Ensuring Efficient Reliability

NEW DESIGN PRINCIPLES FOR CAPACITY ACCREDITATION

A Report of the Energy Systems Integration Group's Redefining Resource Adequacy Task Force

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ESIG
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Ensuring Efficient Reliability: New Design Principles for Capacity Accreditation

A Report of the Energy Systems Integration Group's Redefining Resource Adequacy Task Force

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Contents

List of Abbreviations

ELCC	Effective load-carrying capability
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
ISO	Independent system operator
ISO-NE	Independent System Operator of New England
LOLE	Loss-of-load expectation
LOLP	Loss-of-load probability
MISO	Midcontinent Independent System Operator
MRI	Marginal reliability improvement
NYISO	New York Independent System Operator
PV	Photovoltaics
RA	Resource adequacy
RTO	Regional transmission organization
SPP	Southwest Power Pool
UCAP	Unforced capacity

Executive Summary

As the power system changes due to increased renewables, coal and gas retirements, and the increased use of storage and load flexibility for reliability, new methods and principles are needed to measure each resource's contribution toward reliability. The ESIG Redefining Resource Adequacy Task Force developed this report to provide an overview of capacity accreditation: the measure of the contribution of individual resources toward meeting the system's resource adequacy.

The report details the ways that resources are accredited today, how those processes are evolving with a changing resource mix, and limitations inherent in these techniques, and provides suggestions on ways to simplify the approaches to ensure they can be used across all resource types in a more transparent manner. The report does not outline a single, one-size-fits-all approach to capacity accreditation; rather, it provides a framework and foundational pillars that can be used throughout the industry to improve accreditation processes and ensure resource adequacy in the future.

The key considerations from this work are twofold: (1) to ensure that capacity accreditation methods are applied to all resources, not just wind, solar, and battery storage, in a consistent, non-discriminatory manner, and (2) to ensure there is a linkage between resource accreditation and real-world operations.

The Importance of Capacity Accreditation

While resource adequacy analysis assesses whether there are enough resources to serve load across the system, capacity accreditation measures the contribution of individual resources toward meeting that goal, both in terms of capacity and energy.

The two key considerations from this work are the importance of (1) ensuring that capacity accreditation methods are applied to all resources, not just wind, solar, and battery storage, in a consistent, non-discriminatory manner, and (2) ensuring there is a linkage between resource accreditation and real-world operations.

The power system's changing resource mix—shifting away from baseload fossil generation and toward a portfolio of wind, solar, storage, and load flexibility—has large implications for how the system ensures that reliability needs are met. Traditionally, these new resources were procured primarily to produce energy, displace fuel, and reduce emissions, but the next phase of the energy transition will increasingly look to them to ensure reliability.

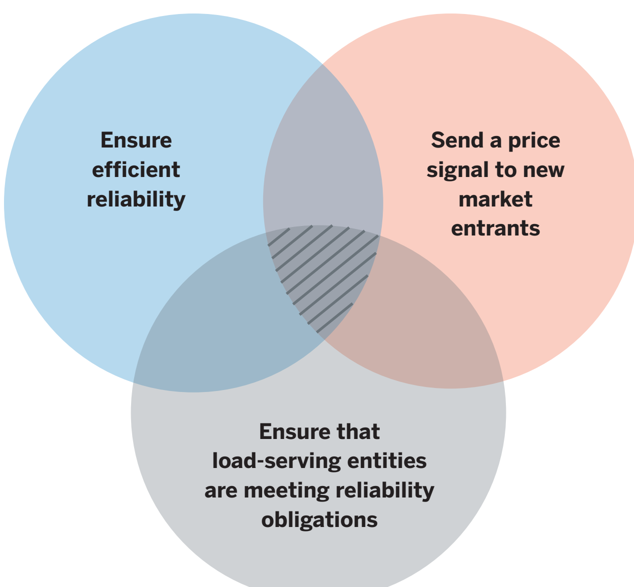
Capacity accreditation methods measure the ability of resources to be available during periods of tight supply. The outcome of accreditation methods—typically a capacity credit for each generator (the percentage of a generator's installed capacity that counts toward resource adequacy)—is used for capacity market offers or selection in competitive procurement processes. A MWh of *energy* on the grid is indistinguishable based on its source, but the same is not true for a MW of *capacity* for resource adequacy. When and where resources are able to provide electricity can differ a great deal, and some resources can provide more reliability benefits than others. The goal of capacity accreditation is to measure effective capacity contributions, in a technology-agnostic manner, and create a reliability-neutral way to allow for exchanging capacity between resources types while meeting resource adequacy needs.

In addition to the shifting resource mix, the timing, location, and causes of reliability risk and tight supply conditions are also changing. In the past, peak risk and tight supply conditions occurred when load was highest. But risk is shifting out of these peak load periods and into periods when load is lower but resource availability is also lower, due to weather (periods of low wind and solar generation) or correlated outages due to extreme weather and fuel supply disruptions. Load profiles are also changing due to increased electrification, climate change, and structural changes in the economy. These changes to both the resource mix and the load profile are shifting risk away from the conventional risk periods (e.g., summer afternoon peak in much of the United States) and toward new periods, underscoring the importance of understanding the resource adequacy contributions of different resources.

A robust capacity accreditation framework accomplishes three goals of planning: to secure reliability in an economically efficient manner, send a price signal to new market entrants, and ensure that load-serving entities are equitably meeting their obligations to reliably serve load (Figure ES-1).

FIGURE ES-1

The Nexus of Capacity Accreditation



Source: Energy Systems Integration Group.

Ways That Capacity Accreditation Is Done Today

Today, accreditation methods can be characterized by three overarching elements that need to be considered when evaluating a capacity accreditation technique:

- **Deterministic or probabilistic:** Deterministic metrics use a single-point estimate, often based on historical performance. Probabilistic metrics use analytical simulations across hundreds or thousands of potential future conditions.
- **Prospective or retrospective:** Prospective (forward-looking) methods are often used in the planning and investment time frame to help understand the incremental benefits of future resources. Retrospective (historical) approaches include the use of historical operating conditions to inform resource accreditation.
- **Marginal or average contribution of a resource:** Marginal approaches accredit the entire cohort of a resource type based on the reliability contribution of incremental additions to that resource type, whereas average approaches accredit the entire cohort based on the contribution of the entire fleet.

None of these elements is perfect and there is no right answer; a lot depends on the methodology of implementing each technique and the assumptions used. When redesigning accreditation frameworks, it is important that planners and market designers make clear and intentional choices in these three properties.

Gaps in Current Accreditation Methods

Complexity and lack of transparency. Today's capacity accreditation methods have several limitations, which are leading planners to adjust their process or accreditation rules. First and foremost, methods in use today are complex and, as a result, lack transparency for many industry stakeholders. While the discipline of probabilistic analysis and power system modeling is improving in accuracy, it is also growing more complex. It is necessary to ensure that accreditation processes are understood across a broad range of stakeholders—and not just the modeling community. Simpler heuristics, though perhaps not as precise, may provide a valuable alternative and beneficial trade-off.

Sensitivity to modeling assumptions. Accreditation techniques are also sensitive to modeling assumptions, potentially leading to significant changes in capacity payments or a system's portfolio due to modeling decisions. Capacity credits derived from modeling are only as good as the input assumptions and underlying modeling. Any limitations, oversights, or failures in the probabilistic modeling will also flow through to a resource's capacity credits and payments. In practice, capacity credits are the one area of power markets where a resource is compensated based on expected—or modeled—performance rather than actual performance.

Heterogeneity and unique aspects of resources. Another limitation in current accreditation processes is the difficulty of differentiating resources based on their unique configurations, locations, or operations. Capacity accreditation is intended to measure a resource's contribution to resource adequacy and its ability to reduce system risk. While in theory, this process should be done at the individual unit level, in practice it is often done for aggregated resource classes, which can encompass a great deal of heterogeneity among generators even within the same resource type. (For example, they may have different patterns of generation or plant configurations (e.g., turbine sizes or hub heights for wind, presence of tracking systems or inverter-loading ratios for solar).) This miscorrelation can lead to a wind or solar resource in one region having a higher capacity credit even if it is a lower energy yield. At a minimum, capacity accreditation should evaluate groups of similar resources, but with enough resolution to notice different timing of generation or miscorrelation between resource groups. The objective is for accreditation to result in each individual resource receiving the capacity credit commensurate with its reliability contribution.

Difficulty of disentangling portfolio effects. The reliability contributions of a resource are also linked to the availability or performance of other resources and load throughout the system. Portfolio effects arise because the capacity value of any resource is dependent on what the rest of the system's resource mix looks like. For example, battery storage capacity credit may depend on the amount of solar energy available earlier in the day for charging, because high levels of solar provide surplus energy to charge the storage and create narrower (shorter) periods of peak evening net loads, making storage duration more effective. In addition, a system with high levels of solar may shift risk to the evening or overnight hours or to the winter season. Disentangling these types of synergistic portfolio effects is difficult, and often an arbitrary decision of the modeler.

Circularity and ex ante challenges. These challenges also introduce circularity and ex-ante challenges. The capacity credit of any resource is dependent on the existing system portfolio and the amount of each accredited resource on the system. Therefore, evaluating the capacity contribution of a resource in isolation is highly dependent on the assumptions made for the rest of the system. While these assumptions can be forecasted, they will change over time, partly due to the capacity accreditation afforded to the resource. This ex-ante challenge—where the result of the capacity expansion or capacity auctions affects the capacity credits—requires additional modeling and analysis.

Pillars of Capacity Accreditation

Today, there is no uniform set of best practices for capacity accreditation. Given different market structures and regional resources, uniformity may not be desirable or feasible, but foundational pillars can be applied.

Despite the array of resource adequacy and accreditation methods, there are foundational elements that should be consistent across accreditation techniques. These can be used as guidelines for planners, regulators, and other stakeholders to evaluate accreditation options in new market designs or integrated resource planning processes. The ESIG Redefining Resource Adequacy Task Force developed five pillars of resource accreditation to serve as foundational elements that can be applied to all accreditation methods (Figure ES-2, p. x).

FIGURE ES-2
Five Pillars of Resource Accreditation

Non-Discriminatory	Robust	Transparent	Reliable	Predictable
Accreditation is applied to all resources using a similar methodology.	Accreditation continues to work as the resource mix, load patterns, and system risk change over time.	Accreditation can be effectively communicated to stakeholders, and data are readily available for decisionmaking.	Accreditation accurately measures performance during real scarcity events.	The process is repeatable and consistent. It does not yield volatile or unexplained changes year to year.

Source: Energy Systems Integration Group.

Capacity Accreditation for All Resources

The first pillar highlights the importance of non-discriminatory capacity accreditation methods. If specific capacity accreditation methods are applied to some resources, they should be applied to all resources in a consistent manner, with the same calculations and methodologies.

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Today, capacity accreditation techniques are applied to variable renewable resources and energy-limited resources (storage and load flexibility), while fossil fuel generation often receives either a perfect capacity credit or unforced capacity (UCAP) credit equal to its capacity minus a forced outage rate. This approach inherently misses risk and overstates the capacity contribution of conventional resources. In addition, other resources, like transmission, can significantly improve resource adequacy, but are often excluded from capacity accreditation techniques.

Correlated outages—such as extreme weather and fuel supply disruptions—can create situations where large portions of capacity are removed from service simultaneously. While this is typically embedded in the renewable generation profiles used in accreditation, the same details are often not applied to thermal generators. Recent winter weather events during Winter Storm Uri (February 2021) and Winter Storm Elliott (December 2022) have shown unique vulnerabilities to thermal resources and the impacts of correlated outages on resource adequacy.

In order to ensure that capacity accreditation is done in a non-discriminatory manner for different resource types, capacity accreditation should be applied to all resources in a consistent manner.

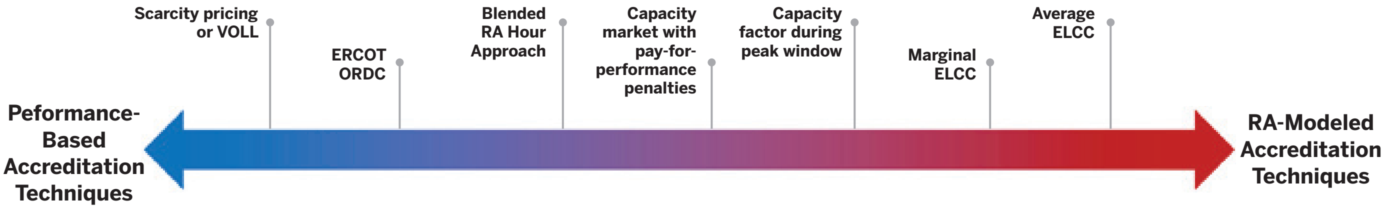
Linking Accreditation to Operations

A key concern regarding capacity accreditation approaches is that imperfect economic signals during a high-risk event might mean that accredited capacity will not deliver during the event. A perfect accreditation calculation can still result in a resource not showing up, even if it was capable of producing power. Accreditation approaches need to be linked to operations in order to ensure that resources deliver in the moment.

Relying exclusively on modeled performance disregards the reality of actual plant performance. There is a need to better link forward-looking capacity accreditation with retrospective operations to ensure that resources actually show up when needed. A performance-based accreditation methodology for individual resources could avoid many

Accreditation approaches need to be linked to operations in order to ensure that resources deliver in the moment.

FIGURE ES-3
Performance-Based vs. RA-Modeled Accreditation Techniques



Notes: VOLL = value of lost load; ERCOT = Electric Reliability Council of Texas; ORDC = Operating Reserve Demand Curve; RA = resource adequacy; ELCC = effective load-carrying capability.

Source: Energy Systems Integration Group.

of these risks while offering a lower level of complexity, because accreditation is based on actual performance rather than simulations.

Because prospective and retrospective accreditation approaches consider different drivers of system risk, a blended approach that accredits resources based on historical scarcity hours and simulated loss-of-load events may balance the alignment of incentives and operations in an energy-only market with the uncertainty of future risks evaluated using modeled accreditation techniques (Figure ES-3).

Regardless of the approach chosen, decisionmakers will want to ensure that incentives or governing rules—including accreditation or capacity market revenues—are aligned so that generators will supply power during times when it is needed.

Recommendations

This report focuses attention on two key considerations. First, accreditation methods should be expanded and applied to all resource types, not just wind, solar, and battery storage. This includes considering the reliability implications of correlated outages on thermal resources, the benefits of interregional transmission, and the details of load flexibility. Second, given that power system modeling is never perfect and there are inherent risks with accrediting resources solely based on models reliant on the underlying assumptions chosen, there is a need to link simulated accreditation with actual operations.

The ESIG Redefining Resource Adequacy Task Force offers the following recommendations to improve how accreditation is currently practiced and help ensure efficient reliability of the power system.

Recommendation 1

Ensure that the foundational pillars are clearly communicated to stakeholders.

Recommendation 2

Be cautious if using capacity credits—in isolation—as the basis for ensuring reliability.

Recommendation 3

Consider accreditation methods that evaluate not only a resource's capacity, but also energy available during periods of high risk.

Recommendation 4

Accredit all resource types using similar metrics and methods.

Recommendation 5

Align incentives in capacity accreditation and real-time performance, in order to not only simulate availability during typical risk periods but ensure performance during actual scarcity events.

Recommendation 6

Evaluate methods to simplify and streamline accreditation calculation techniques.

Introduction

Global power systems are experiencing an energy transformation at a pace and scale like never before. New installations of wind, solar, and storage resources are accelerating concurrently with increasing fossil plant retirements. The fundamental behavior of the load is also changing as energy efficiency and electrification of traditionally non-electric energy-consumption sectors. Power system operators and planners are having to rethink the ways to ensure a reliable, economic, and clean power system throughout this transition (ESIG, 2021).

Resource adequacy analysis measures whether a power system has enough resources to serve load and uses probabilistic analysis to quantify the likelihood of being caught short or failing to serve load. This analysis takes into account uncertainties in the power system, including unexpected increases in load due to economic growth or weather, the availability of variable resources like wind and solar, quantities of stored energy, and unexpected generator and transmission outages.

While resource adequacy analysis measures the bulk system reliability, capacity accreditation is used to measure the contribution of individual generators or utilities toward resource adequacy.[1] Increasingly, renewable resources, energy storage, hybrid resources, and load flexibility products are selected because of their capacity and resource adequacy benefits (in addition to energy or environmental attributes they may provide). While a megawatt-hour of electricity on the grid is indistinguishable based on its source, the same is not true for a megawatt of capacity. Differences in when and where a resource is able to provide electricity can differ significantly, and some could provide more resource adequacy benefits than others. The goal of capacity accreditation is to measure effective capacity, in a technology-agnostic manner, and create a reliability-neutral exchange rate between resource types (Newell, Spees, and Higham, 2022).

While a megawatt-hour of electricity on the grid is indistinguishable based on its source, the same is not true for a megawatt of capacity. Differences in when and where a resource is able to provide electricity can differ significantly, and some could provide more resource adequacy benefits than others.

Capacity accreditation methods measure the ability of these resources to provide bulk reliability, specifically by providing availability during periods of tight supply (low reserve margins). The outcome of these accreditation methods—often expressed as a percentage quantifying a resource's effective capacity (or firm capacity) relative to its installed capacity—is used as the basis for capacity market offers or selection in competitive procurement processes. In deregulated capacity markets, a capacity auction procures a necessary amount of effective capacity (often denoted as unforced capacity (UCAP)) to meet resource adequacy needs. In vertically integrated utilities, a resource's capacity accreditation will be evaluated in competitive procurement to ensure a resource portfolio

1 Capacity accreditation is also commonly referred to as capacity credit, capacity value, capacity contribution, effective capacity, or firm capacity, which are used interchangeably in this report.

is procured in an efficient manner to provide energy, capacity, and other desired attributes.

At the highest level, there are two ways to approach resource accreditation. The first is through modeled simulation of risk periods and performance (a prospective approach), and the second is through resources' availability during actual scarcity events and performance during realized operations (a retrospective approach). The former is used for metrics like effective load-carrying capability (ELCC) and used to compensate resources in a capacity market or competitive procurement, while the latter is a market-based signal based on actual resource operations and high energy price incentives.

Given the changes taking place in the energy transition, grid planners across the world are adjusting their capacity accreditation methods and metrics, resource procurements, and capacity markets with new frameworks, rules, and metrics. Most systems have less surplus capacity than they did in the past, as thermal plants retire and climate change affects load uncertainty and the availability of wind, solar, and hydro resources. It is therefore crucial to accurately determine the capacity credit of variable renewable (wind and solar) and energy-limited (storage and load flexibility) resources. Several capacity accreditation methods are in use today; however, all of them suffer from limitations.

Many grid operators and electricity markets are currently evaluating new processes to adjust either their accreditation techniques, capacity market (or compensation) design, or both in the coming years. However, while there have been some lessons learned among different jurisdictions and some cross-examination of resource adequacy methods, there is no uniform set of best practices for capacity accreditation. Given the diversity in resource mixes and regulatory regimes in each region, uniformity may not be desirable or feasible, but a set of best practices and guidelines can be useful.

Translating Resource Adequacy Needs of the System to Individual Resource Contributions

While resource adequacy analysis assesses whether there are enough resources in the portfolio to serve load across the entire power system, capacity accreditation measures the contribution of individual resources toward meeting the system's resource adequacy, both in terms of capacity and energy. Unlike resources' energy contribution, which is measured throughout the year(s) of operation, the capacity contribution specifically measures the resource's availability during times of scarcity or tight supply. Capacity accreditation provides the link between resource adequacy—measuring overall system reliability—and the reliability contributions of individual resources.

While resource adequacy analysis assesses whether there are enough resources in the portfolio to serve load across the entire power system, capacity accreditation measures the contribution of individual resources toward meeting the system's resource adequacy, both in terms of capacity and energy.

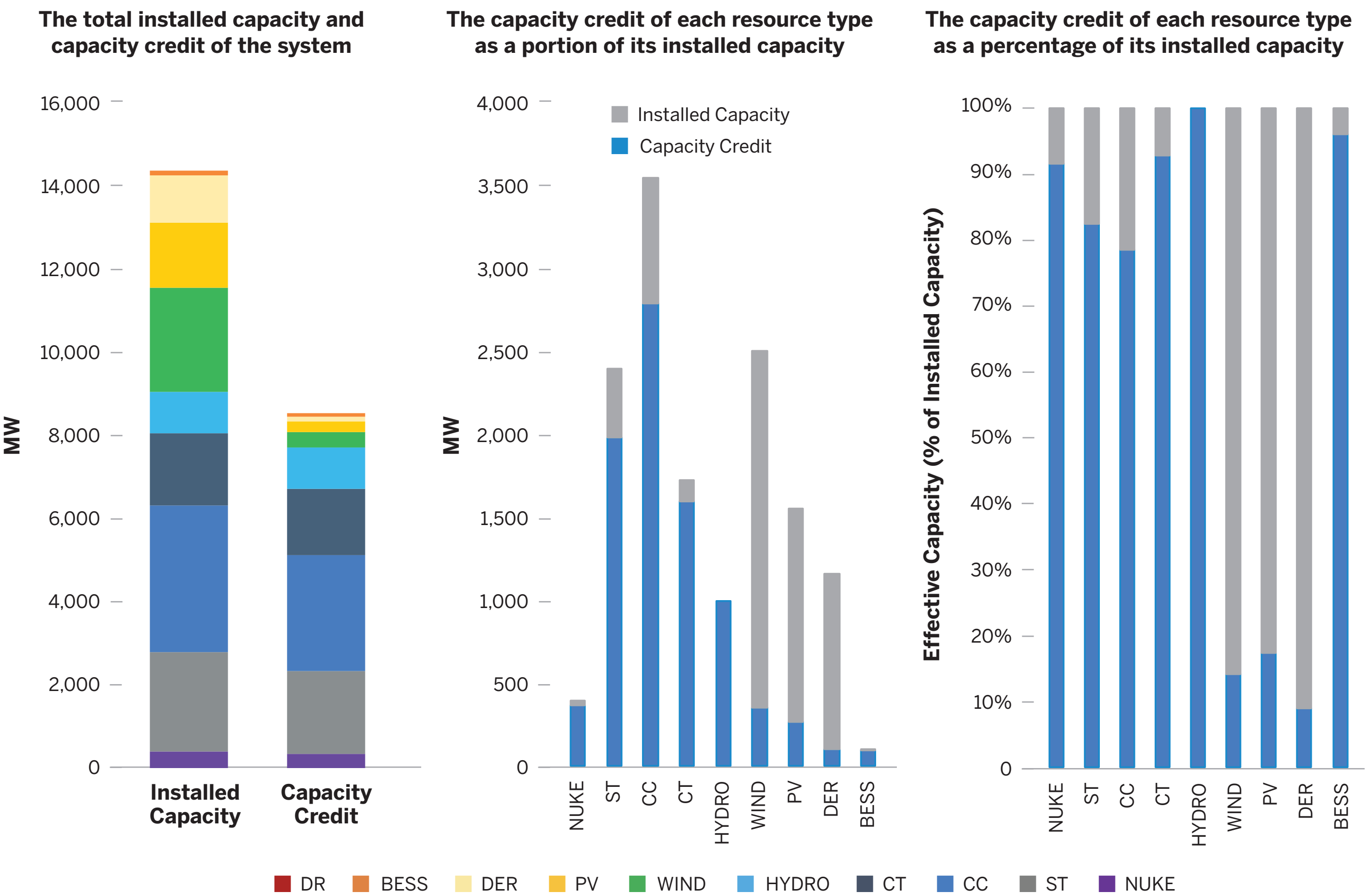
Different types of resources contribute to reliability in different amounts and at different times. For example, wind and solar resources contribute to reliability when the weather conditions are favorable. Fossil fuel resources contribute to reliability as long as fuel is available and they are not on outage—due to either planned maintenance or unexpected equipment failures. Storage resources can also contribute to resource adequacy depending on their duration, their state of charge, and the availability of energy to charge before they are needed to discharge.

Figure 1 illustrates the difference between installed capacity and capacity credit (or effective capacity) across a range of resource types. The data are presented three ways, first showing the total installed capacity and capacity credit of the system (left), then capacity credit as a portion of each resource type's installed capacity (middle), and, lastly, capacity credit as a percentage of the installed capacity for each resource type (right). It shows that some resources, on an installed capacity basis, can make up a large portion of the resource mix, but the capacity contributions for resource adequacy are provided by other resource types.

The interaction of these resources is complex and can be beneficial; for example, strong wind output can reduce

FIGURE 1

Comparing Installed Capacity and Capacity Credit Across Resource Types



These graphs show that some resources, on an installed capacity basis, can make up a large portion of the resource mix, but the capacity contributions for resource adequacy are provided by other resource types.

Notes: These data were developed using the Reliability Test System, Grid Modernization Lab Consortium (RTS-GMLC) and modeling conducted by the ESIG Redefining Resource Adequacy Task Force. DR = demand response, BESS = battery energy storage system, DER = distributed energy resources, PV = photovoltaics, CT = combustion turbine, CC = combined-cycle plant, ST = steam turbine, NUKE = nuclear generation.

Source: Energy Systems Integration Group.

the need for just-in-time fuel supply of natural gas during cold weather. This in turn could allow for line pack to occur that then helps natural gas–fired resources generate power when the wind output drops—just one example of the complex interactions that can occur. Solar and storage resources provide another valuable example of interactive effects. While regions with large amounts of solar energy tend to have tight supply conditions in the evening hours, additional solar can provide a modest contribution to delay the evening net load ramp further, shortening the peak net load period.[2] The remaining load can thus be served better by storage or demand response resources.

To account for the uncertainty in demand, weather, and resource availability, most independent system operators and regional transmission organizations (ISOs/RTOs) and utilities are using some variation of probabilistic, prospective techniques for capacity accreditation. This allows system planners to consider resource availability and capacity contributions across a wide range of potential conditions and tight supply periods.

While no resource can guarantee its availability at a specific moment in time, power system planners can measure the likelihood or probability of capacity being available during the most crucial moments, times of scarcity or tight supply conditions. For example, if a wind resource's availability fluctuates throughout the year, it may be available—on average—with 20 percent of its rated capacity at times when its output is beneficial to reduce risk of a shortfall. This likelihood of a resource's availability when needed for resource adequacy is determined through capacity accreditation and expressed as its capacity credit. This capacity credit is often stated in the form of a percentage of the resource's nameplate capacity. (Capacity credit should not be confused with a resource's capacity factor, which measures the total amount of energy produced across an entire year relative to the unit's size.)

The energy transition is bringing changes to resource adequacy analysis in general, and capacity accreditation in particular. The changing resource mix—shifting away from baseload fossil generation and toward a portfolio of wind, solar, and storage—has large implications for how the system ensures that reliability needs are met. Traditionally, these new resources were procured primarily to produce energy, displace fuel, and reduce emissions, but the next phase of the energy transition will increasingly look to them to ensure reliability. Resource adequacy is increasingly provided by variable renewables like wind and solar, and the use of energy-limited resources like storage, demand response, and load flexibility.

Traditionally, wind, solar, and storage were procured primarily to produce energy, displace fuel, and reduce emissions, but the next phase of the energy transition will increasingly look to them to ensure reliability.

In addition to the shifting resource mix, the timing, location, and causes of reliability risk and tight supply conditions are also changing. Traditionally, peak risk and tight supply conditions occurred at times when load was highest. But risk is shifting out of these peak load periods and into periods when load is lower, but resource availability is also lower, due to weather (i.e., low wind and solar periods) or correlated outages due to extreme weather and fuel supply disruptions. In addition, load profiles are also changing due to increased electrification, climate change, and structural changes in the economy. Changes to both the resource mix and the load profile are shifting risk away from the conventional risk periods (e.g., summer peak in much of the United States) and toward increased winter risk. These changes have implications for the contribution to resource adequacy of different resources.

Linking Resource Adequacy and Capacity Accreditation Using the Planning Reserve Margin

While resource adequacy analysis measures the reliability of the system and capacity accreditation measures an

2 Net load refers to the system's gross load, minus variable renewable energy. This represents the remaining load that must be served by non-variable resources, including thermal, hydro, and energy storage.

individual resource's contribution to reliability, there needs to be a link between the two so that grid planners can design a portfolio of resources to meet reliability objectives. To link resource adequacy and capacity accreditation, power system planners traditionally use a planning reserve margin, which allows them to calculate the total megawatts of accredited capacity need. The resource adequacy analysis is used to determine the planning reserve margin—the amount of available capacity required, often denoted in a percentage above peak demand, to meet the system' reliability criterion. For example, a power system may need a 15 percent planning reserve margin (i.e., 15 percent more accredited capacity than peak load) to ensure a loss-of-load expectation (LOLE) of one day in 10 years. Power system planners then have typically met the planning reserve margin by "stacking up" individual resources according to their capacity accreditation. These linkages are defined in Table 1.

However, with risk shifting to periods outside of the single peak demand period, a static planning reserve margin based on a percentage of peak demand is no longer appropriate. The capacity contribution of different resource types will change significantly as the underlying resource mix changes. Solar may shift risk to the evening hours, reducing the reliability contributions from the solar and increasing contributions from storage, wind, or flexible load resources, for example. In isolation, any resource's contribution to reliability is closely intertwined with the resource mix and underlying load profile of the system. As a result, the system's capacity requirement must be adjusted up or down to reflect these changes. This recalibration process has become standard practice, but can be challenging when the resource mix is rapidly changing. In other words, the linkage between A and B in Table 1 must be continually updated as the system evolves; this is discussed further in the next section.

With risk shifting to periods outside of the single peak demand period, a static planning reserve margin based on a percentage of peak demand is no longer appropriate. The capacity contribution of different resource types will change significantly as the underlying resource mix changes.

As renewable energy and storage take on an increasing share of the overall energy mix, it is important to understand their contributions toward resource adequacy. Figure 2 (p. 6) shows how different resources make up the resource mix over time and how they constitute different levels of installed capacity, effective capacity (for which they receive capacity accreditation for resource adequacy), and annual generation. In this example, clean

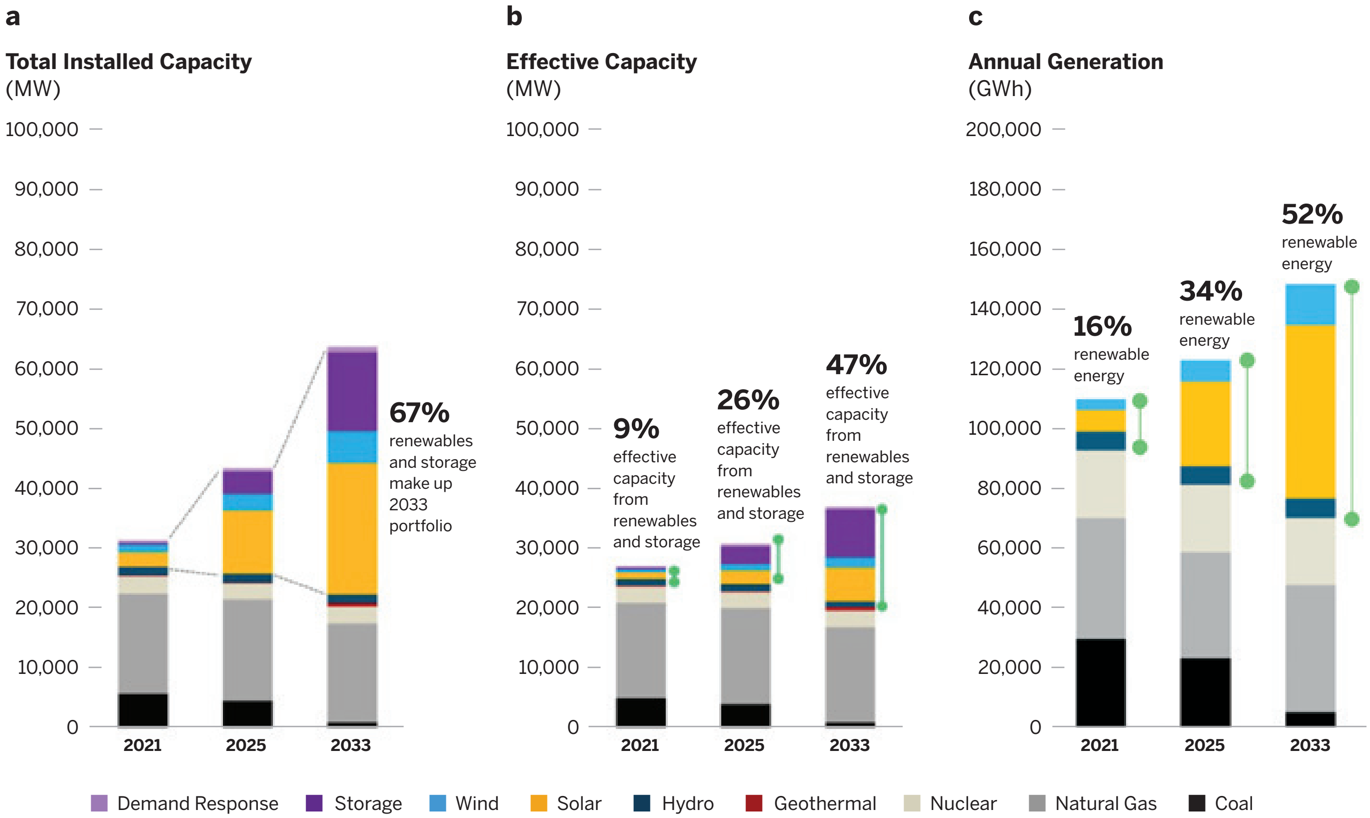
TABLE 1
Linkages Between Resource Adequacy Analysis and Capacity Accreditation

	Term	Definition	Use
A	Resource adequacy analysis (loss of load probability)	Quantifies the overall bulk power system reliability of an entire resource mix, measuring the ability of a system to serve load across a wide range of uncertain future conditions and assessing the probability of a shortfall	Determines whether a system is reliable or not based on the criteria set
B	Planning reserve margin	Establishes the total amount of accredited capacity (also referred to as firm or effective capacity) necessary to meet the resource adequacy criterion evaluated in [A]	Sets the system capacity need
C	Capacity credit (% of nameplate capacity)	Quantifies the ability of an individual resource to support resource adequacy and the amount of effective capacity that can be counted toward the planning reserve margin	Quantifies the ability of an individual resource to contribute to meeting the planning reserve margin

Source: Energy Systems Integration Group.

FIGURE 2

Comparing Installed Capacity, Capacity Credit, and Annual Generation Across Resource Types



An illustration showing how different resources make up the resource mix over time and how they constitute different levels of installed capacity, effective capacity (for which they receive capacity accreditation for resource adequacy), and annual generation. In this example, clean energy resources, predominantly wind, solar, and storage, make up 67 percent of the portfolio's installed capacity in 2033, about half of the overall energy (68 percent from carbon-free sources), and 47 percent of the effective capacity for resource adequacy needs.

Source: Schlag et al. (2022)/Energy and Environmental Economics.

energy resources, predominantly wind, solar, and storage, make up 67 percent of the portfolio's installed capacity in 2033, and about half of the overall energy (68 percent from carbon free sources), and 47 percent of the effective capacity for resource adequacy needs. A power system's supply mix can be measured across all of these metrics; each is important for power system planning.

How Capacity Accreditation Is Used for Power System Planning

While the planning reserve margin may have ensured reliability in a conventional system organized around fossil-based generation, under today's more diverse resource mix, it may not. Too often, the process of stacking up resources (according to their capacity accreditation) in order to serve a planning reserve margin is used as a proxy for determining whether or not a system is reliable. But while this planning process can serve as a simple heuristic to estimate reliability, capacity accreditation does not necessarily ensure a reliable system under all potential future conditions.

The difficulty of using capacity accreditation to ensure a reliable system lies in the static nature of capacity credits, which may not capture interaction effects between resource contributions in a changing portfolio (Schlag et al., 2020). The contribution of any individual resource depends on the rest of the underlying system—what the load shape looks like and how much variable renewable generation and storage is already on the system. If a resource's capacity accreditation is determined relative to a static resource mix, any changes

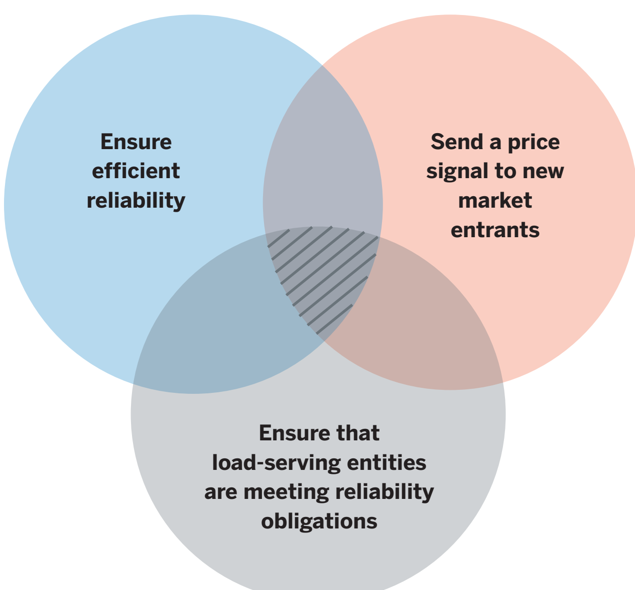
Too often, the process of stacking up resources (according to their capacity accreditation) in order to serve a planning reserve margin is used as a proxy for determining whether or not a system is reliable. But while this planning process can serve as a simple heuristic to estimate reliability, capacity accreditation does not necessarily ensure a reliable system under all potential future conditions.

to the resource mix can significantly change the contribution a resource makes to the system's reliability.

This is the case both in vertically integrated utility planning processes (such as integrated resource plans) when the results of a capacity expansion model change the underlying resource mix, and in a deregulated capacity market that may select (award) a different set of resources than what was expected. The result is that the capacity credits developed for one resource mix may no longer accurately reflect the reliability contribution of resources in a different resource mix.

To overcome this potential reliability risk, regular iteration in modeling must be conducted between the individual resource accreditation and the aggregate system needed (i.e., the power needed to serve peak net load plus the planning reserve margin). To ensure reliability, more holistic, system-level planning studies would better identify potential shortfalls and further refine capacity needs.

FIGURE 3
The Nexus of Capacity Accreditation



Source: Energy Systems Integration Group.

A robust capacity accreditation framework accomplishes three goals of planning: to ensure efficient procurement of reliability, send a price signal to new market entrants, and ensure that load-serving entities are equitably meeting their obligations to reliably serve load. The nexus of these three criteria is illustrated in Figure 3.

Ensure Efficient Reliability

While probabilistic resource adequacy analysis can provide a strong indication of whether a system is reliable, capacity accreditation is needed to provide the accounting approach for achieving and maintaining this reliability most affordably. Ensuring reliability is easy if economics are not a factor: Additional investment in new generating capacity can continually improve reliability, but may lead to a capacity overbuild and increased cost. However, when system planners can compare resources' capacity credits against investment costs, they can make cost-effective procurement decisions across potentially diverse technology choices to ensure that resources are available when needed for reliability.

When system planners can compare resources' capacity credits against investment costs, they can make cost-effective procurement decisions across potentially diverse technology choices to ensure that resources are available when needed for reliability.

In addition, without a way to measure individual resources' contribution to reliability, planners may over-invest in resources for reliability—using some resources like a combustion turbine or battery storage solely to meet reliability needs, and other resources like wind and solar solely to meet clean and low-cost energy objectives. Proper capacity accreditation can ensure that these trade-offs, both in terms of avoiding overbuilding for reliability and balancing multiple investment objectives, can be met with an appropriate portfolio of resources.

Send a Price Signal to Guide Resources Entering or Exiting the Market

Different resources will have varying contributions toward resource adequacy, and a resource's contribution will vary over time as the system's portfolio changes. For example, early additions of solar PV to a power system may provide significant reliability contributions for systems with summer peaks that often occur in the afternoon. However, after continued deployment of solar, the reliability benefit of future additions of this resource type declines as system risk and tight supply conditions shift to evening periods when the resource is less available. Proper accreditation methods would then guide investors or utility planners to seek alternative resources to meet reliability needs.

If new investment is required to improve reliability (due to either increasing loads, shifting demand profiles, or plant retirements), capacity accreditation can guide that investment toward resources that can meet the reliability needs of the system at that point in time, being available during periods of highest risk of scarcity. In the solar example, if risk is shifted to evening or overnight, although continued investment in solar may still be beneficial for clean energy or cost objectives, it may not provide a meaningful incremental contribution to reliability. In this case, investments for reliability would be guided toward storage or other resources that can be available during the evening hours.

Capacity accreditation helps to ensure that these trade-offs can be understood and can provide a price signal to new entrants or plants considering retirement (exiting the market), to encourage investment decisions that secure reliability in an economically efficient manner.

Ensure That Load-Serving Entities Are Meeting Their Share of Reliability Obligations

While the previous objective for accreditation is focused on individual resource decisions, the process is also important to ensure that load-serving entities are meeting their reliability obligations across their entire

portfolio of resources. If, for example, an ISO or RTO has multiple load-serving entities with heterogeneous resource mixes, capacity accreditation can be used to compare the ability of each to meet capacity requirements with its portfolio of resources. This is done to ensure that no individual load-serving entity in the group is a free-rider—not bringing enough resources to meet its share of reliability needs.

Properly done, a robust capacity accreditation framework provides a numerical approach for planning new entrants, informs resource procurement decisions, evaluates economic and reliability trade-offs between resources, can be used to compensate resources for reliability service, and allocates responsibility to the load-serving entities. But if capacity accreditation is computed improperly, or interpreted incorrectly, the ramifications can be large, potentially jeopardizing system reliability and leading to inefficient investment in new resources.

Changes in Capacity Accreditation Needs over Time

Structural changes to resource adequacy risk and the electricity portfolio are driving the need to change the way resources are accredited. These changes can be described in five phases by the way resources have been, are, and will increasingly be accredited for their contribution to resource adequacy. Different power systems are transitioning through the phases of the accreditation process based on their unique resource mix, load profiles, and risk composition, but the general transition between phases can be described as follows (Figure 4).

Structural changes to resource adequacy risk and the electricity portfolio are driving the need to change the way resources are accredited. These changes can be described in five phases by the way resources have been, are, and will increasingly be accredited for their contribution to resource adequacy.

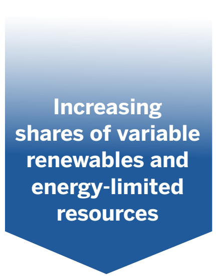
PHASE 1: Nameplate Capacity of Resources

Historically, there was little distinction between a resource's nameplate capacity and its contribution toward reducing risk. In phase 1, the original simplistic planning reserve margin framework counted all resources at full capacity, on the assumption that the resources were uniformly available at all times throughout the year. Unavailability of resources was assumed to be only due to randomly occurring forced outages and was covered by adding a sufficiently high reserve margin "cushion" to cover uncertainties in higher-than-expected load or generator outages.

PHASE 2: Expected Capacity Available at Time of Peak Load

Traditionally, power systems with little or no variable resources or energy-limited resources have had capacity accreditation that is closely linked to periods of peak

FIGURE 4
Transition of Capacity Accreditation Methods



1. Nameplate capacity of resources
2. Expected capacity available at the time of peak load
3. Expected capacity available at the time of peak net load
4. Expected capacity available at the time of high risk
5. Expected capacity and energy available from resources during periods of high risk

Source: Energy Systems Integration Group.

load. Here, in phase 2, most supply-side resources are uniformly available (their availability does not vary significantly from hour to hour or seasonally), so risk is isolated to periods where the demand side (load) increases to higher-than-expected levels. For thermal resources this means that capacity accreditation was commonly calculated as its UCAP—installed capacity minus its forced outage rate—and the planning reserve margin ensured enough capacity to meet load under some expectation of generator outages (Billinton, 1970).

As a result, the capacity accreditation of a variable resource in phase 2 is highly correlated with its output or availability during peak load periods; there is a strong correlation between availability during a peak load window and the reliability contributions of a resource. In addition, because the peak demand period lasts for only a short period of time and a few hours per year, energy-limited resources (storage, load flexibility, and demand response) are typically available throughout the highest risk periods. Because of this, simple heuristics, like average capacity factor during the peak load hours, served as a useful proxy for a resource's capacity contribution.

PHASE 3: Expected Capacity Available at Time of Peak Net Load

With increased additions of variable renewable resources, accreditation in phase 3 shifts away from the peak load period to the expected capacity available during peak net load periods (or load minus available wind and solar generation). This occurs because the wind and solar resources increase total resource availability during some periods, when weather conditions are favorable, but are unavailable overnight for solar or during low wind periods. As a result, the peak load period (often occurring in the early afternoons) is no longer the riskiest. In many systems this resource change will shift the peak net load to evening hours, which have lower load but also lower renewable resource availability. Phase 3 is most pronounced for systems with high levels of solar, but a similar shift occurs (albeit at different times) with systems with high levels of wind.

PHASE 4: Expected Capacity at Times of High Risk, Often Correlated with Weather

With a changing resource mix and growing load flexibility, periods of risk continue to shift in phase 4. Eventually, resource adequacy risk may be largely independent of high load periods, and instead will be predominantly related to unique weather events that can have a pronounced, correlated negative effect,

Increasingly, periods of risk are driven by correlation among many components that are often weather-related, including high load, low renewable resource availability, drought, and correlated outages and fuel supply disruptions from the fossil fuel generators.

increasing load and reducing the output of multiple resource types at the same time. For example, a winter cold snap may lead to low solar availability, calm wind conditions, fuel restrictions on natural gas infrastructure, and increased equipment failures and forced outages. In this case, load, while potentially higher than the seasonal norm, may no longer be the primary driver of risk. Increasingly, periods of risk are driven by correlation among many components that are often weather-related, including high load, low renewable resource availability, drought, and correlated outages and fuel supply disruptions from the fossil fuel generators.

PHASE 5: Expected Capacity and Energy Available from Resource During High Risk

Finally, as the system transitions to reliance on a high degree of energy-limited resources like storage and load flexibility for reliability, capacity accreditation in phase 5 will again need to shift to not only account for capacity, but increasingly ensure that there is sufficient energy available during previous hours to charge the storage resources. During risk periods, these resources may be constrained by their energy limits, even if nameplate capacity is sufficient. In hydro-dominant regions, these energy limitations—due to seasonal profiles or drought conditions—have always been a key component of capacity accreditation, and other types of energy-limited resources will increasingly be considered in a similar manner.

The energy limitations during times of system risk are also a growing concern for thermal resources, especially for natural gas, which can also have energy risks due to fuel supply disruptions. While these resources are not typically considered energy-limited, fuel supply disruptions (particularly in cold-weather events) can limit their ability to perform during periods of high risk.

In regions that increasingly rely on storage or demand response for reliability, these resources may not be able to sustain their collective output long enough to last throughout the period of risk. In phase 5, as storage deployment increases, the periods of risk will lengthen (as peak net demand periods flatten), requiring a longer response to reduce the risk of unserved energy further. Just as important, in this case, is the availability of energy to charge storage resources earlier in the day or days leading up to a risk period. If tight energy supply conditions occur over a longer period of time, such as in a multi-day low wind and solar weather event, there may not be enough energy available to fully charge storage resources or shift demand to alternative times. Therefore, capacity accreditation methods must also measure a resource's ability to provide sufficient energy, in addition to capacity.

The reliability of future systems will largely be based on energy limitations across a wide range of hours rather than simply not having enough capacity available in a given moment.

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Characteristics of Capacity Accreditation Methods

The confluence of the energy transition, a changing resource mix, the increasing electrification of loads, and a changing climate is requiring system planners and market designers to reconsider the way in which resources are accredited for resource adequacy and how the number of resources needed for a reliable system is determined. This process is underway at nearly every ISO, RTO, and utility in the United States. For example, new capacity market design or capacity accreditation rules have been proposed or put in place over the past year in PJM (FERC, 2021b), the New York Independent System Operator (NYISO) (NYISO, 2022), Independent System Operator of New England (ISO-NE) (ISO-NE, 2022), Midcontinent Independent System Operator (MISO) (MISO, 2022b), Southwest Power Pool (SPP), Electric Reliability Council of Texas (ERCOT) (PUCT, 2022), California Independent System Operator (CAISO) (CPUC, 2022), and across the vertically integrated landscape (Newell, Spees, and Higham, 2022).

While many of these regions are moving toward ELCC and a planning reserve margin framework for variable renewable resources and storage, there is only limited consistency across ISO/RTO markets, and even less so for vertically integrated utilities. Given the ongoing nature of these reforms, this report outlines the key decisions faced by grid planners and regulators.

Accreditation methods can be characterized by three overarching elements that need to be considered when evaluating how to adjust a capacity accreditation technique:

- Deterministic or probabilistic
- Prospective or retrospective
- Based on the marginal or average contribution of a resource

None of these overarching elements is perfect and there is no right answer; a lot depends on the methodology of implementing each technique and the assumptions going into performing the calculations.

There may be reasons to select a deterministic metric over a probabilistic one or to measure average contribution instead of marginal. The objective of this section is to evaluate the options and trade-offs between different mechanisms.

Deterministic vs. Probabilistic Accreditation Metrics

While market design and tariff rules will be unique to the system and region, there is a set of consistent options that are being considered, proposed, or implemented across North America. One consideration is whether capacity accreditation uses deterministic or probabilistic accreditation metrics. Deterministic metrics use a single-point estimate, often based on historical performance, while probabilistic metrics use analytical simulations across hundreds or thousands of potential future conditions. Both types have benefits and limitations.

Deterministic Approaches

Deterministic approaches use predefined hours, or predefined criteria for selecting hours, of resource availability or generation to determine the capacity accreditation of a resource. For example, the expected output of wind and solar resources during a predefined set of afternoon hours in the summer months was historically used to accredit resources in NYISO (Smith, 2021), ISO-NE, and other regions (Newell, Spees, and Higham, 2022).

Other deterministic options include using exceedance. The exceedance approach measures the minimum amount of generation produced by the resource in a certain percentage of selected hours. For example, a 70 percent exceedance level of a resource is the generation amount that it produces at least 70 percent of the time. A 70 percent exceedance value of 10 MW for a 20 MW generator means that a resource is producing 10 MW or more 70 percent of the time. This metric was used in California until 2017 (CAISO, 2019) and is again being considered for the proposed "Slice of Day" resource adequacy framework, which calculates exceedance across each month and hour within a day. Unlike probabilistic methods which measure a resource's contribution toward reducing simulated loss-of-load events, exceedance provides hourly estimates by month and is based on historical observations, thus requiring no specialized modeling tools (Pappas, 2021).

Other deterministic options, like the ones proposed by MISO, measure a resource's availability during a set of risk hours based on actual tight margin conditions (e.g., the lowest 2 percent of operating margin hours), and emergency conditions (FERC, 2022).

The benefits of these approaches include the simplicity of the calculations and the transparency provided to project developers, regulators, environmental advocacy groups, and others, because they can easily understand the method and process used to accredit different resources. In addition, a unique accreditation value can be ascribed to specific, individual resources rather than ascribing an average by technology type. This allows for an easier method to differentiate between technologies and plant configurations that could change a resource's availability during scarcity events—such as the use of solar tracking systems, larger turbines, or higher inverter-loading ratios.

The limitation of deterministic approaches is the use of *predetermined* hours, or criteria for selecting hours, of resource availability. If risk periods shift, as can happen with changing resource mixes, load profiles, or other changing system behavior, then the deterministic approach may no longer accurately reflect the proper resource contribution toward resource adequacy.

Probabilistic Approaches

Probabilistic approaches to resource adequacy modeling measure the likelihood of a resource's availability not during predetermined hours, but rather during expected reliability events, which, as discussed above, are undergoing continual shifts due to resource and load changes on the system. Probabilistic resource adequacy modeling determines the probability of loss of load under certain conditions (expressed as loss-of-load probability (LOLP) or LOLE, with and without the resource whose capacity accreditation is being calculated, and determines the ability of the resource to reduce or eliminate loss-of-load events.

These probabilistic loss-of-load metrics are converted into capacity accreditation using ELCC, and associated metrics.[3] To calculate the ELCC of a resource, a four-

The limitation of deterministic approaches is the use of *predetermined* hours, or criteria for selecting hours, of resource availability. If risk periods shift, as can happen with changing resource mixes, load profiles, or other changing system behavior, then the deterministic approach may no longer accurately reflect the proper resource contribution toward resource adequacy.

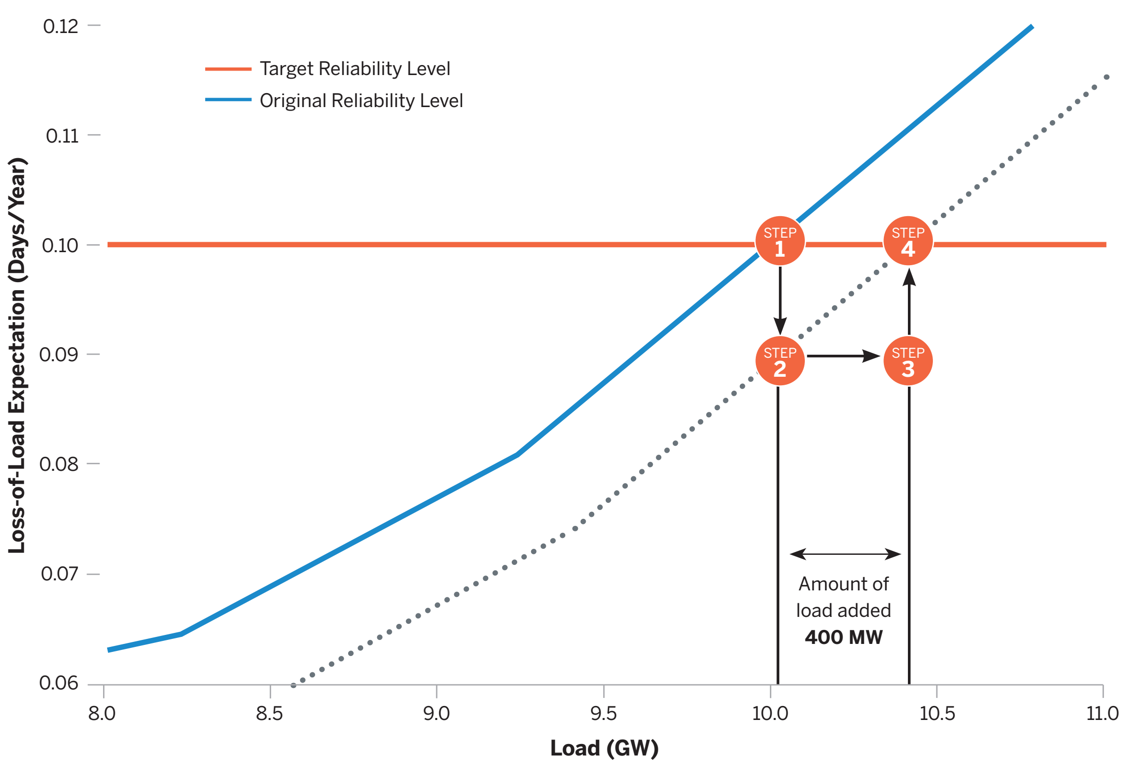
3 In this paper, effective load-carrying capability (ELCC), equivalent firm capacity (EFC), and equivalent conventional capacity (ECC) are treated similarly. While their exact calculation steps may differ, each quantifies the probabilistic reduction in loss-of-load expectation when adding a resource to the system.

step process is conducted using probabilistic loss-of-load modeling (Figure 5). The system is first brought to the reliability criterion (e.g., 1-day-in-10-year LOLE). In step 2, a resource is added to the system, thus reducing LOLE and making the system more reliable. The modeler then adds a fixed amount of load to the model (i.e., fixed block of load across all hours) in step 3 until the original LOLE criterion is reached (step 4). The difference between the amount of load added relative to the capacity added for a given resource is its ELCC.

The benefits of using probabilistic approaches include the consideration of changing drivers and timing of resource adequacy risk. For example, if a system has a large increase in solar capacity, risk may shift later to the evening periods—or even to winter seasons—which would be reflected in the timing of loss-of-load events. Theoretically, if the modeling is done correctly, a probabilistic approach will reflect a resource's ability to reduce system risk more accurately and across a wider set of potential future conditions than a deterministic one, which only considers performance during a relatively short historical period.

The primary limitation of using probabilistic approaches is that the modeling needs are time-intensive (both computationally and for human analytical time), require detailed data, and can be prone to errors or bias if done incorrectly. They are also complex, opaque for industry stakeholders, and challenging to implement during a period when the resource portfolio is changing rapidly.

FIGURE 5
Illustration of the Four Steps in the ELCC Methodology



To calculate the ELCC of a resource, the system is first brought to the reliability criterion (e.g., 1-day-in-10-year LOLE) (step 1). In step 2, a resource is added to the system, thus reducing LOLE and making the system more reliable. The modeler then adds a fixed amount of load to the model in step 3 until the original LOLE criterion is reached (step 4). The difference between the amount of load added relative to the capacity added for a given resource is its ELCC.

Source: Ibanez & Milligan (2014)/National Renewable Energy Laboratory.

FIGURE 6

Comparison of Probabilistic and Deterministic Approaches

	Deterministic Approaches	Probabilistic Approaches
Variations	• Capacity factor during pre-defined number of peak load hours or static risk window (i.e., afternon hours during summer months) • Exceedance (i.e., capacity available more than 70% of the time)	• Effective load-carrying capability (ELCC) • Equivalent firm capacity (EFC) • Marginal reliability improvement (MRI)
Advantages	• Simple, transparent, and easy to understand • Does not require modeling to calculate • Provides certainty for generation owners	• Evaluates resource performance during periods of scarcity, not just peak demand • Considers correlation of resources and load • Accounts for weather-driven resource performance
Challenges	• May not align with scarcity periods • Requires regular updates to the pre-defined risk windows to stay relevant, especially with high penetrations of renewables and storage	• Computationally intensive • Sensitive to inputs and assumptions • Opaque for market participants • Difficult to apply to all resources and capture plant-specific configurations

Source: Adapted from Newell and Higham (2022) / The Brattle Group.

A summary of the deterministic and probabilistic approaches is provided in Figure 6.

Prospective vs. Retrospective Accreditation Metrics

A second characteristic of different accreditation techniques is whether or not they use prospective (forward-looking) data or retrospective (historical) data. These approaches can be used for either deterministic or probabilistic approaches, and both have limitations.

Prospective Approaches

Prospective approaches include simulations of both the power grid and the underlying atmospheric weather data to determine likely or expected resource performance (expected capacity factors and hourly resource profiles) and system risk (loss-of-load probability). Retrospective approaches use actual, measured performance of resources (actual generation profiles) and sometimes actually observed risk periods in order to measure a resource's contribution to reducing risk.

Prospective methods are often used in the planning and investment time frame to help understand the incremental benefits of one or more additional future resources. This process may include the assessment and comparison of many potential future resource additions.

The benefits of using prospective data are that these simulations can forecast changing characteristics of the system risk (i.e., shifts to different time periods) and changing characteristics of technology which could affect resource availability, including higher inverter-loading ratios of solar resources (larger build-out of panels at a given plant to increase output) and larger turbines for wind resources. In addition, simulated performance data are required for storage and other energy-limited resources, as their operation is not determined by a fixed generation profile but can be adjusted to meet the actual reliability needs of the system. For example, basing the capacity credit of energy storage on historical operations may not be appropriate because the storage might have been able to operate differently had the system needed energy in a different manner and had the system included a different underlying resource mix. In contrast, variable renewable resource operation is based almost exclusively on the underlying weather and there is no decision on when to produce energy, so the historical generation profiles can be used as a proxy for future utilization.

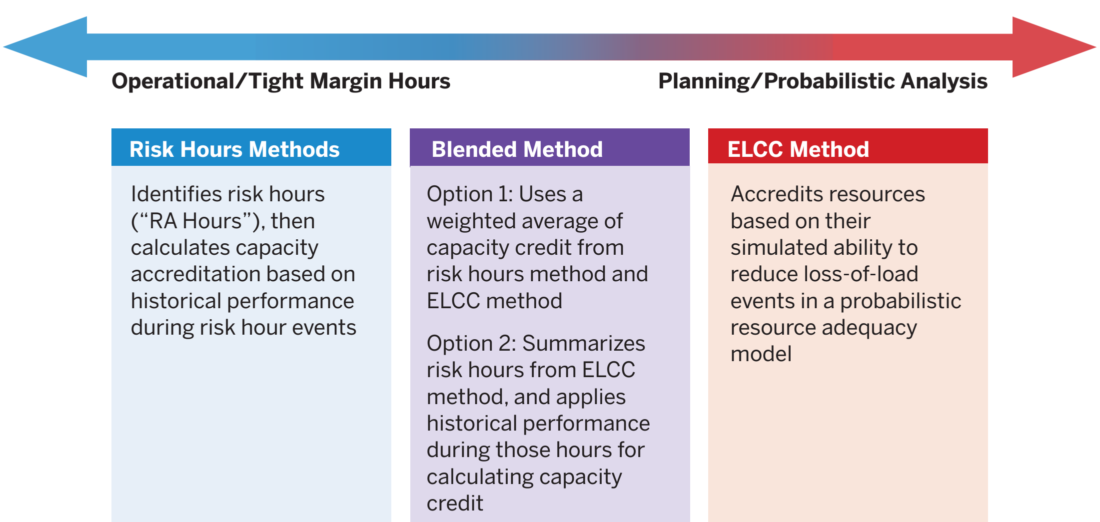
The limitations of using prospective data are that these simulations may not accurately reflect the availability of individual resources during tight supply conditions; the generator's actual performance could depart from that seen in the simulations due to forecast errors, mis-operation of the resource, or equipment failure. While weather modeling has improved significantly, there may still be inaccuracies in resource availability. Similarly, weather models do not have sufficient spatial and temporal resolution to analyze the effect of changing weather patterns on correlated changes in renewable generation and load. While planners can create climate scenarios to characterize multi-decadal future risk, it is important to exercise caution when forecasting the weather (versus climate) for individual resource accreditation and near-term procurements.

Retrospective Approaches

Retrospective approaches, typically used in deterministic methods discussed in the previous section, include the use of historical, actual operating conditions to inform resource accreditation. Retrospective approaches can be used to assess actual performance, and it is appropriate in an operational setting. For example, ISO-NE and NYISO historically accredited resources based on generation during peak demand windows. MISO uses actual resource availability during tight margin hours for its thermal accreditation and is considering using a similar approach for renewable resources (MISO, 2022b). Both the resource availability and tight margin hours are based on historical data over the prior three years, rather than simulated likely conditions.

Figure 7 shows a comparison of retrospective historical performance "RA [Resource Adequacy] Hour" accreditation (left side in blue) and prospective (simulated)

FIGURE 7
Comparison of Probablistic Methods vs. Operational Risk Hours in MISO



Source: Midcontinent Independent System Operator (2022b).

ELCC methods (right side in red) currently being considered by MISO for non-thermal resources (MISO, 2022b). On the left are retrospective methods that identify contributions of resources based on historical performance. On the right, there are methods for accreditation (in this case ELCC) that are based on system planning and prospective/probabilistic methods. The middle facet shows a potential third option that blends the two.

The benefits of using retrospective data are that this approach does not introduce potential bias and inaccuracies of using simulated data. It also creates an incentive for resources to optimize performance for tight operating conditions regardless of when these conditions occur. This is because a resource's capacity credit is based not on how it performed during expected shortfalls in the modeling, but rather on how it actually operated during tight margin hours. Aligning actual operations with capacity accreditation creates a performance-based methodology and avoids overreliance on simulated values for capacity credit. A retrospective approach also benefits from taking into account several factors that planning models typically cannot anticipate, such as combinations of load forecast errors with forced outages, unusual weather, constraints imposed by the specific commitment stack, and others.

The limitation of using retrospective data is that they capture only historical system changes and will lag new technology adoption and efficiency gains such as larger wind turbines, more efficient solar panels, or new resources added to the portfolio such as offshore wind and new storage mediums. Using retrospective data in isolation will also not be able to capture future system risks that lie outside the historical hours, driven by uncertainties; changing weather; a changing resource mix; or high-impact, low probability events that may not have occurred over the previous few years. Given the relative infrequency of scarcity events (less than one every 10 years, for example), using a short historical record of actual operations may not provide enough observations to accurately characterize risk or individual unit performance. Even if risk hours are broadened to include low margin periods instead of load shed events, the total sample size is small.

Marginal approaches accredit the entire cohort of a resource type based on the reliability contribution of the incremental changes to that resource type, whereas average approaches accredit the entire cohort of a resource type based on the contribution of the entire fleet.

Marginal vs. Average Accreditation Metrics

A third characteristic of different accreditation methods is whether the method quantifies the marginal or average contribution of a resource. Marginal approaches accredit the entire cohort of a resource type based on the reliability contribution of the incremental changes to that resource type, whereas average approaches accredit the entire cohort of a resource type based on the contribution of the entire fleet. All else being equal, resources of a single type (e.g., solar or wind) will hit a limit in their ability to reduce risk with additional installations, but the rate at which each resource type saturates is dependent on the amount installed, the resource's availability during risk periods, and its correlation with other resources and load on the system. If a resource type's capacity credits are calculated using marginal accreditation techniques, the capacity credits of the cohort will decline at a faster rate than average accreditation calculations.

Marginal Accreditation Techniques

Marginal accreditation techniques evaluate a resource's incremental benefit of providing a small addition of capacity to the system. If, for example, a system has no solar capacity and system risk occurs during early afternoons, early additions of solar can be a valuable resource to reduce risk, thus they have high capacity credit. However, as additional solar capacity is added to the system, risk starts to shift toward evening hours, and the solar's ability to reduce load (and resource adequacy risk) diminishes. In a marginal accreditation framework, the entire cohort of resources within a class (e.g., all solar) receives the same capacity credit calculated for the last set of additions, and does not differentiate between early additions and later ones. So as additional resources are added, the capacity credit afforded to existing resources will diminish. Marginal accreditation techniques can be applied in prospective and probabilistic analysis including ELCC and similar methods. This approach is currently being considered by ISO-NE and NYISO.

The marginal accreditation framework involves regularly recalculating the total amount of effective capacity (firm capacity) needed to meet the resource adequacy criterion (defined as the planning reserve margin). In the solar example above, if the risk is shifted to later evening or overnight hours when load is lower, all solar resources receive a marginal credit near zero because solar resources, by themselves, do not improve the resource adequacy risk on the system. In this case, the total system effective capacity needed (the sum of individual capacity credits of all resources) is reduced because early additions of solar shifted system risk; however, solar is now counted with a zero capacity credit on a marginal basis.

The process defining the total effective capacity requirement and the resource capacity credits thus requires tight linkage with the resource adequacy system requirement. When levels of renewables become very high, the planning reserve margin requirement may fall below peak demand, because the period of peak risk may occur when demand is lower than peak load. For example, if a period of peak risk is a winter cold period when renewable generation is low, the planning reserve margin requirement could fall below peak demand. This is counterintuitive and is often a forgotten step.

In the future, because risk is decoupled from peak demand, the planning reserve margin can be articulated in a total system effective megawatt value (e.g., 10,000 MW of effective capacity based on resource capacity accreditation) rather than a percentage of peak load (e.g., 115 percent of peak load) to avoid confusion. This transition to a purely accounting framework is important, as it shifts the objective from planning a system that can

cover a single peak demand hour to one that is developed to cover an entire year of operation, regardless of when the risk is present (see section on "Linking Accreditation to Operations").

Proponents of marginal accreditation techniques contend that it conforms to traditional economic principles, which state that the most economically efficient pricing (or value) of a resource occurs if it is based on the marginal supply of the next resource addition. This is consistent with how electricity markets value locational marginal pricing of energy and consistent with how other commodities are priced in competitive markets. This analogy assumes homogeneity of the commodity (load in the case of energy pricing, and resources in the case of accreditation). In order to ensure homogeneity, it is important to calculate the accreditation value in a way that is representative to those resources it is being used for. In addition, this approach provides a clear price signal for new entrants into the market. If saturation has occurred and a resource type no longer provides capacity and reliability benefits, it will receive a low capacity credit and thus low payment for reliability services, whereas a different resource that has higher availability during risk periods will be compensated at a higher level. This signal better incents efficient new investment for the next increment of reliability.

If saturation has occurred for a resource type, it will receive a low capacity credit and thus low payment for reliability services, whereas a different resource with higher availability during risk periods will be compensated at a higher level. This signal better incents efficient new investment for the next increment of reliability.

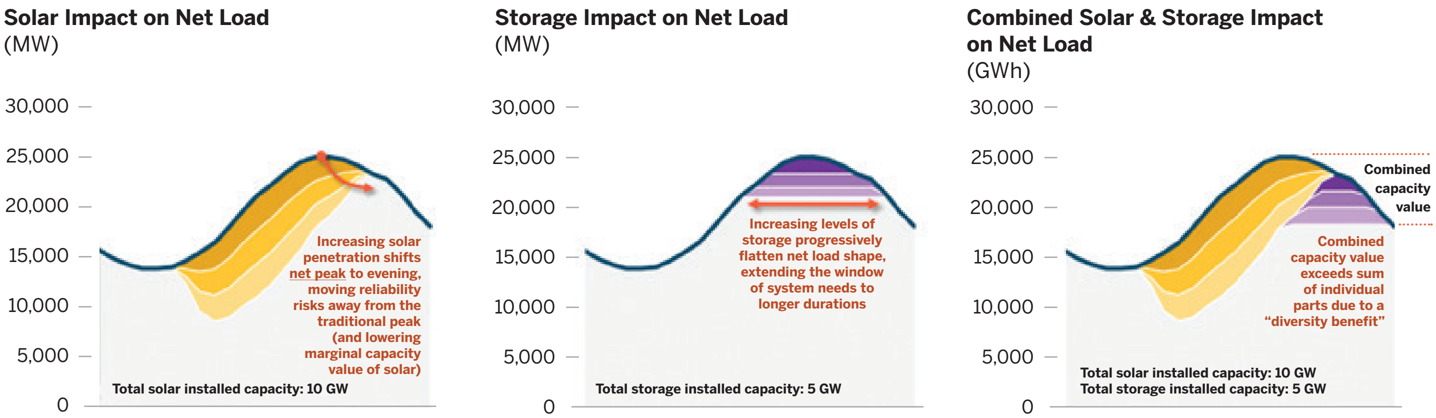
However, marginal accreditation techniques have many implications that are important to consider. First, while they provide a better incentive for the next increment of reliability investment, they are prone to rapid saturation. If all resources, including existing ones, are accredited based on the last addition, a resource's future capacity revenue stream can quickly diminish to zero. From an asset owner's perspective, the marginal accreditation technique also increases the likelihood that saturation effects occur quickly, potentially reducing capacity revenues significantly and preventing investors from recouping initial investments. This in turn makes financing of new projects more uncertain and difficult, and increases the risk of stranded assets that are not recouping investment and thus losing money. Knowing this saturation is likely, investors and developers may choose not to build an asset, missing out on potentially large reliability benefits for early additions, just because potential future ones would change its capacity revenues significantly.

Second, the marginal approach does not ascribe any value to reliability benefits that accrued due to the shift in the timing of scarcity conditions. Instead, it only values resource availability during the remaining reliability risk periods. As a result, owners of some resources could claim that they are not being fairly compensated for their reliability contribution. For example, in a high-solar system, risk is shifted to the evening hours after the sun sets. The marginal benefits of adding more solar will be very low (or zero), but the early additions of solar provided significant reliability benefits that they are no longer getting compensated for. This system benefit of early additions that provided high levels of reliability, but are now counted with very low marginal credit, is recognized by lower overall capacity needs, but some solar resources are not necessarily compensated for that benefit. Storage, on the other hand, may have a high capacity credit, but only if it has energy from a resource earlier in the day.

In addition, marginal accreditation techniques may not equitably assign value to different resources that have synergistic benefits (Schlag et al., 2020). For example, if in the solar example, risk occurs during evening hours, storage will be valuable for reducing risk and thus have a high capacity value. However, for the storage to be effective it requires energy to charge, which could be provided by a resource's availability earlier in the day. In a marginal accreditation framework, most of the capacity credit is assigned to the storage resource despite the energy provided by solar, or other resources, necessary to charge it.

FIGURE 8

Evaluating Marginal Capacity Credit and Synergistic Benefits



The gray field represents the net load. In the left panel, increasing levels of solar (shown in the dark-to-light yellow bands) shift the peak net load to evening. In the center panel, increasing amounts of storage (shown in dark-to-light purple bands) flatten the peak net load and increase the duration of the risk period. In both cases, significant risk remains after the resource type reaches high levels. In the right panel, the combination of solar and storage results in (1) a lower peak net load than for solar alone, and (2) a shorter-duration peak net load than for storage alone.

Source: Schlag et al. (2022)/Energy and Environmental Economics.

The diminishing marginal capacity credits are shown in Figure 8, first for solar (left pane) and then for storage (middle pane). Each resource in isolation has diminishing returns because the risk periods shift to other parts of the day. However, when the two resource types are evaluated in conjunction with one another, there are synergistic benefits—the total is larger than the sum of the parts. This portfolio benefit has been shown to occur for multiple types of synergistic resources (Schlag et al., 2020).

Vintaged Marginal Accreditation Techniques

One way to solve the implications of saturation effects and the economic uncertainty that marginal accreditation imposes on resources is to use a vintage process. In this approach, early additions to the system are assigned a capacity credit commensurate with the reliability benefit they provide when they are built. Subsequent additions, then, receive a different capacity credit based on the system characteristics at the time they are added. This allows for resources to be compensated in the market (or selected in a competitive procurement process) based on the reliability benefits they provide at that time, and the credit would be locked in for a defined period of time.

The vintage marginal accreditation approach works well in a regulated utility integrated resource plan and procurement process. This is because the resource procurements occur at specified intervals, and the utility can choose the appropriate resource (balancing reliability contribution and costs) depending on the conditions of the system and enter into a long-term contract with the resource. The utility can also look out into the future via integrated resource planning and forecast how the capacity credits will change over time.

While this approach solves some of the saturation and economic uncertainty challenges for new resources, it cannot be applied in a wholesale competitive market, because the approach would compensate similar resources differently based solely on the dates they came online. Thus, it would favor incumbent generators and, according to the Federal Energy Regulatory Commission (FERC), is unjust for new entrants. According to FERC,

> The [vintage marginal] mechanism would discriminate between resources in a class based on vintage despite the fact that all resources within a class bear equal responsibility for the decrease in the capacity contribution of their ELCC class (FERC, 2021a).

> ELCC Class Ratings [are calculated] on an annual basis to account for changes to the resource mix, load shape, weather patterns, and other factors that affect ELCC Resources' contribution to meeting . . . reliability requirements. To the extent that the ELCC Class Rating varies from one year to the next, we find that it is just and reasonable to assign the same ELCC Class Rating to all resources within a class regardless of vintage, because all resources in the class contribute to the change in ELCC Class Rating. Furthermore, we affirm our finding in the Initial ELCC Order that "[it has not been demonstrated] that resources entering the capacity market in different years are differently situated in a manner that warrants granting more favorable treatment to resources the earlier they enter into the capacity market. To argue that existing ELCC Resources deserve special treatment is a collateral attack on this finding (FERC, 2021b)."

For this reason, it is likely that vertically integrated utilities can continue to use a vintage marginal approach for accrediting resources because they use long-term power purchase agreements to procure capacity, while wholesale capacity markets must choose either a marginal or average accreditation technique.

Average Accreditation Techniques

Average accreditation techniques, on the other hand, assign resources' capacity credits by measuring the reliability of an entire resource class (or group of multiple resource classes) at one time. Both marginal and average methodologies assign every resource in a class the same capacity credit, but they differ according to whether the class of resources is measured by a small change of the capacity of the class or by mesauring the contributions of the class in its entirety. Average accreditation techniques, rather than valuing all of the resources of a given type based on the next (incremental) small change to the class, evaluate the entire installed base of a particular resource type together and calculate the aggregate resource adequacy contributions of the group. This approach is being implemented or considered by PJM, MISO (for wind resources only), and SPP.

Figure 9 (p. 22) illustrates the average versus marginal capacity accreditation process for a system with both conventional, non-variable generation (thermal generators and hydro) and solar and wind generation. In the gross load profile (blue), assuming the resources in the system are sufficiently available, the most risk will occur during the peak load period. As solar and wind are added to the system, the net load curve (red) shows the remaining system load that must be served by thermal and hydro resources. The average ELCC can be illustrated as the total contribution of a set of solar and wind resources that shifts the risk from gross peak to net peak, simultaneously shifting the risk period later and reducing the megawatts required to serve the net load.

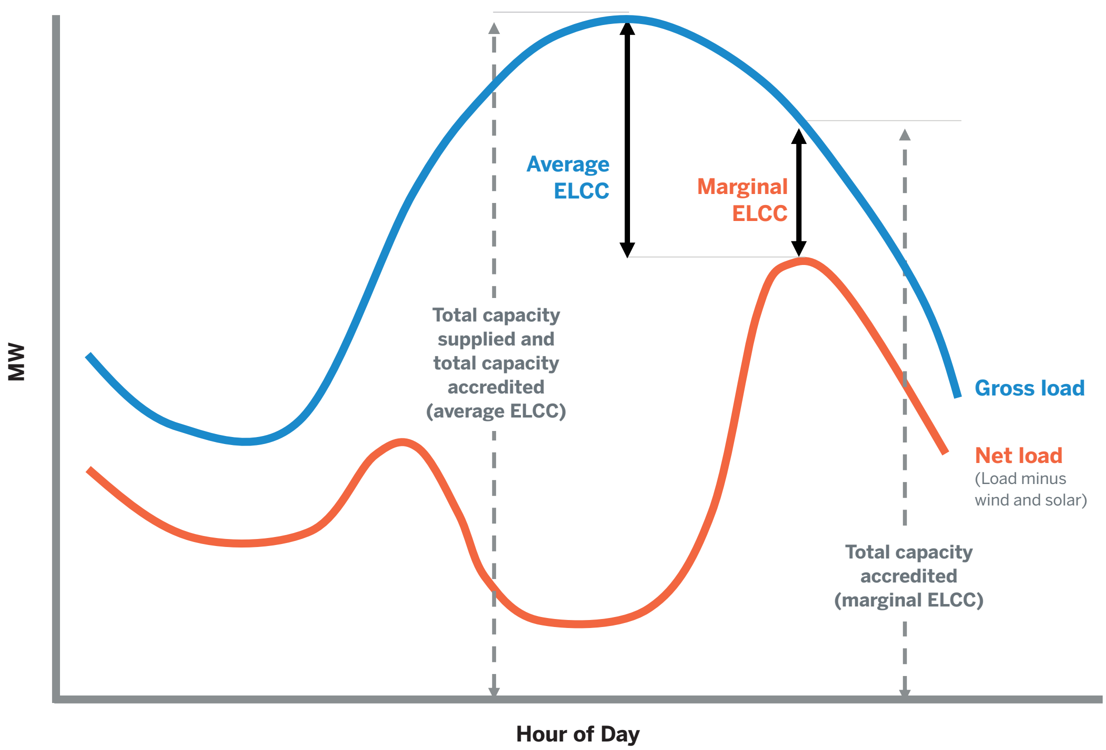
Both marginal and average methodologies assign every resource in a class the same capacity credit, but they differ according to whether the class of resources is measured by a small change of the capacity of the class or by measuring the contributions of the class in its entirety.

In contrast, the marginal ELCC can be visualized as the reduction of risk during the final risk periods (later evening risk). In this case, the marginal ELCC is lower because the overall contribution of the solar and wind resources during the remaining risk period is lower. In the marginal case, the resources receive a lower capacity credit based on the final risk rather than the original risk period, but the overall total accredited capacity needed is also reduced. As a result, the total accredited capacity need is reduced, but this benefit is realized by the load (as customers do not have to pay for as much accredited capacity) and not attributed to any individual resource.

Proponents contend that it compensates a fleet of resources for the reliability services they provide, such that the sum of individual resource credits is equal to the aggregate capacity value of the system (Carden, Bellon, and Dombrowsky, 2022). In contrast to the marginal framework, this allows the planning reserve margin, which dictates the total capacity needed of the system, to change less dramatically with a changing resource mix, because the average contribution of an

FIGURE 9

Average vs. Marginal Accreditation of Solar and Wind Resources



Note: The figure is for illustrative purposes only. Output during net load peak is a reasonable proxy for marginal ELCC for variable renewable resources but not for dispatchable resources with energy limitations. Risk periods and loss-of-load events can occur outside of the peak and net peak demand periods.

Source: Carden, Bellon, and Dombrowsky (2022)/Astrapé Consulting.

entire class will diminish at a slower rate (Newell, Spees, and Higham, 2022).

In addition, the average accreditation technique can reflect the synergistic benefits associated with two or more different resources types, for example, solar and storage resources. This is because the resources are evaluated together—if the modeler chooses to do so—as they would operate on the system, where the solar could add energy in the middle of the day (when capacity need is low), to be used later in the evening when scarcity events are most likely to occur. It is important to note that these pairings need to be determined a priori and can lead to arbitrary combinations being evaluated. The modeler must determine the most important pairings to evaluate.

In an average framework, the approach does not clearly provide a signal for what the most efficient resource is for new investment. This is because it does not reflect the full saturation in a resource's capacity value. While it assigns the average capacity value for the entire class, it overstates the reliability benefits of new entrants (Newell, Spees, and Higham, 2022). As a result, there is a lag between when resources are added to the system and the adjustment to the class average capacity contribution. In short, an average framework favors the measurement of a portfolio of a resources group's reliability over efficient market signals for new capacity. In addition, evaluating a portfolio of resources together still requires an allocation of the total capacity benefit to individual resources, which is often done arbitrarily. In the solar and storage portfolio, if solar has a 20 MW capacity credit and storage has a 60 MW capacity credit in isolation, but they have a 100 MW credit when evaluated together, it is not clear which resource should receive the additional 20 MW of benefits.

While the average accreditation technique is used to calculate an entire class of resources together in order to show the contribution of the group rather than the incremental (marginal) benefits, this process can be modified to calculate the average contribution of a portfolio of different resource types together. This alternative would, for example, evaluate the capacity accreditation of an entire portfolio of multiple resources like wind, solar, and storage, together as a group and get the synergies reflected in the capacity credits. The added challenge to this approach is the need to develop a mechanism to take the portfolio capacity credit and disaggregate it to the individual resource components.

Summarizing Accreditation Options

The three characteristics discussed above, deterministic vs. probabilistic, retrospective vs. prospective, and marginal vs. average methods can be used in different ways and for different use cases for a variety of different accreditation techniques. A summary of the different accreditation methods, how they are calculated, and regions considering their implementation are provided in Table 2.

TABLE 2

Summary of Accreditation Options

Accreditation Technique	How It's Calculated	Deterministic	Probabilistic	Retrospective	Prospective	Marginal	Average
Peak load window	Considers average, or percentile, output relative to nameplate capacity during peak load windows (e.g., the top 200 load hours per year, or 4 peak load hours per day in three peak load months)	X		X	X		X
Exceedance	Statistical approach that indicates the amount of generation one can expect from a resource a given percentage of the time (e.g., at 12:00 pm in September, we expect at least 0.87 MW of solar per installed MW on 75% of days)	X		X	X		X
Resource adequacy hours	Measures production during resource adequacy hours—measured by either loss-of-load events or tight operating margins but decoupled from load level	X	X	X	X		X
ELCC (effective load-carrying capability*)							
– Marginal	Measures the contribution to reduced loss-of-load events for an incremental addition of installed capacity for an individual resource or resource type, relative to the amount of fixed load that can be added		X		X	X	
– Average	Measures the aggregate contribution of the entire resource type (e.g., the contribution of all wind generation on the system)		X		X		X
– Portfolio	Measures the contribution of an entire portfolio of resources (wind + solar + storage), with individual resource accreditation prorated from the portfolio total		X		X		X
Marginal reliability improvement	Measures the change in loss-of-load expectation for an incremental addition of installed capacity relative to an equivalent amount of perfect capacity additions		X		X	X	

* Note: For the purposes of this comparison, ELCC is treated similarly to equivalent firm capacity (EFC) and equivalent conventional power (ECP), which vary by the modeling mechanics but not the underlying theory.

Source: Energy Systems Integration Group.

Gaps in Current Accreditation Methods

Today, most ISOs/RTOs and utilities are conforming to some variation of probabilistic, prospective accreditation techniques. Some version of probabilistic accreditation (ELCC, marginal reliability improvement, etc.), either marginal or average, is gaining the most traction for accreditation techniques and new market designs. However, all of the accreditation methods and metrics discussed in the previous section have limitations. Because of this, many grid operators and electricity markets are currently evaluating new processes for either their accreditation techniques, capacity market (or compensation) design, or both, in the coming years.

To understand these limitations, the ESIG Redefining Resource Adequacy Task Force developed a gap analysis of current accreditation methods to understand where the industry's processes and accreditation techniques currently fall short, in order to then describe the most viable improvements to current techniques at this point in time. These limitations must be addressed by grid planners, market designers, and regulators, or the long-term use of capacity accreditation could be limited throughout the energy transition. These limitations can have significant unintended consequences—leading to either over-procurement of resources, high cost, and inefficient investment or potentially eroding reliability.

The major gaps and limitations of current accreditation methods are:

- Methods' complexity and lack of transparency
- Methods' sensitivity to modeling and assumptions
- The heterogeneity and unique attributes of resources that make it problematic to treat them as a group
- The difficulty of disentangling portfolio effects
- Circularity and ex-ante challenges

Methods' Complexity and Lack of Transparency

Complexity is not unique to accreditation techniques, but is rather a potential problem with the underlying resource adequacy analysis in general. While the discipline of probabilistic analysis and power system modeling is getting more sophisticated and more accurate, it is also getting more complex. Modelers must now consider many weather years of operations, resource availability, and load variation. They must also include chronological, hour-to-hour operations in their assessments to manage energy limitations. And they are increasingly incorporating correlated events in generator outages. This burgeoning complexity has the potential for two unintended consequences.

First, a more complicated and sophisticated process will require more time and resources (more human capital and computing resources) to conduct the analysis

The discipline of probabilistic analysis and power system modeling is getting more complex. Modelers must now consider many weather years of operations, resource availability, and load variation. They must also include chronological, hour-to-hour operations in their assessments to manage energy limitations. And they are increasingly incorporating correlated events in generator outages.

effectively. These are niche modeling approaches that require several model iterations and can only be performed effectively by a limited number of practitioners. The industry in general is already experiencing a shortage of qualified and experienced engineers, planners, and system modelers. A significantly more complex and time-consuming accreditation process will lead to delays in planning processes and allocate resources away from other planning needs.

For example, ELCC modeling requires many—perhaps dozens of—probabilistic model runs for each resource type, at various levels of saturation. To further complicate this process, ELCC should, in theory, be applied to any unique set of resources (see the third gap on the heterogeneity and unique attributes of resources), rather than applying a single ELCC for all resources of a given type. For example, wind ELCC should ideally vary by region, turbine size, and potentially plant configuration. Conceivably, an ELCC analysis could require hundreds or thousands of model runs, which would have to be repeated for every unique system configuration or planning year.

Importantly, capacity credit is not calculated consistently across markets, creating barriers to new entry and undermining overall market efficiency. One of the benefits of the ISO/RTO structure is that it brought consistent energy pricing (location-based marginal pricing) to various markets. Even ancillary service and reserve products are relatively homogenous across markets. However, capacity accreditation and associated capacity markets vary considerably by ISO/RTO, utility, and market construct.

A second unintended consequence is the lack of transparency for other industry stakeholders. While a small team of engineers at an ISO or consultants can perform the analysis, most stakeholders (developers, regulators, etc.) do not have the technical capability, data access, or funding to do so themselves. Project developers and advocacy organizations are largely beholden to the modeling results provided by the grid operator, and disagreements about methodologies, assumptions, or results can yield costly delays and litigation.

Improving the industry's capabilities and knowledge on the topic of capacity accreditation and resource adequacy is possible, and an important goal, but this is an immense task. The growing complexity of the power system will lead to a large increase in iterations of probabilistic modeling, which can be time-consuming and require significant resources. For example, if a resource's capacity contribution changes based on the underlying resource mix, a future analysis would have to evaluate a wide range of potential future conditions to show how the credits change across different resource configurations. In an integrated resource plan, for example, that uses capacity credit as an input to capacity expansion modeling, a multi-dimensional array of ELCC values would have to be pre-constructed across ranges of resource mixes and load profiles (Schlag et al., 2022).

System planners should ask themselves whether the increased precision of detailed capacity accreditation techniques (like various options of ELCC) warrants the additional time and effort. Detailed accreditation analysis may be appropriate for long-term planning but may overcomplicate near-term market design or procurements. Simpler heuristics, though perhaps not as precise, may provide a valuable alternative and beneficial trade-off. Further research on the accuracy of simpler approaches should be considered (see the section below on "Opportunities for Simplification").

Despite the growing complexity of resource adequacy analysis in general, and capacity accreditation in particular, there is a need to make the process transparent and tractable to a broad set of industry stakeholders, and not just to the power system modeling experts conducting the analysis.

Methods' Sensitivity to Modeling and Assumptions

When modeling techniques are used for capacity accreditation, the resulting capacity credits are only as good as the input assumptions and underlying modeling. Any limitations, oversights, or failures in the underlying probabilistic resource adequacy modeling will also flow through to a resource's capacity credits. In deregulated electricity markets, capacity accreditation is one of the only revenue streams based on *modeled* outcomes (in the capacity markets) rather than actual generator offers and awards in the day ahead and real time operations (as is the case in energy and ancillary service markets).

When modeling techniques are used for capacity accreditation, the resulting capacity credits are only as good as the input assumptions and underlying modeling. Any limitations, oversights, or failures in the underlying probabilistic resource adequacy modeling will also flow through to a resource's capacity credits.

If the probabilistic resource adequacy analysis misses underlying risk in the system, it inherently also misses a resource's ability to mitigate that risk and provide effective capacity. Unfortunately, current processes can miss significant aspects of risk or have trouble quantifying it. For example, most resource adequacy analysis performed today does not include time-varying forced outage rates—for example, resulting from temperature dependencies of fossil units' availability or their fuel supply availability—thus underestimating resource adequacy risk during winter cold snaps and summer heat waves (Murphy, Sowell, and Apt, 2019). Sufficiently granular and correlated weather and load data are also not readily available for all regions across a long historical record, often requiring modelers to bootstrap the data into longer, synthetic datasets. This process requires significant expertise, in both power systems and atmospheric sciences, and can potentially be highly problematic if done incorrectly.

Bootstrapping a weather dataset takes a limited historical record of high resolution data, one to three years, for example, and extends it to a long historical record, often 30 years or more. This is done in lieu of conducting atmospheric modeling and thus omits the physical linkages to weather variation. The bootstrapping process is often done by day sampling around temperature (where multi-decadal datasets are common) and assuming that wind, solar, and load conditions in the small sample are representative of the longer historical record. While this approach can be helpful to inspect larger sets of data, it runs the risk of not actually being representative of weather conditions for wind and solar resources. Moreover, even when a long historical record of data is available, there is nothing guaranteeing that it is representative of future conditions, especially considering climate change impacts.

In addition, the adjustment used in capacity accreditation to determine a resource's contribution to reducing risk in a system may not be reflective of the current system. This adjustment is typically done by first bringing the system to the reliability criterion (e.g., 1-day-in-10-year LOLE) and then adding fixed blocks of perfect capacity (resources that are always available) or fixed blocks of load across all hours. If this adjustment is not reflective of the current system because the system is actually oversupplied and not at the reliability criterion, the further away the base system is from the reliability criterion, the less representative it is of actual operations and timing of risk periods. This is especially true for seasonal accreditation techniques, which bring the system to a reliability criterion for each season, even if there is traditionally no loss-of-load risk during those periods. For example, disaggregating capacity accreditation by season may require modelers to artificially increase load so that resource adequacy risk appears during shoulder seasons (spring and fall). This process therefore measures a resource's availability during risk periods that do not actually occur.

Simplifications or inaccurate modeling assumptions like these can bias resource adequacy results and make capacity credits (and payments to generators) sensitive to assumptions. As a result, a resource's capacity credit may not align with availability during periods of actual tight operating conditions.

Changes in system modeling techniques, assumptions about what the future system looks like, and how resources are evaluated will fundamentally change the accreditation process. As a result, there is a growing need to ensure that capacity accreditation techniques are *robust* to changes in the resource mix, load patterns, and the way resource adequacy analysis is modeled.

Difficulty Recognizing Unique Attributes of Resources

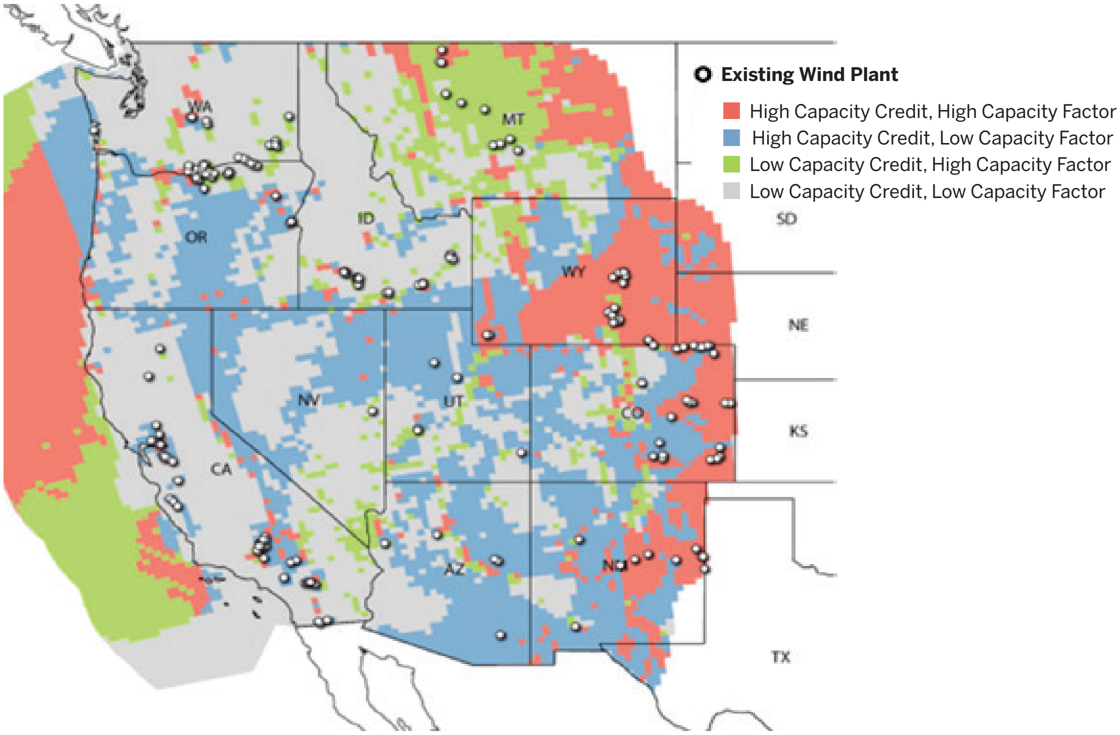
While the power system is changing significantly at the macro level, there are also significant changes occurring at the micro level, that of the individual unit. Capacity accreditation is intended to measure a resource's contribution to resource adequacy and its ability to reduce system risk. While in theory, this process should be done at the individual unit level, in practice it is often done for a large resource class, either to save computational time and analyst effort or because sufficient granular data are unavailable. For example, all wind resources in a particular region are often aggregated to evaluate the reliability contribution of the entire resource class. The same is often done for solar and storage resources.

However, because the capacity accreditation is being used to compensate resources for their reliability contributions—either in a capacity market or in a competitive solicitation request for proposals or bilateral contract for new resources—it is important to capture unique attributes in the plant that may distinguish it from other plants of the same resource class.

There is a growing disparity between the resources themselves, as they are becoming increasingly heterogeneous. First, there can be differences in the geographical location of different resources. For example, a wind or solar resource in one region may have a different diurnal or seasonal chronological pattern compared to one in a neighboring region. This miscorrelation can lead to a wind or solar resource in one region having a higher capacity credit even if it is a lower energy yield (capacity factor) resource (Jorgenson et al., 2021).

FIGURE 10

A Comparison of Average Wind Output and Capacity Credit by Region



Source: Jorgenson et al. (2021)/National Renewable Energy Laboratory.

Take, for example, wind resources across the Western Interconnection. Figure 10 shows a wide range of capacity credit for wind resources across the region, sometimes with pronounced local effects. While some of the higher capacity credit can be ascribed, at least in part, to higher annual output (high capacity factor denoted in red shading), while other places that have relatively low annual output but still high capacity credit (blue), because the timing of generation aligns during periods of system risk. Conversely, regions with high annual output (green) can have low capacity credit.

Second, resources can differ in terms of plant configuration. For example, wind turbines of different sizes, hub heights, etc. can yield very different generation profiles. Solar plants with or without tracking systems or different inverter-loading ratios can also yield significantly different generating profiles. Battery storage and hybrid plants also have large disparities in their durations, solar-to-battery ratios, and charging constraints. For this reason, it is important to understand the specific characteristics of individual resources and how they affect the resulting capacity accreditation.

At a minimum, capacity accreditation should evaluate groups of similar resources, but with enough resolution to notice different timing of generation or miscorrelations between resource groups. If possible, accreditation should be conducted in a way that each individual resource receives the capacity credit commensurate with the reliability contribution it provides. The objective should be a technology-agnostic framework that accounts as best as possible for all the factors that limit a resource's contribution to reliability. Evaluating an entire resource class together without distinguishing unique characteristics, design, or location of individual resources would yield a discriminatory result, where some resources gain at the expense of another.

The Difficulty of Disentangling Portfolio Effects

Another gap in the current accreditation frameworks is the way in which portfolio effects are disentangled. Portfolio effects arise because the capacity value of any resource is dependent on what the rest of the system's resource mix looks like. For example, battery storage

capacity credit may depend, in part, on the amount of solar energy available earlier in the day for charging, because high levels of solar create narrower (shorter) periods of peak evening net loads. In addition, a system with high levels of solar may shift risk to the evening or overnight hours or to the winter season. As a result, the increased solar penetration shifts risk to the winter and overnight period (when load is lower)—this increases the marginal capacity credit of other resources, such as wind resources in the winter, even though the solar provided the original benefit. Load flexibility and demand response programs can also have pronounced effects on the ability of other resources to reduce or shift the remaining risk in the system.

Portfolio effects can be described as either synergistic, where the combination of two or more resources improves their respective contribution to reducing risk, or antagonistic, where a combination of two or more resources reduces their respective contributions (Schlag et al., 2020). Average and marginal ELCC metrics (discussed above in the section "Characteristics of Capacity Accreditation Methods"), mitigate some of this challenge, but there are limitations to how they are applied today.

Typically, system planners select resources to evaluate in a portfolio. In this case, they will evaluate wind, solar, and storage in a so-called "novel resource" portfolio because they have synergistic benefits, and they are the new entrants on the system. However, the amount of natural gas, geothermal, or hydro resources on the system are often not included in the portfolio even though they will affect wind or solar's capacity contribution. A natural gas generator, for example, can provide energy to be used later by storage in the same way solar can. Portfolio or average ELCC metrics may work well today where the novel resource portfolio (the wind, solar, and storage) is a relatively modest amount of the overall capacity mix. But in systems where this novel resource portfolio is the predominant resource mix in the system, it may not make sense to evaluate the reliability of the system with and without this portfolio because the change in reliability represents too large of change. This would make the portfolio approach inapplicable once renewables reach a certain level. In addition, it is largely arbitrary which resources are selected by the power system planner to be included in the portfolio assessed, and which resources are not. Finally, the methodology used to allocate the portfolio benefits back to individual resources can be done in an arbitrary manner.

All of these challenges make capacity accreditation metrics and results unpredictable, and may result in capacity accreditation that is volatile from one resource assessment to the next.

Circularity and Ex-Ante Challenges

The capacity credit of any resource is dependent on the amount of the resource on the system as well as all of the other specifics in the resource mix. Therefore, evaluating the ELCC of a resource in isolation is highly dependent on the assumptions made for the rest of the system. While these assumptions can be forecasted, they will change over time, in large part due to the capacity accreditation afforded to the resource.

Take, for example, integrated resource planning and competitive procurements conducted by utilities. In order to make an efficient investment decision, the utility needs to assign a capacity credit to each resource so that it can make an informed decision about how to procure enough capacity to meet reliability needs in a least-cost manner. All other things being equal, resources that get higher capacity credits will get selected more in the integrated resource plan modeling if their costs are competitive. The result is not only saturation of that resource's contribution to resource adequacy (which can be modeled with decreasing capacity credits at higher installations), but also a change in the capacity credits of all of the other resources on the system of any type. Therefore, the resulting portfolio may no longer be the least cost, and may no longer be reliable because of these changes. This circularity poses challenges for system planning.

The same challenge exists in a deregulated capacity market. Each resource participating in the capacity auction is assigned a capacity credit that determines how many megawatts can be offered into the market. This is based on modeling of a particular portfolio prior to the capacity auction (or a forecast of what may result from the auction). However, resources with higher capacity credits may be selected in the market, while other resources may not be selected in the capacity auction (and thus exit the market). This would change the original capacity credit assigned to each resource.

To ensure reliability, a subsequent resource adequacy evaluation of the resulting portfolio is needed, but is seldom done due to time constraints or due to overconfidence in the ELCC and planning reserve margin approach. This type of "round-trip modeling" would yield more robust results that correctly assign capacity credits to the changing system risk profile. This process would be conducted by a power system planner that conducts a capacity expansion plan or capacity market forecast.

1. The "round-trip modeling" process starts with initial estimates of resource capacity accreditation (using ELCC or another method), based on the assumed system resource mix, load profile, etc.

2. The results of step one—ELCC estimates—are then used to run a capacity expansion model or a capacity market auction to identify what the resulting portfolio is.

3. The resulting portfolio of resources is tested in a probabilistic resource adequacy model to ensure that the final portfolio meets or exceeds the reliability criterion and captures portfolio effects that arise with the new portfolio identified in Step 2.

4. The planning reserve margin requirement and/or ELCC values are adjusted, to iterate between the models or incorporate an addition or retirement outside of the capacity expansion model to meet the reliability criterion.

5. If iterating on inputs assumptions does not work, an additional resource may need to be selected exogenously to the capacity expansion model to ensure reliability.

This ex-ante challenge—where the result of the capacity expansion or capacity auction affects the input capacity credits—is technically not a fault of capacity accreditation metrics, but rather an improper application by practitioners. Failing to proceed through steps 3 and 4 could have one of two adverse impacts. First, it could lead to over-building of resources because accreditation misses portfolio effects that increase reliability benefits when resources are added together. Alternatively, it could lead to reliability shortfalls because the resulting portfolio may not be as reliable as individual resource accreditation metrics suggest. Iterative analysis outlined in the four steps above can ensure that improperly calculated capacity credits do not lead to inadequate systems; however, this round-trip process is rarely done in either capacity expansion analysis (integrated resource planning) or in actual capacity market results (Stenclik, Welch, and Sreedharan, 2022; MISO, 2022a). In many situations today, there is a potential gap in whether or not accreditation methods ensure a *reliable* outcome.

Pillars of Capacity Accreditation

In order to address the accreditation gaps, grid planners and utilities across the world are adjusting their capacity accreditation methods and metrics, resource procurements, and capacity markets with new frameworks, rules, and metrics. However, while there have been some lessons learned among different jurisdictions and some cross-examination of resource adequacy methods, there is no uniform set of best practices for capacity accreditation. Given the unique resource mix and regulatory regimes in each region, uniformity may not be desirable or feasible, but foundational pillars can be applied.

Despite the mélange of resource adequacy methods, there are some foundational elements that can and should be consistent across any capacity accreditation technique. These pillars can be used as guidelines for planners, regulators, and other stakeholders to evaluate accreditation options being considered in new market designs or integrated resource planning processes.

First and foremost, it is important that accreditation techniques can be used in a planning process (or capacity auction) that results in a reliable system, especially in systems undergoing rapid transition. For example, they need to capture the changing phases of counting firm capacity, moving from expected capacity available at time of peak load toward the expected capacity and energy available from resources during periods of high risk. This places an emphasis on processes that can consider both capacity and energy limitations of resources, and can adapt to the specific timing of risk (both diurnally and seasonally) if the risk periods evolve as the resource mix changes.

FIGURE 11

Five Pillars of Resource Accreditation

Non-Discriminatory	Robust	Transparent	Reliable	Predictable
Accreditation is applied to all resources using a similar methodology.	Accreditation continues to work as the resource mix, load patterns, and system risk change over time.	Accreditation can be effectively communicated to stakeholders, and data are readily available for decisionmaking.	Accrediation accurately measures performance during real scarcity events.	The process is repeatable and consistent. It does not yield volatile or unexplained changes year to year.

Source: Energy Systems Integration Group.

To ensure some consistency across accreditation techniques, the ESIG Redefining Resource Adequacy Task Force developed a set of five pillars of resource accreditation intended to serve as foundational elements that can be applied across the menu of options for resource accreditation (see Figure 11).[4]

PILLAR 1: Accreditation Methods Should Be Non-Discriminatory

A primary objective of capacity accreditation, regardless of the specific metric used, is to provide a technology-agnostic means of comparing the resource adequacy contributions across different resources. This allows system planners to develop a portfolio of resources that serves load in a reliable and least-cost manner and to compensate resources fairly for their specific contribution to reducing resource adequacy risk.

However, in current practice, accreditation techniques are often applied differently to different resources, for example:

- Accreditation techniques are often applied only to a subset of resources—they are often applied to wind, solar, and storage but not to thermal generators.
- Class average accreditation is used without a resource performance adjustment, which measures a group of resources together and produces a single capacity credit value, but does not recognize unique plant characteristics that may differentiate resources' performance during risk periods.
- Modeling limitations may not accurately capture the operational characteristics or constraints of specific technologies. For example, some capacity accreditation techniques may not capture uncertainty in storage scheduling or fuel supply risk associated with natural gas resources.
- The order in which a resource is evaluated relative to other resources can change its accreditation.

Such differences in application can lead to discriminatory treatment of resources and can result in some resources being compensated more than their true reliability contribution would suggest, while others are compensated less. The cost of these differences can be significant. But the implications of these decisions can be even more problematic, and ultimately jeopardize the resource adequacy of the system. Modeling bias or market design bias, whether intentional or not, can give false assurance that a system is reliable and/or economic when in fact it is neither.

Ultimately,

> [i]n pursuing accreditation approaches and all the technical details, it is essential that all resources are treated equitably to provide an accurate exchange rate of value for resource investors to consider. This equitable treatment requires that the accreditation concept (though not necessarily the specific approach) should be applied to all resource types, including thermal resources, and that individual resources should have the incentive and opportunity to innovate and improve performance

4 This work draws on similar concepts from other relevant redesign proposals (MISO, 2022b; Schlag et al., 2020).

beyond the class-average estimated accreditation (Newell, Spees, and Higham, 2022).

"Capacity accreditation for all" is a growing refrain across the electric power sector that captures the sentiment of non-discriminatory treatment. If capacity accreditation is used to measure the performance of one type of resource, it should be applied to all types of resources in a similar manner. The fair application of methods across resources ensures that the capacity credits are technology-neutral and provide accurate incentives for improved performance and innovation through plant design and hybridization, and increases the likelihood that the capacity accreditation leads to a reliable and least-cost portfolio of resources.

"Capacity accreditation for all" is a growing refrain across the electric power sector that captures the sentiment of non-discriminatory treatment. If capacity accreditation is used to measure the performance of one type of resource, it should be applied to all types of resources in a similar manner.

Additional information and recommendations regarding capacity accreditation for all resources is provided below in the section "Capacity Accreditation for All."

PILLAR 2: Accreditation Methods Should Be Robust Against a Changing System

When designing or adapting an accreditation method, considerable thought should be given to how well the construct holds up over time and with a changing power system. The resource mix will undoubtedly change, and the specific mix will depend on location, resource availability, public policies, and technology costs. Load profiles will also change, driven in large part by sectoral changes in the economy, replacement of existing loads with new technology, increased electrification of the transportation and building sectors, and climate change–induced changes to temperature and weather conditions.

Not all accreditation techniques are robust to these changes. For example, the average capacity factor during peak load hours historically used in NYISO, ISO-NE, and others, worked well for systems with low levels of renewables, but starts to break down as variable renewables shift periods of risk to other hours or seasons. ELCC approaches can solve this challenge but may be intractable as the variety of resources and differentiation of resources increases.

Designing capacity accreditation metrics and methodologies that are robust against changing system dynamics is difficult. Any change, or potential change, leads to debates among stakeholders, uncertainty for financing, and the potential for stranded assets. But while it is challenging to predict the future resource mix, testing methods against a wide array of potential future conditions is important. Without this, accreditation techniques will have to be changed and updated regularly. These updates are currently underway at many of the ISOs/RTOs and utilities across the country. Each subsequent change becomes more difficult, as the number of affected plant owners and stakeholders increases.

PILLAR 3: Accreditation Methods Should Be Transparent for All Stakeholders

Resource adequacy and capacity accreditation techniques were traditionally a niche technical subject, understood and evaluated by a small group of system planners at the ISOs/RTOs and utilities. Limited attention was given to the processes, in large part because most systems were oversupplied and had sufficient resources, and new renewable projects rarely financed their projects based on their capacity credit. In addition, low levels of renewables combined with predictable loads made assessing resource adequacy risk, and the contribution from different resources, relatively straightforward, as it was highly aligned to output during consistently predictable peak load hours.

Today, the system is more complex. Increasingly, clean energy projects—and particularly energy storage, hybrid resources, and load flexibility products—are selected in a competitive procurement process predominantly for their capacity and resource adequacy benefits. In addition, most systems have less surplus capacity than they did in the past, as fossil plants retire and climate change

impacts load uncertainty and the availability of wind, solar, and hydro resources. These trends, in turn, draw increased attention to resource adequacy and capacity accreditation techniques from a broad range of stakeholders. These metrics are no longer confined to a grid operator's resource planning department, but are also pivotal to project developers, financiers, regulators, load-serving entities, corporate energy buyers, and environmental advocates.

As a result, it is important to make any capacity accreditation technique as transparent, easily accessible, and understandable as possible. Unfortunately, many accreditation methods are opaque, and, perhaps due to a limited workforce, outreach to facilitate their understanding by broader audiences has not been prioritized. For example, ELCC calculations require highly detailed models of the power system, usually developed by the system planners, and resulting capacity credits are then posted for specific resources. This complexity makes it difficult for many market participants to emulate accreditation methods for their portfolio of resources in order to properly evaluate their own projects or alternative clean energy portfolios. Stakeholders often only see a "black box" modeling exercise, with limited knowledge of how or why capacity credits may change over time.

The lack of transparency has serious implications for market design, investment, and transaction decisions. Market participants may be unable to accurately forecast future resource capacity values and therefore unable to attract needed investments to support projects that would contribute to grid reliability. Instead, developers and investors are left guessing what their capacity value will be, with no clear way to improve their value and no incentive in actual operations to support grid reliability. This results in a discrepancy between the desired system attributes and actual market outcomes. It also leads to financing challenges, which delay project development.

There are two complementary approaches to improving transparency. The first is to improve training resources in how to interpret and carry out capacity accreditation analyses. The second is to prioritize techniques that are

There are two complementary approaches to improving transparency. The first is to improve training resources in how to interpret and carry out capacity accreditation analyses. The second is to prioritize techniques that are simplified or more naturally transparent.

simplified or more naturally transparent. In some cases it might be appropriate to use a hybrid approach, such as using a more detailed probabilistic resource adequacy model to evaluate the reliability of the system overall, but use a simpler model or method for the compensation of individual resources in a resource adequacy program. The former would provide a robust system-level analysis to ensure reliability of the overall system, while the latter could be a faster analysis applied to many different potential future resource mixes and combinations of resources.

An example of this hybrid approach is MISO's approach to thermal accreditation, which uses a thermal plant's UCAP EFORd (recent actual forced outage rate) for class-level accreditation, and then a scalar to adjust a specific unit's accreditation up or down based on actual performance. This compensates fossil fuel resources based on their average availability during tight margin conditions over the preceding three years. While this simple heuristic is used for accrediting individual thermal resources for use in the capacity market or capacity expansion modeling, the ISO still performs a robust probabilistic resource adequacy assessment to ensure that the aggregate system is resource adequate.

PILLAR 4: Accreditation Methods Should Support Resource Adequacy

As discussed above, even a perfect capacity accreditation methodology does not ensure a reliable system. But if capacity accreditation does not ensure that planners and stakeholders reach a reliable system, then what is the use of the accreditation? It is important that the accreditation techniques support resource adequacy analysis and decisionmaking.

First and foremost, any accreditation technique should be designed to measure a resource's availability during times of risk, whenever the risk occurs. The evaluation of static time periods—like peak load windows—should be avoided, because they will not capture changing dynamics of the resource mix and load shape. The same is true for accreditation that is only based on limited time periods or particular seasons.

Second, resource accreditation techniques should consider not only capacity availability during periods of system risk, but also energy sufficiency requirements. While the former counts the megawatts available on the grid during periods of system risk, the latter ensures that resources have enough fuel and state of charge to be available throughout the risk period. The need to determine energy sufficiency is obvious for energy storage or flexible demand, which have limited energy to discharge during risk periods. What is not obvious is how to also ensure there is enough surplus energy *preceding* a risk period to charge a storage resource, or, in the case of flexible demand, how to ensure that the duration or quantity of the flexibility is sufficient to persist across the entire risk period (and ensure that loads can be shifted to outside of this period). Simplified metrics that only consider the duration of a storage resource or flexible load, and not the energy requirements for charging storage or shifting loads to before or after periods of system risk, have limited value. It is also important to consider energy sufficiency for fossil fuel and hydro resources, which may also have use limitations, with the former having limited on-site fuel storage and the latter being affected by hydrological conditions.

Third, accreditation techniques need to recognize the saturation effect of resources, where capacity value at certain times diminishes as the quantity of similar installations increases. This requires system planners to regularly re-evaluate the aggregate resource need. If accreditation techniques are used, accreditation for new installations of variable renewables and energy-limited resources will diminish as risk is shifted to lower- demand time periods and is extended over longer periods of time. This shift in timing of high-risk hour(s) can also decrease the aggregate capacity needed (in firm megawatts) to meet the reliability requirement. This linkage between the capacity accreditation and firm system capacity required should be captured within an iterative evaluation method.

Finally, it is essential that the *resulting portfolios* from any capacity market auction or procurement be fully evaluated using a probabilistic resource adequacy analysis. Rather than evaluating the capacity credit of individual resources and stacking up the system's resources to a planning reserve margin, it is critical to evaluate the entire system together, to ensure that portfolio effects are accurately captured. This iterative "round-trip modeling" is necessary to ensure that the estimated capacity credits accurately reflect saturation effects and portfolio effects of different resource mixes. If individual contributions of resources do not add up to the total requirement of the portfolio, the system will be either higher cost than needed (i.e., overbuilt) or be less reliable than desired.

PILLAR 5: Accreditation Methods Should Yield Predictable Results over Time

It should be expected that capacity credits for specific resources can change over time. That ensures that a particular resource's accreditation accurately reflects its contribution to mitigating system risk. This need for flexibility occurs because the system risk changes temporally and locationally as the system's resource mix and load profiles change over time. In other words, the calculations must sufficiently encompass the change in the system needs—this allows for resource accreditations to change, in a manner that can be predicted.

However, even as resulting capacity credits may change over time, the accreditation methodology should be largely static (see Pillar #2) and predictable. The predictability of a resource's credit over time is essential for development and financing of projects. For many stakeholders, a lower, but stable and predictable, capacity credit is more important than a higher, but volatile, one.

From a system planner or ISO perspective, a change in accreditation methodologies and values can immediately change whether or not a system is deemed reliable. This creates volatile pricing; if the accounting rules suddenly show that the system is short of capacity, it will immediately trigger procurement of new resources. However, these shortfalls take time to fill as resources have to go through various stages of project development (permitting, interconnection, procurement, construction, etc.). Therefore, having more predictable results from capacity accreditation analyses can avoid fluctuations in the capacity market–like auctions and insulate many stakeholders such as asset owners and the end-use public from volatile pricing.

To achieve this predictability, it is important that capacity accreditation methods remain consistent, modeling assumptions are consistent year-to-year, and new resources and technologies are treated in a similar manner as existing resources for determining system reliability.

Capacity Accreditation for All Resources

Pillar 1, perhaps the most important foundational element identified by the ESIG Redefining Resource Adequacy Task Force, highlights the importance of non-discriminatory capacity accreditation methods. If specific capacity accreditation methods are applied to some resources, they should be applied to all resources in a consistent manner, with the same calculations and methodologies. While the industry has devoted considerable attention to accrediting wind, solar, and storage technologies, less attention has been afforded to other resource types.

In most regions, capacity accreditation techniques are applied to variable renewable resources and energy-limited resources (storage and load flexibility), while fossil fuel generation receives either a perfect capacity credit or UCAP credit equal to its capacity minus a forced outage rate. This approach inherently misses risk and overstates the capacity contribution of the conventional resources. In addition, other resources, like new transmission, can provide significant capacity contributions to improve resource adequacy, but are often excluded from capacity accreditation techniques altogether.

Standard Practice for Accrediting Thermal Resources

The standard practice for accrediting thermal resources is either to use the installed capacity (ICAP) or to slightly reduce the capacity by the unit's forced outage rate and use the UCAP. This implicitly assumes that generator forced outages are uncorrelated from one another and occur randomly. There are, however, additional factors that could further reduce a thermal unit's capacity accreditation, which include outage variability, common mode outages, weather-dependent outages, and fuel supply disruptions (Dison, Dombrowsky, and Carden, 2022).

- **Outage variability:** Resource adequacy analysis typically uses the average long-term outage rate of a resource. However, each unit's outage rate is likely to fluctuate significantly over time and across samples in a resource adequacy simulation. This can lead to fluctuations in the realized generator outages relative to the average or expected value. Using an average outage rate (i.e., UCAP) will smooth out the average amount of capacity on outage, whereas actually simulating hundreds or thousands of forced outage events will create a distribution that includes outlier risk events with high amounts of capacity on outage. This is most impactful for disproportionately large generators whose discrete outages can swing overall loss-of-load expectation.
- **Common mode outages:** These outages can occur when underlying failures or common causes lead to multiple units going on outage simultaneously. Outside of weather-dependent outages and fuel supply disruptions (discussed separately below), this could include multiple generators interconnecting at a single point of interconnection and all being affected by the loss of an individual transformer.

While standard practice for resource adequacy modeling uses long-term average forced outage rates for thermal generators, there are times when outages can be considerably higher due to extreme heat or cold weather conditions.

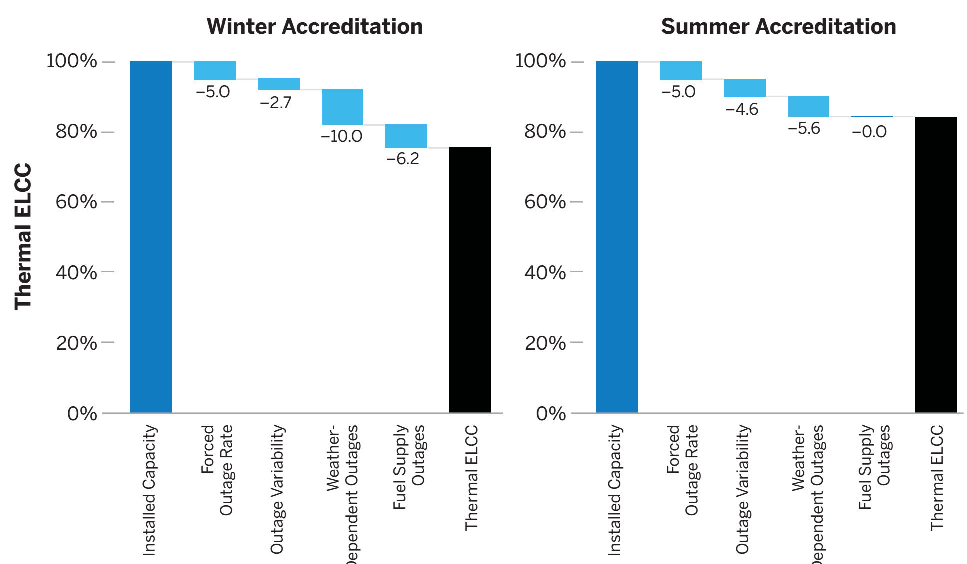
- **Weather-dependent outages:** While standard practice for resource adequacy modeling uses long-term average forced outage rates for thermal generators, there are times when outages can be considerably higher due to extreme heat or cold weather conditions. For example, recent cold snaps in PJM, MISO, and ERCOT showed that forced outages increased from 8 to 10 percent on average to 20 to 45 percent during specific weather events (ESIG, 2021). This correlated outage risk is significantly underrepresented in conventional resource adequacy analysis and excluded entirely from accreditation processes.
- **Fuel supply disruptions:** Multiple generators can also be affected by fuel supply disruptions. This is inherently included in the accreditation of wind and solar resources, which are modeled with variable weather conditions on atmospheric conditions, but is not incorporated for fuel availability for thermal resources. The natural gas system, while highly reliable in most circumstances, can suffer from shortages and outages. These can, in turn, affect large portions of the electricity generating mix that is tied to the same fuel network. As a result, a generator's capacity accreditation should be limited based on the probability of losing its single fuel source, thus giving additional credit to dual-fuel units.

Today, the system as a whole covers for this uncertainty, and the costs are distributed across the loads via a planning reserve margin. In this case, the loads (ratepayers) are paying for the uncertainty and unreliability of thermal generators rather than that risk being assigned to individual generators.

Today, the system as a whole covers for this uncertainty, and the costs are distributed across the loads via a planning reserve margin. In this case, the loads (ratepayers) are paying for the uncertainty and unreliability of thermal generators rather than that risk being assigned to individual generators. This leads to two problems. First, it is discriminatory, as the uncertainty in variable renewables is assigned to the individual resource and not socialized across the load, as is done for thermal resources. Second, it does not provide an incentive for individual generators to improve their performance through routine maintenance, plant upgrades, winterization, and by adding dual-fuel capability.

FIGURE 12

Additional Factors for Capacity Accreditation for Thermal Resources



Source: Energy Systems Integration Group; data from Astrapé (Dison, Dombrowsky, and Carden, 2022).

A representative example of thermal capacity accreditation with and without these correlated factors is shown in Figure 12 (p. 38).

All resources have unique attributes that can sometimes limit their ability to serve load during critical risk periods. Wind and solar are limited by weather variability. Hydro can be limited by normal seasonal fluctuations as well as extreme drought conditions. Battery storage can be limited by the duration of charge and availability of charging energy. Large nuclear, coal, and natural gas plants can have disproportionate impact on resource adequacy due to the blocky nature of outages, where a large unit is either off or on. In contrast, wind and solar resources are modular, so the likelihood of an entire plant being on a forced outage simultaneously is significantly reduced. Thermal resources can also have correlated weather-dependent outages, water limitations, and fuel supply constraints. While this weather dependence is evaluated in a detailed manner for wind and solar resources, it is often ignored for others. Table 3 (p. 40) highlights these potential limitations.

Four Consistency Principles

To ensure that resources are evaluated in a consistent and non-discriminatory manner, the task force suggests four consistency principles when evaluating new resource accreditation options (Milligan, 2022).

Resource Consistency

In order for an accreditation method to be resource consistent, all resources would need to be assessed during the same periods of risk and in a system operating at the same level of risk. Regardless of how risk periods are identified, it is important that all resources are considered based on their availability during those periods.

Horizontal Consistency

In order to be horizontally consistent, the accreditation method needs to be applied to all resources across various classes and not just a subset of resources. Two resources with the same contribution (MW) to reducing risk should receive the same capacity credit, even if they are of different types. For example, if a wind resource, natural gas–fired thermal resource, and battery storage resource each provides 100 MW of available capacity during a

shortfall period, they would all receive the same credit (for that period) regardless of individual resource limitations such as variability or duration limitations.

Vertical Consistency

The corollary to horizontal consistency is vertical consistency: ensuring that resources that contribute more during risk periods receive a higher capacity credit. This vertical consistency ensures that resources are differentiated based on their contributions to reliability, specifically during risk periods, regardless of other limitations. This creates clear incentives for innovation, performance, and higher plant reliability.

Order Independence

A final consistency principle is order independence, which ensures that the ordering assumed in the accreditation method does not materially affect individual resource accreditation. For example, in a simulation-based capacity accreditation method, there are often assumptions about when a resource deploys in the model relative to other resources on the system. The ordering assumption could affect the resources' relative contribution to risk periods, and thus violate order independence. This is especially true for energy-limited resources like storage and demand response. The order in which they are deployed will affect their capacity contribution because resources that are deployed earlier will not be available during the risk period, but in an energy-limited system provide value equal to that of resources deployed later.

TABLE 3

Considerations for Capacity Accreditation for Different Resource Types

Resource Type	Resource Adequacy Contribution or Challenges	Currently Considered in Capacity
Wind and solar	Weather variability and resource availability	✔✔✔
	Geographical location	✔✔✔
	Forced outage rates	✔✔
	Icing and snow cover	✔
Hydro	Seasonal hydro availability	✔✔
	Type of hydro system (e.g., run-of-river, small reservoirs)	✔✔
	Drought conditions	✔
Nuclear	Forced outage rates	✔✔✔
	Type-faults that can affect multiple units at the same time	✔
	Refueling outages during shoulder seasons	✔✔
Coal	Forced outage rates	✔✔✔
	Correlated weather-dependent outages	✔
	Frozen coal piles (fuel availability)	✔
Natural gas	Forced outage rates	✔✔✔
	Correlated weather-dependent outages	✔
	Fuel supply constraints	✔
Energy storage	Duration for which the storage asset can discharge	✔✔✔
	State of charge at the beginning of the tight/stress periods	✔✔✔
	Charge constraints for hybrid or co-located resources	✔✔
	How storage will operate during a tight/stress period	✔✔
	Forecast error or mis-timed discharge	✔
Hybrids	All of the considerations for the individual resource types located on the site	✔
	Transmission constraints that limit all individual resources exporting onto the grid at the same time	✔
Load flexibility	Duration for which any load-shifting could apply	✔
	Where the load moves to (e.g., whether it creates a tight/stress period at another time of the day)	✔
	Maximum calls per month or year, etc.	✔
	Pre-event load increase or post-event rebound	✔
	Price-sensitive response of loads	✔
Transmission	Forced outage rates of the transmission circuits	✔
	Whether the capacity accreditation should be awarded to the transmission line or to the resources located at the other end of the line	✔

✔ Rarely considered in resource adequacy assessments or capacity accreditation
✔✔ Sometimes considered
✔✔✔ Often considered

Source: Energy Systems Integration Group.

Linking Accreditation to Operations

A key concern regarding capacity accreditation approaches is that a limited economic signal during a high-risk event might mean that resources that were accredited to provide capacity might not deliver that capacity during an event. A perfect accreditation calculation can still result in a resource not showing up, even if it was capable of producing power during the event. Accreditation approaches need to be linked to operations in order to ensure that resources deliver in the moment.

The reliance of capacity accreditation on modeled performance has two drawbacks. One is that it requires the underlying probabilistic resource adequacy modeling to appropriately capture the underlying reliability risk on the system. This necessitates detailed and accurate modeling of weather impacts, changes to the underlying load profile, and impacts of extreme weather and climate change over time. While the industry is improving its approaches to the increased complexity of probabilistic resource adequacy analysis, any shortcomings in the underlying probabilistic assessment will inherently flow down to shortcomings or inaccuracies in individual resource accreditation.

In addition, a modeled accreditation technique is predictive, so it can also mis-estimate resource contributions to actual risk events. This can occur for many reasons. For example, if the modeling does not accurately reflect unit performance—due to unexpected outages, local weather effects, or nuances in plant design and operation. Another example is that the actual risk event might be different than any of the types of events considered in the modeling exercise. The modeling might also fail to account for decisions that can be made by the resource owner either to change operations or to make design changes in order to improve a resource's contribution to meeting reliability requirements. These changes could include, for example, dual-fuel capability or winterization of thermal plants, or cold-weather packages installed on wind turbines to avoid icing and cold-weather shutdown. Changes can also include the creation of hybrid resources, the addition of storage to solar or wind plants or other combinations of resources to improve the total availability of the plant during periods of risk—provided that incentives and regulatory requirements allow.

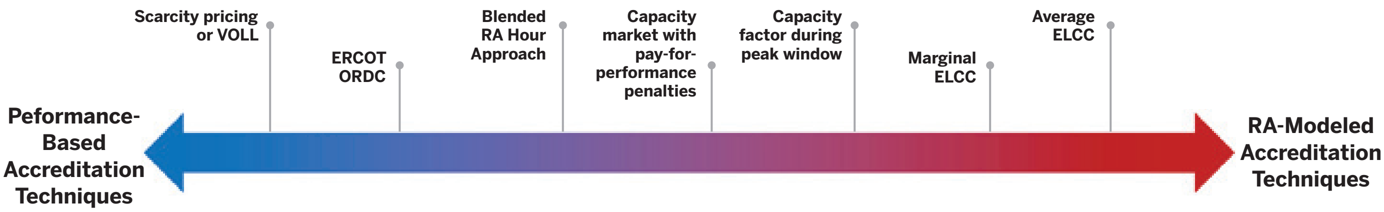
Relying exclusively on modeled performance disregards the effects of a multitude of factors that play into actual plant performance. There is a need to better link forward-looking, or simulated, capacity accreditation with retrospective, actual operations to ensure that resources actually show up when they are needed most by the system.

A performance-based accreditation methodology for individual resources could, in contrast, avoid many of these risks and a lower level of complexity because accreditation is based on actual performance rather than modeled resource availability. Continued reliance on simulated values for capacity credit should be justified based on clearly identified reliability benefits to ensure the added complexity is justified.

There is a need to better link forward-looking, or simulated, capacity accreditation with retrospective, actual operations to ensure that resources actually show up when they are needed most by the system.

FIGURE 13

Performance-Based vs. RA-Modeled Accreditation Techniques



Notes: VOLL = value of lost load; ERCOT = Electric Reliability Council of Texas; ORDC = Operating Reserve Demand Curve; RA = resource adequacy; ELCC = effective load-carrying capability.

Source: Energy Systems Integration Group.

Aligning Incentives

The two approaches to resource accreditation, retrospective (using resources' availability during actual scarcity events and performance during realized operations) and prospective (through modeled simulation of risk periods and performance) differ in how well they incentivize resources to show up when needed for reliability. Prospective approaches are used for metrics like ELCC and used to compensate resources based on its simulated performance during modeled risk events, while retrospective approaches are a market-based signal based on actual resource operations and high energy price incentives (scarcity pricing) (see Figure 13). The two options both have benefits and limitations as far as measuring their likelihood of reducing system risk, as outlined in Table 4 (p. 43).

The major argument for using scarcity prices as a tool to ensure reliability is that they provide a clear price signal and market-based incentive for generators to: (1) be available during scarcity events, regardless of why and when they occur, and (2) make investments either in plant modifications (winterization, addition of energy storage, improved maintenance, etc.) or in new generation resources to improve a resource's or portfolio's availability during scarcity vents.

Most power markets today rely mostly on capacity procurement using modeled accreditation metrics, the exception being ERCOT, the Australian Energy Market Operator, and the Alberta Electric System Operator, which rely on energy-only scarcity price signals—with some adjustments to reflect tightening supplies during tight margin hours. While many economists argue that real-time scarcity prices are the best mechanism to align resources' incentive to generate power when they are needed most for reliability, there is continued concern by regulators, policymakers, and market designers about whether real-time scarcity prices should be relied on for reliability. This concern is valid for a variety of reasons; there may not be a political appetite to allow real-time prices to rise to the extreme levels required to incent new investment, especially if electricity consumers only pay monthly average prices or may not be sophisticated enough to change electricity usage based on real-time signals. In addition, the overall volatility in an energy-only market makes it difficult to finance new projects needed for reliability.

Options for Linking Accreditation and Operations

Increasing attention is being given to approaches that combine resource adequacy metrics with real-time operations. These include pay-for-performance mechanisms and blended RA hour accreditation.

Pay for Performance

Some capacity markets include pay-for-performance mechanisms that either penalize a resource if it is unavailable during a shortfall event or reward a resource further for showing up (Borgatti, 2016). For example, if a resource is accredited 20 percent of its nameplate as effective capacity in the capacity market but only 10 percent shows up during a scarcity event, it can get

TABLE 4

Comparison of Performance-Only Compensation vs. RA-modeled Accreditation

Type of Decision	Performance-Based Compensation (i.e., Scarcity Pricing)	RA-Modeled Accreditation (i.e., ELCC)
Risk tolerance	Risk tolerance (for example, top 3% of tight margin hours) is selected by each individual group of generators or loads, because long-term contracts and hedging can be utilized to avoid price volatility based on individual preferences of generators or loads.	RA-modeled accreditation assessments must accurately determine system-wide risk level(s) (for example, 1-day-in-10-year LOLE), including size, frequency, duration, and timing of shortfall events.
Forecasting the future resource mix	Individual generators and loads make their own assumptions about what the future might look like when making investment decisions, rather than using projections developed by the system operator or planner.	Various market participants (load-serving entities, generators, and market operators) are required to have an agreed-upon view of what the future will look like in order to model capacity credits (including resource mix, load changes, etc.).
Use of market tariffs or rules	There are limited market rules, other than price caps and must-offer obligations (if applicable).	All stakeholders are subject to the same accreditation rules regardless of risk preference.
Capacity revenues	No payments or revenues are determined by accreditation techniques or calculation rules because payments are based only on operations.	Capacity payments and plant revenues are tied up in accreditation rules because they are based on modeled, or potential, operations.
Stakeholder process	Performance-only compensation does not require broad stakeholder agreement because generators and loads can make decisions for themselves about investment decisions.	RA-modeled accreditation requires more consensus in the stakeholder process, with stakeholders weighing in on the appropriateness of accreditation rules.
System operator control	Performance-only compensation is generally considered a bottoms-up approach to accreditation, with limited or no control on the total portfolio by the system operator.	RA-modeled accreditation is generally considered a top-down approach to accreditation and planning where the total portfolio can be evaluated.
Responsibility for ensuring sufficient capacity	This approach does not allow system planners to procure more resources when an RA assessment is indicating that they are short; rather, they depend on pricing as an incentive for resources to have the ability to serve load during periods of scarcity. However, high prices during a tight event do not guarantee that new resources will be built or that loads will voluntarily withdraw.	RA-modeled accreditation allows system planners to procure more resources if the system does not meet RA targets but does not necessarily guarantee that those resources will be available to show up when needed.

Notes: RA = resource adequacy.

Source: Energy Systems Integration Group.

penalized for underperformance. The monetary penalty provides an incentive for resources to meet their obligations set forth in the capacity accreditation process. However, it also provides a risk that generators can hedge by requesting a lower effective capacity amount, thus increasing the overall reliability of the system (because generators can likely deliver more energy than they are accredited for) but potentially leading to oversupply and overbuilding.

Operating Reserve Demand Curve

While "energy-only" markets (such as ERCOT's) do not use capacity accreditation, there are mechanisms in place to provide incentives for system reliability. The Operating Reserve Demand Curve (ORDC) is a price adder in the energy-only market that adds a premium to prices paid to generators with available capacity during periods when capacity reserves are limited. This link to short-term market conditions does not require central planning or accreditation and is thus presented as an alternative system with which to ensure long-term resource adequacy in the market (Bajo-Buenestado, 2021). In ERCOT, as reserves get tighter, and the probability of scarcity event increases, prices are increased beyond the marginal energy price of the next resource, up to $5,000/MWh, providing a clear incentive for resources to be available during tight supply conditions regardless of when they occur.

Blended Risk Hours

An alternative to the pay-for-performance mechanism is to accredit resources based on their average availability during a set of predetermined resource adequacy risk hours (RA hours). These hours could be a blend of ELCC based on simulated loss-of-load hours along with historical performance during tight margin hours and actual operations. For example, a unit's capacity credit could constitute an average of its actual availability during tight margin hours in the preceding year(s) and its simulated availability during unserved energy events in probabilistic modeling. This combines both simulated and actual performance. MISO, for example, is accrediting thermal resources based on their average output during risk hours (the top 2 percent of tight margin hours) over the previous three years of operation. Recent proposals have suggested accrediting wind resources, in contrast, using ELCC, which is then scaled up or down based on a multiplier that is determined based on unit-specific performance during the resource adequacy risk hours (MISO, 2022b).

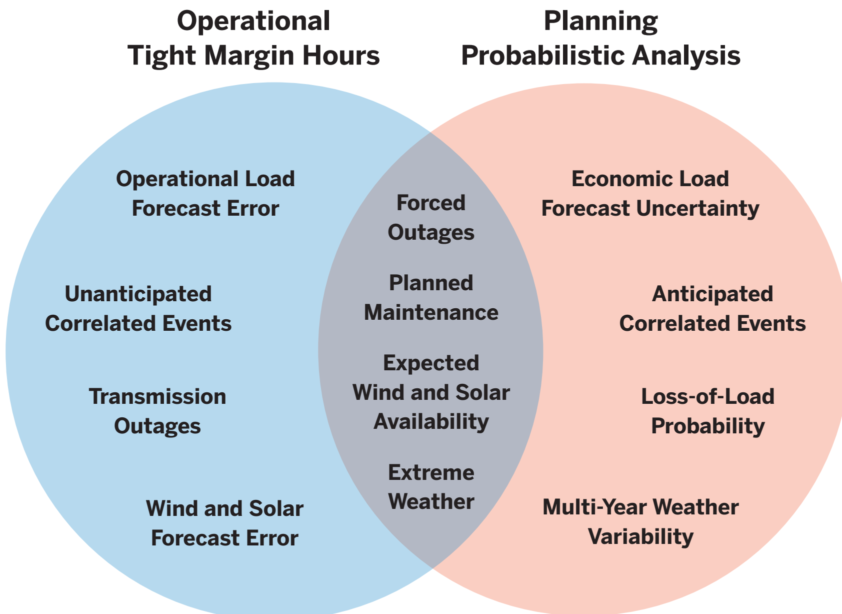
Accounting for the Known Unknowns

While real-time scarcity pricing and accreditation that is based on retrospective historical performance during tight supply conditions can incent resources to show up at the time of higher risk, there are drawbacks to such approaches.

First, resource adequacy constructs, designed to cover a wide range of uncertainty in power system planning, require a sufficiently long historical record to capture the occurrence of infrequent high-impact events. For example, a resource adequacy criterion of 1 day in 10 years assumes that shortfall periods are very unlikely to occur. As a result, there may not be sufficient periods in the historical record to properly incent resource investments to improve reliability if scarcity events only occur once every few years (or more). If a system is relying on scarcity pricing events to ensure reliability, a stretch of a few years without a scarcity event could lead to market exits or reduced investment in new resources. This could leave the system susceptible to a high-impact, low-probability event that only occurs one every several years.

Second, the evolution of risk over time driven by resource mix changes, electrification, load profile changes, or

FIGURE 14
A Comparison of Risk Drivers Based on Historical Operations vs. Probabilistic Modeling



Source: Adapted from Midcontinent Independent System Operator (2022a).

climate change can change the periods of and reasons for risk seen in recent historical experience versus forward projections. These changes will not be captured by historical performance, which instead would be a lagging indicator of risk, and system planners would not be able to proactively design the system based on projected risks. Markets that rely on real-time scarcity events, for example, will not be able to pre-emptively prepare for changes in the resource mix and underlying reliability. In contrast, simulated accreditation techniques can be designed to cover unlikely scenarios or situations that are expected in the future but have not occurred in the past.

Figure 14 compares risks that are identified effectively based on historical operating conditions (left circle) versus risks that are better captured in modeled probabilistic resource adequacy studies (right circle). Risks that are captured well in both approaches occupy the overlapping area in the middle. On the far left are conditions that occur in actual operations that are difficult, if not impossible, to accurately capture in probabilistic models. The conditions on the far right are rare events that may not be captured in the historical record but should be planned for via resource accreditation techniques.

Because the two accreditation approaches—those based on historical versus forward-looking modeled accreditation methods—consider different drivers of system risk, a blended approach, which accredits resources based on both historical operations during tight margin hours and simulated loss-of-load events, may balance the alignment of incentives and operations in an energy-only market with the uncertainty in future risks evaluated in modeled-only accreditation techniques.

Regardless of the approach chosen, decisionmakers will want to make certain that any incentives or governing rules—including accreditation or capacity market revenues—are aligned in order to ensure that generators will supply power during times that the power is needed.

Opportunities for Simplification

As the previous sections discussed, an accreditation process should capture the contribution of individual resources (rather than a resource class average), be applied to all resource types, be evaluated across a range of future resource mixes, be computationally feasible, and be readily understood by a wide range of stakeholders. While current accreditation methods may be able to meet these objectives, it is becoming increasingly complex and time consuming. Simplification of the accreditation process may be considered—while it might forgo precision, it can still provide an accurate investment and planning signal.

One major differentiator between the deterministic accreditation techniques (i.e., average output during a peak load window) and the probabilistic accreditation techniques (ELCC) is the computational and analytical effort required to calculate capacity contributions of resources. A single ELCC calculation of a resource class may require up to a dozen model runs. For example, the modeling first brings the system to the reliability criterion (requiring multiple model runs), a tranche of a resource is added (or removed) to change the system LOLE or associated metric (another model run), and then load is added to the system in equal increments to identify when the system is brought back to the reliability criterion (multiple model runs). Each model run is evaluated across hundreds or thousands of randomly generated samples of forced outages and weather. This process must then be repeated across multiple resource

FIGURE 15

Calculation of Marginal Reliability Improvement

$$\text{Capacity Value} = \frac{LOLE_i - LOLE_m}{LOLE_i - LOLE_p} = \frac{\Delta LOLE_{resource}}{\Delta LOLE_{perfect\ capacity}}$$

Source: Ibanez and Bringolf (2022)/GE Energy Consulting.

types or for individual units, requiring a vast array of model runs, computation effort, and analytical review.

However, simplifications to the approach could reduce the effort, both computationally and analytically. Options include the marginal reliability improvement (MRI) process and an average output during a sliding risk window (LOLP capacity factor) approach.

Marginal Reliability Improvement

Rather than iterate across multiple cases to calculate ELCC, the marginal reliability improvement technique compares how the LOLE (or alternative resource adequacy metric) changes for a resource relative to the equivalent amount of perfect capacity. For example, if an additional tranche of wind resources improves LOLE from 0.1 days/year to 0.08 days/year, and a perfect tranche of capacity reduces LOLE to 0.06 days/year, the resulting capacity credit would be [(0.1–0.08)/(0.1–0.06)] or 50 percent (Figure 15).

The resulting values from the marginal reliability improvement process have been shown to be highly similar to marginal ELCC values (Ibanez and Bringolf, 2022; Newell and Higham, 2022), and this approach is being considered in the NYISO and ISO-NE market redesign process. The benefit of this approach is that after evaluating a base system with and without a perfect block of capacity, it only requires a single model run for the capacity credit calculation for each resource class (or individual resource) and incorporates the probabilistic benefits of marginal ELCC calculations.

LOLP Capacity Factor

The LOLP capacity factor method calculates the average availability of a resource during a sliding risk window, identified by loss-of-load hours or low margin periods. This methodology calculates the average availability of a generator or generator type during loss-of-load hours (see Figure 16, p. 48) for an illustration of a hypothetical system and solar resource). This process was developed in part by the ESIG Redefining Resource Adequacy Task Force but builds on work done previously (Milligan, 2002; PacifiCorp, 2021).

The key difference between this and the deterministic peak load window approach (discussed above in the section "Deterministic Approaches") is that it only considers resource availability during periods of shortfall or tight margin, regardless of when they occur—not necessarily peak demand windows only. It still captures benefits of probabilistic modeling best practices (rather than deterministic simplifications), considers the full chronology of resources across 8,760 hourly profiles, and captures the correlation of resources' availability because weather years are maintained.

Figure 16 shows a simplified illustration of the LOLP capacity factor method. On the left is a matrix of unserved energy shown across six probabilistic samples. In reality, this matrix spans 8,760 rows, and most hours and samples would have zero unserved energy. An important distinction in this figure is that both weather year correlation and full hour-to-hour chronology are maintained in the calculation. The unserved energy events are highlighted in orange. These windows—of varying size, frequency, duration, and timing (ESIG, 2021)—are the ones against which resources are measured for accreditation purposes in the matrix on the right.

FIGURE 16

Illustration of the LOLP Capacity Factor Accreditation for a Solar Resource

System Unserved Energy

	Weather Year 1			Weather Year 2		
Hour of Year	Sample 1	Sample 2	Sample N	Sample 1	Sample 2	Sample N
1	0	0	0	10	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	20	0	0	0	0	0
5	40	0	0	0	30	0
6	10	0	0	0	10	0
7	0	0	0	0	5	0
8	0	0	0	0	2	0
9	0	0	0	0	1	0
10	0	0	0	0	0	0
...	0	0	6	0	0	0
8758	0	0	10	0	0	0
8759	0	0	2	0	0	0
8760	0	0	0	0	0	0

Two weather years, six outage samples
LOLE = 0.67 days/year
LOLH = 2 hours/year
EUE = 24.3 MWh/year

Generator Availability (installed capacity = 10 MW)

	Weather Year 1			Weather Year 2		
Hour of Year	Sample 1	Sample 2	Sample N	Sample 1	Sample 2	Sample N
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	1	1	1	0	0	0
4	4	4	4	2	2	2
5	8	8	8	3	3	3
6	3	3	3	1	1	1
7	1	1	1	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	1	1	1	2	2	2
...	5	5	5	6	6	6
8758	10	10	10	0	0	0
8759	6	6	6	6	6	6
8760	3	3	3	1	1	1

Average output during events = 3.33 MW
Nameplate capacity = 10 MW
Capacity accreditation = 33%

The matrix on the left shows unserved energy across six probabilistic samples, with unserved energy events highlighted in orange. These windows are the ones against which resources are measured for accreditation purposes. The matrix on the right illustrates the availability of a generator (solar, in this case) over the same weather years and chronology. The blue shading illustrates periods where the generator is available; however, only the generation during the unserved energy events (denoted by the black boxes) is counted toward the generator's accreditation. The final calculation is provided in the text below the chart.

Notes: LOLE = loss-of-load expectation; LOLH = loss-of-load hours; EUE = expected unserved energy.

Source: Energy Systems Integration Group.

The matrix on the right illustrates the availability of a generator *over the same weather years and chronology* as the unserved energy events on the left. The blue shading illustrates periods where the generator—in this case a solar resource—is available. However, only the generation during the unserved energy events (denoted by the black boxes) is counted towards the generator's accreditation. The final calculation is provided in the text below the chart.

LOLP capacity factor can be additionally weighted to ascribe more value for resource availability during large events (as a function of unserved energy). This process can be adapted to consider risk from either a probabilistic resource adequacy analysis, historical tight margin hours, or a blended (weighted) combination of both.

The benefit of this approach is that it only requires a single resource adequacy simulation to set the unserved energy hours and does not require any iterative modeling for each resource type. As a result, it can easily be applied to all resource classes and even individual resources in a consistent, non-discriminatory manner. This also increases transparency, because stakeholders can easily calculate the contribution of their resource, or preferred portfolio, provided that the underlying unserved energy data from the resource adequacy model (or risk hour assessment) are provided. If desired, it is also simple to incorporate a set of tight margin hours into the accreditation. This increases the predictability of results and accounts for unit-level performance in the operational time frame.

The LOLP capacity factor approach only requires a single resource adequacy simulation to set the unserved energy hours and does not require iterative modeling for each resource type. As a result, it can easily be applied to all resource classes and even individual resources in a consistent, non-discriminatory manner.

Both the marginal reliability improvement method and the LOLP capacity factor method show promise in reducing the computational and analytical effort in capacity accreditation. Their use would free up resources that can be applied toward more robust underlying resource adequacy analysis and allow the methods to more easily be applied across all resource types and even individual resource configurations. More effort should be applied to calibrating these metrics on test systems and developing other analytical simplifications.

Future Options and Recommendations

This report shows the increasing complexity of resource adequacy analysis in general and resource capacity accreditation in particular, with a growing number of ways to evaluate capacity accreditation. It identifies several gaps in current accreditation methods and suggests five foundational pillars for capacity accreditation that can be used by market designers, regulators, and system planners to better accredit resources for the benefits they bring to system reliability. This will ensure that planners and investors can efficiently select resources that best meet the needs of system reliability, ensure that load-serving entities are meeting their reliability obligations, and send a clear price signal to new market entrants.

This report identifies the need for system planners to focus attention on two key considerations. First, accreditation methods should be expanded and applied to all resource types, not just wind, solar, and battery storage. Second, there is a need to better link forward-looking (simulated) capacity accreditation with retrospective, actual operations.

Most importantly, this report identifies the need for system planners to focus attention on two key considerations. First, accreditation methods should be expanded and applied to all resource types, not just wind, solar, and battery storage. This includes considering the reliability implications of correlated outages on thermal resources, the benefits of interregional transmission, and the details of load flexibility (ESIG, 2021).

Second, given that power system modeling is never perfect and there are inherent risks with accrediting resources solely based on probabilistic resource adequacy models and reliant on the underlying assumptions chosen, there is a need to better link forward-looking (simulated) capacity accreditation with retrospective, actual operations. The ESIG Redefining Resource Adequacy Task Force offers the recommendations below to improve how accreditation is currently practiced and help ensure efficient reliability of the power system.

RECOMMENDATION 1

Ensure that the foundational pillars are clearly communicated to stakeholders.

The five pillars for improved resource accreditation outlined in this report are for accreditation methods to be non-discriminatory, robust, transparent, reliable, and predictable. Any new accreditation methods should clearly identify how the process improvements address each of these pillars.

RECOMMENDATION 2

Be cautious if using capacity credits—in isolation—as the basis for ensuring reliability.

While the use of capacity accreditation and the planning reserve margin can serve as a simple heuristic to estimate reliability, the results of a single capacity accreditation process does not ensure a reliable system over time because it is based on expected portfolio compositions. Changes in load and resource mix could change the accreditation of individual resources. Probabilistic loss-of-load expectation studies should be used to determine whether a portfolio is reliable, rather than relying on a planning reserve margin. This is because the static nature of capacity credits may not capture interaction effects between resource contributions in a changing portfolio. To ensure reliability, more holistic, system-level planning studies need to be used to identify potential shortfalls and further refine capacity needs. It is essential that resulting portfolios from any capacity market auction or procurement be fully evaluated as a portfolio, such as by using a probabilistic resource adequacy analysis. This iterative "round-trip" modeling is necessary to ensure that the estimated capacity credits accurately reflect saturation effects and portfolio diversity effects of different resource mixes.

RECOMMENDATION 3

Consider accreditation methods that evaluate not only a resource's capacity, but also energy available during periods of high risk.

It is important that accreditation techniques lead to a reliable system, even in systems undergoing rapid transition. For example, accreditation techniques must capture the succession of phases of the way resources have been, are, and will increasingly be accredited for their contribution to resource adequacy. This starts with the traditional approach of counting firm capacity, moves to expected capacity available at time of peak load, and then continues toward the expected capacity and energy available from resources during periods of high risk. This places an emphasis on processes that can consider both capacity and energy limitations of resources and can adapt to the specific timing of risk, both diurnally and seasonally, as the risk periods evolve alongside changes in the resource mix.

RECOMMENDATION 4

Accredit all resource types using similar metrics and methods.

If capacity accreditation is used to measure the performance of one type of resource, it should be applied to all types of resources in a similar manner. The fair application of methods across resources ensures that the capacity credits are technology-neutral, ensures they provide accurate incentives for improved performance and innovation through plant design and hybridization, and increases the likelihood that the capacity accreditation leads to a reliable and least-cost portfolio of resources. Care should be taken to ensure that individual resources that can materially differentiate themselves from the resource class average—by location, technology, or plant configuration—are assigned a different capacity credit in order to incent improved availability for reliability.

RECOMMENDATION 5

Align incentives in capacity accreditation and real-time performance, in order to not only simulate availability during typical risk periods but ensure performance during actual scarcity events.

A perfect accreditation calculation still can result in a resource not showing up when needed, even if it was capable of producing power during the event. Since the capacity revenues of the resource were ascribed during a modeling exercise, there are limited real-time incentives for the resource to operate in a specific way. An integrated approach may balance the real-time performance of resources during periods of scarcity with capacity accreditation of resources based on modeled-only accreditation techniques. Regardless of the approach chosen, decision-makers can make certain that incentives or governing rules are aligned to ensure that generators will supply power during times that the power is needed.

RECOMMENDATION 6

Evaluate methods to simplify and streamline accreditation calculation techniques.

ELCC metrics are computationally and analytically resource-intensive. However, some simplifications are available to reduce this effort considerably. More effort could be applied to calibrating these metrics on test systems and developing other analytical simplifications. Both the marginal reliability improvement method and the LOLP capacity factor method show promise in reducing the computational and analytical effort to capacity accreditation. This will benefit the overall process, freeing up resources to apply toward more robust underlying resource adequacy analysis and allowing the methods to more easily be applied across all resource types and even individual resource configurations.

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PHOTOS

Ensuring Efficient Reliability: New Design Principles for Capacity Accreditation

A Report of the Energy Systems Integration Group's Redefining Resource Adequacy Task Force

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The report is available at https://www.esig.energy/new-design-principles-for-capacity-accreditation.

To learn more about the recommendations in this report, please send an email to info@esig.energy.

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