Resource Adequacy For a Decarbonized Future

2024 TECHNICAL REPORT

Resource Adequacy Scenario Selection Guide

EPRI Resource Adequacy Assessment Framework

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ABSTRACT

Recent supply deficiency events have shown that traditional resource adequacy (RA) processes, metrics, and tools may not be fully able to address adequacy requirements in the context of changing climate, changing resource mix, and extreme weather scenarios. One of the key factors for ensuring a successful RA assessment is that the scenarios considered are appropriate for the study at hand—the resource mix, the region to be studied, and the study horizon.

The goal of this document is to guide resource planners in the process of selecting scenarios for both traditional adequacy and stress testing scenarios. Adequacy assessment methodologies have historically focused on assessing generation outages during peak demand across various economic load growth projections. However, growth in renewables, energy limited resources, end-use electrification, and the increasing adoption of distributed resources, has increased the variability and uncertainty of future operating conditions, driven by weather and behavioral factors. This work focuses on developing guidelines to construct appropriate scenarios to assess the adequacy for each system, considering a wide spectrum of influencing factors.

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EXECUTIVE SUMMARY

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KEY RESEARCH QUESTION

Supply deficiency events and accelerating load growth in the recent past have shown that traditional resource adequacy (RA) processes, metrics, and tools may not be fully able to address adequacy requirements in the context of changing climate, changing resource mix, evolving load, and extreme weather scenarios. One of the key factors for ensuring a successful RA assessment is that the scenarios considered are appropriate for the study at hand—the resource mix, the region to be studied, and the study horizon.

RESEARCH OVERVIEW

This report investigates scenario selection possibilities for the various inputs of the resource adequacy assessment process and categorizes them by level of potential impact on the outcomes of study. Recommendations are put forward for system planners regarding which modeling option may be most appropriate to consider under different circumstances. Three levels of scenarios, ranging from low to high fidelity, are proposed. Level I, representing the lowest fidelity options, is generally acceptable for studies with a limited scope; when the influencing factor is relatively certain and has low materiality on study outcomes; when the influencing factor is subject to external guidance; or when factors are determined exogenously. Level III fidelity ensures the broadest representation of the factor. These approaches are generally more computationally and data intensive than lower fidelity models; however, they may be warranted depending on a specific system's characteristics.

KEY FINDINGS

- A set of modeling recommendations by levels of fidelity can guide the choice of where additional effort should be placed to increase the likelihood that impactful outcomes are explicitly studied in RA.
- Short and mid to long term assessment timeframes have different needs given the range of uncertainties for various factors.

- The various uncertainty factors which guide scenario selection choice can be categorized into various subcategories; namely geographic and temporal scope and resolution, climate and policy, customer choices, electricity supply, electricity networks, and fuels.

WHY THIS MATTERS

The choice of which scenarios to include can have significant implications on resource adequacy. Modeling simplifications when it comes to resource adequacy scenarios may result in underestimating system risk or, on the other hand, overestimating risk and sending signals for investment that are too conservative. Similarly, complex modeling options may result in increased efforts and cost of data collection and computation. It is essential for planners to understand the range of scenario modeling options available for different future uncertainty pathways and to be able to match them to their specific system needs.

HOW TO APPLY RESULTS

End users can implement the results of this report by either taking themselves, working with their third parties, and their counterparts in other organizations to both raise awareness of opportunities for improvement in resource adequacy assessment processes. Together with the other findings from this EPRI initiative, they can assess where their own organization stands in terms of scenario selection fidelity levels and work to address any gaps identified as part of this exercise over the coming years.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- This project is part of the EPRI *Resource Adequacy for a Decarbonized Future* project. For further reports and summary material from the project, please review the reports linked at https://www.epri.com/resource-adequacy.
- EPRI project 173C (Flexibility and Resource Adequacy Assessment) carries out work in the resource adequacy area. EPRI also organizes a bimonthly Resource Adequacy Forum to engage with stakeholders in the resource adequacy space.

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1 INTRODUCTION

Resource Adequacy Assessment Framework

The RA problem can be defined as assessing whether a given resource mix has a high probability of meeting customer demand at any moment, accounting for uncertainty in both supply and demand. There are many factors that must be carefully considered to ensure a successful RA analysis. Figure 1 shows a simplified schematic categorizing the main components of the RA assessment process. The focus of this report is on Scenario Selection, which is highlighted in light grey. Other topics are covered in other parts of EPRI's RA For a Decarbonized Future Initiative in other reports.[1]

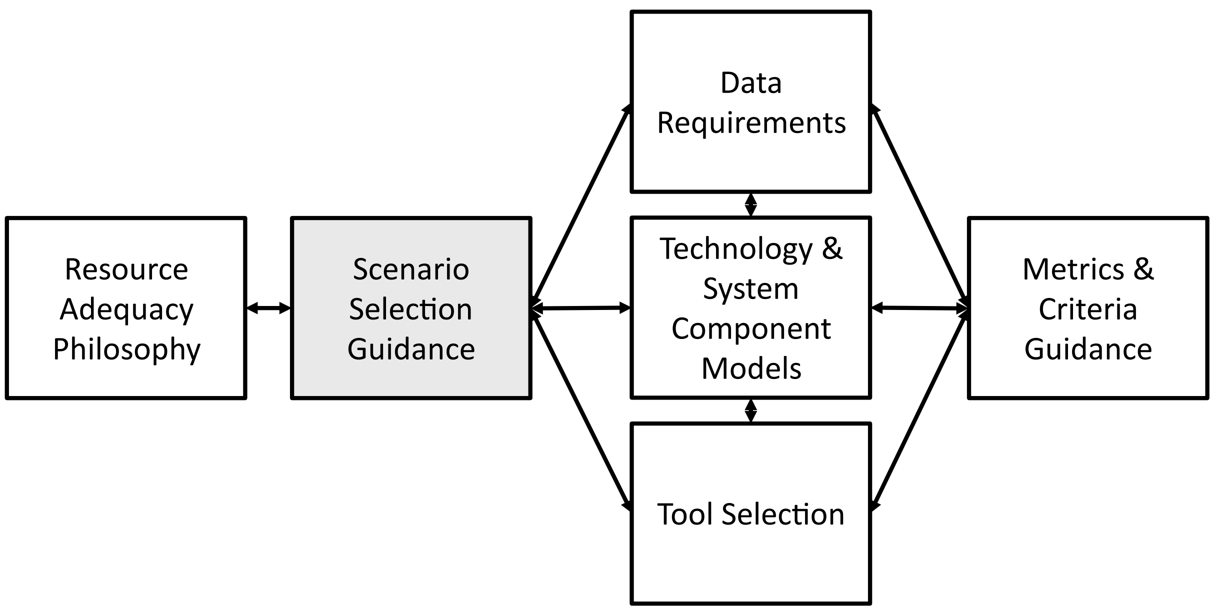

Figure 1. Simplified RA component schematic

The arrows in Figure 1, connecting the different RA components of an integrated assessment approach, are all bi-directional to illustrate component inter-dependencies. For example, Data Requirements dictate which Technology & System Component Models can be applied but also, when the need for a particular technology model arises, a model influences the Data Requirements. Collected data also constrains the selection of demand, weather, renewable energy generation, and outages represented in the Scenario Selection Guidance, and vice versa.

Leveraging the technology and system component models that have been identified and developed, along with scenarios capturing a range of possible future system conditions, RA simulation tools are employed, scheduling generation to minimize periods of lost demand,

[1] See www.epri.com/resource-adequacy, where reports will be available when published.

generally at the lowest production cost. The primary outputs of RA analyses come in the form of adequacy metrics such as loss of load expectation (LOLE), expected unserved energy (EUE), and loss of load hours (LOLH). RA assessments may also be carried out with the purpose of ascribing an accreditation to resources, often expressed as their effective load carrying capability (ELCC) or unforced capacity (UCAP), which may be then fed as an input to capacity expansion models or used to inform capacity market design.

There exists a set of traditional approaches employed for each of the RA components presented in Figure 1. However, recent supply deficiency events suggest that they may underperform in the context of a changing climate, changing resource mixes, and extreme weather scenarios. As such, work addressing challenges across all components of the RA schematic has been conducted under EPRI's *Resource Adequacy for a Decarbonized Future* initiative.

RA Assessment Timeframes

Adequacy assessments are carried out across several time frames. In the long-term planning timeframe from a year to decades ahead, adequacy studies inform the need for investment in generation, demand-side measures, inter-regional transmission, mothballing, retirement, and fuel supply. In the mid-term planning timeframe, from a year to several months ahead, adequacy studies are used to inform market decisions, such as capacity remuneration mechanisms. In the short-term planning timeframe, from several months ahead to several days ahead, adequacy assessments inform decisions about generator planned maintenance.

The approach to scenario selection may differ across the short-term, mid-term, and long-term planning timeframes. As such, these timeframes and their impact on scenario selection guidelines have been explicitly stated throughout this report.

Configuring Assessments

The definition of scenarios studied is intrinsically linked to the setup of a model.

Scenario Definition

Adequacy related risk is influenced by a wide range of factors, including temporal factors, weather factors, and resource related factors. In the resource adequacy philosophy guideline, an emphasis is placed on ensuring that factors that drive adequacy risk are represented in adequacy assessments. Many of these factors are variable over time (e.g., demand) or uncertain in nature (e.g., resource forced outages).

In this guideline, we consider scenarios to be alternate, discrete sets of parameters associated with the variables that describe a bulk power system under study. Examples of these variables may include the quantity of each type of generation, demand, interconnection capacity, geographical boundaries or weather years. Scenario definitions most commonly involve alternate time-series values for specific variables and may depend on historical information.

In reality, scenario selection is typically governed by data availability in the first instance. While this approach may persist in practice, first developing the desired scenario set and then determining what is achievable to study given data limitations will better highlight the range of future cases that are covered and illustrate the risks that are not feasible to assess given the constraints faced by planners.

It should be noted that, while scenario selection approaches are disaggregated by component in the following chapters, it is necessary for planners to ensure that selected modeling approaches by component are aligned and consistent within in the global RA framework applied.

Scenario Selection Scale

A tabulated summary of the proposed scenario selection scale by level of fidelity is provided for each section in this report. The goal of this approach is to provide a simplified set of scenario selection options for practitioners. It should be recognized that tradeoffs are required in most assessment studies because of real-world constraints on resources, data, models, and toolsets. Three levels of scenario selection approaches are proposed, as demonstrated in Table 1. The fidelity level of different modeling approaches is classified as follows:

- Level 1 - Basic: these scenario selection approaches are generally the least extensive, often limited to a single view of how the future emerges. Level I approaches are generally acceptable for studies with a limited scope, when the influencing factor is relatively certain and has low materiality on study outcomes, when the influencing factor is subject to external guidance, or when factors are determined exogenously.
- Level 2 – Intermediate: these factors are important to consider with some intermediate level of detail, because of the level of impact that a change in foreseen conditions would have on the outcome of the adequacy assessment. A more detailed treatment may be warranted when compared with Level 1, potentially including the assessment of alternate parameterizations of a model or to represent a specific factor with a higher level of detail than would be otherwise warranted.
- Level 3 – Advanced: this scenario selection level systematically ensures the highest fidelity representation of the range of outcomes a given factor could take, given its expected and significantly material influence on outcomes. This approach is generally the most resource and data intensive and may not always be needed, or justified, depending on a specific system’s characteristics.

Table 1. Considerations for scenario selection by level of fidelity: Sample table

	Level I	Level II	Level III
Scenario Selection	Most basic representation: generally acceptable for studies with a limited scope, when the influencing factor is relatively certain and has low materiality on study outcomes	Mid-fidelity representation: may be necessary when a change in foreseen conditions could have an impact on the outcome of the adequacy assessment	Highest fidelity representation: may be required for systems when a given factor's influence is expected to be significantly material to adequacy outcomes

Report Intended Uses

This report focuses on the development of a structured, repeatable, and transparent approach to making choices in the design of adequacy assessments. The primary objective is to align the scenarios defined for analysis with the principal risks and their range of uncertainty in the study period.

Document Organization

The rest of the report is organized as follows: Section 2 describes a range of study configuration choices that inform all downstream activities, foremost amongst which is scenario selection.

Section 3 through 7 outline the scenario selection possibilities for the various inputs of the resource adequacy assessment process, including geographic and temporal scope and resolution, climate and policy, customer choices, electricity supply, electricity networks, and fuels, respectively. Section 8 provides concluding remarks, including a summary of other relevant reports available as part of the *Resource Adequacy for a Decarbonized Future* initiative.

2 STUDY CONFIGURATION: SCOPE AND RESOLUTION

Geographical scope and resolution refer to the geographical area and granularity captured in adequacy studies, as well as considerations relating to the temporal horizon and resolution. In reality, these two choices are interrelated; smaller scope allows the potential for higher resolution and vice versa. A summary of scope and resolution scenario choices by level is presented in Table 2.

Table 2. Scenario selection levels for scope and resolution

Category	Timeframe	Level I	Level II	Level III
Geographical Scope	All	Utility, balancing area, or country	Reliability regions	Combined countries or regions
Geographical Resolution	All	Regional	Zonal	Nodal
Study Horizon	Long & Mid Term	3-5 years	5-10 years	10 – 20 years
	Short Term	Season ahead	Year ahead	1-3 years ahead
Temporal Resolution	Long & Mid Term	Seasonal Peak	Daily Peak	Full year modeled at an hourly resolution (8760)
	Short Term	Daily peak	Full year modeled at an hourly resolution (8760)	

Geographical Scope (Inter-Area Exchanges)

The geographical scope covered by adequacy studies may be set up in a variety of ways, depending on the decision being informed. Selection of an appropriate geography may be informed by the risks related to dependence on exchange of power with neighboring entities. In self-contained regions or entities, a smaller scope may be envisaged. In cases with significant trade and those vulnerable to co-incident peak demand or wide area weather fronts exerting stress on the system, a wider area may be warranted.

Studies that model larger geographical areas can capture in greater detail inter-area exchanges. Advanced models include the widest geographical scope, often conducting continental-scale modeling, paired with state or country level resolution.

Level I approaches are suitable for self-contained power systems, with no anticipated dependence on trade or exchange of power flow with other regions or where out of area resources can justifiably be counted as within the area. An example for this is a single utility integrated resource plans.

Level II approaches are suitable for a self-contained set of regions or entities, who frequently rely on trade, a common capacity procurement mechanism, or similar. Level II approaches model reliability regions and the trade within the sub regions. Examples of this include ISO-wide adequacy assessments for regions such as PJM in the US, or the Gulf Coordinating Council Interconnection Authority (GCCIA).

Level III approaches are suitable for very large-scale continental scale studies, suitable for large interconnections and adjacent markets that trade with each other. The European Resource Adequacy Assessment conducted by ENTSO-E models most countries in Europe (as well as other non-European interconnected regions) and is an example of an RA model employing a Level III approach in the Geographical Scope category. Overall, advanced approaches enable planners to capture the impact of wide area climate events on adequacy.

Geographical Resolution (Intra-Area Exchanges)

The choice of geographical resolution in resource adequacy studies is directly related to the level of representation of intra-area transmission constraints and geographical scope.

Level I studies represent each region as a copper plate, where it is assumed that intra-region flows are never constrained. Regions may represent a country, a state, or a balancing authority. Depending on the specific process requirements, these may be suitable for long range integrated resource plans or where downstream activities are responsible for assuring deliverability, or where no trade is modelled.

Level II approaches recognize transmission constraints between zones, which are transmission constrained areas within regions, with a copper plate assumption made for intra-zone flows. Comparison of flow inter-tie constrained (L2) adequacy with copper-plate (L1) adequacy reveals the value of transmission limits on reliability. Examples of this are the zonal approach taken by New York ISO in their adequacy assessments related to the NY capacity market.

The highest fidelity approach to capturing geographical resolution in adequacy studies (Level III) is to use a nodal representation of the area under study. This approach is rarely a requirement but should be considered in systems that anticipate significant congestion and consequently, generation curtailment.

Study Horizon

Study horizons should align with the information required to take a consequent decision. Long lead time investment needs studies that have further horizon, often stretching decades into the future. Meanwhile immediate decisions relating to outage timing or fuel purchases may only require a horizon of several days ahead.

When the choice of study horizon does not compromise modeling detail, studies with longer lookaheads (wider horizons) can capture more information regarding new unit interconnection, as well as decommissioning, along with associated adequacy challenges.

Long and Mid-Term Decision Making

In the long and mid-term, the choice of horizon is best related to the class of decisions which are being made:

Level I considers a 5 to 10 year horizon and is most suitable for mothballing, retirement decisions, demand flexibility product design and investment decisions in assets not longer than 5 years (e.g. CCGTs).

Level II considers a 10 to 20 year time frame and is most suitable for investments in longer lead time resources such as inter-ties, pumped hydro storage and nuclear power plant.

Level III consider a longer term 10 – 20-year horizon are suitable to inform and characterize the need to develop new technologies and to understand long term and structural changes in demand over the lifetime of an existing fleet.

Short Term

In the short term, decisions focus on options other than investment.

Level I choices examine seasons up to 1 year ahead, informing the need for fuel procurement, maintenance scheduling, conservation and trade.

Level II considers one to three years ahead and is used to inform the same decisions as Level 1, but on a longer timeframe, as well as the need to secure emergency generation and the design of demand side tariffs.

Level III approaches look from 1 to 5 years ahead and are used to inform systems related to the same as the previous two levels as well as the delivery risk associated with investment and retirement decisions taken.

Temporal Resolution

Assessments face a choice of how granular a time step to represent in a model. Higher fidelity models capture more hours in the year, while lower fidelity models focus on those hours where loss of load risk has been highest historically. As generation mixes change to incorporate increasing levels of wind and solar power, as well as energy storage, and computational capability and data availability improve, there has been a growing need to move from Level I towards Level III approaches.

Level I approaches focus only model seasonal peaks. These are more suitable for systems facing little to no variable generation, energy limited resources or extreme weather.

Level II approaches model daily peaks hours and while an improvement on L1, are similarly only suitable for systems with immaterial wind, solar PV and batteries. This approach has a greater chance of identifying risk associated with extreme weather than L1, but not as good as L3.

Level III approaches represent a full year at an hourly resolution. This enables a higher fidelity representation of units that have time-dependent constraints, such as energy storage.

3 CLIMATE AND POLICY SCENARIOS

Climate and policy scenarios refer to the variability in public policy and climate pathways that may affect the bulk power system during the period under assessment. A summary of climate and policy scenario choices by level of fidelity is presented in Table 3.

Table 3. Scenario selection levels for climate and policy

Category	Timeframe	Level I	Level II	Level III
Energy and Emissions Policies	Long Term	Prevailing policy for horizon	Multiple plausible policies modelled	
	Mid & Short Term	Business as usual	Committed policy for horizon	
Climate	Long Term	Consider all historical weather years	Adjusted and unadjusted historical weather years	Include multiple climate trajectories based on global climate models

Energy and Green House Gas (GHG) Emission Policy

Energy and emission policy can impact adequacy by setting an environment that influences the availability or performance of a range of generation, demand and networks assets. Methodologies for accounting for energy and GHG policy differ depending on whether studies are long, or mid and short term. In the case of energy and emissions policies, unless significant change is foreseen across the horizon, prevailing or business as usual policies are sufficient. However, in cases where such policies are likely to result in potentially different outcomes in terms of demand, supply, storage, fuel or interconnection, these alternatives should be represented to the extent that they are likely foreseeable and material.

Climate

Climate can have multiple impacts on resource adequacy; it not only directly impacts outputs from hydro, wind, and solar units, but also (strongly) impacts customer load, as well as generator outages and fuel delivery. Methodologies for accounting for climate differ depending on whether studies are long, or mid and short term.

Long Term

In long term studies, the most basic (Level I) approaches assign an equal probability of materializing to all historical weather scenarios. Intermediate approaches may to account for climate change impacts compared to a historical counterfactual. Advanced approaches include multiple possible climate trajectories, informed by global climate models.

In the case of climate, in the short and mid-term, the impacts of climate trajectories are most appropriately reflected through choices related to data and modelling, dealt with in other parts of the framework. Where Climate becomes a decision for scenario selection is over the long term, when multiple outcomes are possible. A basic approach for systems that do not expect to experience any significant deviation in climate from the historical record over the assessment period is to consider historical weather years without adjustment for climate.

In systems where some level of impact is possible, particularly for temperature and precipitation, selection of both climate adjusted and unadjusted weather years as distinct scenarios may be justifiable, to determine the need for mitigation measures. The climate adjusted scenario may be adjusted to a single 'most plausible' trajectory.

In the case that the impact of climate change is likely to be seen over the assessment horizon, but several trajectories are plausible and meaningfully different, it may be prudent under such cases to explore the impact of a range of scenarios following alternate emissions pathways. One such approach is to follow the Shared Socioeconomic Pathways (SSPs) defined through the most recent Intergovernmental Panel on Climate Change assessment report.

4 CUSTOMER BEHAVIOUR

Electricity end use factors represent the influence of load consumption patterns on scenario selection. Decisions regarding load representations do not require differentiation for different study timeframes. A summary of customer choice scenario choices by level of fidelity is presented in Table 4.

Table 4. Scenario selection levels for customer choices

Category	Timeframe	Level I	Level II	Level III
Demand forecast	All	Single load forecast	Multiple scaled load projection	Alternative load growth trajectories, considering structural changes in demand
DER Adoption	All	Single adoption forecast, net from load	Considered as part of supply side Multiple adoption forecasts	
Energy Efficiency	All	Single forecast	Range of forecasts	

Demand Forecast

Level I represents demand growth rely on a single load (timeseries) forecast. This is suitable in cases where no structural change and there is little feasible uncertainty in the demand.

Level II approaches expand on Level I by scaling load up and down, while maintaining existing load shapes, by a given set of positive or negative percentage points to represent the influence of economic factors on load growth. This is suitable in cases where there is no structural change in demand but some uncertainty relating to demand growth exists.

Level III approaches are required when structural changes in demand are anticipated. In this case, a bottom-up approach to constructing a load forecast may be required for major demand categories. Examples of the constituent categories which may require individual treatment are heating and cooling, electric transportation and industrial end use, as noted in the following table. For each of these categories a similar classification of scenarios may be applied. Level I may be suitable where there is certainty about how the specific end use demand category will materialize in future. Level II is suitable when there is uncertainty (may be aligned to policy) in the anticipated adoption, behavior or its potential flexibility.

A summary of additional customer choice scenario choices by level of fidelity is presented in Table 5.

Table 5. Scenario selection levels for additional customer choices

Category	Timeframe	Level I	Level II
Electric Heating & Cooling	All	Single demand profile	Alternate adoption profiles and flexibility
Electric Transportation	All	Single demand profile	Alternate adoption profiles and flexibility
Industrial End Use	All	Not explicitly considered	Alternate adoption profiles and flexibility

Electric Heating and Cooling

As for global load growth, Level I approaches rely on a single profile representing heating and cooling loads. Level II approaches build on Level I by considering multiple electrified heating and cooling adoption profiles. Level II approaches may also discern between how end use tariffs, such as time-of-use, demand charge, or adoption of real-time-price-correlated tariffs, can impact heating and cooling load profiles.

Electric Transportation

As for the above categories, Level I and Level II approaches rely on a single or multiple electric transportation adoption profiles, respectively. Level II approaches may also consider the impact of customer tariffs incentivizing electric vehicle charging shifting (such as time-of-use tariffs) on global vehicle load shapes.

Industrial End Use

Industrial electric demand is not explicitly considered in Level I assumptions, rather as part of the main load forecast. This is partly driven by the fact that it has not been necessary to do so in the past (and still may not be needed) in many systems. Level II assumptions may consider a single industrial electrification trajectory and the resulting distinct load profile. Level II may consider multiple possible industrial electrification trajectories and flexibilities driven by a set of different decarbonization pathways – e.g. hydrogen electrolysis with hourly additionality rules.

DER Adoption

A basic approach to DER adoption is to forecast one level of adoption, a related production profile (perhaps cognizant of incentives) and to net it from demand. This is suitable in cases where DER adoption uncertainty is low.

Level II approaches treat DER similarly to bulk system resource adoptions, considering DERs in the same manner as supply-side assets. In this level multiple adoption trajectories may be considered.

Energy Efficiency

Basic consideration of energy efficiency in scenario selection (Level I approaches) involve a single profile capturing the forecasted impact of energy efficiency schemes on load profiles. In the case of energy efficiency, there is no differentiation between Level II and III approaches: both cases consider a range of profiles forecasting the influence of energy efficiency schemes on demand, instead of a single one, based on the potential for multiple trajectories to appear over the assessment period (e.g. building heat retention forecasts).

5 ELECTRICITY SUPPLY

After demand, variations in the availability and performance of supply and storage resources are the next most material impact on adequacy outcomes. The approach to selecting electricity supply scenarios may vary, depending on the timeframe of the resource adequacy study. The following set of factors relating to supply-side units must be considered in scenario selection. A summary of electricity supply scenario choices by level of fidelity is presented in Table 6.

Table 6. Scenario selection levels for electricity supply

Category	Timeframe	Level I	Level II	Level III
Installed Capacity	Long & Mid Term	Single resource portfolio	With and without uncertain retirements and incomplete additions	Incorporates economic viability assessment
	Short Term	Single plant availability profile	With and without maintenance profiles	Incorporates return of mothballed or recall of on maintenance plant

Installed Capacity

Long and Mid Term

In mid- and long-term assessments, basic scenario selection approaches for accounting for installed capacity consider declared or intended future capacity additions and retirements in forecasts. This is suitable in cases where no deviation from the set of forecasted supply resources is possible, with high certainty. Intermediate (Level II) methods, evaluate alternate sets of scenarios considering the potential for accelerated retirement of aging plant or delayed completion of assets under development. This approach is recommended for systems undergoing significant transition in the generation fleet over the assessment period.

Advanced approaches iterate between adequacy studies and economic viability assessments for generating plant, removing plant in each iteration that appear to be at high risk of mothballing or retirement. This approach is suitable in cases where the risk of uneconomic operating conditions for marginal assets is likely.

Short Term

In short term assessments, Level I methods generate installed capacity scenarios based on a single profile of available capacity values. This is suitable when short term uncertainty is low, which is a large number of cases. Level II scenario selection reflects the inclusion of a range of maintenance profiles that may be expected across the operating horizon. In cases where supply assets are anticipated to be in a mothballed state, advanced analysis to consider the return or exclusion of those resources to service is recommended (Level III).

6 ELECTRICITY NETWORKS

When it comes to scenario selection, the dominant factor in adequacy assessments is the degree to which external trade is considered. For self-contained systems or systems with fixed trade, this is more straight forward. For systems interconnected with many other systems upon who there is interdependence, representation of those links becomes a question of scenario selection.

Decisions regarding electricity network representations do not need to be differentiated as a function of study timeframes. A summary of electricity networks scenario choices by level of fidelity is presented in Table 7.

Table 7. Scenario selection levels for electricity networks

Category	Timeframe	Level I	Level II	Level III
External Transmission (inter-area)	All	Fixed sales, purchases, or interties	Alternate intertie availabilities	Stress test

External Transmission (Inter-Area)

Level I methods account for external transmission through the inclusion of a single set of (projected) inter-area sales and purchases or a single set of interties.

Level II scenario selection evaluates adequacy under a range of intertie capacities, typically based on anticipated build outs of new connections. This is suitable for systems where the interconnection capacity is anticipated to change over time.

Level III requires the definition of a stress test scenario which may focus on the performance of a system during a period of elevated stress due to high demand or low supply, as well as variations based on available inter-area transmission capacity.

7 FUELS

Two key fuel-related aspects are relevant at the resource adequacy level: fuel availability and fuel prices. Decisions regarding fuel availability and price representations do not require differentiation depending on study timeframes. A summary of fuels scenario choices by level of fidelity is presented in Table 8.

Table 8. Scenario selection levels for fuels

Category	Timeframe	Level I	Level II	Level III
Fuel Availability	All	Not considered	Alternative fuel availability profiles	Alternative fuel availability profiles & stress tests
Fuel Prices	All	Single price profile	Alternative fuel availability profiles	

Fuel Availability

Basic scenario selection methods do not consider the impact of fuel availability and consider the fuel as firm supply in all cases. The underlying assumption being that fuel is never constrained. This assumption has been acceptable in many regions in the past and may still be in certain regions. However, more and more regions, particularly importing regions, have seen fuel constraints over the past years (often related to fossil gas delivery). As such, Level II and III methods are increasingly necessary to appropriately capture fuel availability in resource adequacy scenarios.

Level II approaches include multiple alternative fuel availability profiles which may be configured to represent pipeline constrains, unavailability of terminals, coal pile freezes or similar. Level III approaches not only represent such cases, but also define specific stress test conditions to evaluate the performance of the system under defined extreme operating conditions with low fuel supply.

Fuel Prices

While fuel prices may appear to be more of a matter of economic performance, in systems with significant penetrations of energy limited storage, such as batteries, economic factors may influence the state of charge of such units. As a result, this factor may be material in certain systems and to varying degrees.

Basic methods for representing fuel cost in resource adequacy scenarios consider a single, static (often annual) price per fuel. This assumption may be suitable for regions that do not feature significant energy storage resources or where fuel prices are unlikely to affect mothballing decisions. A more advanced approach may be required in regions seeing (or expecting) sufficiently significant fuel price fluctuations to impact mothballing or storage dispatch in a material manner. Such approaches may consider alternative seasonal fuel scenarios, annual fuel profiles or fuel price shocks price fluctuations. Advanced methods consider multiple price forecasts at, at least, a seasonal resolution.

8 CONCLUSION

The choice of modelling configuration and scenarios selected have a significant implication for the assessment of resource adequacy. Modeling simplifications when it comes to resource adequacy scenarios may result in underestimating system risk or, on the other hand, overestimating risk and sending signals for remediation that are too conservative or are not aligned with the nature of the risk.

Similarly, complex modeling options may result in increased efforts and cost of data collection and computation but may offer false precision if the true uncertainty space is significantly larger. It is essential for planners to understand the range of scenario modeling options available for different future uncertainty pathways and to be able to match them to their specific system needs. This report identified different needs in short and mid to long term assessments given the range of uncertainties and the timelines in which studies must be completed.

While a range of configuration and scenario selection options are presented here, even with diligent scenario selection and study configuration, two major issues remain that assessors should be aware of:

1. **Internal consistency**

   While a hard ruleset to ensure internal consistency between configuration, scenario, model and data selections does not exist, assessments should attempt to aim for internal consistency between the scenarios evaluated. To this end, the use of storylines has evolved into practice across the energy industry, an example of which is implemented in the European Resource Adequacy Assessment. Establishing storylines from the outset will aid the alignment of parameterization of a specific scenario for a specific variable with those elsewhere in the system.

2. **Human bias**

   Without actions to the contrary, decision biases are likely to be prevalent across the scenario selection and modelling setup process. These biases may introduce structural misalignment between the adequacy assessments and the reality under assessment. The list of potential biases is long, but their effects are generally mitigated through consultation and review with a wide set of stakeholders.

Throughout the *Resource Adequacy for a Decarbonized Future* project, EPRI has sought to accelerate the evolution of RA processes and tools in collaboration with industry partners. The *Resource Adequacy for a Decarbonized Future* initiative has developed a series of reports and guidelines targeting a range of topics elements that are critical to setting up robust RA studies. A list of the *Resource Adequacy for a Decarbonized Future* initiative's outputs is presented in Table 9.

Table 9. Deliverables under EPRI's Resource Adequacy for a Decarbonized Future initiative.

	Deliverable	ID and link
Reports	Metrics and Criteria for Resource Adequacy	3002023230
	Resource Adequacy Scenario Selection Guide	3002027829
	Modeling New and Existing Technologies and System Components in Resource Adequacy	3002027830
	Data Collection Guide	3002027831
	Resource Adequacy Assessment Tool Guide	3002027832
	Resource Adequacy Gap Assessment	3002027833
Case studies	EPRI Resource Adequacy for a Decarbonized Future Case Study: Western US	3002027834
	EPRI Resource Adequacy for a Decarbonized Future Case Study: Northeastern US and Canada	3002027835
	EPRI Resource Adequacy for a Decarbonized Future Case Study: Southwest Power Pool	3002027836
	EPRI Resource Adequacy for a Decarbonized Future Case Study: Midcontinent	3002027837
	EPRI Resource Adequacy for a Decarbonized Future Case Study: Texas	3002027838
	EPRI Resource Adequacy for a Decarbonized Future Case Study: Southeastern US	3002027839
Tools	Resource Adequacy Viewer Tool (RAVT)	3002026144
	Resource Adequacy Fuel Insufficiency Screening Tool (RAFIST)	3002028168

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

PROGRAM

Bulk System Integration of Renewables and Distributed Energy Resources, 173

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