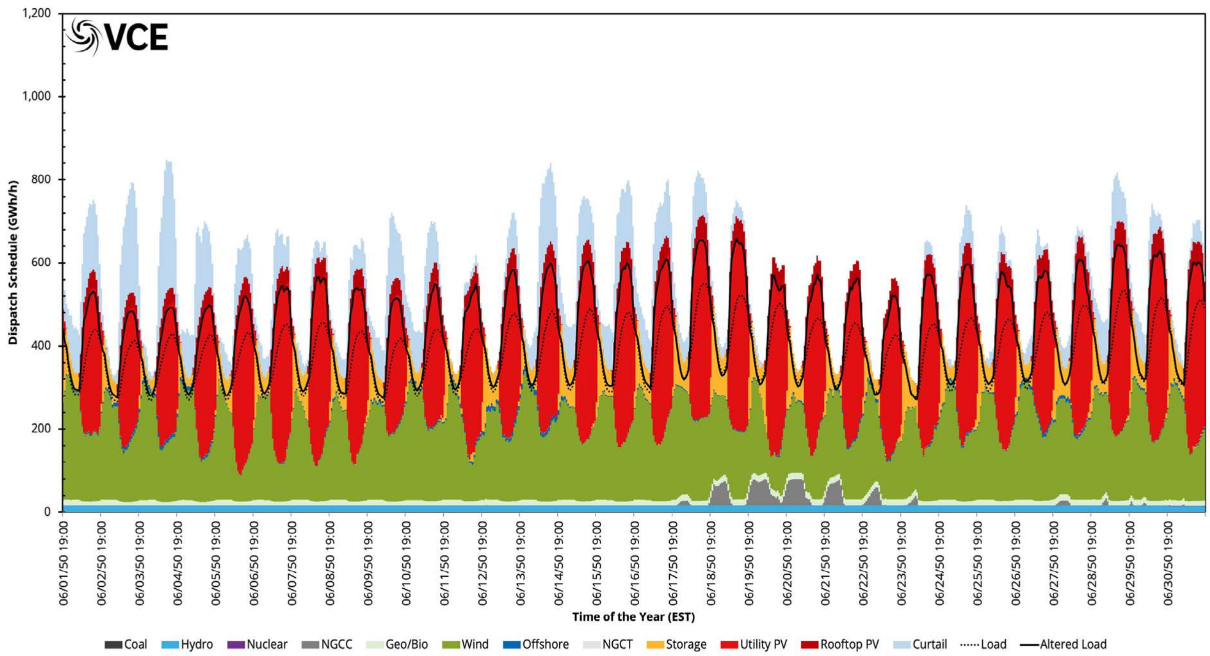

FIGURE 1. *Modeled output by resource for June 2050 in the eastern interconnection. Source: VCE*[3]

The main thrust of resource adequacy is how to ensure enough resources are available at those times when wind, solar, and gas output fall short of meeting demand. A key policy objective for renewable energy interests is to do that in a way that recognizes renewables' contributions and does not discriminate or impose barriers to entry.

The increased role of wind, solar, storage, and load flexibility requires the industry to rethink the way reliability planning and resource adequacy methods are considered and how analysis should be conducted. As the NERC Integrating Variable Generation Task Force concluded, "planning reserve margin, calculated as a percentage of system peak, will become less meaningful with large penetrations of [variable generation]."[4] This confluence

3 Clack et al., *Consumer, Employment, and Environmental Benefits of Electricity Transmission Expansion in the Eastern U.S*, October 2020.

4 North American Electric Reliability Corporation, "Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning," March 2011.

of changes requires new data, methods, and metrics to better characterize evolving risks.

But these shifts are not just due to renewables. The system's resource mix in many regions is also shifting away from a relatively diverse supply of thermal generation (coal, nuclear, natural gas) and becoming more dependent on natural gas. As NERC has stated, "The electric power sector is now tightly coupled with the natural gas delivery system, which delivers fuel on demand, with little or no storage located at the power plant. As a result, correlated outages due to fuel supply failures is now a key reliability risk, especially during the winter months when multiple power plants may experience interrupted fuel supplies simultaneously."[5]

System needs are therefore shifting and becoming more regional. Resource adequacy risk is no longer just about the peak-load hours. In some regions, "peak risk" may no longer be synonymous with peak load and is shifting later in the day, outside of the mid-day solar period and into the evening peak net-load period. In other regions, resource risk is shifting to the winter months due to fuel availability and increasing electrification. Still further, some regions may experience increasing risk in historically low load months, as planned maintenance periods for thermal generation may be challenged if there is an unexpected multi-day lull in wind and solar availability.

These changes in the resource mix are precipitating a need to fundamentally rethink the way we conduct resource adequacy analysis, and the way capacity procurement, accreditation, and markets are designed. For more information on the shifting risk and the traditional resource adequacy analysis problems and their causes, please refer to the recent Energy Systems Integration Group (ESIG) paper on "Redefining Resource Adequacy for Modern Power Systems."[6]

3. Which resource adequacy metrics are useful for systems with high penetrations of renewable energy and energy storage?

One way resource adequacy analysis and market design may require adjustment is in the resource adequacy metrics that measure system risk. As discussed previously, a common resource adequacy criterion used throughout most of North America is a "1 day in 10 years" (or 0.1 days/year) LOLE, which counts the average number of days per year when there are insufficient resources to serve load (shortfall event). However, this reliability criterion was developed in the middle of the 20th century, with limited rationale as to how the criterion was selected, and with limited evaluation of the costs and benefits of reliability.

Alternative metrics include loss of load events (LOLEv), which counts the average number of events per year, loss of load hours (LOLH), which counts the average number of hours of shortfall per year, and loss of load probability (LOLP), which translated the metrics into a probability between 0 and 1 of a shortfall event occurring.

But these metrics can be opaque when used in isolation as they only count the number or probability of shortfall events. They provide little or no information on the size, frequency

5 North American Electric Reliability Corporation, "Integration of Variable Generation Task Force: Summary and Recommendations of 12 Tasks," pp. 21, June 2015.

6 Energy Systems Integration Group, "Redefining Resource Adequacy for Modern Power Systems," August 2021.

duration, and timing of the shortfalls. In the past, when shortfall events were solved exclusively by adding new fossil generation, this information was less important. Today, when most new capacity additions are wind, solar, storage, or demand response and load flexibility, this information is critical. For example, a shortfall of 1 percent of load for 10 hours is measured the same way as a shortfall of 10 percent of load for 10 hours. These disparate events are not differentiated well by conventional resource adequacy metrics even as they represent dramatically different situations in terms of options for meeting demand in today's power system.

Expected unserved energy (EUE) is another resource adequacy metric commonly calculated in resource adequacy analysis, but rarely used as a reliability criterion. Because EUE measures the amount of unserved energy, as opposed to the count of shortfalls, it may be a better measure of system risk and capture the implications of energy limitations on storage and demand response. Figure 2 shows how resource adequacy metrics can have difficulty characterizing the size, frequency, and duration of disparate events.

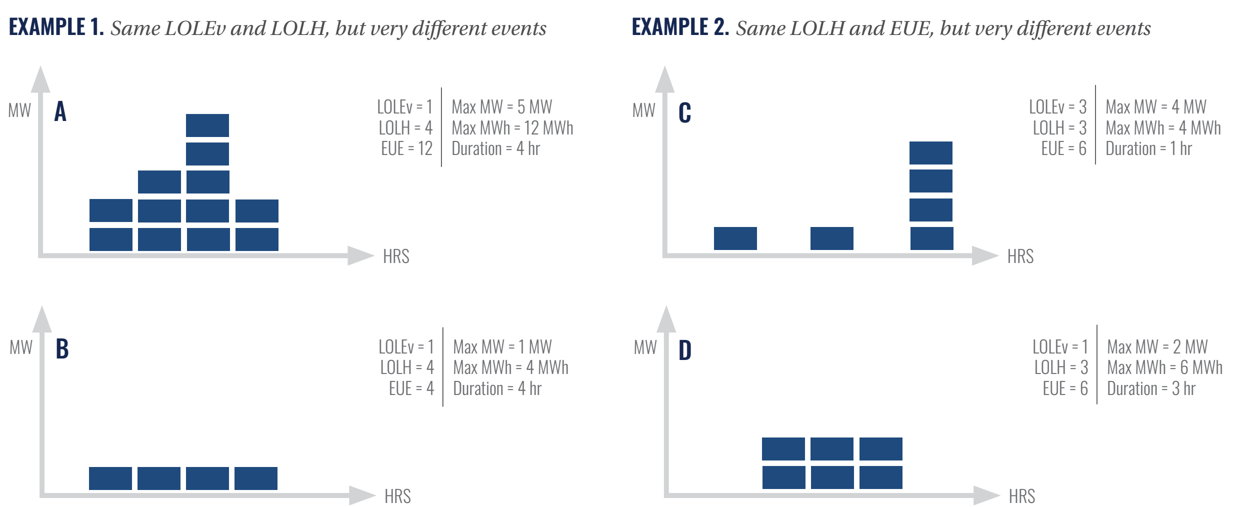

FIGURE 2. *Differentiating resource adequacy metrics by size, frequency, and duration. Source: ESIG*[7]

The planning reserve margin metric also has limitations as system risk shifts outside of peak demand periods. Reliability periods are shifting to periods with lower renewable output and to winter cold snaps as correlated outages on the fossil fleet, along with fuel supply disruptions, limit availability. The increasing need to account for correlated events and chronology makes the PRM – based solely on peak load — obsolete. A consensus is forming that PRM has to be adapted, but the final outcome is still undetermined. If the planning reserve margin is going to be continued, it may need to be adjusted to capture a wider range of system conditions, as described in the three proposals below:

- Utilize the peak net-load (net of expected wind and solar generation) rather than gross

7 ESIG, 2021

load as proposed by Southern California Edison,[8]

- Calculated for multiple seasonal and hourly time blocks (see PG&E "slice of day approach"[9]), or
- Calculated across all hours of the year (see HECO's "energy reserve margin proposal"[10])

Finally, one limitation of resource adequacy metrics like LOLE, LOLH, and EUE is they are all expected values. While resource adequacy analysis may evaluate thousands of random samples, the results are averaged and reported as a single value representing all randomized years of simulation. Over-reliance on single point, average metrics can cause planners to miss outlier tail events. Additional insight into the size, frequency, duration, and timing of shortfall events themselves can better ensure that the right "type of resource" is valued accordingly. This will help differentiate the value of short-duration resources (demand response, short duration storage, etc.) versus long-duration resources (long duration storage, thermal generation, clean firm renewables, etc.).

4. Are current industry models adequate for the task? What types of models need to be developed?

The current industry models and tools are continuing to evolve to address these challenges. Unfortunately, many of the methods and metrics used by the industry today originated in the mid-1900s and have only been improved incrementally as the resource mix continues to change. Many tools have transitioned from only evaluating peak load days/hours, to ones that evaluate an entire 8,760 hours of operation. This is a critical first step. Where there is still discrepancy between tools is how they address *chronological grid operations and correlated event*s.

Chronological grid operations are increasingly important for grid modeling generally, and resource adequacy analysis specifically. While many tools step through a full 8,760 hourly analysis with varying load and renewable availability, they differ in the ways generation is scheduled. Energy storage and demand response, for example, have energy limitations so they are often referred to as "energy limited resources." The availability of these resources in one hour is highly dependent on system conditions in preceding or following hours and days. In addition, some generating resources — like steam generators — may be highly inflexible, and while it may be technically available, there may be a risk that it cannot start in time. All of these factors require modeling be conducted in sequential Monte Carlo simulations that evaluate the actual commitment, dispatch, and scheduling of grid resources.

8 Southern California Edison Company and California Choice Association, "Track 3 Proposal for the Restructure of the Resource Adequacy Program," before the Public Utilities Commission of the State of California, 8/7/2020.

9 *See* PG&E Proposal: California Public Utilities Commission, "Decision on Track 3B.2 Issues: Restructure of the Resource Adequacy Program," 7/16/2021.

10 See HECO Energy Reserve Margin: Hawaiian Electric Company, "Grid Needs Assessment & Solution Evaluation Methodology," June 2020.

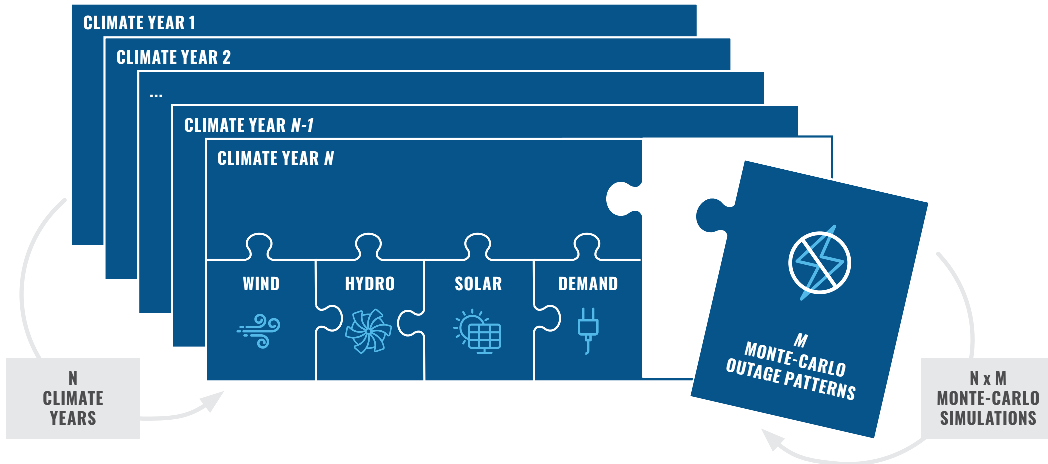

FIGURE 3. *ENTSO-E modeling example of Monte Carlo simulation principles. Source: ENTSO-E*[11]

The second discrepancy is around how modeling tools handle correlated events. In many tools, the availability of thermal generators is determined by the convolution method. This process evaluates each generator's forced outage rate and develops a probability distribution of the system's cumulative capacity on outage. Underpinning this analysis is the assumption that generator outages are purely random and uncorrelated with one another. However, during some events, underlying conditions - like extreme weather and fuel supply constraints - are a driving factor in generator outages. This was the case in the Texas shortfall events of February 2021. NERC and others have demonstrated that in many regions, large, correlated outage events occur far more frequently than would be expected if thermal generator outages were random uncorrelated events.[12]

Thus, it is important that modeling tools be capable of evaluating chronological grid operations and correlated outages. Stakeholders should ensure accurate representation of these drivers, and their impact on different resource types, when they are used for procurement and accreditation decisions.

Often the limitations are not just a factor of the tool being used, but also a function of the planning metrics being reported (previous question) or the data being utilized (following question).

5. **How can weather data be better incorporated into RA modeling and accreditation?**

While the previous question evaluated potential limitations in modeling tools, the related input data and assumptions must also be considered. There is consensus among the system planners that weather data used for resource adequacy analysis is an increasingly important, if not the most important, data need. For example, it is critical that multiple years of correlated wind, solar, and load be considered in the analysis to determine that weather effects are properly evaluated across a wide geographic footprint. It is also important to

11 ENTSO-E, Mid-term Adequacy Forecast 2020: Appendix 2; Methodology, 2020

12 https://www.cmu.edu/ceic/assets/docs/publications/working-papers/ceic-17-02r1-resource-adequacy-risks-to-the-bulk-power-syste.pdf, https://kilthub.cmu.edu/articles/thesis/Correlated_Generator_Failures_and_Power_System_Reliability/8204510

highlight the interdependencies between these resources and the underlying weather. This is commonly implemented by system planners across North America, but often differs in the number of weather years evaluated and the process used to estimate weather data across many generating resources in a region.

It is important that weather data accurately capture the temporal and geographic diversity of weather-dependent resources across the study footprint, and with neighboring jurisdictions. This ensures that the capacity value of variable renewable resources[13] are evaluated with the proper resource diversity. Large national datasets, such as the NREL National Solar Radiation Database (NSRDB)[14] were developed for this purpose, but data availability on load and wind resources is more complex and thus limited. It is also important that historical wind and solar output data not just be linearly scaled up to represent wind and solar output patterns at higher penetrations, as this misses the inherent geographic diversity benefit from adding wind capacity, and to a lesser extent solar capacity, at new sites.[15] In addition, improvements in wind and solar plant performance are increasing output in what had previously been lower output hours, boosting their capacity value.[16]

One way most resource adequacy analysis can be improved is in the use of data for temperature effects on fossil generation, namely gas turbine technology. Gas turbine technology is affected by ambient air temperatures. Extreme heat will derate the systems output coincident with peak load. While resource adequacy analyses in many regions utilize a summer rating for this technology, it may not include the effects of extreme heat. In addition, all generating equipment has a higher likelihood of failure during extreme temperatures, especially extreme cold. This is clearly illustrated in the outage data from the ERCOT 2021 rolling blackout event, which started on Monday February 15th during extreme cold (Figure 4). In many cases this weather data can be better included in the analysis.

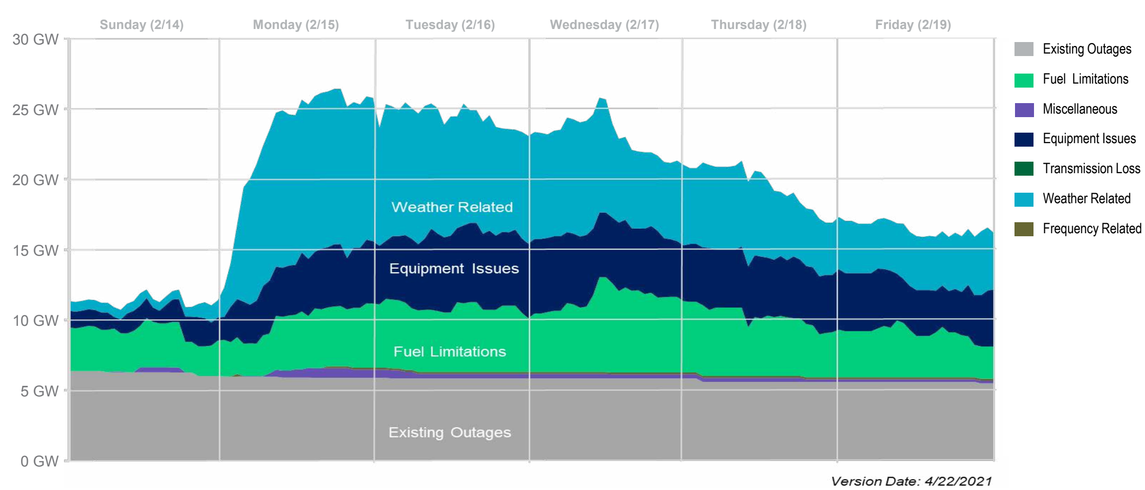

FIGURE 4. *Correlated Outages for Natural Gas Generators by Cause During the ERCOT February 2021 Event. Source: ERCOT*[17]

13 Additional information on accreditation methods is provided in Question 10.

14 National Renewable Energy, "National Solar Radiation Database," https://nsrdb.nrel.gov/

15 https://www.nrel.gov/docs/fy11osti/51860.pdf, at 27-29

16 https://www.sciencedirect.com/science/article/pii/S0140988316300317

17 ERCOT, "Update to April 6, 2021, Preliminary Report on Causes of Generator Outages and Derates During the February 2021 Extreme Cold Weather Event," 2021.

Resource Accreditation

6. To facilitate regulation, compliance, and trading, a clear definition of the requirement or "product" is needed. Is there a single definition of "capacity" that works in a high renewable grid? Would there instead be multiple overlapping products reflecting different time periods and reliability needs?

In the historical context, "firm capacity" was rather easily defined. The system required a reserve margin of capacity above and beyond peak load, and generation capacity was "stacked up" to reach the reserve margin target. Fossil generation was given near full capacity credit, discounted only by the unit's forced outage rate, if at all. Firm capacity therefore meant a resource's availability during peak (often summer) load conditions. Total nameplate capacity with an adjustment for forced outage rates (assumed to be random) sufficed.

Today, the notion of "firm capacity" is less clear, as variable renewable resources provide capacity benefits sometimes, but not others. Energy limited resources like battery storage and demand response can provide a high degree of availability during peak load conditions but have a limited response duration. Even natural gas resources, as discussed previously, are not as firm as unforced capacity (nameplate minus a forced outage rate adjustment) would indicate due to correlated outages during extreme temperature and fuel supply outages. Even fleets of nuclear plants have suffered from drought-induced cooling water loss, and fleets of coal plants have simultaneously experienced frozen coal piles or interruptions in coal deliveries.

This is changing the notion of "firm capacity" as there is no such thing as a perfect resource for resource adequacy. Instead, the definition of capacity is increasingly associated with the ability of a resource to be available during times of system need and scarcity events. A given resource therefore does not have to be firm or dispatchable to have high capacity value. However, it also means the capacity value of a given resource changes with the amount of that resource type, and of other resources, on the system. These include saturation effects due to positive output correlations within individual resource types, and portfolio benefits due to negative correlations among different types of resources. These effects can make resource accreditation - the value at which a given resource is ascribed capacity value — highly dependent on the region, weather conditions, the load profile, and resource mix. Not only does this vary by region, but it also changes over time as the resource mix evolves.

Saturation effects are common with any resource with correlated output that is only available during certain periods or has energy limitations, as the first "tranche" of the resource added to the system can mitigate certain scarcity events, but subsequent additions are unable to fill in the remainder of events.

Portfolio effects also challenge attempts to assign individual resources a capacity credit. For example, storage capacity value is altered by the amount of solar on the system, as an increase in solar generation increases the availability of surplus energy to charge to storage, and it shortens evening peak load periods. Similar effects are seen with other types of resource diversity (i.e., complementarity between wind and solar output profiles) or changes with the underlying load profile over time.

Generation planning tools used by utilities and grid operators do not typically account for complementary portfolio effects among wind, solar, and storage, as these interactions introduce multivariate complexity into the tools' calculations. As a result, the widely used utility capacity expansion optimization models understate the capacity value contributions from adding portfolios of wind, solar, and storage resources. This both biases the model's optimization against selecting wind, solar, and storage resources, and also causes the model to overbuild capacity and overshoot reliability targets.[18] Portfolio effects can be captured by iteratively assessing dozens of potential portfolios of resources in a probabilistic resource adequacy modeling tool, but that is much more time-intensive than running a capacity expansion model once and letting it search for optimal resource mixes.

For a simple analogy, the traditional resource adequacy construct stacked a set of uniform "blocks" of capacity until the reserve margin was met. On the other hand, the changing resource mix resembles trying to stack a set of blocks that are all different shapes and sizes, which also change shape over time. This makes the capacity accreditation process difficult and the ability to treat capacity as a commodity increasingly challenging.

One way to overcome the disparate resource capabilities is to segment the capacity needs by time of day, by season, or both. Instead of using a single annual planning reserve margin, the resource adequacy analysis and procurement process could break down the year into distinct blocks (see PG&E "slice of day" approach[19]) and ensure there are enough resources available to cover each block, somewhat independently of one another.

The key takeaway from these trends is that there is no one type of "perfect capacity." System planners should recognize that all resources have both benefits and limitations and defining "firm capacity" is difficult due to the portfolio and saturation effects of various resources.

7. Should resource adequacy constructs differentiate between resource flexibility and include other types of grid services?

Another way to potentially define capacity needs is related to resource flexibility. For example, if a resource is not variable due to the weather, nor energy limited, it still may not be available during system needs and scarcity events because it cannot be started in time, or it was not anticipated to be a scarce supply period. This can be true for older steam oil or steam coal units, which may be uneconomic to run on a regular basis but remain in the market (or in a vertically integrated utility portfolio) because of the capacity credit and resource adequacy needs.

Historically, this inflexible capacity receives full capacity accreditation, but there is growing concern that the capacity may not be available when called upon – either due to start time limitations or the possibility of a failed start. Some ISOs, like PJM and ISONE, have introduced a pay for performance penalty that would penalize these resources for not showing up during a resource adequacy event. Others are potentially considering minimum start time requirements. Part of the growing demands to evaluate all generation, not just

18 For a discussion of how not accounting for portfolio effects causes a widely-used capacity expansion model to overstate reliability targets, see footnote 28 on page 81 in PNM's recent IRP: https://www.pnmforwardtogether.com/assets/uploads/PNM-2020-IRP-FULL-PLAN-NEW-COVER.pdf

19 PG&E, 2021.

variable renewables and energy limited resources, through an ELCC construct is to ensure that start times and/or failed starts are accounted for in resource accreditation.

California is one region considering flexibility in their resource adequacy requirements. The state's resource adequacy construct distinguishes between three types of resource adequacy; 1) System RA, 2) Local RA (based on localized needs), and 3) Flexible RA. The latter sets a requirement to cover the largest three-hour ramp for each month and sets an obligation for load serving entities that have a portfolio of resources that can meet a Flexible RA requirement. Similar argument could be made for resource adequacy covering other grid services, like ramping reserves, regulation reserves, spinning reserves, etc.

However, for the purposes of this report, short-term flexibility products — while essential for operational reliability — are considered a separate product than capacity for resource adequacy. This short-term flexibility is distinct from multi-day capacity needs for multiple reasons. For one, it is of lower concern in the future given the likely supply of fast-responding storage and demand response, as well as the physical abilities of wind and solar to ramp down, and reserve headroom to ramp up when there is wind or solar energy available.

Second, there is a continuum of grid services ranging from sub-seconds (inertia and fast frequency response), to seconds (regulation), to minutes (spinning reserve), to hours and days. Figure 5 below illustrates these time frames. Short-term market design needs to attract sufficient fast-responding resources to keep supply and demand in balance in these intra-second/hour/day time frames and that is a short-term market design question, separate issue than the longer-term periods of day/multi-day periods with insufficient energy supply.

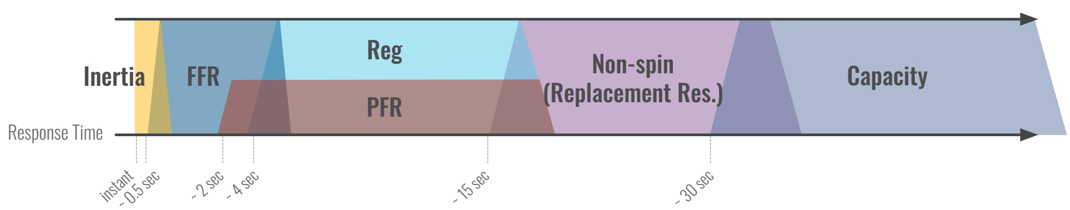

FIGURE 5. *Representative layering of short-term grid services. Source: Telos Energy*

In addition, the short-term flexibility needs are often an order of magnitude smaller than capacity and energy needs, with ancillary service markets in most regions only identifying a need for a few thousand Megawatts (MWs) of various reserves in each market.

At the same time, flexibility is also a system requirement, and grid operators and planners need to ensure it is in sufficient supply. California has a separate flexibility resource adequacy requirement from its "system resource adequacy" requirement.

From a resource adequacy perspective, the supply risk is less concerned with short-term intra-day flexibility needs and focused instead on risks associated with extreme peak loads, unexpected generator outages, and multi-low wind and solar resource days.

8. **Which resources can meet load when wind and solar output is low on a day-to-day, seasonal, or annual basis?**

The previous question identified saturation effects that occur with increasing levels of variable renewable energy integration. While wind and solar resources can be effective at reducing system risk during some time periods, they are not always available. As a result, at high renewable penetrations resource adequacy risk shifts to periods without high wind and solar resource availability, such as summer late evening hours or winter early mornings and evenings with light wind conditions. While battery energy storage may be effective at shifting available capacity from one time of day to another to mitigate some risk, it too experiences saturation effects at high penetration due to energy limitations and duration.

Eventually — at high penetration of variable renewables, energy storage, and fossil retirements — the resource adequacy risk will be concentrated into periods of multi-day low wind and solar events, or seasons with lower resource availability. Battery energy storage, in its current two-to-eight-hour duration form, has limited ability to solve these resource adequacy challenges. While multi-day periods of sustained low wind and solar resources may not be common, they do occur and need to be planned for in resource adequacy and portfolio analysis.

When focusing on extended multi-day periods with little renewable energy output, the options to preserve reliability widen from the traditional set. While traditional system planning relied on conventional combustion turbine capacity to meet peak reliability requirements, other options are likely available.

The first way to mitigate multi-day and seasonal periods of low wind and solar production is to increase the geographic footprint of the planning area. By expanding the size of the system, via transmission and through inter-regional coordination and planning, geographic diversity increases, and the threat of sustained multi-day low wind and solar production is mitigated.

Storage sources that are long-duration and slow-moving might come into play. Costs can be reduced significantly for storage sources that do not need to charge and discharge quickly or be used very often. Long duration storage could include new chemistries for batteries, pumped storage hydro, traditional reservoir hydro, compressed air energy storage, gravity-based systems, and many other emerging technologies. For example, Form Energy provides one type of resource (iron air storage) that is low cost (for long duration storage) and slower moving, yet available when needed.[20] Canadian hydro plants across the West, Central, and Eastern provinces provide months' worth of storage that could fill in gaps in US supply, if connected through more transmission.

Mothballing old gas plants with low forced outage rates but inefficient heat rates is another low-cost option. Even environmental groups have supported this option in some Integrated Resource Planning cases. These resources can be mothballed at essentially no cost and then restarted in six to eight weeks if load growth occurs, or unexpected long-duration outages occur on other plants. The system's net emissions impact is trivial for a plant that may only be called upon to run during critical emergencies.

20 Utility Dive, "Form Energy's $20/kWh, 100-hour iron-air battery could be a substantial breakthrough," 7/26/2021.

Any resource adequacy solution in a highly decarbonized grid will likely also include an increased role for load flexibility. While much of the demand response used today is focused on short-term voluntary load curtailments (i.e., air conditioning or water heating), load flexibility options will likely broaden due to increased communications and interactive end use loads as well as shifts towards more real-time or time-of-use pricing.

Finally, the highly decarbonized grid also has a role for clean resources that are not variable, otherwise referred to as “clean firm” resources. These options include reservoir hydro (which is still subject to some long-term weather conditions), geothermal, biomass, waste-to-energy, nuclear, fossil with CCS, and generators running on fuels containing hydrogen produced through renewable electrolysis. A large part of the justification for these options is rooted in resource adequacy.

9. To what extent do the physical resource needs vary by region and change over time?

Developing a national construct for resource adequacy is challenging because the underlying reliability risks and resource mixes for each region drive different physical resource mixes. A large part of this is due to the different load profile for each region. For example, California and the Southwest have extreme summer peak load conditions, but relatively modest winter loads. Many power systems in the Northwest currently experience winter peaks, the Southeast is largely a dual-peaking region (with similar summer and winter peak loads), and the Northeast is a summer-peaking region that may switch to winter-peaking over time with increased electrification.

The regional variation is also a function of the underlying resource mix. Some regions with increased solar integration may have physical resource adequacy needs in the evening hours, where other regions with larger amounts of wind generation likely have a different resource adequacy need.

While each region is unique, there is consensus that physical resource needs also change over time. Part of this is due to changes in the load pattern, either due to climate change (i.e., increasing frequency of summer peak loads in the Pacific Northwest), or structural changes in the load factor (i.e., increasing residential demand relative to industrial). With changes taking place both on the supply and demand side of the resource adequacy equation, the physical resource needs for capacity ultimately change over time as well.

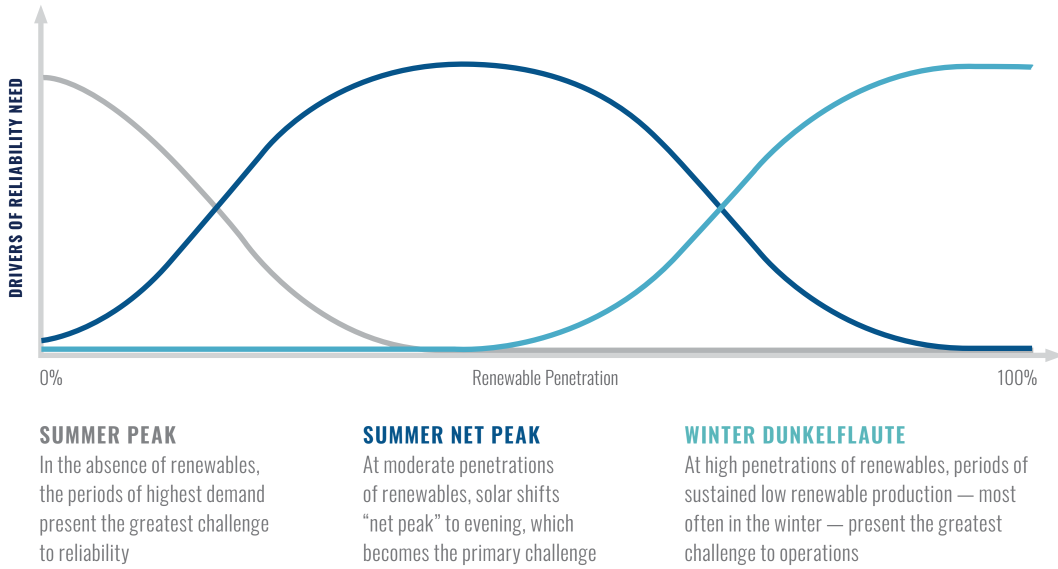

FIGURE 6. *Evolving grid challenges at increasing renewable penetrations. Source: E3*[21]

However, a resource doe s not have to be available every hour of the year to be effective for resource adequacy and capacity needs. However, the necessary timing and duration of availability is constantly changing. This makes capacity accreditation difficult and requires regular updates. This also challenges the ability to "lock-in" a resources' capacity value over a long period necessary for financing.

Because of the regional variation in the load profile, resource mix, and climate trends over time, any resource adequacy construct will likely need to have different physical needs. When combined with differences in regulatory structures and markets, a single resource adequacy construct is difficult. However, a broad regional framework does increase both resource and load diversity, allowing for lower cost solutions for resource adequacy needs, provided that adequate transmission can ensure the transfer of available resources from one region to another.[22]

10. What are the best ways to determine the capacity contributions of various resources? How should Effective Load Carrying Capability (ELCC) be determined, and should it apply to all resources?

Because the physical needs of the system are changing, so are the methods to accredit variable renewables and energy storage. Traditionally, fossil units are counted as "firm capacity," at the level of their nameplate capacity (sometimes seasonally adjusted) discounted slightly to unforced capacity (UCAP) based on their forced outage rates. Variable renewables and energy storage were accredited with rough rules of thumb for capacity value, discounting their nameplate capacity based on their availability during peak load.

21 Olson, A., Ming, Z., Carron, B., "ELCC Concepts and Considerations for Implementation," Prepared for August 30th, 2021 NYISO Installed Capacity Working Group, 2021, Energy and Environmental Economics.

22 Additional information on transmission and regional coordination is provided in Question 12.

There are different methods to technically measure capacity accreditation, including average capacity factor during peak load hours, and more sophisticated ELCC calculations. Over the past several years, ELCC has become the most accepted way to measure variable renewable and storage capacity credit as it is based on detailed resource adequacy simulations.

However, ELCC also has limitations as the resource mix changes. First, it is often not applied to all resource technology types, but rather only to variable renewables, energy storage, and demand response resources. This is biased, as there is no such thing as perfect capacity. Fossil generation has risks associated with fuel supply constraints, degraded performance during extreme heat, increased failure during extreme cold, and potential for large, discrete forced outages. These limitations should be reflected in the resource adequacy analysis and ELCC should be applied to all resources, not just variable renewable energy and energy limited resources. As the NERC Integration of Variable Generation Task Force (IVGTF) stated, "The fundamental calculations of loss of load probability, LOLE, and ELCC are not new, nor are they unique to variable generation. The reliability-based approach to calculating resource adequacy is a robust method that allows for the explicit estimate of the shortfall of generation to cover load. The traditional use of LOLE is to determine the required installed capacity, based on expected capacity during peak periods, and ELCC measures an individual generator's contribution to overall resource adequacy."[23]

ELCC for a given resource is highly dependent on the underlying resource mix, load profile, and other system characteristics that are constantly changing. For example, the capacity accreditation of storage and demand response technology depends on the amount of solar on the system. This is because high solar penetration reduces midday and afternoon loads and narrows the peak load risk to be better handled by limited duration storage and demand response. The same is true for balanced solar and wind resource mixes, as the resources are complementary. In addition, as the load profile changes due to energy efficiency, electrification, and rate structures — the peak risk periods will also change and may be suited to the underlying variable renewable resources. It also raises the question of who should be assigned credit for the diversity benefits. A system with increasing solar will increase the incremental ELCC of storage, but the same could be said about solar in a system with increasing storage.

These interdependencies — referred to as portfolio effects — make long-term ELCC attribution difficult. While ELCC may be a valuable metric for near-term compensation structures — like forthcoming capacity market auctions – it is problematic for long-term planning. Some resources such as wind, solar, and short-duration batteries are complementary such that more of one increases the capacity contribution of the other, while putting more of the same resource at the same location reduces ELCC (Figure 7). On the other hand, resources with similar output profiles reduce the other's capacity value. For example, in PJM, whether storage is dispatched before or after demand response leads to a 47 percent ELCC[24] with one method and 97 percent with another.[25] These interactions make assigning clear credit to any one resource difficult.

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23 North American Electric Reliability Corporation, "Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning," p. 9, March 2011.

24 Rocha-Garrido, "Public 1st Draft ELCC Results and the Process to Provide Preliminary ELCC Results," July 10, 2020.

25 Astrapé Consulting, "Dispatch Effects on Storage ELCC in PJM," July 16, 2020.

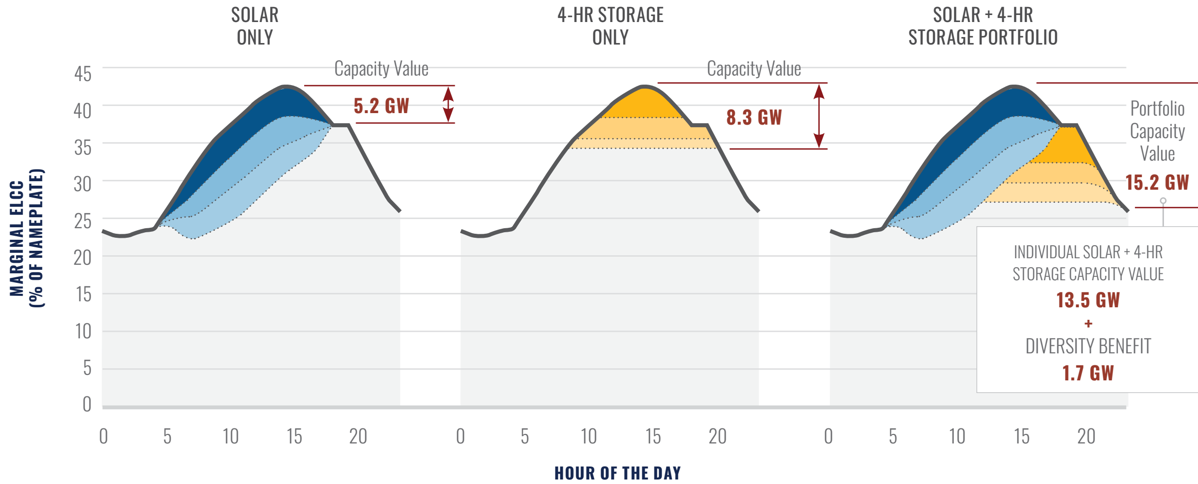

FIGURE 7. *ELCC of Solar, Storage, and Portfolio Effects. Source: E3*[26]

11. Are renewables getting fair treatment for capacity value?

The capacity accreditation process (and ELCC methodologies specifically) is one of the most contentious issues in resource adequacy constructs, whether in a deregulated capacity market or in vertically integrated IRP processes. Regardless of the process, capacity accreditation often relies on system modeling and assumptions.

It should be noted that increasing renewable energy is not leading to an increase in resource adequacy risk — but rather the subsequent retirement of fossil generation and increased reliance on variable renewables and energy limited resources for capacity needs. Without fossil retirements, the addition of variable renewables does not lead to increased reliability risk. Said another way, adding renewable energy never decreases the resource adequacy of a power system. Therefore, resource adequacy discussions should not be an impediment to adding variable renewables to the system, but rather a discussion on when to retire traditional fossil capacity and what to replace it with.

Disputes on equitable treatment are often on when the saturation point occurs for each resource type — which can be highly dependent on modeling assumptions. These assumptions include the following:

- **Weather profiles used:** a generator's ELCC is highly dependent on the assumed weather profile, which may vary considerably from year-to-year, and its correlation with the underlying load profile and other variable renewable plants in the region. To address this concern, many modelers use many decades of synthetic renewable output and load patterns that retain the correlations among those profiles.
- **Plant configuration:** each variable renewable plant or storage system is unique, but its attributes may not be reflected in ELCC calculations. This may include the inverter loading ratio (where higher ratios increase plant availability during low solar conditions), solar panel direction, turbine hub height and rotor diameter, storage duration, etc.
- **Hybrid resources:** an increasing trend in hybrid resources (solar+storage, wind+solar,

26 Schlag, N., Z. Ming, A. Olson, L. Alagappan, B. Carron, K. Steinberger, and H. Jiang, "Capacity and Reliability Planning in the Era of Decarbonization: Practical Application of Effective Load Carrying Capability in Resource Adequacy," 2020, Energy and Environmental Economics.

etc., with varying types of connection to the grid) is also making the accreditation process more complex for plant owners.

- **Storage utilization and forecasting:** whether the storage resources are used strictly for reliability, or other use cases (operating reserves, energy arbitrage, etc.) will influence the capacity accreditation. The order in which these resources are scheduled relative to other energy limited resources also impacts their valuation.

Perhaps the most notable issue regarding equitable treatment of renewables is the lack of an ELCC or accreditation process for incumbent fossil generation. Currently most regions either ascribe full capacity credit for fossil generation (assuming the installed capacity for planning reserve margin purposes), or discount the resources slightly based on their unforced capacity (UCAP) associated with the generator's historical forced outage rate. This, however, does not include the effects of correlated events that may occur across the fossil fleet due to the following:

- **Fuel supply disruptions,** specifically on the natural gas system,
- **Increased probability of forced outages** during extreme weather events,
- **Higher than average ambient derates** during extreme heat,
- **Flexibility constraints** that may make the generator unavailable when needed.

While the industry has taken great effort to quantify and measure the capacity accreditation of variable renewable and energy limited resources because they are new entrants, there has been less attention given to measuring capacity contribution of fossil generation which is likely overstated. As a result, any process that is used to accredit variable renewables and energy limited resources should also apply to fossil-fueled resources.

Transmission & Regional Coordination

12. How should neighboring balancing areas and jurisdictions be considered in resource adequacy assessments?

According to the ESIG Redefining Resource Adequacy Task Force, the incorporation of transmission and regional coordination is one of the six principles that needs to be considered in evolving resource adequacy analysis and modeling:

Resource adequacy modeling can be complex and is often computationally challenging; a large power system must typically be simulated across hundreds or thousands of Monte Carlo samples. To make this problem tractable, simplifications are required. Often that means only limited representation of neighboring power systems and the transmission network in general.

However, resource sharing can be a significant, low-cost alternative to procuring new resources. Imports from neighboring regions are likely to become more valuable for resource adequacy due to the increased diversity of chronological wind, solar, and load patterns over a much larger area. A typical wind plant output tends to have little correlation with other wind plants a few hundred miles away. Solar output varies with cloud cover and time zones. Load diversity is greater across large areas. While extreme weather can happen anywhere, it does not happen everywhere at once.[27]

As a result, it is critical to not evaluate a region's resource adequacy needs in isolation, but to ensure transmission is both modeled as a supply option, and to consider the likelihood of available imports from neighboring systems.

The same is true for resource adequacy markets. Expanding the load and renewable resource diversity across regions can reduce the need for capacity significantly. This was one of the primary drivers for the creation of early ISO markets. It is also evident across the Western Interconnection, which (outside of California) is currently composed of many vertically integrated utilities, each of which does resource adequacy planning individually. This leads to a potential overbuild of capacity across the region, which is discussed in the following question.

13. Should each region be required to meet its own load locally? Do imports need to be contracted?

While the benefits of transmission and regional coordination on resource adequacy are clear, the mechanics are not. Ultimately the regulatory structure in each region determines who is responsible for resource adequacy, which in turn sets requirements one needs to be self-reliant. Regulators and planners in most regions believe a system should be self-reliant and able to serve load without requiring imports from neighbors during critical time periods. This approach is not unreasonable; ultimately the utility or system operator is responsible for reliably meeting its customer's needs, regardless of what happens in neighboring regions. Oftentimes, regulators require that imports that count towards resource adequacy requirements be contracted.

An example of this accounting across jurisdictions is evident in a recent proposal for the Northwest Power Pool,[28] is seeking to bring a regional framework to resource adequacy planning across much of the Western Interconnection. It would establish a voluntary program where each load serving entity could join a bilateral construct where participants would be able to enter into capacity agreements with one another. This process would largely normalize the accounting principles — ensuring resources are not double counting, develop a consistent framework for resource adequacy targets and ELCC calculations, and establish a transparent contracting process. A similar development in the Southeast, and coordination across ISOs, could yield significant resource adequacy savings, without new capacity additions.

14. How should transmission deliverability factor into resource adequacy assessments for wind and solar resources? Do interconnection study deliverability modeling and assumptions need to evolve with the growth of wind, solar, and storage?

The interaction between transmission deliverability and resource adequacy is complex. For conventional generators whose output during peak periods is typically binary (either the resource is producing at full capacity, or the generator is on outage and producing 0%), it makes sense to require full deliverability. That ensures that if one generator experiences a forced outage, the others are fully deliverable to pick up the slack and meet peak demand.

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27 ESIG, 2021.

28 Northwest Power Pool, "Resource Adequacy Program - Detailed Design," July 2021.

However, wind and solar plant output profiles are not binary, and the output during peak net load is typically less than 100% of nameplate capacity, so 100% transmission deliverability should not be required for the resource to provide its full capacity value. Most wind projects pay for sufficient grid upgrades to ensure they can deliver the vast majority of their annual energy, with some acceptable level of curtailment that mostly occurs during low load periods in the spring and fall. Because wind output tends to be below average during peak demand periods, and because wind projects tend to be located in remote parts of the grid where there are few conventional generators delivering their maximum output into the local transmission zone during those peak periods, in most cases there will be adequate transmission to deliver their output during those peak periods. This is confirmed by data showing very low levels of wind curtailment during peak months.[29]

Similarly for solar, most peak net load periods occur in the late afternoon or evening when solar resources are well below their maximum output, particularly once solar penetrations are high enough to push peak net load later in the day. As a result, whatever level of transmission deliverability is built to ensure a solar plant's energy is not heavily curtailed at noon should be more than adequate to ensure deliverability of the plant's output during peak net load periods.

In addition, there is significant geographic diversity in renewable output profiles within a given generation pocket, particularly for wind resources. As a result, plants that are producing less than others will help to ensure that transmission constraints are not exceeded.

However, at higher renewable and storage penetrations, it will become increasingly important to model transmission deliverability to understand the complex time and spatial interactions of renewable output and flows on the transmission system. As computer processing power increases, moving away from interconnection studies based on snapshots of peak, off-peak, and shoulder periods to a sequential hourly approach that models renewable output patterns and the duration limits of storage. In the interim, grid operators should continue to update their interconnection study assumptions to account for how increased renewable penetrations are shifting the time periods of greatest transmission congestion and peak net load. For example, this can better capture the fact that storage resources located in solar-heavy areas can be deliverable at peak net load without causing a major need for grid upgrades because solar output has dropped off by the evening, while storage can also reduce congestion that limits the deliverability of solar resources midday by charging during that period.

New assumptions are also needed for modeling storage and hybrid resources in interconnection studies. Because battery storage can be flexibly dispatched to charge or discharge based on locational marginal prices, storage should tend to reduce and not exacerbate transmission congestion.

Grid operators should also focus interconnection studies and required grid upgrades on addressing reliability concerns, like determining what grid upgrades are needed to ensure the deliverability of resources at peak net load, and leave economic decisions about upgrades that ensure the deliverability of energy during other time periods up to the interconnecting generator.

29 https://www.pjm.com/-/media/committees-groups/subcommittees/irs/2020/20200302/20200302-item-08-wind-power-curtailment-graph.ashx