NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Technical Reference Document: Considerations for Performing an Energy Reliability Assessment

Volume 2

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RELIABILITY | RESILIENCE | SECURITY




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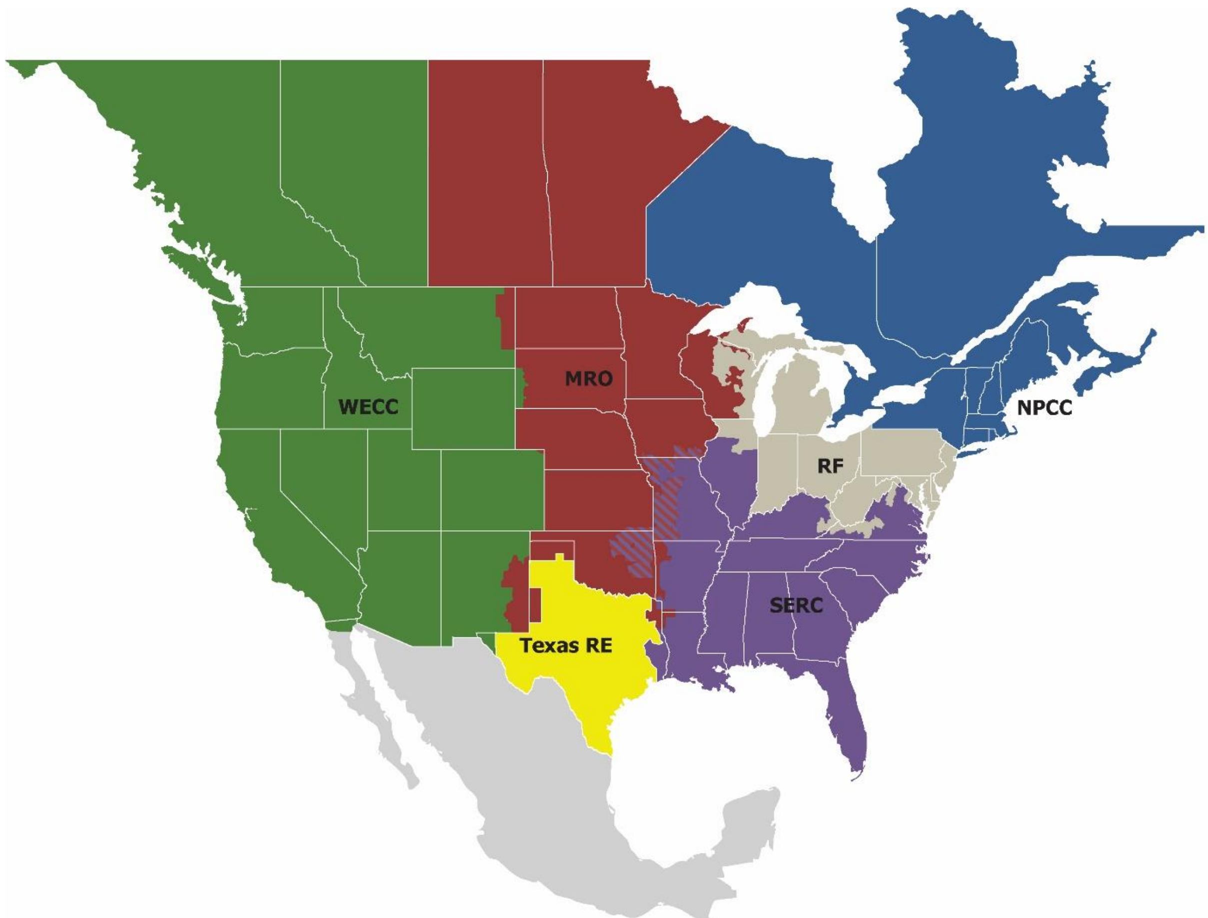
Preface

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

Reliability | Resilience | Security

Because nearly 400 million citizens in North America are counting on us

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



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

Statement of Purpose

Considerations for Performing an Energy Reliability Assessment, Volume 1[1] (Volume 1), which provided an overview of the basic elements of an energy reliability assessment (ERA) and general considerations for performing an ERA, was published in March 2023. Volume 2 details how to perform an ERA, including different methods for building analysis tools, how metrics can be defined in terms of energy, and approaches to corrective actions when those metrics cannot be met. **The purpose of this technical reference document was not to dictate how to perform an ERA but rather to highlight inputs that should be considered when performing an ERA.**

Several key pieces of prerequisite knowledge, including Volume 1, *NERC Reliability Guideline: Fuel Assurance and Fuel-Related Reliability Risk Analysis*,[2] and the *NERC Special Report on Maintaining Bulk Power System Reliability While Integrating Variable Energy Resources (VER)*, lead into the topics discussed in this document.[3] The fuel assurance reliability guideline discusses the individual risks associated with specific fuel types, helping the reader understand how upstream fuel supplies may impact power generation—a key input to any energy analysis. Likewise, the need for flexibility in a committed fleet to maintain reliability is discussed in greater detail in this document.

This technical reference document is organized into eight chapters. Chapters 1 through 4 outline the considerations and recommended data needed to perform an ERA in the NERC-defined[4] time horizons. Chapter 1 highlights general elements that are applicable to all time horizons. Chapters 2, 3, and 4 are more specific to the near-term, seasonal, and planning ERAs, respectively. To get the full picture of an ERA in a specific time horizon, the reader is encouraged to review Chapter 1 before reading the applicable chapter for the time horizon being assessed. Later chapters cover methods (Chapter 5), case development and scenario modeling (Chapter 6), and metrics (Chapter 7). The discussion of methods will help in the development and design of tools. The chapter on case development and scenario modeling discusses a recommended approach for base case and scenario development. Chapter 7 discusses existing metrics that can be used to compare the results of an ERA. Lastly, Chapter 8 enumerates remedies available when energy shortfalls are identified on corrective actions.

As factors that may play a role in promoting energy reliability differ significantly across North America, this document proposes an array of solutions that may apply to each particular system that could be considered under certain situations. Factors that are known to introduce this variety include the following:

- Generating capacity and density (e.g., how much and where) of wind and solar resources are a primary driver for the high degree of generation diversity among areas, including the performance characteristics for each (e.g., certain areas, such as the southwestern United States, are more likely to support highly productive solar resources than those in the north).
- Storage capabilities and capacities for fuels like oil, coal, natural gas, and fissile nuclear material differ across areas but also within areas depending on their geographic size. For instance, if an area has only limited reliance on stored fuels, it may be able to model energy reliability as a series of capacity assessments and rely on more general assumptions for impact of one hour to the next.
- Fuel replenishment delay times and diversity of supply and delivery options impact specific factors of an ERA. For example, anticipated long delays between arranging and receiving fuel deliveries could require longer ERA study periods to produce meaningful results.
- Available natural gas pipeline capacity, gas pipeline network topology and the diversity of the available gas supply to the pipeline network from production or storage areas can impact an ERA's input assumptions.

[1] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/CLEAN_ERATF_Vol_1_WhitePaper_17MAY2023.pdf
[2] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Fuel_Assurance_and_Fuel-Related_Reliability_Risk_Analysis_for_the_Bulk_Power_System.pdf
[3] https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC-CAISO_VG_Assessment_Final.pdf
[4] https://www.nerc.com/pa/Stand/Resources/Documents/Time_Horizons.pdf

These differences would factor into scenario selection. A high degree of diversity in supply and transportation options is likely to render single points of failure less extreme and more likely to be mitigated with fewer actions.

- Regulatory considerations differing from one area to the next may play a role not only in the options available for correcting energy deficiencies but could also change how input assumptions are accounted.

These are just some of the factors that make ERAs non-universal; however, the general concepts can be consistently applied across different systems.

The appropriate actions resulting from deficiencies identified by ERAs may also differ based on the points discussed above. Longer lead times may be required to address potential energy deficiencies than capacity deficiencies. For example, shifting the way planners consider storage in analyses would be a required consideration for an energy assessment even if this may be one of the actions that should not be considered for capacity. Storage optimization over periods of time becomes part of the solution as VER output fluctuates throughout a day, a week, or longer.

Chapter 1: Inputs to Consider When Performing an ERA in Any Time Horizon

The information needed to perform an ERA is like what is required for capacity assessments but with the additional component of time. The time component of an ERA accounts for the impact of operating conditions and actions that occur at one point in time and their impact on future intervals.

Volume 1 discussed the differences between capacity and energy assessments. Capacity assessments are performed today in nearly every time horizon, from operations to long-term planning. Connecting the hours and transforming operations at one point into future availability is what expands a capacity analysis into an energy analysis.

Supply

Supply resources can be categorized into generation, electric storage,[5] and load-modifying resources[6]. They can be modeled as either supply additions or demand reductions as decided by the analyst. Accurately modeling the energy availability of generation resources requires an understanding and representation of the underlying fuel supply and the generator system.

Fuel supply will be categorized in this document as either stored fuels or just-in-time fuels. Tangible inventory and replenishment strategies should be considered for stored fuels. Just-in-time fuels require considerations for transportation capacity, fuel deliverability, and the immediate impact of disruptions. Furthermore, just-in-time fuels include weather-dependent fuel sources such as solar irradiance and wind, that introduce significant volatility for which an analyst should account.

Power generation is not the only sector that consumes fuel. Fuels like oil and natural gas are directly used in other applications. For example, the U.S. Census Bureau's *American Community Survey*[7] includes information on the types of fuel used to heat homes broken down by individual U.S. states. This information is one of many inputs that would guide an analyst in building future profiles of fuel demand for input into an ERA. Competing fuel demands should be considered when looking holistically at an interconnected and interdependent energy system.

A more detailed introduction to fuel assurance that is specific to a variety of fuel types is provided in *Reliability Guideline: Fuel Assurance and Fuel-Related Reliability Risk Analysis for the Bulk Power System*.[8]

Stored Fuels

Power generators with stored fuels are those where fuel inventory is on site or reasonably close to the generator so that fuel transportation risks are minimal. Fuels are most commonly stored in tanks, reservoirs or piles and have a measurable inventory. Examples include, but are not limited to, nuclear fissile material, fuel oil, coal, water for hydro facilities, and natural gas as liquefied natural gas (LNG) or in subsurface geological formations.

Once inventory information is gathered and/or estimated, it must then be converted into electric energy based on the specific generator that uses the fuel. For thermal generators, that calculation requires two additional pieces of information: fuel heat content and generator heat rate. Generator heat rate is typically expressed in terms of Btu/kWh or MMBtu/MWh. Heat rates range from less than 6,000 Btu/kWh (6 MMBtu/MWh) to over 20,000 Btu/kWh

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[5] For the purpose of the discussions in this technical reference document, *electric storage* is a device or facility with electric power as an input, a storage medium of some kind that stores that energy, and electric power as an output. This contrasts with stored fuel in that the source of stored fuel is external to the power system. Both electric storage and stored fuel can be labeled *energy storage*.

[6] Load-modifying resources are (behind-the-meter) generators that modify demand rather than provide additional supply.

[7] https://data.census.gov/table/ACSDT1Y2019.B25040?q=heat

[8] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Fuel_Assurance_and_Fuel-Related_Reliability_Risk_Analysis_for_the_Bulk_Power_System.pdf

(20 MMBtu/MWh) and can vary across the operating range of a resource, with considerations for efficiency at various output levels. Oil heat content varies slightly by the type of oil and how it was refined and ranges between 135,000 Btu/gallon to 156,000 Btu/gallon. Figure 1.1 walks through a conversion from gallons of oil to MWh of electric energy and the amount of time that a generator would continue to operate at a specific power output. A similar calculation could be completed for other types of stored fuels using the respective fuel-specific heat contents and generator heat rates.

Calculate the energy production capability (MWh total and hours at maximum output) of a 135 MW oil generator with a heat rate of 9,700 Btu/kWh and 1,000,000 gallons of fuel oil with a heat content of 135,000 Btu/gallon.

$$1{,}000{,}000\ gallons * \frac{135{,}000\ Btu}{gallon} * \frac{kWh}{9{,}700\ Btu} * \frac{MWh}{1{,}000\ kWh} = 13{,}918\ MWh$$

$$\frac{13{,}918\ MWh}{135\ MW} = 103\ hours, at\ maximum\ output$$

In an ERA, once this specific generator produces 13,918 MWh of energy, it must be set as unavailable for all remaining hours or fuel replenishment must occur.

Figure 1.1: Converting Stored Fuel to Available Electric Energy

Multiple generators at a single site often share a fuel inventory, meaning that more than one generator could deplete fuel during operations. This is further complicated when different generator technologies with different efficiencies are operating on the same fuel and by the fact that efficiencies of a given unit may vary based on its operating point. For this reason, discrete modeling of generators and their individual demands on the common fuel supplies at sites provides for a more accurate solution than a generalized approach.

Stored fuel replenishment is a key consideration in an ERA that is impacted by a number of factors. Proximity to additional storage affects assumptions for replenishment, as power generator stations that are adjacent to larger storage facilities have fewer obstacles to replenishment than generators far from supply sources or in residential areas. Transportation mechanisms also affect the ability to replenish stored fuels. Generators are typically replenished by pipeline, truck, barge, or train, each of which has its own set of advantages and/or disadvantages. The experts on each generator fuel supply arrangement are the owner/operator of the generator and their fuel suppliers. Performing an ERA requires communication with the Generator Owners and Operators to ensure that the modeling for fuel supplies is accurate. Once the analyst becomes familiar with the information needed from the Generator Owner/Operators, the specific fuel information can be obtained and properly accounted for through routine surveys.

Table 1.1 is useful for modeling stored fuels in an ERA for any time horizon:

Table 1.1: Information Useful for Modeling Stored Fuels in an ERA in Any Time Horizon		
Data	**Potential Sources**	**Notes/Additional Considerations**
Specific, usable[9] inventory of each generation station	Generator surveys Assumptions based on historical performance	Inventory is often shared for a group of generators located at a single station. Surveys should be performed as often as necessary to initialize an assessment with accurate information. It is recommended to start each iteration of an assessment with updated data. Hydroelectric resources may need to consider the availability of water as a fuel input – change over the course of the year or vary by year. Environmental limitations: water flows/rights priority, dissolved oxygen (DO) limitations, etc. Stored fuels may be used for unit start-up with a portion embargoed for blackstart service provision.
Minimum consumption requirements of fuels that have shelf-life limitations	Surveys of Generator Owners or Operators Assumptions based on historical performance	May result in a fuel being consumed at a time when it is less than optimal.
Replenishment assumptions	Generator surveys Assumptions based on historical performance	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA.
Shared resources	Generator surveys or registration data	Modeling the sharing of fuel between multiple resources allows for precise modeling of fuel availability.
Global shipping constraints	Industry news reports	Stored fuel supply is often impacted by world events that cause supply chain disruptions, including port congestion, international conflict, shipping embargoes, and confiscation.
Localized shipping constraints	Weather forecasts or assumptions, direct communication with local transportation providers, emergency declarations[10]	Considerations for local trailer transportation of fuels over wet/snow-covered roads, rail route disruptions due to weather or debris, as well as seaport weather when docking ships or river transportation route restrictions for barge movements.

[9] Usable inventory is the amount of fuel that is held in inventory after subtracting minimum tank levels that are required for quality control and fuel transfer equipment limitations.
[10] https://www.fmcsa.dot.gov/emergency-declarations

Specific Considerations by Generator Type

Fuel Oil Generators

Fuel oil for generators, diesel fuel for transportation, and home heating oil all share supply chain logistics. Though there are subtle differences between each type, they are nearly identical at the supply side. As such, stresses on supply from one mechanism can lead to deficiencies in supply to a seemingly unrelated mechanism. A likely scenario is that cold weather that increases demand on home heating oil creates a need for an accelerated replenishment to residential and commercial heating oil tanks, resulting in reduced availability of replenishment stocks for power generation. In an ERA, this should be considered as a limitation on the inventory available for replenishment when conditions are cold, and oil heating is prevalent in the area.

Fuel oil delivered by truck can face a number of obstacles. For example, truck drivers are legally allowed to drive only a set number of hours,[11] and trucking can be susceptible to delays caused by snow and debris. Both scenarios may cause delays in fuel delivery to generators that should be considered. However, waivers to some rules during specific conditions have been granted by state and federal agencies during emergencies.[12]

Delivery by ship or barge may be available to resources with access to waterways, typically allowing larger cargoes than truck delivery. Oil trucks can typically transport 5,000–12,000 gallons of fuel per truck. River barges have capacities ranging between 800,000 gallons and nearly 4 million gallons. The largest oil tankers can transport over 50 million gallons of fuel.[13] Challenges in delivering by water include rough seas and waterway freezing.

Fuel replenishment in an ERA can be modeled as a multiplier or an adder to initial fuel supply expectations from the start or can be more precisely modeled at an hourly granularity. The simpler calculation ignores the specific constraints surrounding replenishment and assumes that the total amount of fuel will be available when it is needed. The following simple example sets the initial tank level equal to the actual (or assumed) starting inventory plus all replenishments throughout the study period. For example, if a 1-million-gallon tank starts with 500,000 gallons and is expected to replenish that quantity twice, start with 1.5 million gallons and ignore the constraint of the tank size and deplete the oil inventory from the new starting point. A more complex refinement of this approach would account for replenishment strategies, time constraints from the decision to replenish to the time of delivery, rate of refill, individual delivery amount, and transportation mechanisms. More effort is required to apply the specific constraints of a fuel oil tank and the associated replenishment infrastructure. While modeling more granular replenishment will be more precise, it may not result in significant improvements in accuracy depending on the time horizon of the study. Both methods can be employed in the same study. Analysts should consider the appropriate levels of constraints on the replenishment capabilities of various oil tanks depending on the attributes of the system under consideration.

Dual-Fuel Generators

Dual-fuel generators can lessen the risk of outages caused by a lack of a specific fuel supply but require additional information to perform ERAs and develop appropriate Operating Plans. Consideration should be given to formulating operational models that include the decisions that lead to the use of each fuel, the time required to swap fuels, limitations of the generator during a fuel swap, and output reductions or environmental restrictions while operating on the alternate fuel. Some generators can operate on multiple fuels simultaneously, and some can swap fuels while continuing to operate, perhaps at a lower output for a controlled swap. Other generators are required to shut down before swapping fuel. Since each generator is different, the specific processes should be understood when developing an ERA.

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[11] https://www.ecfr.gov/current/title-49/subtitle-B/chapter-III/subchapter-B/part-395/subpart-A/section-395.3

[12] https://www.fmcsa.dot.gov/emergency-declarations

[13] https://response.restoration.noaa.gov/about/media/how-much-oil-ship.html#:~:text=Inland%20tank%20barge%20(200%E2%80%93300,7%20million%E2%80%9314%20million%20gallons

Dual-fuel capability auditing and reporting is the most comprehensive method of obtaining fuel switching information. However, surveys can provide similar information if auditing cannot be accomplished, and the survey information is dependable or vetted for accuracy. Generator Owner/Operators are the experts in the logistics of fuel swapping and should be consulted when performing an ERA.

Coal Generators

Coal storage capacity is usually larger than fuel oil storage capacity but comes with its own unique challenges. When stored outdoors and exposed to the elements, causing frozen or wet coal, coal's outage mechanisms can differ from other generator types. Given the relatively large storage volumes and replenishment options associated with coal-fired generators, an analyst performing an ERA may assume that the fuel supply is unlimited, simplifying the overall process. However, care should be taken to ensure that this assumption is prudent and will not result in unexpected conditions when the fuel supply is depleted or unable to be replenished.

Nuclear Generators

Nuclear fuel (e.g., uranium or plutonium) is stored in a reactor. Nuclear replenishment is a well-planned process that is scheduled months or years in advance. Depletion of nuclear fuel is measured in effective full power hours (EFPH), where a given supply of fuel is depleted based on the percent of full power at which the plant is operated over time. Refueling typically requires the reactor to shut down and be opened to replace fuel assemblies. Although advancements in reactor technologies that could change how a nuclear generator would be modeled in an ERA are regularly proposed, most of the operating plants in North America remain generally the same. The key points for modeling nuclear power in an ERA focus on long durations of operation and outages and typically a considerable amount of energy produced in comparison to generators with similar footprints.

Hydroelectric Generators

Pondage water available for hydroelectric generation is a function of past precipitation. Considerations should be made for environmental requirements for minimum and maximum flows at specific times, which would impact the quantity of water that is available for power generation throughout an ERA. Forecasting hydroelectric availability and demand is among the first parameters for power system operations and planning, and significant experience has been gathered over the last century.

Just-in-Time Fuels

Various types of natural gas, run-of-river hydro, solar, and wind generators rely on just-in-time fuels, which are consumed immediately upon delivery. Each generator type has its own specific considerations for fuel constraints that should be well understood while building an energy model and performing an ERA. Just-in-time fuels are delivered immediately prior to, or within moments of, conversion to electric energy, either by combustion in a gas turbine or boiler, conversion through photovoltaics, or directly applying force to spin a wind turbine for generation.

Natural Gas

Natural gas-fired generators rely on the delivery of fuel at the time of combustion in a turbine or boiler. Natural gas is a compressible fluid, primarily transported by pipelines. Gas pipeline operators can typically operate their pipelines with a range of operating pressure, which provides some level of flexibility by, in effect, storing natural gas in the very pipelines that are used for transportation. This flexibility allows for some intraday mismatches between natural gas supply and natural gas demand, so long as mismatches do not preclude operating within specifications. The minimum pressure needed for generator operation is typically lower than the main pipeline pressure, and regulator(s) are used to maintain proper inlet pressure to the generator. For generators that require pressure that is higher than pipeline pressure, on-site compression is typically included in the site design.

For natural gas delivery to be scheduled to a generator, there are two required components. The first major component is procurement of the physical gas, the commodity. The commodity can be procured through natural gas marketplaces, directly from producers through bilateral arrangements, or via marketers holding bulk quantities. Shippers may elect to schedule natural gas from storage locations. Natural gas volumes typically would be scheduled in advance according to the specific pipeline rules and requirements (usually gas-day ahead) to allow pipelines to assess their ability to supply the nomination.

Secondly, there must be transportation arranged for the gas to ensure delivery to the desired location. Gas transportation can be firm or non-firm. Firm transportation usually must be acquired well in advance of the anticipated need, usually months or seasons, and most often years in advance, but can be released for others to use when it is not needed by the primary firm transportation holder. In addition to firm transportation, there are other varying degrees of firmness. Interruptible contracts may also be available, and the pipelines decide when to allow each level of transportation firmness to flow based on conditions and demands on the pipeline. Also, there can be periods where even firm transportation can be curtailed based on pipeline conditions. Understanding each generator's specific situation and gas contract requirements is crucial for performing an ERA. Pipeline flexibility to accommodate unscheduled receipts and deliveries is at the discretion of the pipeline operators and should be accounted for in an ERA. Communication and coordination with pipeline operators, as well as historic observations, can give the analyst the information necessary to model the expected flexibility.

Natural gas pipelines that deliver to power generators usually serve multiple generators as well as other types of demand. Competing demand must be accounted for in an ERA in order to produce an accurate solution. Depending on the contractual arrangements that have been made by different natural gas customers, demand will be served in a specific order. Higher levels of firm transportation arrangements provide more certainty and come with higher fixed costs. It is important to understand the individual arrangements for commodity and transportation for each generator when modeling the amount of natural gas that would be available for power generation. It is also imperative that an analyst understand transportation constraints and non-power-generation demands when calculating the remaining quantity of gas available for power generation. Operating generators when there is no fuel available produces an infeasible solution.

Natural gas is scheduled daily (i.e., the gas day). The gas day is defined by the North American Energy Standards Board (NAESB)[14] as 9 a.m. to 9 a.m. (Central Clock Time). Quantities of gas are scheduled in terms of MMBtu per day, fitting the construct of the 24-hour gas day. Electric energy is scheduled on a more granular basis (usually hourly) that relies on a daily allotment of fuel to be profiled over that 24-hour period. An ERA should consider the limitations that could be created by this misalignment between the gas and electric day and the magnitude of hourly gas flow imbalances that are allowed by the individual pipelines serving the generators in the study area.

Depending on the constraints that are in place on the gas pipeline network for a given area, the model can be simple or it can be more granular, as determined by the analyst. In a system where the gas demand is distributed similarly to the gas supply capabilities, a homogeneous gas model can be used. Homogeneous models consider a single energy balance of gas supply and gas demand. Homogeneous models require less effort to model and likely will solve faster but could miss potential constraints if not evaluated properly.

Additional information concerning the natural gas supply chain is provided in Chapter 2 of *NERC Reliability Guideline: Fuel Assurance and Fuel-Related Reliability Risk Analysis for the Bulk Power System*.

In its simplest form, the gas supply/demand balance equation is similar to the electric supply/demand equation.

$$Gas\ Supply = Gas\ Demand$$

More complex calculations can help an analyst determine the availability of natural gas for generation.

[14] https://www.naesb.org//pdf/idaywk3.pdf

$$Gas\ Supply = Gas\ Demand_{Heat} + Gas\ Demand\ _{Industrial} + Gas\ Demand\ _{Generation}$$

For this example, assuming that natural gas demand for heat and industry has a higher priority level for their gas transportation service (e.g., primary firm) than generation, the equation can be rearranged to solve for gas available for generation, a proxy for gas demand for generation.

$$Gas\ Available\ _{Generation} = Gas\ Supply - Gas\ Demand_{Heat} - Gas\ Demand\ _{Industrial}$$

Typically, natural gas supply would be a fixed daily quantity, based on the transportation of the pipeline network. In a more complex system, it would also be a function of production assumptions. In the most complex form, the gas pipeline network may require nodal modeling, similar to the electric system, in order to solve for specific conditions, operations, or disruptions, but that level of complexity would come with a steeper computational price.

Natural gas demand for heating is a function of weather, usually temperature and wind speed, and will differ for every geographic area. A simple form of modeling natural gas demand for heating could use a linear function of average temperature, or heating degree days.[15] On the other end of the spectrum, complex gas heating demand modeling could employ artificial neural network forecasting methods with inputs like temperature, wind speed, day of week, time of year, and any other pertinent inputs that would drive gas demand. A simple example of calculating natural gas available for power generation is shown in the following example.

In the following example, assume that a given natural gas pipeline system can transport 1,000,000 MMBtu/day and has adequate supply injections at that level with no additional supply sources in the area. Also, assume a fixed quantity of industrial demand of 100,000 MMBtu/day and that heating demand is a linear function of heating degree days defined by the points 0 MMBtu/day at 0 HDD and 600,000 MMBtu/day at 75 HDD.

Calculate the quantity of natural gas that would be available for power generation at 40 heating degree days under these assumptions.

$$Gas\ Available\ _{Generation} = Gas\ Supply - Gas\ Demand_{Heat} - Gas\ Demand\ _{Industrial}$$

$$Gas\ Available\ _{Generation} = 1{,}000{,}000\ \frac{MMBtu}{day} - \left(600{,}000 * \frac{40\ HDD}{75\ HDD}\right)\frac{MMBtu}{day} - 100{,}000\ \frac{MMBtu}{day}$$

$$Gas\ Available\ _{Generation} = (1{,}000{,}000\ - 320{,}000 - 100{,}000)\ \frac{MMBtu}{day}$$

$$Gas\ Available\ _{Generation} = 580{,}000\ \frac{MMBtu}{day}$$

Given that 580,000 MMBtu/day is available for power generation, calculate the MWh that would be available using an average heat rate of 8,000 Btu/kWh.

$$Generation\ (MWh) = Gas\ Available/\ Heat\ Rate\ (MMBtu/MWh)$$

$$Generation\ (MWh) = \frac{580{,}000\ MMBtu}{8.0\ MMBtu/MWh} = 72{,}500\ MWh$$

Convert 72,500 MWh to hourly MW, evenly distributed across all hours

$$\frac{72{,}500\ MWh}{24\ hours} = 3{,}020\ MW$$

[15] https://forecast.weather.gov/glossary.php?word=heating%20degree%20day

Figure 1.2 shows how the amount of available natural gas will vary based on this specific model of non-power demand and remaining availability.

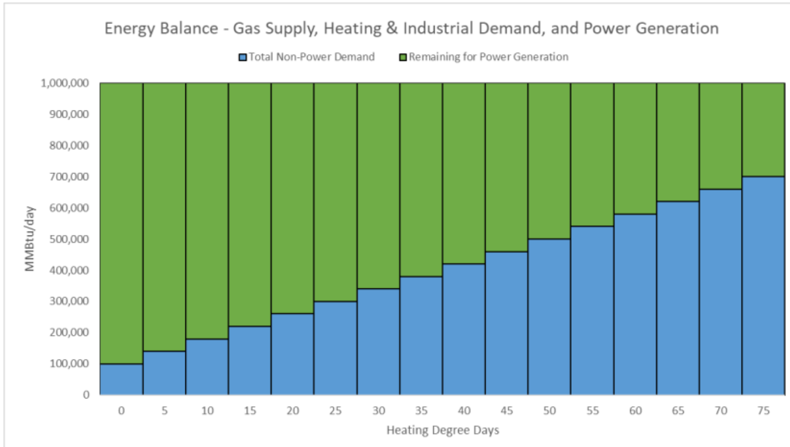

Figure 1.2: Natural Gas Availability

While a single event or set of conditions may cause disruptions on a pipeline that could impact several delivery points, internal line pack storage capacity of pipelines could reduce the downstream effects of interruptions are not necessarily immediate as pipeline operators work to control the changes in operating pressure. Studies[16] have shown that there may be significant time between pipeline disruptions and resulting generator outages. ERAs can account for disruptions by staggering outages according to the expected rate of pressure drop and/or operator decisions to operate valves and shut-in gas customers (specifically generators). In the first few hours of a disruption, studies focus on the replacement of natural gas generation by the remaining fleet that is unaffected by the disruption. This includes start-up times and ramping capability of generators from off-line to high utilization. After the first few hours, once generation is replaced, ERAs should focus on the long-term (i.e., several hours to several days) effects of major disruptions and the impact that will have on the generation fleet that would otherwise be unused. ERAs would generally be focused on the longer-term effects of disruptions rather than the initial events themselves.

Basic mapping of generators to pipelines is key to assessing the impact of disruptions. This information can be gathered from pipeline maps, generator surveys, contract information and registration data. Research is required to place the generators on pipelines in the correct location in reference to injection and receipt points, compressor stations, and other pipeline demand. An ERA can then use this information for scenario development and analysis. There are instances in which a generator's proximity to a pipeline is irrelevant to the pipeline from which it has actually contracted the gas. In these cases, mapping based on contractual counterparties would be more precise.

Table 1.2 useful for modeling natural gas supply in an ERA for any time horizon:

Table 1.2: Information Useful for Modeling Natural Gas Supply in an ERA in Any Time Horizon

Data	Potential Sources	Notes/Additional Considerations
Pipeline transportation capacity	Pipeline Electronic Bulletin Boards (EBB), open season postings, firm transportation contracts	Interstate pipeline information is readily available through public sources, usually directly from the pipeline company itself.

[16] https://www.nerc.com/pa/RAPA/Lists/RAPA/Attachments/310/2018_NERC_Technical_Workshop_Presentations.pdf

Table 1.2: Information Useful for Modeling Natural Gas Supply in an ERA in Any Time Horizon		
Data	**Potential Sources**	**Notes/Additional Considerations**
Gas pipeline constraints	EBB postings of operationally available capacity and planned service outages, pipeline maps	Starting with pipeline maps or one-line diagrams, pinpointing the location of specific constraint points requires research. Communication with pipeline operators is helpful when specific locations are in question or difficult to find.
Generator location on pipelines	Pipeline maps, generator surveys, registration data	Research is required to properly place generators on pipelines in the correct location.
Non-generation demand estimates	Historical scheduled gas to city gates and end users, historic weather data, weather assumptions based on historic weather and climatology	Similar to load forecasting on the electric system, gas estimates play a crucial role in developing a holistic energy solution. Assuming that more gas is available than physically possible could lead to inaccurate study results.
Heating and end-user demand assumptions	Filings with state regulators, historical demand data	Regulated utilities will file their expected needs for natural gas with their respective state regulators.
Contractual arrangements	EBB index of customers, generator surveys, FERC Form 549B	Some information can be obtained via the EBB Index of Customers; however, nuanced data would need to be queried directly from generators. Non-public information includes generator arrangements with gas marketers and participation in capacity release agreements.
Generator heat rates	Registration data, generator surveys	Converting electric energy to fuel consumption and vice versa requires the heat rate of a generator, typically expressed in Btu/kWh or MMBtu/MWh.

Variable Energy Resources

Run-of-river hydro, solar, and wind resources generate electricity when the fuel is available and conditions permit. The amount of energy produced by these resources at any given time is uncertain, and operators cannot require that the generators produce more power when conditions do not allow for it. Forecasts are available for expected variable generation outputs and have improved over time; however, longer-range (from seasonal to several years out) ERAs must make assumptions for inputs that would be difficult to predict. Historical data is a good starting point for developing assumptions; this can be further augmented by known or anticipated conditions, such as drought, and adjusted for additional buildout since the historical conditions were recorded. The resulting input to an ERA is an hourly profile or set of profiles that portrays VER output. For areas where VERs make up a small percentage of the total nameplate of generation, resources may not need to be as specific when building energy models. The model could assume a fixed output over the course of the study period based on historical performance (e.g., capacity factor) and nameplate capability. A simple model is easier to build, maintain, and understand but may fall short when attempting to reveal deficiencies once the resources become a larger producer of electric power for the area.

Energy Supply Variability

Energy supply variability means that ramping capability is needed. Just-in-time fuels or input energy are subject to large- and small-scale energy supply interruptions (in this context, including clouds over solar panels, calm winds, and gas network outages). Variability of one fuel supply stresses other fuel supplies or requires drawdown of storage when replacement energy is sought. The rate of increase or decrease of the production from a resource with a variable fuel supply (e.g., wind or solar) has the potential to overwhelm the infrastructure and capabilities of the replacement generators. An ERA should consider the ability of balancing resources to replace fast-moving variable resources when production wanes and the ability to back down when production returns. Both increases and decreases in generation or demand pose risks.

Figure 1.3 and **Figure 1.4** show an example of actual solar and wind production, respectively, for seven consecutive days in March 2023. As shown, the hourly production of solar or wind can change by thousands of MW for the same hour between consecutive days. To account for the uncertainty associated with VER production, analysts may have to use probabilistic analysis in a near-term ERA to best evaluate the energy reliability risk. Probabilistic methods can allow the assessment to ensure that the flexible capacity is available across a range of scenarios and combine the results to evaluate the risk. Alternatively, to use deterministic methods, specific variable energy production scenarios should be chosen as a design basis that stresses the system to determine if sufficient energy is available in the time horizon being studied. The ability to produce variable production curves based on weather forecasts, forecast errors, and resource characteristics—or, at least, historical production data—is necessary to support near-term ERAs.

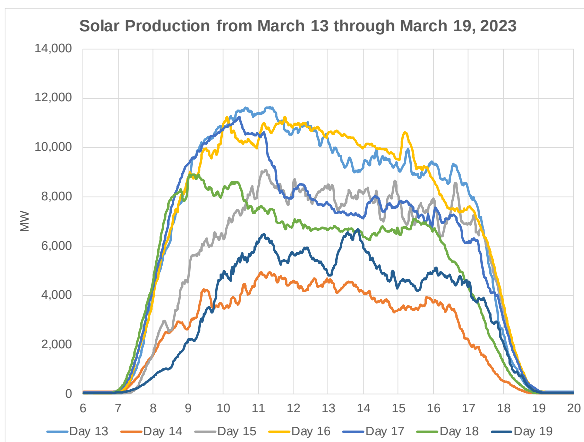

Figure 1.3: Actual Solar Production for Seven Consecutive Days

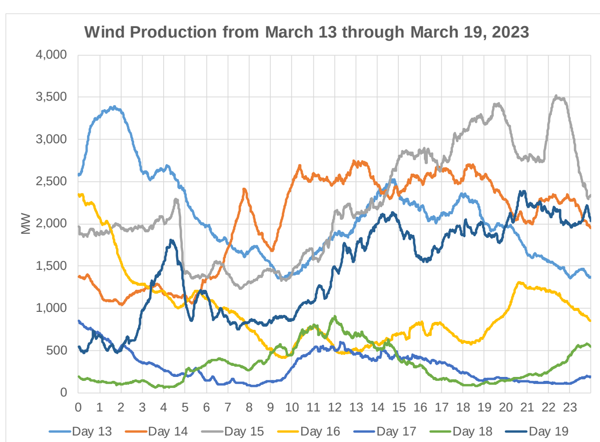

Figure 1.4: Actual Wind Production for Seven Consecutive Days

Evaluating that capability requires knowledge of fuel supply constraints and specific generator capabilities. For example, when solar production has peaked on a system with significant solar power, the evaluation would start by modeling the ramping capability of the resources that are replacing that power. Once the physical capabilities of replacement resources are known, the next layer to consider is the upstream infrastructure that is necessary to support their operation. For example, when replacing solar power as part of the daily cycle of operations, natural-gas-fired generation could ramp up to replace the solar power. Consideration should be made to determine if the natural gas pipeline system has the capability to maintain established gas system tolerances while ramping generation up. Assumptions would need to be made for the initial pipeline pressure, and the analyst will need to know the minimum and maximum allowable operating pressures. Pipeline operators maintain pipeline pressure by limiting the rate at which the demand is allowed to fluctuate and modulating operations of compressor stations along the pipeline. These constraints may limit the flexibility of natural gas resources beyond what is expected without factoring in gas pipeline operational practices. If fuel systems are unable to keep up with ramping generation, ramping generation should be discounted accordingly in an ERA. This type of assessment can get complicated quickly and should be coordinated with natural gas pipeline operators to ensure that accurate information is used.

On the other side of the spectrum is when VERs begin to ramp their production from low to high. This situation is likely not as dire, as conventional resources can generally ramp their output down faster than ramping up, and some variable resources can be curtailed if a system reliability risk emerges. However, the considerations for pipeline pressures and energy storage still apply, just on the opposite side of the spectrum. Using solar power ramping as the example again: when solar production starts to ramp up while demand increases at a lower rate, in the morning, solar over-generation results in a need to back down other supply resources. However, generation problems can arise if gas pipeline pressures are already high and storage is full, resulting in pipeline constraints caused by unused fuel in the pipe. Coordinated operation of the gas and electric systems should provide for multiple mechanisms to ensure that this can be minimized or avoided altogether. Electric System Operators would need to ensure that there is room to charge/pump the storage resources as necessary through the periods of ramping, and an ERA would provide the information necessary to set those plans.

Table 1.3 contains information useful for modeling energy supply variability in an ERA for any time horizon:

Table 1.3: Information Useful for Modeling Energy Supply Variability in an ERA in Any Time Horizon

Data	Potential Sources	Notes/Additional Considerations
VER assumptions	VER forecasts as described in the VER sections of this document	VER production drives the need for flexible generation to be available or online. Additionally, the ability to curtail VER production should be considered as a mitigating option.
Generation ramping capability	Registration data, market offers	Balancing resources would be used to maintain system frequency from moment to moment.
Fuel supply dynamic capabilities	Fuel supply network models, market-based models to determine volumes delivered to specific sectors or historic observations	The key to including ramping capability in an ERA is focusing on the capabilities of the fuel delivery network (e.g., gas pipelines, fuel oil or coal delivery systems at specific generators) and how that network responds to the ramping needs of the system.

Emissions Constraints on Generator Operation

Emissions from all industries, including power generation, are being increasingly restricted, limiting generator capability or operating durations and windows. Emissions limitations are more nuanced than inventory limitations; one additional complexity is that waivers can be granted under emergency declarations, meaning that the limits are not necessarily fixed and require evaluation before becoming binding. Emission limitations may potentially be shared across several generating stations. Results of ERAs can be used to show a need for emissions waivers. Emissions information should be available from Generator Owner/Operators and should be included in routine surveys. Analysts will need to be able to apply an emissions limitation to the operation of a generator or generating station. The information obtained must be in a format that is usable by the analysts performing the ERA (e.g., MWh remaining until emissions constrained rather than tons of CO_2 remaining without a conversion from emissions to electric energy remaining). Emissions limitations will differ by jurisdiction (e.g., state or province), can be on a variety of time scales (e.g., annual, seasonal, or rolling 12-month limits), and can be shared by portfolio within a specific state. They can also have multiple components (e.g., NOx, SOx, and CO_2), all of which should be evaluated, but only the most limiting would likely be modeled in an ERA. Again, relevant information would be provided by the resource owners/operators and, while the analyst performing the ERA should be familiar with the concepts of emissions limitations, they will likely not be the expert who would derive the associated limits. Generators may be further constrained by the lack of availability of emissions credits or offsets during extreme conditions.

Other potential constraints that may impact generation from an environmental point of view, specifically entities with hydro resources, include limitations like required minimum water flows and downstream dissolved oxygen levels. Such regulations could impact desired operation related to scheduling energy from hydro or pumped storage facilities located on non-isolated reservoirs and should be considered for modeling in an ERA.

Table 1.4 is useful for modeling emissions constraints on generator operation in an ERA for any time horizon:

Table 1.4: Information Useful for Modeling Emissions Constraints on Generator Operation in an ERA in Any Time Horizon

Data	Potential Sources	Notes/Additional Considerations
Output limitations for a set of generators	Generator surveys	Each Generator Owner/Operator may know their own operational information, but when determining when a collection of generators will reach a limit would require gathering information that each owner/operator has but not as a collective. The analyst performing the ERA would be the centralized collection point of the information required to accurately model the limit.

Outage Modeling

A common method for modeling generator outages in an ERA is to multiply the generator's maximum output by a function of outage rate (e.g., 1 - EFORd) and assign that as the new maximum output for the duration of the study period. Applying this method consistently to the entire fleet of generators results in a set of input assumptions that is agnostic of how outages occur but accounts for outages in a fairly accurate manner. However, this method will only show the average outage impact from all units, not the risks posed by concurrent outages, especially if there is any degree of correlation in outage patterns.

Alternately, dynamic outage modeling methods assign a probability of occurrence, impact, and duration to each failure mechanism of a specific outage of a specific generator and run a probabilistic analysis, or outage draw. The probability of occurrence would be compared to a random number generator in the software and implement the outage with the associated impact and duration from that point in the study period. This method is much more complex to model than the simpler methods and requires that each type of failure be evaluated for the correct parameters but is more closely aligned with actual conditions. It should be noted, however, that even probabilistic approaches to outage modeling can exhibit significant variability, both in implementation and subsequent accuracy. Understanding the nuances present in probabilistic outage modeling is important for any resource adequacy assessment but especially so for an ERA.[17]

Information on generator outages is available through historical data analysis, specifically operator logs, operational data, or the NERC Generation Availability Data System (GADS).[18]

An ERA should take into consideration the impacts of previous hours on the next hour. For this reason, methods that consider temporal impacts—such as two-state Markov modeling or state transition matrices—are beneficial. In addition to considering mechanical failure of equipment, it is also beneficial to consider a wide range of failure causes, such as fuel availability or ambient air and water temperature.
In reality, Forced Outages are a more complex phenomenon than typical modeling techniques have been able to predict. Model fidelity can be improved by gathering data and incorporating the following:

- Foresight on failures (e.g., start-up failures have limited foresight and therefore may require faster response times from other resources)
- Uncommon causes (e.g., battery cell balancing)
- Time-varying forced-outage rates (e.g., seasonality, hourly variation)
- Common cause failures

Most reliability assessments consider generator outages as independent events, where each generator is modeled separately with its own forced-outage rate that applies for the entire study horizon.

Table 1.5 is useful for modeling energy supply outages in an ERA for any time horizon:

Table 1.5: Information Useful for Modeling Energy Supply Outages in an ERA in Any Time Horizon

Data	Potential Sources	Notes/Additional Considerations
Forced-outage rates	NERC GADS, assumptions based on historical performance	NERC requires outages and reductions to be reported with associated cause codes and makes that information available to registered entities. Alternatively, analysts can observe historical unplanned outage information to determine similar assumptions.

Distributed Energy Resources

Distributed energy resources (DER) are primarily made up of the same types of resources discussed in prior sections (e.g., VERs) but have different considerations associated with their distributed nature:

- DERs generally use just-in-time fuels, are variable in nature, and do not respond to dispatch instructions; however, some DER installations are being installed with integrated storage systems that serve to distribute production more evenly, resulting in a behavior that is less like a just-in-time resource.

[17] https://www.epri.com/research/products/000000003002027832
[18] https://www.nerc.com/pa/RAPA/gads/Pages/GeneratingAvailabilityDataSystem-(GADS).aspx

- DERs are usually installed on lower-voltage systems (i.e., distribution-level systems) that are not modeled by Transmission Operators and can be subject to unknown constraints.
- DERs can be subject to unanticipated operation in response to faults on the transmission or distribution systems.[19]
- Modeling DERs in an ERA can be done on either the supply side of the energy balance equation or on the demand side, to be determined by the analyst and the defined process.

Market-Based Resources and Market Conditions

Market-based resources are those that are registered with an Independent System Operator/Regional Transmission Organization (ISO/RTO), generate revenue for their owner by participating in the area's organized market, and are typically governed by an agreement between the resource owner and the ISO/RTO. The development of an ERA should consider these market rules and understand how market participants will behave in certain situations. These resources are expected to perform in the market (e.g., no economic withholding) but occasionally must make decisions that would impact their availability.

For example, a generator's revenue and dispatch expectations under market conditions may change how a generator is positioned for dispatch, such as increasing its notification-to-start time to avoid staffing its facilities 24/7. Another example would be if a given area's agreements have severe penalties or reduced revenue for generators that are not running during a constraint period. To avoid incurring penalties, non-variable generators may take proactive actions to self-schedule on these days with the intention of mitigating potential operational issues if given enough notice of these availability conditions.

Contracts, both out-of-market and non-power, held by generating units that impose take-or-pay or force majeure penalties may also impact entities. These contracts typically impact co-generation facilities and those that provide power, steam, and/or other services to adjacent facilities, such as refineries and heavy industry, and may reduce the available output and operational responsiveness of impacted units.

Demand

Demand is significantly more complex today than it ever has been. Today's demand is composed of actual demand adjusted by varying types of demand response (including the impact of time-of-use rates) and distributed generation that is considered load-reducing.

Actual demand (i.e., gross demand) can be thought of as loads that are drawing power from the interconnected electric systems. Lighting, environmental controls like heating and air conditioning, household and commercial electronics, and industrial loads all comprise the actual demand on the system. These concepts have been consistent since the power grid was first developed. The specifics may change over time, with energy efficiency and changes to lifestyles, but the concepts remain the same.

The behavior of demand is becoming more difficult to predict due to factors, such as energy efficiency, demand response, and price-responsive loads, which can significantly vary the shape of typical hourly demand. The expansion of electrification (e.g., electric vehicles and heating) within a specific footprint requires the analyst to make assumptions of the electric vehicle charging patterns and other changes to load profile due to electrification of heating or industry. Like air-conditioning units and heating sources, electric vehicle charging assumptions would differ by season, but would be different from assumptions made for those other end-uses leading to changes in techniques for predicting demand.

[19] https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/Distributed_Energy_Resources_Report.pdf

Demand itself is more versatile than it once was. Demand-response programs have been designed to preempt the buildout of additional, or the retention of existing, generation capacity resources by lowering demand during peak hours. Impact on energy will depend on how each program is implemented. For example, interrupting air-conditioning systems for a few hours on peak days may reduce Peak Demand but may not change the total energy demand on the system. Loss of load diversity without a longer-duration change to temperature setpoints may eventually require a similar energy demand to restore temperatures after the peak is shaved. When restored, systems will run longer and more consistently, drawing nearly the same amount of energy as if no demand response was initiated. Voltage reductions may also fall into the same type of construct, depending largely on the makeup of demand in a specific area. These concepts will factor into the decisions that are made to manage energy when situations arise that require actions.

Finally, in some applications, DERs are considered in the demand side of an energy balance equation, while others may include DERs in supply. Both methods have their advantages and disadvantages.

$$Supply + Imports = Demand + Exports + Losses$$

Where

$$Supply = Generators + Distributed\ Energy\ Resources$$

Or

$$Demand = Load - Distributed\ Energy\ Resources$$

Deconstructing demand into its individual components may be helpful in solving for the variability of distributed generation or for building future demand curves. This process may require significant effort and potentially some assumptions in the absence of actual data. The impact of variability can be addressed by reconstituting actual demand (i.e., adding the distributed generation production back into the measured load). Once the components are separated, actual demand forecasts or assumptions can be developed as one input variable and distributed generation can be modeled separately. The same concept applies to electrification. Start with the current demands and the projected growth of existing demand types, then add the assumed incremental demand that is expected from electric heating—then add the assumed incremental demand that is expected from transportation electrification. However, demand will be modeled in an ERA, the analyst should ensure that all aspects are accounted for and not double counted.

Electric Storage

Classification of Electric Storage

As discussed earlier, *electric storage* refers to a device or facility with electric power as an input, a storage medium of some kind that stores that energy, and electric power as an output. Before energy can be supplied by an electric storage device, it needs to be generated somewhere and then stored in the device. Electric storage cannot itself generate energy but can provide electric energy to the grid to the extent it has been charged. An ERA can show when energy storage needs to be charged and when it should be discharged to support energy sufficiency needs. It may also indicate when there may not be enough energy stored to keep the system balanced with variable supply or volatile demand.

Electric storage can be classified as short-duration energy storage (SDES) or long-duration energy storage (LDES),[20] depending on the needs of the system where the storage is built. This technical reference document uses the terms *SDES, Inter-day LDES, Multi-day/Week LDES, and Seasonal Shifting LDES* to describe the types of electric storage and considerations for each. However, an analyst with more extensive knowledge of electric storage systems and a need to model electric storage more precisely may categorize the resources differently. Each area may have a specific need

[20] https://liftoff.energy.gov/long-duration-energy-storage/

(or set of needs) for storage and, quite possibly, multiple types simultaneously. When performing an ERA, all known electric storage resources should be included as supply resources when they are discharging or as demand when they are charging.

SDESs can be used for frequency regulation, energy arbitrage, and peaking capacity. These resources include smaller batteries,[21] less than four hours of storage, and flywheels. These electric storage types can cycle, charge, and discharge quickly and often in response to signals defined to maintain a balanced Area Control Error (ACE).[22] SDESs with duration closer to four hours can be used to arbitrage demand from the low-load periods to the higher-load periods by, for example, charging overnight or when PV production is high and using that energy to serve peak hourly loads. Inter-day LDES includes resources able to store energy for up to 36 hours, such as pumped hydro storage stations and some developing battery storage. These resources fill the upper pondage or charge when net demand is low and generate or discharge energy when demand is high. Inter-day LDESs can be called on when renewable resources (solar and wind) cannot produce power for several hours. For example, inter-day LDESs can be dispatched to cover nighttime demand when solar generation ceases in the evening after the sun sets. In simplified models, the operation of inter-day LDES resources is sometimes modeled as a fixed charge/pump load at normally lower-demand periods and as a fixed discharge/generation at normally higher-demand periods. The more standard and recommended option for modeling inter-day LDES is to include the specific capabilities as part of the energy balance from hour to hour and optimize the charge/discharge decisions. This effectively tells the analyst when to charge/pump and discharge/generate based on the resource's state of charge or other specific system conditions. Multi-day LDES is made up of electric storage resources (e.g., larger batteries and pumped storage hydro stations) that can provide several days to a week of electricity and is intended to be held for longer time periods. Multi-day LDES can be called upon when a natural-gas-fired plant is unable to receive fuel or when renewable resources are not able to produce power for many hours, such as when wind or solar resources are unable to generate energy due to weather systems that reduce wind speeds or solar irradiance for extended periods.

Seasonal shifting LDES, storage that holds energy produced in one period to be used weeks or months later, is currently focused on "Power-to-X"[23] pathways, such as hydrogen, ammonia, and synthetic fuels. Seasonal shifting LDES is in the early developmental process and is not necessarily the focus of this technical reference document.

Electric Storage Configuration

Electric storage can be standalone or co-located or consist of hybrid/storage resources, further complicating modeling. Solar or wind generators with storage devices at the same location as the generation allow the production of electricity to exceed interconnection limitations. The excess energy is then stored at the associated storage device and withdrawn from storage when generation drops off. Additional complication comes from a potential lack of visibility of the generation resource, as the energy may be supplied by the generation or the storage resource. Metering at the output of a co-located storage facility adds a layer of obfuscation between the weather conditions and the production of the renewable resource, or when the electric storage portion of the facility is used to store energy from the grid rather than from the renewable resource. Metering the individual components can remove that obfuscation but potentially at the cost of adding to a project or retrofitting. Modeling these resources in an ERA as individual components may give the analyst more flexibility with modeling tools and a better understanding of the production from the facility.

Reliability Optimization

A charge/discharge cycle usually incurs losses and, thus, electric storage creates a net energy demand when averaged over longer periods of time. This "round-trip efficiency of storage" is an important consideration for performing an ERA, primarily for accuracy, but also for deciding on action plans when energy supplies are inadequate. Both supply

[21] As with all inverter-based resources, it is critical to know if the storage resource functions under grid-forming or grid-following technology.
[22] ACE is defined by NERC in BAL-001-2 (https://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-001-2.pdf)
[23] Power-to-X is described by NETL in Technology in Focus: Power-to-X (https://doi.org/10.2172/2336708)

and demand implications of storage resources should be considered when formulating action plans when facing an energy shortfall.

Optimization of energy in electric storage devices across several hours or several days is a complicated process that requires consideration for how it would be modeled in an ERA. Electric storage is used in many cases to shift available energy from low-demand periods to high-demand periods or to provide Ancillary Services, and an ERA should model that operation accurately according to how electric storage devices would operate in real life. If the actual dispatch and operation would be optimized to meet a certain objective or set of objectives, the ERA should optimize it toward the same objective over the same period. If an electric storage device is not normally optimized and an ERA were to optimize the dispatch and operation to minimize reliability risk, it could mask indications of a shortfall to the analyst.

Table 1.6 is useful for modeling electric storage in an ERA for any time horizon:

Table 1.6: Information Useful for Modeling Electric Storage in an ERA in Any Time Horizon

Data	Potential Sources	Notes/Additional Considerations
Maximum charge/discharge rates (in MW or kW) and total storage capability (in MWh or kWh)	Registration data	These two parameters combined define the primary characteristics of a storage device.
Usable Capacity	Registration data, operational data	Battery storage may not operate well above and below a specific charged percentage. For example, batteries charged above 80% or below 20% may underperform. Therefore, the storage capacity may be less than intended.
Transition time between charge and discharge cycles	Registration data, operational data, market offers	
Cycling efficiency	Operational data	Calculating the cycling efficiency of storage can be done using operational data, dividing the sum of output energy by the sum of input energy over some period. A longer duration will yield a more accurate efficiency value. All storage requires more input energy than the output that will be produced.
Co-located/hybrid or standalone configuration. Charging source – primary and secondary	Registration data	Scenario studies may remove a generation type (e.g., solar), which may eliminate the energy supply source.
Ambient temperature limits	Registration data, operational data	This refers to the ambient temperature limitations at the storage facility, which are part of the formula for calculating cell temperature limitations. There are high- and low-temperature requirements for charging and discharging batteries at a normal rate. Outside that band, the rate of charge could be reduced, potentially to 0.

Table 1.6: Information Useful for Modeling Electric Storage in an ERA in Any Time Horizon		
Data	**Potential Sources**	**Notes/Additional Considerations**
No-load losses	Registration data, operational data	Electric storage facilities may experience a loss of energy even when not delivering energy to the grid.
Emergency limits		Can the storage resource run below the P-Min or above the P-Max, and if so, for how long?

Transmission

Transmission moves power from supply to demand on the Bulk Electric System. Transmission constraints limit how much power can be transferred. ERAs should account for transmission constraints to accurately model transfers, which can occur within and between constrained areas. Inter-area transmission constraints can be modeled as imports and exports while intra-area transmission constraints could be modeled as reductions in supply capability or by dividing the area zonally. Calculation of specific transfer limits are required by NAESB standards and are a well-known quantity. This information may be available through various Open-Access Same-Time Information System (OASIS) postings. These limits are one aspect of determining the available energy that can be transferred over the transmission system. Once the limitations for transfers between areas are known, there should be coordination between areas to determine if the energy is available to use that transmission capability. Coordinating ERAs between neighboring areas is crucial to formulating accurate input assumptions.[24]

Other considerations for transmission capability include grid-enhancing technologies, such as ambient adjusted ratings, dynamic line ratings,[25] controllable ties, transmission and distribution losses, priority to access, and recallable Transactions/cutting assistance. These considerations will change how imports, exports, and additional transmission usage are modeled in an ERA. Ambient adjusted ratings (AAR) will potentially allow for greater Transfer Capability within and between areas, enabling higher energy usage.

ERAs can also be used to determine if transmission outages would cause or worsen shortfalls. Transmission outages can create conditions that constrain or curtail fuel-secure or high-energy production resources. These constraints or Curtailments can be represented to accurately portray the impact of the transmission outage. Conversely, system conditions (including transmission outages) that create must-run conditions for generators should be incorporated into the ERA. For example, a must-run condition of hydroelectric generation (to mitigate thermal overloads or undervoltage conditions) could reduce the available energy from that resource to meet the needs of the ERA. The ERA would inform the System Operator and Operational Planning Analysis when resources are not available due to energy constraints. Using limitations on imports and exports would factor into the neighboring area ERAs as well.

Table 1.7 is useful for modeling transmission in an ERA for any time horizon:

[24] FERC Order 896 [elibrary.ferc.gov] directed NERC to develop a new standard to address the reliability and resilience impacts of extreme heat or extreme cold events on the BPS. A NERC Standards Authorization Request [nerc.com] to address transmission planning energy scenarios was approved by the NERC Standards Committee [nerc.com] in December 2023

[25] To draw distinction between ambient adjusted ratings and dynamic line ratings, ambient adjusted ratings are a function of forecasted temperatures that can be used in real-time and near-term operations planning and are defined in FERC Order 881. Dynamic line ratings are a function of real-time environmental conditions to determine the capability of a transmission system element.

Table 1.7: Information Useful for Modeling Transmission in an ERA in Any Time Horizon		
Data	**Potential Sources**	**Notes/Additional Considerations**
Planned outages and Maintenance	Transmission Operators (TOP), Transmission Planners (TP), or other transmission planning entities	
Import/export transfer limits	Engineering studies	
Import/export resource limits	Coordinated ERA with neighboring areas	Aligning input assumptions between areas would be necessary for ensuring that energy is not ignored or double counted in multiple areas.
Transmission topology and characteristics	Transmission and distribution models	Potentially, using a simplified or dc-equivalent circuit for probabilistic or similar analysis. Considerations for including planned transmission expansion projects.
Transmission outage rates	NERC TADS	Ideally, weather-dependent and facility-specific outage rates could be used to reflect energy scenarios.

Other Considerations

Across all portions of the power sector, inventories of replacement equipment, mean time to repair (MTTR), and lead times for non-inventoried equipment represent critical limitations that should be considered during the application of contingencies in ERAs. Some of these factors may restrict response pathways across all ERA time horizons. Additional factors that may require consideration include component sourcing (domestic material requirements, nuclear “N-Stamp” certification, etc.), tariff and import restrictions, and government policy and regulatory interventions/restrictions/limitations. While these considerations may improve the accuracy of an ERA, the details may be unavailable or unable to be implemented in a model.

Labor availability may also need to be considered during ERAs depending on the variable of concern; for instance, in a short-term horizon, Contingency recovery time may be governed by the availability of skilled labor and trade personnel over a holiday weekend. In longer time horizons, labor availability may drive uncertainty in both maintenance and construction scheduling, potentially leading to increased outages at existing units and delays in synchronization of new units.

Chapter 2: Inputs to Consider When Performing a Near-Term ERA

An ERA in the near-term horizon addresses a time frame that starts about 1–2 days out and then continuously through the following several days or weeks. It effectively starts at the end of the Operating Plan that covers today and perhaps tomorrow as outlined in NERC Standard TOP-002.[26] That said, the period assessed in a near-term ERA can start earlier (i.e., today, or even in the past) if the analyst needs to set up accurate initial conditions. The near-term ERA then looks into future days or weeks to provide the analyst with a representation of what the energy-constrained conditions would be. Considerations for inputs to a near-term ERA are described below.

Supply

Modeling supply in a near-term ERA relies on an analyst gathering information from an existing fleet of generators. This information is usually fairly static in the near term and can be included in registration data or gathered through generator surveys. Additionally, forecast information may be necessary for Balancing Authorities (BA) with high levels of VERs who will use that information to make more informed decisions on required VERs that would be committed on any given day.

Stored Fuels

Stored fuel information in a near-term ERA should start with current inventories and be updated throughout the assessment based on operations and expected replenishment.

Table 2.1 is useful for modeling stored fuels in a near-term ERA:

Table 2.1: Information Useful for Modeling Stored Fuels in a Near-Term ERA

Data	Potential Sources	Notes/Additional Considerations
Current inventory, inventory management plans, and replenishment assumptions	Generator surveys, assumptions based on historic performance, or annually variable conditions specific to the resource type	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA. Performance expectations for hydroelectric resources may be informed by seasonal runoff conditions.

Just-in-Time Fuels

Modeling just-in-time fuels in a near-term ERA relies on the existing fuel supply infrastructure and assumptions of the operation of those facilities.

Natural Gas

Modeling natural gas availability in a near-term ERA requires an understanding of the pipeline infrastructure that is in place.

Table 2.2 is useful for modeling natural gas supply in a near-term ERA:

[26] https://www.nerc.com/pa/Stand/Reliability%20Standards/TOP-002-4.pdf

Table 2.2: Information Useful for Modeling Natural Gas Supply in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Natural gas scheduling timelines	Pipeline tariffs, NAESB	Timelines may differ between pipelines. The NAESB sets five standard cycles that are to be followed by Federal Energy Regulatory Commission (FERC) jurisdictional entities (which generally excludes intrastate pipelines and local distribution networks).
Natural gas commodity pricing and availability	Intercontinental Exchange (ICE),[27] Platts[28]	Natural gas commodity pricing is an indicator of its availability. Continuously monitoring pricing will allow an analyst to estimate the availability of natural gas into a near-term ERA.

Variable Energy Resources

VERs are modeled in a near-term ERA using the technical specifications of the existing fleet and a forecast of weather conditions translated into power (production) forecasts. Developing an ERA that is highly dependent on VERs requires consideration of the uncertainty of the energy available. The forecast error of VER production can be high even over a near-term horizon. The energy available from VERs is based on the following factors:

- VER capacities
- Geographical location of installed VERs
- Typical forecast errors of wind, solar, and weather
- The capacity, configuration, and transmission capacity of co-located energy storage
- Outage rates of resources
- Amount of VERs connected to distribution or transmission

For most BAs with high levels of VER installations, conducting a near-term ERA with deterministic production values beyond 7–10 days may require the use of averaged production assumptions rather than forecasts due to accuracy concerns.

Near-term ERAs will generally use forecasts rather than assumptions and historical observations. These forecasts are available through a variety of weather vendors and national weather service providers that are derived from global models allowing for specific localized weather to be extracted. Model downscaling, blending and improvement efforts generally produce higher accuracy and/or precision. The analyst can interpret the output of weather models coordinated with VER production forecasts and apply the results to generator performance assumptions in an ERA.

Table 2.3 is useful for modeling VERs in a near-term ERA:

[27] https://www.ice.com/index
[28] https://www.spglobal.com/en/

Table 2.3: Information Useful for Modeling Variable Energy Resources in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Weather forecasts	Vendor supplied but could be developed using weather service models In-house models or vendor-supplied data	There could be differences between one or multiple central forecast(s) and the aggregation of independent forecasts. Forecast error analysis of historical data would provide a measure of the performance of available options. Wind/solar profiles can be modified to capture uncertainty associated with rainy, windy, and/or cloudy days. It is important to maintain the correlation between wind, solar, and load in conducting these analyses.
VER production forecasts	Vendor supplied but could be developed using weather service models	Significant research and development have been done in the last decade to create and improve VER/DER forecasts for use in power system operations and analysis, including ERAs. Hourly or sub-hourly profiles of actual production from VERs can be scaled up or down to fit specific scenarios in an ERA.

Emissions Constraints on Generator Operation

Modeling constraints on generator operation in a near-term ERA can be done using the characteristics of the existing fleet, adjusting for any new resources that are expected to become available during the period being studied.

Table 2.4 is useful for modeling emissions constraints on generator operation in a near-term ERA:

Table 2.4: Information Useful for Modeling Emissions Constraints on Generator Operation in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Output limitations by specific generators	Generator surveys	For short-term assessments, generator surveys would be the best source of emissions limitation information. Generator Owner/Operators should be aware of what their limits would be and the plans to abide by those limits.
Output limitations for a set of generators	Generator surveys	Each Generator Owner/Operator may know their own operational information, but when determining when a collection of generators will reach a limit would require gathering information that each owner/operator has but not as a collective. The analyst

Table 2.4: Information Useful for Modeling Emissions Constraints on Generator Operation in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
		performing the ERA would be the centralized collection point of the information required to accurately model the limit.

Outage Modeling

Near-term ERAs have the benefit of scheduled maintenance plans. These plans are usually set months in advance and give the analyst an indication of the work expected to occur, leaving only unplanned outages as a major source of uncertainty.

Table 2.5 is useful for modeling energy supply outages in a near-term ERA:

Table 2.5: Information Useful for Modeling Energy Supply Outages in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Planned outages and maintenance	Maintenance schedules and outage coordination tools	ERAs can use planned maintenance as an input but can also be used to advise the shifting of planned maintenance to minimize energy-related risks.

Distributed Energy Resources

Most area operators do not have real-time telemetry of DER within their footprint but may be able to work with their local energy commissions or local utility operators to get installed DER capacity at a suitably granular level, such as substation or ZIP code, as well as other useful information (e.g., tilt, direction for solar panels). Creating time series data of DER production for near-term ERAs can be challenging. The results of a near-term ERA can show a high degree of uncertainty when DER installation exceeds a certain point (e.g., a few thousand MW for a small- to medium-demand area; more for larger areas). The point where the amount of DER has significant impact on the power system is not clearly standardized and should be understood and defined by the analyst performing the ERA. A lack of visibility and ability to benchmark the DER forecast against actual production creates an additional level of complexity, and the analyst may need to rely on a variety of scenarios to determine the probability of deficiencies.

Table 2.6 is useful for modeling DERs in a near-term ERA:

Table 2.6: Information Useful for Modeling Distributed Energy Resources in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Installation data	Electric utility companies (i.e., Distribution Providers, or DPs), production incentive administrators	DERs are likely to be required to coordinate with the distribution System Operator before interconnecting. Additionally, any DER that is participating in a renewable energy credit program will likely need to register with and provide production information to a program administrator.
Forecasted DER production	Vendor supplied but could be developed using weather service models	Significant research and development have been done in the last decade to create and improve DER/VER forecasts for use in power system operations and analysis, including ERAs.

Table 2.6: Information Useful for Modeling Distributed Energy Resources in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Historical performance, observations of net load	Historical patterns of demand compared to a longer history	Comparing a similar-day demand curve from a more recent year to one from a year prior can give a sense of the difference in DER that was installed year-over-year.
Estimated performance of DERs	Based on limited samples of a subset of the DER type	Modern DERs may have advanced measurement devices that could be made available through vendor aggregation services. Smaller, evenly distributed samples could be used to scale to the full amount. Testing should be done to validate whether the conceived process is accurate.

Demand

In a near-term ERA, demand profiles should be well understood and can be forecasted accurately, reducing the need to make assumptions. The ever-changing demand profiles that are discussed in other chapters of this technical reference document do not really change overnight, and the recent past should be very indicative of the near future, adjusted for weather.

Table 2.7 is useful for modeling demand in a near-term ERA:

Table 2.7: Information Useful for Modeling Demand in a Near-Term ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Weather forecasts or projections	Numerical weather prediction (NWP) models, weather forecast vendors	Weather information is the primary variable input to demand forecasts. Near-term assessments can use weather forecasts.
Actual demand forecasts or projections	Load forecast models using weather information as an input	Historical weather and demand may be useful for projecting future conditions; however, caution should be exercised to ensure that interrelated parameters remain interrelated. Decoupling weather and load could result in implausible outcomes.
Demand-response capabilities	Electric utilities or other organizations (e.g., demand-response aggregation service providers) that manage participation in demand-response programs	

Electric Storage

Primary considerations for electric storage when performing a near-term ERA are that electric storage resources are less than 100% efficient, and modeling how the expected state of charge (i.e., how much energy is stored) of the resource may impact the operation of the storage facility. In the near-term ERA, electric storage may be used to provide ramping flexibility as solar generation drops off as the sun sets. Understanding of the state of charge facilitates this critical service. Specific storage inputs are needed to perform an ERA.

Table 2.8 is useful for modeling electric storage in a near-term ERA:

Table 2.8: Information Useful for Modeling Electric Storage in a Near-Term ERA

Data	Potential Sources	Notes/Additional Considerations
State of charge	Resource owner	Additional considerations may be given to state of charge in a near-term ERA that reflect the recent operation of the electric storage facility.
Ramp Rate (up/down) MW/minutes	Resource owner	Rate that the electric storage resource can discharge or absorb energy when electric demand or supply changes.
Cell balancing	Resource owner	This describes the change-out of cells within a storage device. Specifically, this would apply to faulty cells that could limit the capability of a battery plant. Balancing takes a few days to accomplish once cells are replaced.
Project-specific incentives (e.g., investment tax credits)	Resource owner	Investment tax credits, either production or investment, may indicate how the electric storage resource will run.
Cell temperature limits[29]	Resource owner	This is the ambient temperature at the storage facility. There are high- and low-temperature requirements for charging and discharging batteries at a normal rate. Outside that band, you may reduce the rate of charge, potentially to 0.

[29] Lithium-ion battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 140°F
Lead acid battery: Charge temperature at -4°F to 122°F; Discharge temperature at -4°F to 122°F
Nickel-based battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 149°F

Chapter 3: Inputs to Consider When Performing a Seasonal ERA

A seasonal ERA considers an upcoming season, focusing on energy-related risks that are exposed in that season. The term *season* is used more as a generic term that means a time period longer than a few weeks but not a full year. Seasons, and their associated risks, are unique across areas and do not necessarily fit into the classic definitions. The analyst should have a good idea of what seasons are experienced by the area where they are performing a seasonal ERA and should apply that definition to the input assumptions. Partial seasons (e.g., three weeks of a winter period) may offer a vantage point that captures the representative risks of a full season without requiring the overhead of performing three-month-long assessments. Winter and summer peak periods are traditionally the focal point of seasonal capacity assessments, but there may be unexpected risks in Off-Peak times (including Off-Peak hours within days) that would be identified by an ERA and should not be overlooked. Considerations for inputs to a seasonal ERA are described below.

Supply

Modeling supply in a seasonal ERA relies on an analyst gathering information from an existing fleet of generators plus any generators that are expected to be added prior to the start of the season being assessed. This information is usually fairly static for a single season and can be included in registration data or gathered through generator surveys. VER production assumptions may be necessary for BAs with high levels of VERs. These BAs will use that information to make more informed decisions on required VERs that would be committed on any given day.

Stored Fuels

Stored fuel information in a seasonal ERA is likely similar to the current inventories plus adjustments for replenishment and usage plans between the time that the ERA is performed and the period being assessed. However, there may be season-specific constraints that affect these factors for the study period in a seasonal ERA.

Table 3.1 is useful for modeling stored fuels in a seasonal ERA:

Table 3.1: Information Useful for Modeling Stored Fuels in a Seasonal ERA

Data	Potential Sources	Notes/Additional Considerations
Current inventory, inventory management strategies, and replenishment assumptions	Generator surveys, formal or informal generator outreach, assumptions based on historical performance, or annually variable conditions specific to the resource type	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA. Performance expectations for hydroelectric resources may be informed by seasonal runoff conditions. Generator surveys can still be useful just prior to a specific season; however, this information may still introduce some uncertainty at the time that the ERA is being performed. Communication with the entities deciding on replenishment strategies would result in more accurate assumptions for starting inventories.

Table 3.1: Information Useful for Modeling Stored Fuels in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Availability of overall fuel storage	U.S. Energy Information Administration (EIA) reports	The U.S. EIA reports weekly inventories for five Petroleum Administration for Defense Districts (PADD). This can be an indicator of whether fuel may be available for generator fuel replenishment.
Shipping constraints	Industry news reports	Seasonal ERAs could be impacted by weather patterns and world events that cause supply chain disruptions, including port congestion, international conflict, shipping embargoes, and confiscation.

Just-in-Time Fuels

Modeling just-in-time fuels in a seasonal ERA relies on the existing fuel supply infrastructure and assumptions of the operation of those facilities as well as expected changes (e.g., expansion or planned outages) prior to the start of the upcoming season.

Natural Gas

Natural gas supply infrastructure is a fairly predictable input to a seasonal ERA. Pipeline expansion and demand growth are usually planned far in advance and are implemented prior to peak-usage seasons. Planned outages of interstate natural gas pipelines are posted publicly.

Table 3.2 is useful for modeling natural gas supply in a seasonal ERA:

Table 3.2: Information Useful for Modeling Natural Gas Supply in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Pipeline, production, import, and export expansion projects	Pipeline websites, filings with state and federal agencies, advertising for open seasons	This includes new pipelines, compressor enhancements and expansions, and LNG import and export projects that will increase or reduce the amount of natural gas that is available.
Pipeline Planned Service Outages	EBB	Interstate natural gas pipelines are required[30] by FERC to post maintenance plans on their public-facing EBBs.
Natural gas commodity futures pricing	Several internet sources that monitor futures pricing	Futures pricing can give a sense of what pricing pressures the commodity is facing in the coming year(s). It may not be a fully accurate picture of what the pricing will be but gives an analyst some direction for a starting point for a seasonal ERA.

Variable Energy Resources

The existing fleet with minor adjustments for outages and expected expansions can be used to model VERs in a seasonal ERA. The variability presents an unknown risk that may require analysis from multiple perspectives. Multiple

[30] See U.S. Code of Federal Regulations Chapter I, Subchapter I, Part 284, Subpart A, § 284.13.(d).(1) - https://www.ecfr.gov/current/title-18/chapter-I/subchapter-I/part-284/subpart-A/section-284.13

profiles should be considered because times of low production from VERs could also coincide with high demand or unplanned outages of other resources.

Table 3.3 useful for modeling VERs in a seasonal ERA:

Table 3.3: Information Useful for Modeling Variable Energy Resources in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Weather outlook	NOAA (for the United States), Environment and Climate Change Canada, historical observations, weather models	Seasonal outlooks can provide a direction on which historical observations to select when performing a seasonal ERA.
VER production assumptions	Historical observations adjusted for weather outlooks	Historical observations can set a starting point for what can be expected in upcoming seasons. This would need to be adjusted for other known factors, such as drought conditions or temperature expectations.
New VER installations	Installation queues	New VERs installed between the time that an ERA is performed, and the start of the upcoming season can be large enough to impact the outcome and should be included as accurately as possible. The seasonal horizon should have more certainty on what will be commissioned or not.

Emissions Constraints on Generator Operation

Modeling constraints on generator operation in a seasonal ERA can be done using the characteristics of the existing fleet, adjusting for any new resources that are expected to become available during the study period.

Table 3.4 for modeling emissions constraints on generator operation in a seasonal ERA:

Table 3.4: Information Useful for Modeling Emissions Constraints on Generator Operation in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Output limitations by specific generators	Generator surveys	For short-term assessments, generator surveys would be the best source of emissions limitation information. Generator Owner/Operators should be aware of what their limits would be and the plans to abide by those limits.

Outage Modeling

When performing a seasonal ERA, the expectation for outages is somewhat clearer than a planning ERA, but there is more uncertainty than in the near term. Well-developed outage coordination processes have provisions to schedule and coordinate generation and transmission outages as far out in the future as possible, which would likely include the time period being addressed by seasonal ERAs.

Table 3.5 is useful for modeling energy supply outages in seasonal ERAs:

Table 3.5: Information Useful for Modeling Energy Supply Outages in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Weather-dependent outage rates	Surveys, registration information, assumptions based on historic performance	GADS will provide average outage rates. The information from GADS can be combined with weather information to derive correlations with weather conditions that could be modeled in an ERA.
Outage mechanisms	NERC GADS, operator logs	Outage mechanisms can be used to determine outage duration and impact.
Planned outage schedules	Outage coordination records	Planned outages are a good start for modeling the unavailability of resources, but considerations should be given to the accuracy of plans. Not every outage goes according to plan, and they may finish early or overrun.

Distributed Energy Resources

Seasonal ERAs would depend more on historical performance from DERs while assuming that the resources are distributed similarly to how they are when the ERA is being developed and performed. Some scaling may be needed to account for some rapid new development.

Table 3.6 is useful for modeling DERs in a seasonal ERA:

Table 3.6: Information Useful for Modeling Distributed Energy Resources in a Seasonal ERA		
Data	**Potential Source**	**Notes/Additional Considerations**
Installation data coupled with expansion assumptions	Electric utility companies (i.e., DPs), production incentive administrators	Like the information needed for a near-term ERA, DERs are likely to coordinate with distribution System Operators, providing a path to make information available. Future information may also be available through those same channels but may also need to be inferred based on trends, growth forecasts, or legislative goals.
Historical DER production data	Operations data, assumptions based on past performance	The analyst may choose to model DER explicitly as a supply resource or as a demand reduction. Modeling the DER separately and incorporating it to the resource mix will allow the analyst to vary the assumptions without impacting other facets of the ERA.

Demand

When considering demand on a long enough time horizon, forecasts are unavailable or unreliable. To supplement forecasts, assumptions should be made based on historical demand and projected load growth or contraction based on factors, such as climate change and economic factors.

Table 3.7 is useful for modeling demand in a seasonal ERA:

Table 3.7: Information Useful for Modeling Demand in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Weather forecasts or projections	Historical data, seasonal weather projections (e.g., the National Weather Service, Climate Prediction Center outlooks)[31], Environment and Climate Change Canada,	Weather information is the primary variable input to demand forecasts. Near-term assessments can use weather forecasts. Longer-term assessments, including seasonal assessments, typically require assumptions or projections of weather due to forecast accuracy.
Actual demand forecasts or projections	Load forecast models using weather information as an input	Historical weather and demand may be useful for projecting future conditions; however, caution should be exercised to ensure that interrelated parameters remain interrelated. Decoupling weather and load could result in implausible outcomes.
DER production forecasts or projections	Weather-based prediction models using the assumed weather as an input, which are available from a variety of vendors	This may or may not be considered in the demand side of the energy balance equation. Correlation with modeled weather conditions should be considered.
Demand-response capabilities and expectations	Electric utilities or other organizations (e.g., demand-response aggregation service providers) that manage participation in demand-response programs	Not all demand response operates at the command of the entity responsible for dispatching resources.

Electric Storage

Charging and discharging patterns for electric storage devices may change depending on the season being studied. During summer, electric storage may be used to store excess solar generation to be used during nighttime hours while storage may be used to inject energy into the grid during periods of high demand due to extreme cold during winter. Additionally, storage devices may also be providing Ancillary Services and, as such, would be charging and discharging when required by the System Operator.

Table 3.8 is useful for modeling electric storage in a seasonal ERA:

Table 3.8: Information Useful for Modeling Electric Storage in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Cell temperature limits[32]	Resource owner	This is the ambient temperature at the storage facility. There are high- and low-temperature requirements for charging and discharging batteries at a normal rate.

[31] https://www.cpc.ncep.noaa.gov/products/predictions/long_range/

[32] Typically, today's battery technologies are constrained to the following temperature bands:
Lithium-ion battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 140°F;
Lead acid battery: Charge temperature at -4°F to 122°F; Discharge temperature at -4°F to 122°F;
Nickel-based battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 149°F

Table 3.8: Information Useful for Modeling Electric Storage in a Seasonal ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
		Outside that band, you may reduce the rate of charge, potentially to 0.
Ramp Rate (up/down) MW/minutes	Resource owner	Rate that the electric storage resource can discharge or absorb energy when electric demand or supply changes.
Project-specific incentives (e.g., investment tax credits)	Resource owner	Investment tax credits, either production or investment, may indicate how the electric storage resource will run.

Transmission

Transmission constraints in a seasonal ERA can be modeled using the existing system with any anticipated changes that would occur before the time being studied, including planned outages and new construction.

Chapter 4: Inputs to Consider When Performing a Planning ERA

Planning ERAs are generally performed in the 1-to-10-year time horizon, beyond Operations Planning. The planning horizon offers more uncertainty but also more options to explore for correcting or minimizing shortfalls. The analyst performing a planning ERA will likely need to look at a wider array of possible inputs, resulting in an even wider array of outputs. The methods will be up to the analyst performing the ERA. Considerations for inputs to a planning ERA are described below and would generally apply to any type of analysis.

Supply

Modeling supply in a planning ERA leans heavily on assumptions due to the volatility of future resource mix possibilities. Variability in new construction, retirements, legislative goals, and possible emissions limitations drive a need to assess a variety of outcomes.

Stored Fuels

Electrification of heating is expected to replace oil, natural gas, and other unabated carbon-emitting combustible fuels over time with vast differences between state goals, shifting competing demands for fuel into additional electric demand. Electrification may not necessarily eliminate the need for combustible fuels but just move the combustion from inside each individual building (i.e., at the furnace or boiler) to centralized generating stations. Modeling long-term impacts of electrification of heating and fuel transportation networks will depend on the types of fuels being replaced and be driven by policy, economics, and technical complications.

Table 4.1 is useful for modeling stored fuels in a planning ERA.

Table 4.1: Information Useful for Modeling Stored Fuels in a Planning ERA

Data	Potential Sources	Notes/Additional Considerations
Inventory management and replenishment assumptions	Assumptions based on historical performance and/or commodity market evaluations.	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA.
Availability of overall fuel storage	EIA reports	The U.S. EIA reports weekly inventories for five PADDs. Trending PADD inventories over time may provide insight into how replenishment may occur over longer periods of time.
Intra-annual hydro availability	Historical drought or high-runoff conditions	Since drought and high-runoff hydro forecasts may not cover an extensive enough period to depend on for a planning ERA, assumptions would need to be made based on historical information.

Just-in-Time Fuels

Natural Gas

Modeling natural gas availability in a planning ERA may require more extensive research of infrastructure projects and assumptions for competing demands for fuel. Natural gas pipeline and production expansion tend to require long lead times and have tended to become more uncertain in recent years.

Table 4.2 is useful for modeling natural gas supply in a planning ERA:

Table 4.2: Information Useful for Modeling Natural Gas Supply in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Pipeline, production, import, and export expansion projects	Pipeline websites, filings with state and federal agencies, advertising for open seasons	This includes new pipelines, compressor enhancements and expansions, and LNG import and export projects that will increase or reduce the amount of natural gas that is available.

Variable Energy Resources

Modeling VERs in a planning ERA requires a set of assumptions that depend on several factors. First, the expansion of installed facilities drives the magnitude of available energy. Profitability of VERs is the primary consideration, which is a function of the cost of materials, labor, shipping, and interconnecting to the transmission system. With that information, assumptions can be made on the scaling factors to be used.

Table 4.3 is useful for modeling VERs in a planning ERA:

Table 4.3: Information Useful for Modeling Variable Energy Resources in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Expected installed resources	Interconnection queue, economic analysis and forecasts	
Renewable energy goals	State legislature dockets	These goals drive the rate at which renewable (and likely variable energy) resources are built, including target years and amounts.
Production assumptions	Historical observations, weather models, climate trends	Profiling the expanded fleet across some historical dataset, adjusted for expected trends in climate, gives an ERA plausible inputs.

Emissions Constraints on Generator Operation

Modeling constraints on generator operation in a planning ERA can be done partially by using the characteristics of the existing fleet but also requires an evaluation of planned new construction and retirements. Planning ERAs that go beyond the next few years may require the analyst to make assumptions on state or national policies, retirements, and new construction where final decisions have not yet been made.

Table 4.4 is useful for modeling emissions constraints on generator operations in a planning ERA:

Table 4.4: Information Useful for Modeling Emissions Constraints on Generator Operation in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Output limitations by specific generators	Generator surveys	For short-term assessments, generator surveys would be the best source of emissions limitation information. Generator Owner/Operators should be aware of what their limits would be and the plans to abide by those limits.

Table 4.4: Information Useful for Modeling Emissions Constraints on Generator Operation in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Trends in individual state carbon emissions goals	State government or public utility commission (PUC) websites	When assessing the probability of long-term retirements and new construction, emissions goals may provide insight to the analysts to decide whether a specific resource or a subset of the entire fleet may or may not be viable under the expected rules.

Outage Modeling

While past performance is not a perfect indicator for future performance, it can serve as a guide for the analyst to make assumptions about generation outages.

Table 4.5 is useful for modeling energy supply outages in a planning ERA:

Table 4.5: Information Useful for Modeling Energy Supply Outages in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Forced-outage rates	NERC GADS, assumptions based on historical performance	NERC requires outages and reductions to be reported with associated cause codes and makes that information available to registered entities. Alternatively, analysts can observe historical unplanned outage information to determine similar assumptions.
Weather-dependent outage rates	Surveys, registration information, assumptions based on historical performance	GADS will provide average outage rates. The information from GADS can be combined with weather information to derive correlations with weather conditions that could be modeled in an ERA.
Assumed outage rates for newly constructed supply resources	Fleet averages using existing resources, when possible	New construction using existing plans means that there is likely a similar resource somewhere that has some performance data that can be used to estimate the performance of a new resource.
Outage mechanisms	NERC GADS, operator logs	Outage mechanisms can be used to determine outage duration and impact.

Distributed Energy Resources

In a planning ERA, DERs are modeled similarly to a seasonal ERA but with more uncertainty in installed capacity. Past a certain point, the assumptions being made would overshadow the fact that the supply resources are connected in such a way that they would be less visible to the operator. There is also some uncertainty in whether each resource, once finally built, would even be distributed or not. That uncertainty supports a method of modeling DERs that can accommodate either outcome.

Table 4.6 is useful for modeling DERs in a planning ERA:

Table 4.6: Information Useful for Modeling Distributed Energy Resources in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Growth estimates, renewable energy goals	State government and PUCs, directly or via their websites	

Demand

Demand is expected to become more complicated than ever in the coming years. Today's demand has components of actual demand (e.g., lighting, heating and air conditioning, appliances, industrial demand), varying types of demand response (including the impact of time-of-use rates), and distributed generation that is considered load-reducing. Future demand will change throughout the evolution to decarbonize the power system.

Further expected changes will continue to transform the actual demand profiles and the need for electric energy. Electrification of heating and transportation will likely shift demand curves away from traditional energy supplies of oil, natural gas, and gasoline to electricity. The shifts will result in net load profiles that, although not necessarily less predictable from a day-to-day point of view, are more difficult to predict through the transition when looking several years into the future and making assumptions. ERAs require modeling of multiple hours and should consider the expected changes brought about by changes in demand.

Table 4.7 is useful for modeling demand in a planning ERA:

Table 4.7: Information Useful for Modeling Demand in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
Weather forecasts or projections	Historical data, adjusted using climate models	Weather information is one of the primary inputs to longer-term demand forecasts. Longer-term assessments typically require assumptions or projections of weather due to forecast accuracy concerns.
Actual demand projections	Historical actual demand modified by the expected impact of demand changes, load forecast models using weather information as an input	Historical weather and demand may be useful for projecting future conditions; however, caution should be exercised to ensure that interrelated parameters remain interrelated. Decoupling weather and load could result in implausible outcomes. Performing an energy assessment still requires a profiled demand curve over a period of time. Most legacy long-term forecasts produce a set of seasonal peak values.
Projected changes in actual demand magnitude and profile (e.g., load growth)	Analysis of economic factors, governmental policy, and technical considerations	This should include the impact on demand magnitude as well as changes in demand profiles. This includes energy efficiency and electrification. Electrification of heat is a function of local temperatures. Electrification of transportation will be more linked to commute distances and time of day.

Table 4.7: Information Useful for Modeling Demand in a Planning ERA		
Data	**Potential Sources**	**Notes/Additional Considerations**
DER production forecasts or projections	Historical production data, scaled to future capability	This may or may not be considered in the demand side of the energy balance equation. Correlation with modeled weather conditions should be considered.
Demand-response capabilities	Electric utilities or other organizations (e.g., demand-response aggregation service providers) that manage participation in demand-response programs.	

Electric Storage

As noted in Chapter 1, when performing a planning ERA, it is important to know the source that will charge or fill the electric storage resource. It is expected that electric storage will become a critical resource for maintaining system balance as coal- and natural gas-fired generation retire and are replaced by VERs. Knowing how the electric storage resource is charged/filled, either a direct resource or off the grid, increases the value of the ERA. Information that would be useful for performing a planning ERA is similar to near-term and seasonal ERAs but with more uncertainty.

Transmission

In a planning ERA, transmission can be significantly more variable than the near-term or seasonal ERAs. This time horizon presents an opportunity to build out or upgrade the transmission systems to relieve constraints or for other purposes.

Chapter 5: Methods

Introduction/Overview

The modeling items described in the prior chapters are foundational for performing comprehensive ERAs. Many of these are also considered when performing capacity assessments with a key difference for ERAs being the finite amount of energy available from fuel and energy-limited resources. For example, a hydroelectric power plant with a capacity of 100 MW can only generate a total energy output over time equivalent to the amount of water in storage, and energy generated in one hour is not available to be used in a later period. Capacity assessments historically would count this hydro plant as having 100 MW available in every hour. Most modern capacity assessments instead attempt to account for energy limitations with various probabilistic methods that derate nominal capacity toward an expectation at the time of peak hour or greatest risk. An energy assessment constrains the total energy available, not the capacity. This is achieved through an explicit modeling and enforcing of all energy constraints on the system through the full study horizon.

An additional element of an energy assessment is identifying not only that enough energy is available to meet expected demand for all hours of the study period but also that it is available to ensure that necessary essential reliability service requirements are met, primarily ramping capability and reserves. As more variable generation is added to the system, the need for additional flexible or ramping resources should be evaluated. Ramping resources that can quickly raise or lower their output are essential to the Reliable Operation of the BPS. Certain demand also provides ramping capability, and an understanding of how these demand-side resources operate is essential for modeling and performing energy assessments.

Many methods can be used to perform an ERA and may require the use of both probabilistic and deterministic models to identify when the system may be at risk of energy shortages. Probabilistic vs. deterministic methods are defined in Volume 1. Succinctly, the probabilistic method considers at a high level many possible combinations of supply and demand to screen for potential reliability risks to the BPS. This method can be used to identify periods and conditions under which the system's energy supply and demand are stressed and could lead to unserved load.

A deterministic approach involves modeling one set of events for a given scenario. Running certain iterations of the supply and demand conditions identified in the probabilistic model through a deterministic model allows for a detailed analysis in which increased operational detail is modeled for the identified scenarios. Such a detailed analysis may not be computationally feasible in a probabilistic analysis. As such, deterministic and probabilistic approaches can be used in conjunction with one another to identify and explore high-risk scenarios in greater depth. Many different modeling tools can be used to perform energy assessments, but all fall into a handful of tool families with cross-family integration leading to more robust results.

Tool Families Overview

This section describes the families of tools that an analyst can use to perform an ERA. The subsections are not meant to be comprehensive but to provide the reader with a high-level understanding of the different tool families. By reading the materials presented, the reader can hope to learn at a high level what each family of tools can do, what functionality each family has (i.e., the kinds of questions each family can answer), what each family does well, what each family does not do or does less than optimally, what level of system topology detail is captured, what time horizon each family can study and how time is represented, and where to find models of each family type. The section does not provide recommendations for or names of any specific tools within the described families., The reader should be cognizant of any regulatory requirements that require the provision of filings using a specified file format that may be vendor or program specific (e.g., FERC requires Form 715 power flow cases to be filed in one of six specific formats).[33]

The tools described below can be used separately for some assessments but are recommended to be used in combination with each other (or with other tools that may not be described) to set up the assumptions and initial conditions needed to perform ERAs. The analyst will need to evaluate the value of each tool and employ sound judgment in selecting the proper tools. In the end, a reasonable set of initial conditions is subjective and requires the analyst to understand what each individual component means.

Resource Adequacy

Resource Adequacy (RA) tools are the core set of tools used to perform an ERA.[34] They allow for resource capacity and energy Adequacy to be evaluated probabilistically for a range of possible scenarios. Risk metrics, such as loss of load expectation (LOLE) or expected unserved energy (EUE), are calculated using an RA tool.

Historically, many RA assessments used a convolution algorithm, an analytical method that calculates total available capacity distribution by convolving together the distributions associated with available capacity for each unit in the system. In this method, each time interval is assessed independently of all others, meaning that the intertemporal nature of power systems operations is ignored.

Most RA assessments and tools today instead use a Monte Carlo algorithm, which simulates hundreds or thousands of scenarios using different outage and/or weather patterns to understand the likelihood of load shedding. There are further nuances across Monte Carlo algorithms, with some algorithms considering chronological system operations and others considering every time interval independently. Some methods use a heuristics-based method, while others use a dispatch-based method. A heuristics-based method is simpler and less computationally intensive than a dispatch-based method but may not fully capture all energy constraints on the system. A dispatch-based method provides the most accurate representation of power system operations within the RA framework. Indeed, highly detailed dispatch-based Monte Carlo approaches closely resemble production cost modeling tools.

RA models can answer or provide guidance to determine if the system meets the required reliability level while considering outage probabilities, reserve margins, and load and weather uncertainty. Some of items for consideration when applying an RA model to an ERA are described in **Table 5.1**.

Table 5.1: Considerations for Applying Resource Adequacy Models to ERAs

Consideration	Description
Availability of Stored Fuel	Certain RA models can be used to model the availability of stored fuel by considering inventory levels and replenishment rates. For example, for thermal power plants (coal, natural gas), the model should track fuel inventory levels and factor in delivery schedules to ensure that the plants have sufficient fuel to operate when needed to meet demand. The cost associated with fuel procurement and storage may also be included in the model's calculations. This may not be possible in all RA tools, and such an analysis comes at a computational cost that should be balanced against other modeling decisions within the probabilistic framework.
Just-in-Time Fuel Modeling	RA models may incorporate fuel consumption and delivery schedule forecasts. These forecasts, created externally to the RA model framework,

[33] Part 2: Power Flow Base Cases https://www.ferc.gov/industries-data/electric/electric-industry-forms/form-no-715-annual-transmission-planning-and-evaluation-report-instructions

[34] Further information on RA tools can be found in the EPRI "Resource Adequacy Assessment Tool Guide: EPRI Resource Adequacy Assessment Framework" https://www.epri.com/research/products/000000003002027832

Table 5.1: Considerations for Applying Resource Adequacy Models to ERAs	
Consideration	**Description**
	may be based on historical data, demand projections, and market conditions. Just-in-time fuel modeling ensures that power plants receive fuel deliveries precisely when needed to optimize operational efficiency and minimize costs.
Variable Energy Resources	For VERs like wind and solar, RA models incorporate probabilistic forecasting methods to consider a range of possible generation outputs based on weather forecasts, historical data, and geographic characteristics.
Power-Specific Limits and Emission Modeling	Certain RA models can incorporate generator operating constraints and emissions constraints in the algorithms. The level of constraints that can be incorporated will be dependent on the type of RA tool used (for example, tools with convolution algorithms and certain heuristics-based algorithms may not allow for these constraints) and the computational tractability of the model.
Energy Supply Availability	RA models can assess energy supply availability by considering the availability of generation resources, transmission capacity, and fuel availability. They analyze generation unit availabilities, scheduled maintenance outages, and unplanned downtime to determine the overall energy supply Adequacy in meeting demand requirements. This is done over multiple weather years and/or outage draws and is used to assess RA metrics, such as LOLE and EUE.
Electric Vehicles (EV)	RA models should include representations of EVs by incorporating EV charging demand profiles, vehicle-to-grid (V2G) interactions, and the impact of EV penetration on electricity demand patterns. The model should evaluate the effects of EV charging behavior on load profiles, including the potential for EVs to provide demand-response services to the grid.
Non-Transportation Electrification	Models should consider the uptake and usage patterns associated with electrification technologies in non-transportation sectors. They should assess the impact on system Adequacy of the shifts in timing and seasonality of load profiles and usage patterns.
Energy Storage	RA models vary substantially in the amount of detail included in energy storage modeling. At their most detailed, RA tools allow for consideration of parameters, such as cycling limitations, charging/discharging efficiencies, and transmission constraints. Storage may be dispatched to reduce overall system costs, maximize unit profit, reduce peak or net peak load, or reduce load shortfall events; careful consideration of the dispatch objectives is required to accurately represent storage operations.
T&D Export/Import and Deliverability	Many RA models leverage a zonal consideration of their systems, with major interface limits between areas enforced. Some tools have the capability for nodal modeling, although this should be carefully balanced against the computational cost of implementation. A careful analysis of important transmission and Stability constraints to consider should be undertaken in other analyses (such as production cost modeling and power flow models), and this information should be reflected in RA models as appropriate.
Essential Reliability Services and other Ancillary Needs	Essential reliability services, such as Spinning Reserves, Non-Spinning Reserves, and Frequency Regulation, can be modeled in RA assessments either as an increase to the effective demand, or explicitly modeled. It is important to consider which Ancillary Services would be maintained in a

Table 5.1: Considerations for Applying Resource Adequacy Models to ERAs	
Consideration	**Description**
	load-shed situation, as this distinction will affect reliability assessment results.

Production Cost

Electricity production cost models (PCM), sometimes referred to as rank-order security-constrained models, are a family of tools that provide insights into current and potential future market and system operating conditions. They are used to understand electricity market dynamics and future operational issues, identify potential reliability challenges, and perform economic and environmental benefit assessments. In an ERA context, they can be used to evaluate deterministic scenarios that were identified as high interest in the RA model or to run extreme weather scenarios that were not represented in the probabilistic analysis.

At a high level, PCMs mimic the real-time operation (commitment and dispatch) of resources, considering factors, such as power generation, transmission, and demand. PCMs can answer or provide guidance to answer various questions, including the following:

- What is the total production cost of the resources meeting electricity demand while subject to system constraints?
- What is the optimal commitment and dispatch of energy resources considering factors, such as fuel costs and deliverability, environmental regulations, and technology constraints?
- What is the impact of policy changes (e.g., carbon pricing, renewable energy mandates) on the operation and economics of the power system?

The underlying capabilities of PCMs include the following features by model:

- **Unit Commitment (UC) Models:** Optimize the scheduling of power generation units over a specified time horizon, typically ranging from hours to days. The unit commitment problem considers detailed generation operational constraints, such as minimum unit run/down times, ramp rates, start-up/shut-down durations, and energy storage volume, along with load profiles to schedule the selection of generators that may be committed to operate based on cost, deliverability, and condition in the preceding time step.
- **Economic Dispatch Models:** Further resolves the schedule by determining the level of production from each scheduled resource and unscheduled resources on a rolling basis to satisfy the load in each hour or sub-hourly period at least-cost while satisfying imposed constraints, such as emissions limitations or Ancillary Service constraints. They ensure that the total generation output matches the system load while minimizing fuel and operating expenses.
- **Security-Constrained Unit Commitment/Economic Dispatch Models:** Models extend unit commitment and Economic Dispatch by allowing for transmission constraints to be enforced through a nodal representation of the system. They optimize the dispatch of generating units while representing the reliability and Stability constraints of the power system under normal and Contingency conditions.
- **Ancillary Services Market Models:** Extend the unit commitment and Economic Dispatch models to also simulate the procurement and provision of Ancillary Services, such as regulation, Spinning Reserve, and Non-Spinning Reserve, to maintain grid reliability and Stability. They co-optimize the allocation of resources across Ancillary Services and energy to ensure the availability of essential reliability services in real time.
- **Price Forecasting Tools:** Using PCM tools (unit commitment/Economic Dispatch (UC/ED)) or other approaches to predict electricity prices in wholesale energy markets based on supply and demand fundamentals, market dynamics, weather forecasts, regulatory policies, and other relevant factors. They help

market participants make informed decisions regarding generation scheduling, bidding strategies, and risk management.

PCMs historically assumed perfect foresight and are solved using a two-step security-constrained algorithm that first resolves unit commitment for each simulation time step on a rolling basis before determining the unit dispatch in each simulation time step. PCMs are often used to assess issues, such as the integration of large amounts of variable renewable energy (like wind and solar) into the grid and determine the need for storage or other flexibility options to balance supply and demand. They can also be used to evaluate the potential for demand-side measures (like energy efficiency or load shifting) to reduce the cost of electricity production.

PCMs can be complex and require significant computational resources and expertise to develop, calibrate, and interpret. Results from PCMs can be sensitive to input parameters and assumptions, which may introduce uncertainties in the analysis. While PCMs can simulate various scenarios, they may not fully capture the complexities of extreme events or rare system failures.

PCMs operate at different time resolutions, ranging from hourly to sub-hourly time steps based on the level of detail required. The time horizon of analysis can span from short-term operational planning to long-term investment decisions.[35] Unlike capacity expansion models (CEM), which use aggregated representative time slices across each year, PCMs use sequential hourly or sub-hourly time slices to generate a least-cost solution across the simulated time horizon. PCMs incorporate extensive detail on electricity generating unit operating characteristics, transmission grid topology (typically represented as a dc representation of the ac network), operating characteristics and constraints, and market system operations to support economic system operation and detailed planning.

The results of PCMs provide valuable information on the system and market operations by determining the effects of transmission congestion, fuel costs, generator availability, bidding behavior, and load growth on market prices. PCMs provide forecasts of hourly/sub-hourly energy prices, unit generation, revenues and fuel consumption, external market Transactions, transmission flows and congestion, and loss prices. In non-market-based areas, these models are still applicable as they can be used to understand future operations, provision of Ancillary Services and transmission congestion, and other factors impacting reliability and economics.

Electricity PCMs are built on robust data structures, including the ability to enter time-based data changes at the hourly and sub-hourly granular level and detailed generator data inputs. In addition to unit capacity changes, users can enter data describing future changes to generator and transmission operational data. While PCMs rely heavily upon detailed generator specification, the level of transmission detail is determined by the user and can be aggregated into zonal representations or highly detailed nodal representations. The level of transmission detail included in a PCM simulation significantly influences the rigor of the simulation results, but this comes at the expense of non-trivial increases in simulation run times as more transmission detail is included. While very detailed transmission representations can be included, PCMs do not fulfill the role of the detailed power flow operational analysis tools as they typically use a dc representation of the ac power flow (i.e., no voltage constraints or Stability issues represented) and may produce infeasible power flow results. Many different PCM options are available to an analyst performing an ERA, including both open-source and commercial options. The selection of a PCM, as with all the tools described in this section, should consider the needs of the assessment, the veracity and availability of data within the model, licensing and maintenance costs, and ease of use.

[35] Although CEMs are traditionally leveraged to make long-term investment decisions, PCMs can be used as a complement to this analysis to obtain a more accurate picture of a plant's operating costs.

The boundary between PCM and RA tools is blurring given the increased need for RA analyses to represent a greater level of operational detail than ever before. As such, PCM tools are sometimes leveraged for probabilistic analysis by simulating hundreds or thousands of scenarios and calculating RA risk metrics in post-processing (see **Table 5.2**).

Table 5.2: Considerations for Applying Production Cost Models to ERAs

Consideration	Description
Availability of Stored Fuel	PCMs can be used to model the availability of stored fuel by considering inventory levels and replenishment rates. For example, for thermal power plants (coal, natural gas), the model should track fuel inventory levels and factor in delivery schedules to ensure that the plants have sufficient fuel to operate when needed to meet demand. The cost associated with fuel procurement and storage may also be modeled as an additional generator cost impacting unit commitment and dispatch decisions.
Just-in-Time Fuel Modeling	PCMs may incorporate fuel consumption and delivery schedule forecasts. These forecasts, created externally to the PCM framework, may be based on historical data, demand projections, and market conditions. Just-in-time fuel modeling ensures that power plants receive fuel deliveries precisely when needed to optimize operational efficiency and minimize costs.
Variable Energy Resources	PCMs can be used to study the impacts of uncertainty, where a plan (e.g., day-ahead commitment) is based on one forecast and the system then needs to react as different wind, solar and demand show up in the dispatch.
Power-Specific Limits and Emission Modeling	PCMs account for off-power specific limits, such as emission constraints and Contingency modeling, by incorporating regulatory requirements and operational constraints into the optimization algorithms. For example, emission limits for pollutants like sulfur dioxide, nitrogen oxides, and carbon dioxide are integrated into the model to ensure compliance with environmental regulations while optimizing generation dispatch and scheduling.
Energy Supply Availability	PCMs assess energy supply availability by considering the availability of generation resources, transmission capacity, and fuel availability in the market.
Electric Vehicles (EV)	PCMs should include representations of EVs by incorporating EV charging demand profiles, V2G interactions, and the impact of EV penetration on electricity demand patterns. The model should evaluate the effects of EV charging behavior on load profiles, helping utilities plan for EV integration and infrastructure upgrades.
Non-Transportation Electrification	Models should consider the uptake and usage patterns associated with electrification technologies in non-transportation sectors. They should assess the shifts in timing and seasonality of load profiles and usage patterns.
Energy Storage	PCMs model energy storage systems by considering parameters, such as cycling limitations, charging/discharging efficiencies, and transmission constraints. They optimize the dispatch of energy storage resources to reduce overall system costs, manage Peak Demand, and provide Ancillary Services, such as Frequency Regulation; careful consideration of the optimization objectives is required to represent storage operations. Cycling effects, including degradation over time due to charge-discharge cycles, should also be considered in the model's analysis.

Table 5.2: Considerations for Applying Production Cost Models to ERAs	
Consideration	**Description**
T&D Export/Import and Deliverability	PCM model allows for transmission constraints to be enforced through a nodal representation of the system. However, PCMs do not fulfill the role of the detailed power flow operational analysis tools as they typically use a dc representation of the ac power flow (i.e., no voltage constraints or Stability issues represented) and may produce infeasible power flow results. A careful analysis of important transmission and Stability constraints to consider should be undertaken in other analyses (such as power flow models), and this information should be reflected in PCM models as appropriate.
Essential Reliability Services and other Ancillary Needs	PCMs can explicitly model procurement of essential reliability services, such as Spinning Reserves, Non-Spinning Reserves, and Frequency Regulation, to maintain grid reliability. They optimize the allocation of reserve resources to respond to sudden changes in demand or generation outages, ensuring sufficient capacity to restore system balance and prevent Cascading failures during contingencies. They do not analyze the response after contingencies.

Capacity Expansion Models

CEMs are a family of tools used in long-term system planning to inform investment decisions and potential future system designs through least-cost optimization of system resources given assumptions about future electricity demand, fuel prices, technology cost and performance, policy and regulation, and reliability targets. The output of a CEM would provide an analyst performing an ERA with a resource buildout to which energy constraints would then be applied. The CEM would not provide information on the nature of these energy constraints: This would need to be implemented by the analyst using their knowledge of the system. Many CEM options, including both open-source and commercial options, are available to an analyst. The selection of a CEM, as with all the tools described in this section, should consider the needs of the assessment, the veracity and availability of data within the model, licensing and maintenance costs, and ease of use. Capacity expansion tools excel in providing insights into long-term infrastructure investment decisions by considering multiple factors and scenarios. They help policymakers, regulators, and utilities identify cost-effective strategies to maintain energy reliability while meeting environmental and sustainability goals. These tools can assess the tradeoffs between different investment options and optimize the allocation of resources over time. CEMs can answer various questions related to long-term energy planning, such as the following:

- What is the optimal mix of generation technologies to meet future demand while minimizing costs?
- When and where should new power plants be built or retired?
- What transmission and distribution infrastructure upgrades are necessary to accommodate the future resource buildout? (Many CEM models do not yet have this capability.)

The CEM family of tools typically includes at least a generation capacity expansion capability to help determine the type and quantity of power generation facilities that should be built in a specific time frame to meet future energy demand at the lowest cost. In some cases, CEMs may also represent transmission capacity expansion in a co-optimized or coordinated manner with generation expansion, focusing less on specific transmission lines but more on upgrades between the zones represented in the model. Additionally, several commercially available CEMs have recently started to include high-level representations of distribution upgrade needs to accommodate load growth and DERs. Integrated generation, transmission, and distribution planning assessments may require several levels of tools, including CEMs as well as more detailed transmission and/or distribution analysis, though efforts are underway to improve the existing CEMs to better represent transmission or distribution for a more fully integrated capability.

All these tools can be used to produce a starting point of generation and transmission that would be used to set initial conditions for ERAs.

CEMs rely on assumptions and input data that may not fully capture the complexities and uncertainties of the energy landscape. There is significant uncertainty regarding changes in technology characteristics and cost attributes, fuel prices, regulatory policies, operational flexibility needs, and consumer behavior. These uncertainties in input data translate to a resource buildout that is itself very uncertain. Additionally, these tools may have limitations for representing certain aspects of the power system, such as the dynamic interactions between generation, transmission, and distribution networks during extreme events or emergencies. Scenario analysis can support investigation of these issues.

Unlike the other model families described in this section, CEMs use high-level aggregate assumptions to reduce solve times given the length of time horizon considered. These tools typically operate over a long-term planning horizon, ranging from 10 to 30 years or more, depending on the specific needs and objectives of the analysis. They may use annual or sub-annual time steps to capture seasonal variations in demand, renewable energy availability, and other factors influencing system operations. CEMs typically use a structure built upon the use of time slices reflecting a handful of representative days each year consisting of blocks of hours with similar characteristics. A typical CEM includes fewer than 50 total time slices to represent each simulated year, which may or may not be simulated in time sequential order. Most CEMs include a planning reserve margin as an input or constraint to the simulation to ensure that solutions include sufficient resources to cover for variation from the 50/50 conditions of the representative days and operational experiences such as generator Forced Outages.

Capacity expansion tools can be customized to specific areas or jurisdictions to account for differences in energy resources, demand patterns, regulatory frameworks, and infrastructure constraints. They allow stakeholders to tailor the analysis to reflect the unique characteristics and priorities of their respective areas. Since CEMs sometimes consider transmission solutions as an investment choice, it can be intimated that they are quasi-transmission constrained, but these constraints are only as detailed as the system representation used by the CEM. Since most CEMs use a zonal approximation of the system, the level of transmission constraint reflected is at the zonal interface, meaning that copperplate deliverability is assumed within the zone. Because of the number of simplifying assumptions, level of aggregation, and assumption of perfect foresight reflected in a CEM, it is possible for it to produce a least-cost solution that is infeasible for dispatch and operations or that is not adequate when evaluated probabilistically for a wider range of possible scenarios.

CEM results are normally used in integrated resource plans and regulatory analyses. Advanced CEMs may consider the interdependencies between generation investments and the corresponding transmission upgrades necessary to deliver electricity from remote generation sites to load centers efficiently.

Although CEMs are not directly used to assess energy reliability, a robust analysis that incorporates energy constraints where computationally feasible will allow for a recommended resource buildout that is more likely to be energy adequate than if these constraints were not incorporated. CEMs should be run in combination with other types of models ("round-trip analysis") when direct inclusion of constraints is not computationally or technically feasible. Other types of models can be used to guide a choice of simplified pseudo-constraints that allow for some representation of energy constraints within the CEM in a simplified manner (see **Table 5.3**).

Table 5.3: Considerations for Applying Capacity Expansion Models to ERAs	
Consideration	**Description**
Availability of Stored Fuel	CEMs can incorporate assumptions about the availability and cost of stored fuel, such as coal, natural gas, or uranium, based on historical data and market projections. They can also consider storage capacities and inventory management strategies to ensure a reliable fuel supply for thermal power plants over the planning horizon. One possible approach to incorporating this into a CEM would be to impose operational limits on fuel-limited resources. These operational limits could be informed by a PCM.
Just-in-Time Fuel Modeling	Models should simulate the logistics and transportation infrastructure required for delivering fuel to power plants, including pipelines, railroads, and storage facilities. They can account for lead times, delivery schedules, and supply chain disruptions to assess the reliability of just-in-time fuel delivery systems. One possible approach to incorporating this into a CEM would be to impose forced derates or Forced Outages for resources in time periods where their output is forecast to be limited.
Variable Energy Resources	CEMs should account for the variability and intermittency of renewable energy sources, such as wind and solar, in their analysis. One approach to incorporating weather shape diversity would be to incorporate rolling weather years in the CEM analysis: This would allow for some of the variability of renewables to be reflected in the analysis while maintaining computational tractability. Additionally, CEMs should be run in coordination with RA models, which can allow the Adequacy of the proposed resource buildout to be evaluated across multiple weather years.
Power-Specific Limits and Emission Modeling	Models should incorporate technical constraints and environmental regulations governing power plant operations, including emission limits, generator operating constraints, heat rate curves, and outage schedules, as is computationally feasible. The models have the capability to assess the impact of compliance costs, emissions trading schemes, and regulatory changes on investment decisions. Including important generator operating constraints allows for the flexibility needs of the system to be captured within the CEM framework. One possible approach to incorporating emissions constraints and other energy-based constraints into a CEM would be to impose operational limits on affected resources that are informed by a previous PCM analysis. Emissions constraints in particular may sometimes be overridden during high-risk load-shed periods, so it is important to be aware of the specific area's regulations when modeling this process.
Energy Supply Adequacy	CEM buildouts should be evaluated using RA models to ensure a reliable energy supply for scenarios that minimize costs and environmental impacts. This may require pairing these CEM tools with related tools, as described in earlier parts of this section, or even tools specifically designed to perform ERAs.

Table 5.3: Considerations for Applying Capacity Expansion Models to ERAs	
Consideration	**Description**
Electric Vehicles (EV)	Models should account for the growth of EVs and their impact on electricity demand patterns, grid congestion, and infrastructure requirements. They should analyze charging behaviors, load profiles, and grid integration challenges to ensure that the selected resource buildout is reflective of the needs of the electric transportation system.
Non-Transportation Electrification	Models should consider the uptake and usage patterns associated with electrification technologies in non-transportation sectors. They should assess the shifts in timing and seasonality of load profiles and usage patterns to optimize resource deployments.
Energy Storage	Capacity expansion models should consider the role of energy storage technologies, such as batteries, pumped hydro, and thermal storage, in enhancing grid flexibility and reliability. They should optimize the sizing, placement, and operation of energy storage systems to address intermittency, ramping requirements, and system balancing needs.
T&D Export/Import and Deliverability	CEMs should model the interconnection capacity and transmission constraints between different areas or neighboring systems, considering import/export capabilities and congestion management strategies, as is computationally feasible. In a traditional CEM model, including key interfaces through a zonal constraint model is recommended. Interface limits should be set to account for thermal limits as well as voltage Stability Limits and line losses. In a more advanced CEM model, nodal analysis may be possible, or transmission expansion may be co-optimized with generation expansion. A full analysis of T&D systems is likely an external process but would be useful to gauge the validity of the results from a CEM.
Essential Reliability Services and Other Ancillary Needs	Capacity expansion models should incorporate the provision of essential reliability services, such as Frequency Regulation, voltage support, reserves, and blackstart capability, from diverse sources in the generation mix. Analysts should consider including provisions to evaluate the cost effectiveness and technical feasibility of providing these services through various generation, storage, and demand-response options.

Power System Operational Modeling Tools

At the opposite end of the spectrum from CEM and PCM are power system physical simulation tools. This family of tools is used to study very short-term transient periods, typically only a few cycles (or seconds) in duration, on the system. These tools simulate the physical behavior of power systems under various operating conditions, including Disturbances, contingencies, and dynamic responses. While it may not be readily apparent, these tools may play an important part in the successful execution of an ERA. While not necessarily incorporated directly into an ERA process, these tools would help an analyst gain an understanding of the fundamental engineering-driven equipment responses that are not captured in lower time resolution models (PCMs, CEMs, RAs). Operational modeling tools may provide insights into different concerns and solutions (e.g. fault ride through) and allow them to create more precise models when needed to assess energy reliability.

Operational models can address a variety of questions crucial for ERAs, including the following:

- Can the system maintain synchronism and Stability following Disturbances, such as Faults or sudden changes in load or generation, and what assumptions would be applied in an ERA to such a Disturbance?

- How do the different components of the power system, including generators, transformers, and control systems, respond to changes in operating conditions, resulting in how they would be modeled in an ERA?
- Can the system maintain voltage and frequency within acceptable limits under varying conditions, or is a different set of resources needed to supplement the expected commitment and dispatch?
- How do equipment failures or other contingencies impact system reliability and performance?

Operational modeling tools excel at providing detailed insights into the dynamic behavior of power systems during transient events. They accurately capture the interactions between various system components and can simulate complex scenarios with high fidelity. These tools are valuable for identifying potential vulnerabilities and assessing system resilience under different operating conditions. This family of tools includes the most detailed representation of the transmission system but at the expense of a lesser representation of generator constraints.

Operational models encompass various software packages and computational techniques designed to simulate the dynamic behavior of power systems during operational conditions. Some of the key tools are listed as follows:

- **Transient Stability Analysis Tools:** Simulate the dynamic response of power systems following Disturbances such as Faults, sudden changes in load, or contingencies. They assess the system's ability to maintain synchronism and Stability over short time frames, typically ranging from a few cycles to a few seconds.
- **Dynamic Simulation Software:** Model the behavior of power system components, including generators, transformers, transmission lines, and control systems, under varying operating conditions. They provide insights into voltage and frequency dynamics, system oscillations, and response to control actions.
- **Contingency Analysis Packages:** Evaluate the impact of equipment failures, line outages, or other contingencies on system reliability and performance. They identify critical contingencies and assess the effectiveness of mitigation strategies, such as Remedial Action Schemes and automatic load shedding.
- **Voltage and Frequency Regulation Tools:** Focus on analyzing the system's ability to maintain voltage and frequency within acceptable limits under normal and abnormal operating conditions. They assess the effectiveness of automatic voltage control devices, governor systems, and other control mechanisms.
- **Wide-Area Monitoring and Control Systems (WAMS):** Use real-time measurement data from synchronized phasor measurement units (PMU) to monitor and control power system dynamics over large geographic areas. They provide situational awareness, early Fault detection, and system-wide Stability analysis capabilities that can be used to detect unexpected dependencies that can then be modeled in an ERA.

While these tools offer valuable insights, they have limitations, including computational intensity, complexity, data dependencies, and scalability. Simulating short-term dynamic events requires significant computational resources and time, therefore limiting the scope of analysis. The complexity of power system dynamics can make it challenging to model all interactions accurately. Simplifications and assumptions may be necessary, which can affect the accuracy of results. Operational models rely heavily on accurate data inputs, including system parameters, network topology, and equipment models. Inaccurate or incomplete data can compromise the reliability of simulation results. These tools may struggle to scale up to large, interconnected power systems or to incorporate detailed representations of DERs effectively. They may also be unable to capture impacts of certain issues, such as control interactions between inverter-based resources, for which electromagnetic transient (EMT) tools would be necessary. These issues are well covered by other NERC activities related to modeling for IBRs, including the Inverter-Based Resource Planning Subcommittee (IRPS). Additionally, these tools can only analyze one operational condition at a time and, as such, are not well suited to analyze a large number of uncertainty scenarios for a full study horizon. Since they can only model one system snapshot at a time, they also are not well adapted to analyzing energy sufficiency issues.

Operational models offer flexible resolution capabilities, allowing users to adjust time steps and time horizons based on the specific requirements of the analysis. Shorter time steps enable more detailed simulation of fast transients, while longer time horizons facilitate assessment of system behavior over extended periods.

Operational models typically represent generation and transmission (G&T) components in detail, including generators, transformers, transmission lines, and control systems. These components are modeled using mathematical equations and algorithms that capture their dynamic behavior accurately during transient events. However, the level of detail and complexity in G&T representations may vary based on the specific objectives and constraints of the reliability assessment. Demand is also represented in various ways, with more detailed models that can cover different types of loads, as well as DER, being increasingly represented in such models.

This is currently the only family of tools that is directly covered by established NERC standards—the MOD family of standards. These tools are used directly in the study of power system reliability through the performance of power flow simulation to assess system dynamics, Stability, optimal power flow, and many other short-term transient conditions. Unlike the prior families of tools that produce solutions driven by economic least-cost optimization, power flow tools are not economically constrained. This family offers many tool options to an analyst performing an ERA, including both open-source and commercial options; however, industry has primarily settled around a small handful of mature commercial tools in this space driven by regulatory requirements. Application in an ERA would be limited to having a better understanding of dependencies, which would then be modeled in ERA-specific tools or other modeling tools that feed the ERA process.

Screening Tools

In addition to the detailed tools described above, specialized simple tools covering one or more items are often needed to create a narrowed set of scenarios or considered variables. These may include Contingency screening tools, probabilistic screening tools to identify likely energy reliability risk scenarios for deeper exploration, and/or covariance of inputs (e.g., load dependence on weather, outage dependence on the same weather input, and higher generator capability with cold air input). The choice to use these tools is often narrowed by the need to supplement experience-based judgments.

Interdependence Tools

The family of models in this category are those that simulate items that intersect or impinge on electric system planning and operation that may be used to inform the performance of an ERA or mitigation plan development, including commodity, supply chain, transportation, weather, and economic sector models. Since these models can vary in complexity, cost, and availability to the analyst or entity performing an ERA, performers are advised to closely consider the needs and benefits for including these types of models in an ERA over the use of engineering judgment. Often, it is only feasible for the entities to include these types of models in a planning ERA because of the major differences in modeled time domains compared to the electric sector; however, this is not always the case as information from these models may be available through collaborations with partners and other industries. Examples of benefits from including non-electric sector models in the performance of an ERA include establishing feedback loops to capture the dynamic interdependency concerns that may not otherwise be captured. For instance, inclusion of detailed natural gas models can significantly improve an entity's ability to mitigate against natural gas-electric interdependency concerns as these models can be used to develop price and congestion forecasts, which can be integrated with or used to inform electricity models, such as a PCM, to determine re-dispatch or fuel switching solutions. Similarly, rail and truck transport models can be used over a longer-term horizon, enabling an entity to assess whether mitigating actions are needed to accommodate fuel and consumables stockpile replenishment timelines.

Implementation

Any analyst performing an ERA would need to evaluate the benefits and shortcomings of each model and consider the needs and objectives of the ERA when determining what model, or models, should be employed in the performance of their assessment. Models can feed bi-directionally to inform each other, as binding constraints from one family may not be captured or identifiable in another. For example, it may be desirable to move from a low level of detail to a higher level of detail to evaluate identified periods of concern or to pass constraints identified in higher-detail models to the lower-detail model (i.e., congestion constraints identified in a power flow that are not captured in a first-pass PCM or CEM). Implementation and performance of an ERA may be iterative within and between tools depending on the scenario design and desired outcomes. Figure 5.1**Error! Reference source not found.** illustrates the interdependencies of tools involved in the ERA process, including some of the tools detailed above.

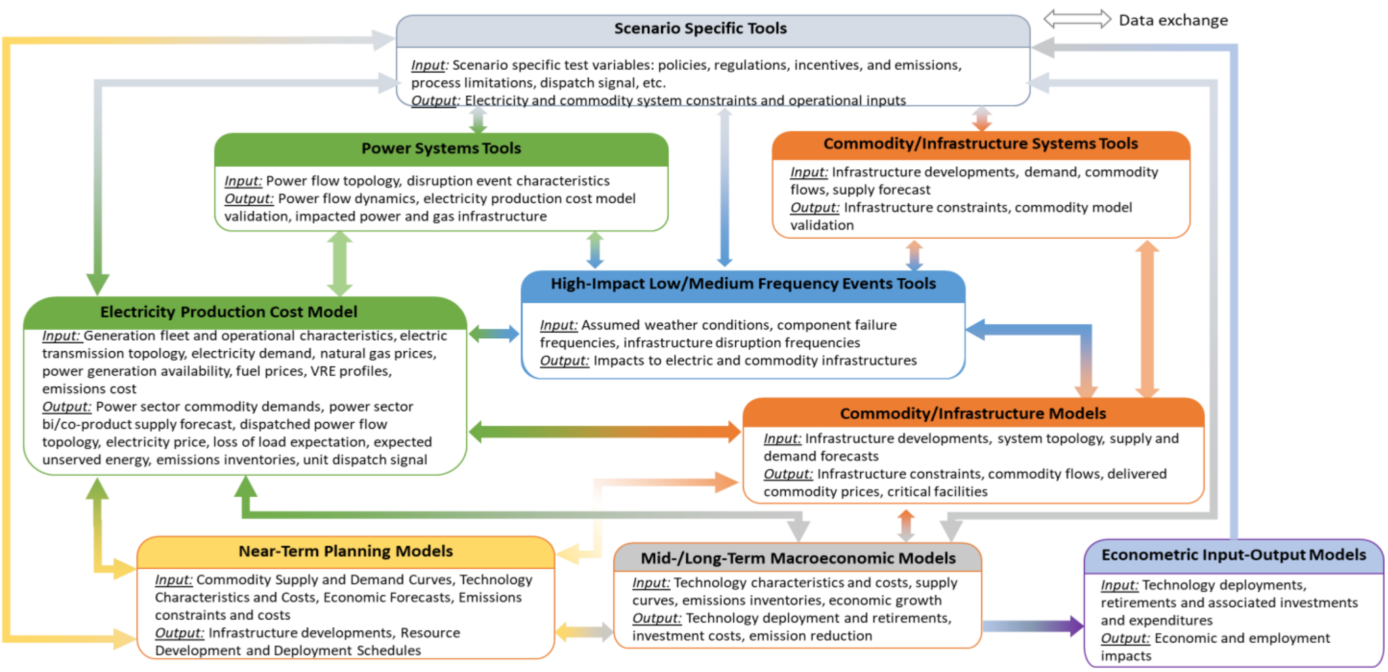

Figure 5.1: Illustrations of the Interdependence of Tools as They Relate to the ERA Process

Chapter 6: Base Case and Scenario Modeling

Base Case

The base case for an ERA is a model of projected power system conditions for a specific point in time. From the base case, additional scenarios and contingencies can be applied for further analysis of risks. Studying the base case will give an analyst a view of a standard starting point. Since ERA is a look at a certain time period, a base case would include the most-likely-to-occur series of conditions over the defined period.

Several input considerations should be included in an ERA. Ultimately, the base case represents the *expected* quantity for all the input considerations in each interval (e.g., hour, day, week) of the assessment. The contributing factors that the analyst will associate with are their contribution to energy, either from the supply or demand point of view. Starting with demand, and the input factors that contribute to demand. All the contributing factors that drive demand (e.g., weather, behind-the-meter generation, industrial processes, seasonal considerations, electrification) would be modeled as the *expected* value for each, resulting in an *expected* demand value. Likewise, for supply capabilities and availabilities, the analyst would use the *expected* values for production capabilities, fuel supply factors without Contingency, and any other factor that would contribute to the availability of supply resources.

The term "base case" in an ERA is used generically, meaning that it is a set of baseline assumptions that define a reference point by which scenarios and contingencies would be applied. The term base case is **not** intended to draw any similarities to transmission base cases that are used for transmission planning studies; however, it is also not intended to disallow transmission studies to be coupled with ERAs. How a base case is defined may depend on the time horizon of the ERA. Near-term, seasonal, and planning base cases have a variety of differences in how particular inputs are modeled or formulated.

Near-term base cases will likely start with a forecast set of conditions or verified known quantities. Near-term base cases start off with higher certainty in weather, demand, planned outages, fuel availability, transmission capability, etc. In a deterministic analysis, a median forecast or known quantity would serve as the base case for all parameters and then be varied using specific scenarios as needed. In a probabilistic analysis, a number of probabilistically weighted replications representing operational uncertainties (primarily due to Forced Outages and weather uncertainty) would be used to create a base case, with various specific scenarios relating to other system risks being subsequently analyzed as needed.

Seasonal base cases introduce some uncertainty over near-term base cases due to the longer time horizon but still require the outlining of an appropriate set of system conditions representative of the time horizon modeled. These system conditions need to be determined by the analyst using the tools and information available but are intended to be similar in nature to near-term base cases. Longer time horizons will likely depend more on scenarios than shorter-term base cases, but a base case should be established to introduce uncertainty. With enough scenarios, emphasis on the accuracy of a base case gives way to a variety of possibilities. There will be seasonal considerations for both supply and demand. Seasonality will have a different impact depending on what system is being assessed. The intent of modeling the *expected* conditions does not change based on the season being studied; it just changes what the literal assumptions are.

Planning base cases again should outline an appropriate set of system conditions, even given the increased uncertainty associated with a more distant study time horizon. As such, planning ERAs will depend much more heavily on a comprehensive scenario analysis to form a complete picture of future risk as compared to short-term ERAs, where a base case analysis may be sufficient.

While scenarios and contingencies gain importance as the horizon increases, it remains necessary to define a reasonable base case. The results of the ERA on the base case will be important in conveying risk. If base-case assumptions result in energy shortfall or other unfavorable conditions, the base case may not be defined properly, or the proposed system may not be prepared to reliably serve energy demands and require corrective actions sooner than anticipated. It is also helpful when applying scenarios to have a base case to compare results, which allows an analyst to point to specific parameters and convey trends.

All base cases should be defined as part of a repeatable process, especially if the ERA is intended to be performed routinely, to allow for comparison and metric tracking and trending. That process can be updated over time as knowledge and experience dictates. There is some likelihood that base cases will be developed in accordance with stakeholder-approved processes and may not have the flexibility to change frequently. Provisions for updating assumptions in the base case and then again in subsequent sensitivities and scenarios should be included in the process for when large, unexpected changes happen that were not included in the original base case or new methods become available that make for more robust modeling in a base case. Examples would include large resource unplanned outages (e.g., nuclear power station trips) or major transmission system element failures.

One last consideration for base-case assumptions is the verification of the reasonability of assumptions, after the time that was assessed has passed and actual observations are available. Items that were identified in prior scenario models may influence an evolution in base case modeling. It is impossible to forecast energy assessment conditions with 100% accuracy. However, with a large enough sample size and a series of assessments, they can be benchmarked against actual conditions and the analyst can detect and minimize or eliminate biases.

Scenarios and Risk Assessment

Risk is a product of three primary components:

- The events or scenarios considered
- Their likelihood of occurrence
- Their associated impact

Choosing the scenarios (or method of generating scenarios) appropriately is critical to a robust risk assessment and tolerance definition because these choices determine the outcome of an ERA, either implicitly or explicitly by their likelihood of occurrence. While defining an objective standard is not easy, the analyst should consider the expected or likely, credible, and even worst credible scenarios with their associated risk metrics or criteria based on their inherent risk tolerance to fully assess risk through an ERA. **Chapter 7:** discusses how to use metrics and criteria to evaluate risk and communicate that risk based on the method and scenarios used.

Sensitivity and Scenario Modeling

Sensitivities and scenarios are not new concepts to industry planners but are looked at from a different angle in an ERA.

The following is an excerpt from page 13 of the NERC Probabilistic Assessment Technical Guideline Document:[36]

Sensitivity Modeling: Sensitivity analyses are run to assess the impact of a change in an input (either load, transmission, or resource-related) on resource Adequacy metrics. The runs are performed by changing one input at a time to isolate the potential impact of each input. Ideally, the change in each input should be accompanied by an associated probability.

Scenario Modeling: In its most general form, a scenario analysis is performed to assess the impact of changes in multiples inputs (either load, transmission, or resource-related) on resource Adequacy metrics. The runs are performed by changing multiple inputs at the same time. Ideally, each scenario should have an associated probability calculated based on the changes in inputs included within the scenario. Scenarios are likely to be identified in the

[36] https://nerc.com/comm/pc/pawg%20dl/proba%20technical%20guideline%20document_08082014.pdf

NERC *Long-Term Reliability Assessment* or by sensitivity analysis results. In some cases, scenario analysis may require additional inputs (not included in the Core Probabilistic Assessment) relevant to address a specific reliability concern.

While these descriptions are specific to the NERC Probabilistic Assessment (ProbA), application to an ERA is similar. Sensitivity modeling adjusts one input parameter and scenario modeling adjusts multiple input parameters.

In probabilistic ERAs, each uncertainty will have an associated probability of occurrence. The analyst should understand what the appropriate probability is and what it means for an ERA's outcome. Some inputs may have equal chances of occurrence (e.g., weather assumptions for upcoming seasons), while others may have a higher chance to a specific value (e.g., weather forecasts for the next seven days). Further, some inputs may have a lesser chance of occurrence but a larger impact on the outcome of an ERA. However, it is challenging to assign a probability of occurrence to certain uncertainty pathways. This is particularly true for the evaluation of macro risks, such as policy changes and shifts in macroeconomic conditions. A sensitivity or scenario analysis would be particularly useful for analyzing the risk associated with these types of uncertainties.

Scenarios should be selected to analyze certain conditions, either simple or complex, with a reasonable risk of occurring that stress the system beyond the conditions modeled in the base case to examine risks that the system may experience. This is especially important for conditions for which the entity wants to be prepared. Scenarios in an ERA would have varying levels of severity. Consideration should be given for how the results of a scenario will be compared to specified criteria. For example, low-impact scenarios should not result in outcomes with unacceptable consequences (e.g., a scenario similar to the base case probably should not result in a relatively large-magnitude energy shortfall). Conversely, it may be appropriate to get results with large-magnitude energy shortfall when the worst-case scenario for all inputs is selected. The analyst would need to determine the degree of variance that would be needed to create that stress and approach shortfall. It is likely that multiple iterations would be required when initially setting up multiple scenarios (e.g., if the first attempt adds no stress, more variances may be required).

Credible risks are events that are plausible to occur and would have a severe impact. The choice of scenarios, paired with the selection of metrics and criteria (discussed in Chapter 7), helps set the level of risk or reliability around which an entity plans and designs a system and expects reliability to be maintained. Scenarios should be chosen such that the entity can describe and document the scenarios that have some risk of occurring, and their system should be designed to operate reliability through that occurrence.

As the term "credible" is inherently subjective, formulating conditions that would be considered credible may require research and effort to ensure that a scenario would be accepted as "credible." Some examples that will lend credibility to scenarios include industry assessments, academic research papers, documented historical event reports, verified analyst experience, the judgment of subject matter experts, and statistical evaluations. Conditions that have happened before, locally or in other similar locations, also lend credibility in terms of historical events. Nevertheless, just because an event has happened before does not necessarily mean that it will happen again. Similarly, just because an event has not happened in the recorded past does not mean that it cannot happen in the future.

Finally, scenarios will have inputs that are co-dependent on a similar driving factor, such as demand, variable supply (e.g., solar and wind), outage assumptions, and fuel availability all being co-dependent on weather. These inputs should be coupled together when modeling input assumptions. Decoupling related co-dependent assumptions can result in impossible scenarios. Including these scenarios in a solution set and comparing the results of that solution set to a criterion can give biased results, potentially triggering actions to be taken for a scenario with a 0% probability of occurrence. Worse, these impossible scenarios dilute the pool of results and can potentially mask indications of real problems in ERAs. Additionally, certain severe events that are only present when weather outputs are properly correlated could fail to be captured within the analysis.

Near-term scenarios will likely have less variability than seasonal or planning scenarios. Higher certainty in data allows for the use of forecasted conditions rather than assumptions in the base case and can limit the variability in scenarios. Demand, fuel supply availability, generation and transmission outages, stored fuel inventories, emissions limitations, and most other input assumptions present some level of clarity in the near term, and a high degree of variability may not be necessary. Resources that inherently operate with a high degree of variability (e.g., wind and solar) are exceptions, and the variability of some inputs may not change from near-term to planning ERAs.

Scenarios in seasonal ERAs may need to offer more variability than those in the near term. Some variability would remain similar, as mentioned before with wind and solar supplies. Some inputs (e.g., weather, demand, planned outages) would introduce some additional variability and should be understood by the analyst to define scenarios that would be considered credible. Further, some inputs would remain predictable with limited variability (e.g., which generators and transmission capabilities are built). Weather scenarios in seasonal assessments can be limited by long-range forecasts (e.g., NOAA outlooks, El Niño conditions and forecasts), which should be used with caution to avoid overlooking potential real conditions. Long-range forecasts provide a general direction over a long period of time (i.e., month or months) but may not capture the possibility of shorter-duration spell of more extreme weather embedded within the outlook period.

Scenarios in planning ERAs are completely based on assumptions rather than forecasts. Historical information coupled with assumptions for expected changes gives the analyst information that can be used to determine credible scenarios. For example, historical demand could be used to represent future demand, so long as it is adjusted for any known changes in climate, coupled with growth/contraction assumptions. For longer-term ERAs, this becomes even more critical given the anticipated greater reliance on weather-dependent resources on the BPS. Supply resources are more uncertain in long-term ERAs but are not completely uncertain. A variety of factors need to be considered when creating long-term scenarios. For example, the future resource mix will be influenced by economics, technological advances, environmental policy and regulations, and other incentives to build new resources. Many of those factors will impact all infrastructure expansion and would need to be researched to be plausibly varied in a longer-term ERA.

Chapter 7: Study Metrics and Criteria

Purpose of Metrics and Criteria

An ERA will show an analyst what the outcome of a range of events or operating conditions would look like. To determine what the risk is and whether that risk is acceptable, there must be some metrics and associated criteria (or minimum thresholds) for comparison and evaluation of risk. The evaluation of system Adequacy using these metrics and criteria will drive when and what corrective actions may be required to minimize the impact of the perceived risks. Metrics are measurements derived from deterministic or probabilistic Adequacy analysis to indicate the reliability or risk to the system while criteria are a set standard to determine if the level of a metric is acceptable. In the case of ERAs, a criterion for a metric might be set such that if it is not met, some mitigation activities need to be performed.

Metrics and criteria are useful for four purposes: quantifying the risk, setting a risk tolerance or identifying what risk is acceptable, evaluating whether the risk of the system is acceptable, and comparing potential risk-reduction activities. Based on these purposes, the method and scenarios of the ERA should quantify the current risk, the analyst should have defined a risk tolerance specific to the scenarios based on evaluation criteria, and the analyst should use those criteria or metrics to evaluate whether and what interventions are needed.

Traditional RA processes, metrics, and tools may not be fully able to evaluate Adequacy requirements and properly articulate risks in the context of an evolving resource mix, changes to demand profiles, and extreme weather scenarios. The evaluation criteria and associated metrics should be based on the methods used in ERAs, the level of risk that entities can tolerate, and how entities want to quantify and present the risk. Considerations for stakeholder involvement in the development of metrics will be a key input to the process. Expertise, responsibility, and authority to address deficiencies will all likely fall with different entities and should be coordinated for all stakeholders. A significant challenge is to identify appropriate ERA metrics that provide a comprehensive picture of system risk to planners, operators, regulators, and policymakers and to set minimum Adequacy criteria that reflect both the costs and benefits of avoiding excessive unserved energy, the frequency and duration of loss-of-load events, and the risk of energy deficiency that areas can accept. The names of some of the metrics are not different whether used in a capacity- or an energy-based assessment but represent the specific capacity or energy risk depending on the methods and quality of the analysis method used to calculate the metrics.

Existing Metrics

Many reliability and Adequacy metrics used within the capacity assessment framework can be directly used in an energy assessment framework. To understand the risk of losing load, an analyst needs to consider the duration of events, the magnitude of the loss of load, and frequency of the loss of load.

Deterministic Metrics and Criteria

Deterministic metrics can be useful in examining a specific forecasted scenario or set of scenarios that the analyst expects to occur, including, in certain situations, tail-risk events (high impact/low frequency [HILF]) that can provide a system design basis for planning purposes. Using deterministic scenarios is especially helpful if the analyst wants to stress test an electrical system model to understand if the system can reliably meet certain minimum thresholds with respect to criteria including unserved energy, energy emergency alert (EEA) levels, or a higher reserve margin under extreme weather or system conditions.

Creating credible lower-probability but high-impact events and assigning a deterministic criterion to them allows the analyst to set a risk tolerance for those events and what their expectations are for handling severe events. The analysis of these high-impact events is useful to understand how the system may behave during these events and allow for planning that is more resilient even if the expectation is that the system may experience some adverse or abnormal conditions if those events occur.

Unserved Energy

Unserved energy is the amount of load that is not served in terms of energy for a given time period, generally expressed in MWh. Unserved energy can be determined for individual deterministic scenarios with a limit in the amount that you will accept during severe contingencies for a given time period, generally expressed in MWh.

Forecasted Energy Emergency Alert

EEAs are defined in NERC Standard EOP-011-1,[37] Attachment 1 as follows:

- **EEA 1**: All available generation resources in use
- **EEA 2:** Load management procedures in effect
- **EEA 3:** Firm load interruption is imminent or in progress

These thresholds are useful for connecting the forecasted or possible Energy Emergency that might be observed in an ERA to the actual Energy Emergency events that the analyst is trying to avoid. These thresholds indicate system conditions that would be considered energy emergencies even if load loss is not expected to occur. Using the increasing level of impact of the EEAs as criteria may be useful to setting criteria for increasingly less probable but impactful events.

For example, ISO New England uses Forecasted EEAs[38] (FEEA) in near-term ERAs, leveraging the existing and well-understood EEA definitions. FEEAs can be used as an indication that available resources during any hour of an ERA are forecasted to be less than the quantity defined by EEAs. The EEA metrics have been used consistently for many years in ERAs.

Reserve Margins

Reserve margins requirements can be set as criteria to have a sufficient amount of excess energy or capacity available beyond generation levels needed to meet demand. This threshold provides an additional buffer before expected load loss and therefore a lower expectation of impact in any scenarios that are simulated. These reserve margin requirements could be based on a fixed value or a set percent of energy demand or be related to Ancillary Service requirements or uncertainty of supply or demand variables.

Probabilistic Metrics and Criteria

Probabilistic methods allow the analyst to assess risk based on a wider range of scenarios and better incorporate the likelihood of the events occurring than individual deterministic scenarios. The resulting probabilistic metrics are based on all the events simulated or statistical calculations and combined into statistical values of shortfall events. The metrics more explicitly reflect risk across a range of operating conditions instead of a design around a specific defined scenario's result. However, individually the metrics may not reflect as clearly the frequency, durations, and magnitude of expected events.[39]

All the following metrics can potentially be calculated based on the same set of ERA simulations and may not necessarily require separate probabilistic analyses to be performed.

Loss of Load ExpectationError! Bookmark not defined.

LOLE is the expected number of days per periods (generally studied for a year) for which the available generation is insufficient to serve demand. The calculation is based on whether shortfalls are observed during individual scenarios and the likelihood of those events occurring. As a result, the metric reflects the frequency of events or at least the

[37] https://www.nerc.com/pa/Stand/Reliability%20Standards/EOP-011-1.pdf
[38] https://www.iso-ne.com/static-assets/documents/rules_proceds/operating/isone/op21/op21_rto_final.pdf
[39] See: Probabilistic Adequacy and Measures Report - 2018

number of days with loss-of-load events but does not give any information of the expected duration or magnitude of these events or even if multiple events occur on the same day.

In an ERA, LOLE would be tailored to the defined study period but would effectively mean the same as in capacity assessments, event-days per period. LOLE would not show depth of shortfall, only the likelihood of the occurrence of a shortfall. Used in combination with the EUE metric, this metric can have criteria defined to trigger corrective actions. For example, a threshold for the number of shortfall days you are willing to risk loss of load for a given time period, such as 0.1 days per year (similar to the 1 day-in-10 year reliability metric that is often cited across the industry), might be useful.

Loss of Load Events

Loss of load events (LOLEv) is the number of events per period (generally on a per-year basis) when load is lost. This metric differs from the LOLE metric in that LOLEv takes into account days with multiple loss of load events and records one event for multi-day loss of load events. Using LOLE alone will obscure multiple events occurring during a single day. Multiple events in a single day may be different magnitudes and may occur at different times of day, reflecting inherent differing system conditions and associated risk.

Loss of Load Hours

Loss of load hours (LOLH) is the expected number of hours per period (generally on a per-year basis) when a system's hourly demand is projected to exceed the available generating capacity. This metric is calculated using each hourly load in the given period instead of using only the daily peak in the classic LOLE calculation.

With LOLH reflecting the duration of energy shortfalls better than LOLE, LOLH can be used in an ERA in combination with EUE, and perhaps LOLE, to set a limit on the number of LOLH. Limits could be conditional as well by including system conditions with the metric, for example, limiting LOLH to 12 hours as long as no more than 2 of the hours are below 32°F.

One caution to this approach is that higher precision does not necessarily lead to higher accuracy. When working in a longer-duration energy space, actions are available to move some shortfall from one period of time to another. LOLH may not be an appropriate metric for this reason.

Expected Unserved Energy

EUE[40] is the measure of the resource availability to continuously serve all loads at all delivery points while satisfying all planning criteria. EUE is energy-centric and analyzes all hours over a period of time. Results are calculated in MWh or can be normalized to expected demand. EUE can be normalized (NEUE) as a percentage of total energy demand. In an ERA, EUE can be used to show the expected energy shortfall over the duration of a study period. The study period would be carefully defined to examine the impact of a specific risk (e.g., the duration of a long-duration cold spell or heat wave or duration of a drought). EUE would be cumulative over the selected duration but could also be combined with LOLE or LOLH. For example, a limit can be placed on the total MWh of EUE while also satisfying a limit on the number of days or hours where a shortfall may occur throughout the study period.

Limits on EUE could then be used to inform and/or trigger corrective actions to be taken to maintain reliability.

Loss of Load Probability

Loss of load probability (LOLP) is the probability of system daily peak or hourly demand exceeding the available Electrical Energy during a given period.

LOLP can be useful for probabilistic ERAs when defining risk associated with EUE or LOLE/LOLH.

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[40] https://nerc.com/comm/pc/pawg%20dl/proba%20technical%20guideline%20document_08082014.pdf

Value at Risk and Conditional Value at Risk

Value at risk (VaR) and conditional value at risk (CVaR) are risk metrics that evaluate the tail Adequacy risk instead of an average or expected risk. VaR and CVaR are used in the finance industry to measure risk, especially related to tail risk or the magnitude of impact of lower-probability but higher-impact events. VaR is the maximum loss at given probability or confidence interval and can be calculated as the loss for a given percentile of scenarios. CVaR is similar to VaR but is the average risk of losses above a given percentile of losses (e.g., average losses of the 95th percentile or higher losses). These metrics are not specific to any energy concept but can be applied to many energy metrics, such as LOLE, LOLH, or EUE. These metrics differ from the other probabilistic methods discussed in this document as the VaR results are based on a percentile or confidence level, while CvaR is based on a conditional metric. These metrics are therefore good indicators of tail risk and the impact of lower-probability and higher-impact events. LOLE95 and LOLH95 are currently used examples of these metrics.

Figure 7.1 illustrates an example of VaR and CVaR of energy deficiencies based on a probabilistic ERA. The figure is a histogram of the energy deficiency results calculated from the assessment. The 95% VaR of energy deficiencies (shown by the black line) is 236.6 MWh, which means that the assessment expects that 95% of scenarios will have 236.6 MWh or less of load loss.

The 99% CVaR of energy deficiency of 485.3 MWh loss means that the average load loss for the worst 1% of scenarios is 485.3 MWh.

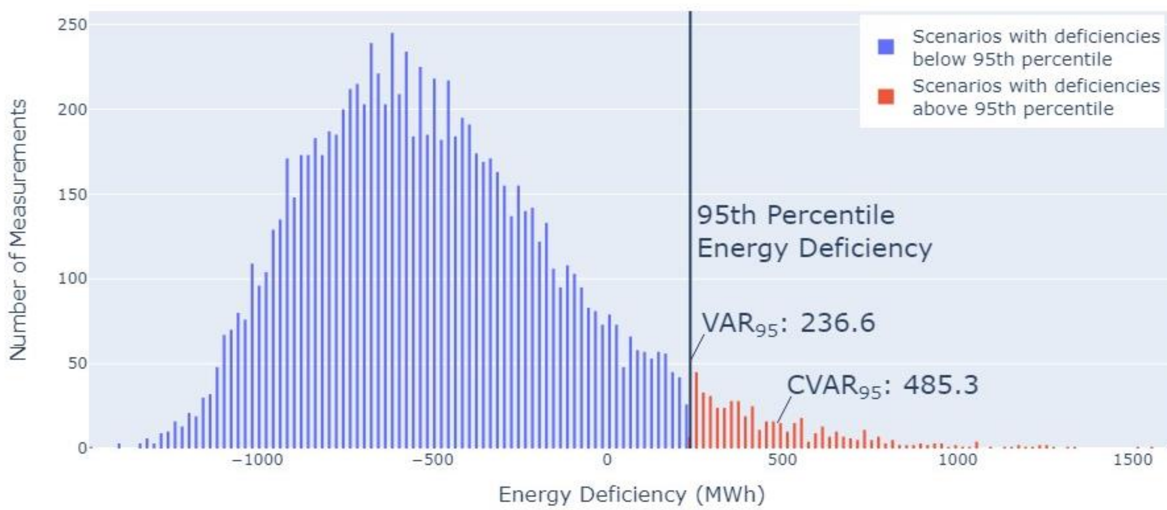

Figure 7.1: Example of VaR and CVaR for the 95th percentile of energy deficiency. VAR is 236.67 since it is the 95th percentile of the measurements and CVAR is the mean of the values greater than the 95th percentile (shown in red).

Selecting the Right Metrics and Criteria

The methods used to perform an ERA should be decided on in the early stages of development and will drive subsequent decisions and/or potential corrective actions. Methods and metrics would likely be developed in tandem with one another and are inherently subject to the risk tolerance of stakeholders. Considerations for scenario-dependent, deterministic metrics would also be part of that development. Probabilistic ERAs will have different metrics and criteria than deterministic ERAs. Similarly, scenarios with varying levels of supply loss or additional demand will have different minimum criteria than “all-facilities-in” or “normal conditions” ERAs.

It is also necessary to decide what parameters are important for measuring while staying in alignment with existing standards or other requirements. For example, the decision point on either maintaining some amount of Operating Reserves[41] or avoiding energy shortfall (i.e., load shed) comes early in the process and may vary by scenario simulated. Considerations for operations procedures or actions should also be taken into account when establishing criteria. This decision will also guide the analysts on what information is needed to come out of the ERA.

Using Deterministic Metrics

Deterministic ERAs and associated scenarios imply that a small set of discrete possibilities are examined. These scenarios make it easier to inspect and determine what mitigation activities would lower the risk of specific scenarios. This facilitates communication of the choice of mitigation activities and identified problems.

Using Probabilistic Metrics

Probabilistic metrics can be similar to those used in deterministic ERAs, with the addition of an associated probability, resulting in a metric that is defined as a criteria curve rather than a single point. The criteria curve would be on axes of the metric and probability, and the results of the ERA could be plotted against the criteria curve. The result of the defined criteria would then be a curve showing the results of the ERA versus a curve showing the pass/fail criteria.

Using Multiple Metrics and Criteria

Given that each metric represents an aspect of risk (frequency, duration, or magnitude), combining metrics is likely necessary to achieve the specified goals in performing the ERA. The use of multiple metrics will evolve and may even include using both probabilistic and deterministic methods to enable a better understanding of resource and energy Adequacy conditions.[42]

The reliability or risk thresholds can be set by a number of entities, not always the one performing the ERA or implementing the corrective or preventive actions. Criteria should be set through some stakeholder process, formal or otherwise, to ensure that affected parties are able to contribute and convey their concerns.

Table 7.1: Representation of Metrics in ERAs

Metrics	Type of Metric	Can Represent Duration	Can Represent Frequency of Event	Can Represent Magnitude or Impact of Events	Can Represent Tail Risk
Forecasted EEA	Deterministic			X	X*
Energy Reserve Margin	Deterministic			X	X*
Unserved Energy	Deterministic			X	X*
Loss of Load Probability (LOLP)	Expected or Average	X	X		
Expected Unserved Energy	Expected or Average			X	

[41] Note, for one example, that NERC Standard *BAL-002-3 – Disturbance Control Standard – Contingency Reserve for Recovery from a Balancing Contingency Event* may provide useful guidance on developing an ERA-based criteria for maintaining operating reserves throughout the duration of an ERA.

[42] See "New Resource Adequacy Criteria for the Energy Transition" for more discussion on choosing and using multiple criteria. https://www.esig.energy/new-resource-adequacy-criteria/

Table 7.1: Representation of Metrics in ERAs					
Metrics	**Type of Metric**	**Can Represent Duration**	**Can Represent Frequency of Event**	**Can Represent Magnitude or Impact of Events**	**Can Represent Tail Risk**
Loss of Load Events (LOLEv)	Expected or Average		X		
Loss of Load Expectation	Expected or Average		X		
Loss of Load Hours	Expected or Average	X			
Value at Risk	Conditional or Percentile	X**	X**	X**	X
Conditional Value at Risk	Conditional or Percentile	X**	X**	X**	X

* Deterministic metrics can represent tail risk if being applied to a stress test or "extreme" scenario

** VaR and CVaR metrics can represent duration, frequency, or magnitude depending on whether they are applied to LOLH, LOLE/LOLEv, or EUE

Chapter 8: Considerations for Corrective Actions

After performing an ERA and comparing the results to a set of defined criteria, if it is determined an energy shortfall is forecasted, the following actions could delay, reduce, or eliminate a potential realization of the forecasted energy shortfall or forecasted conditions that exceed the pass/fail criteria. Likely, the pass/fail criteria will be more conservative than a real-life situation that would cause an energy shortfall, ensuring that there is some level of Contingency Reserve or energy reserve to manage the uncertainty associated with the conditions being studied. However, there may be some allowable shortfall depending on the risk tolerance, reiterating the importance of understanding, and establishing the appropriate criteria when developing a response. A set of corrective actions can be formulated into an operating plan, Operating Process, Operating Procedure, Corrective Action Plan (all of which are NERC-defined terms),[43] or any number of documented or undocumented actionable steps to minimize the impact of an energy shortfall.

Possible corrective actions can range from some fairly limited in scope (e.g., enhanced communication and/or more frequent assessments) to widely expansive (e.g., controlled power outages across a Wide Area to conserve fuel that can be used when system conditions are at their worst), depending on the time horizon of the ERA. Near-term ERAs provide fewer options for mitigation than planning ERAs. Actions should be commensurate with the forecasted risk. Care should be taken to maintain reliability and minimize the impact on the BPS and the general public whenever possible. For example, public appeals should be considered before firm load shedding, when the option is available. Low-probability events may not require extreme responses. Awareness and outreach with regulators and other stakeholders will help define the acceptable and proper responses to energy shortfalls and may also help with the establishment of more defined criteria commensurate with the risk tolerance. For longer-term planning purposes, corrective actions would include actions targeted at addressing the specific deficiencies noted in the ERA, such as enhancements to market structures, delaying planned retirements, or increasing the projected new builds on the system.

Examples of and considerations for possible actions, along with the time horizon where the actions would be appropriate, are outlined in **Table 8.1**. This is not intended to be an all-inclusive list and may not apply in every situation. The responsible party performing these steps should use caution to ensure that they are effective and practical. It is becoming increasingly apparent that there is no single authority that can take action to remediate all energy reliability issues. Responsibility and authority depend on the actions being taken and can be assigned to the federal government (i.e., legislatures and agencies/regulators), state and/or provincial governments (e.g., legislatures and regulators), and registered entities (e.g., resource owners, independent System Operators). Sound judgment, awareness, and collaboration between all entities and organizations, coupled with a well-defined problem and a range of options for practical solutions, is the most appropriate path to finding a solution to the forecasted energy reliability problem.

Table 8.1: Considerations for Recommended Corrective Actions in Response to Energy Shortfalls

Corrective Action	Time Horizon(s) [44]	Considerations
Enhanced Communication	NT S P	For many actions that can prevent or minimize an energy shortfall, the entity performing the assessment may not have the authority to take all the necessary corrective actions. Communicating early with parties that do have that authority

[43] https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf

Time Horizon definitions:

- NT = Near Term Operations Planning
- S = Seasonal Operations Planning
- P = Planning

Table 8.1: Considerations for Recommended Corrective Actions in Response to Energy Shortfalls		
Corrective Action	**Time Horizon(s)** [44]	**Considerations**
		allows for time to implement actions in the most efficient and successful manner. Pre-deficient communications should be considered as well. Depending on the time horizon, this can be in the form of seasonal workshops and tabletop exercises or simply holding meetings to inform parties of what indications they may receive and what actions they could take.
Perform more frequent ERAs	NT S	In a situation where highly variable inputs are driving the studied system into an energy shortfall, more accurate forecasts may be the solution. An assessment for several months or years in the future with a low to moderate probability of an energy shortfall may require more frequent assessments that refine the inputs as they become more certain. This allows the analyst to formulate plans with more concrete impact.
Capacity deficiency actions	NT	There are several capacity deficiency actions that would occur at the time when load shed is being used, in accordance with capacity-deficiency procedures. For an energy shortfall, there should be an understanding of what impact those actions will have to reduce or remedy the reliability issue. One example is using demand-response programs that target thermostats, hot or cold. When the setpoint of a thermostat is changed in response to a capacity deficiency, the temperature of a building is allowed to drift further away from comfortable settings. Unless those setpoints are maintained indefinitely, the energy requirement would remain relatively unchanged. Lowering the temperature setpoint on a cold day will draw less power over time but restoring the setpoint within only a few hours of lowering it will cause a temperature recovery, drawing the same amount of overall energy, just at different times.
Replenishment of fuel supplies	NT S P	ERAs will show when generators are expected to run out of fuel. Fuel replenishment is key to extending the operations of stored fuel resources. Replenishment actions are highly dependent on how the power system is operated in a given area. Vertically integrated utilities can procure and schedule fuel directly, where power market operators are limited in the actions that they can take, mostly to providing more information to those responsible for operating generators
Outage coordination	NT S	Outages can cause or worsen energy reliability issues. When detected, rescheduling planned outages of energy resources may be the solution to deficiencies.

Chapter 9: Conclusion

ERAs are a necessary component in the suite of tools used by power system planners and operators as more VERs and stored fuel dependencies gain prevalence. Gaps in traditional capacity assessment methods, when applied to energy-related issues, present risks where potential shortfalls can go undetected before a reliability event occurs. Efforts are underway to bolster assessment requirements and provide some clarity to industry such that these gaps can be better understood and undergo assessments that will allow planners and operators to take actions to reduce the impact of energy shortfalls or eliminate them altogether.

This technical reference document provides the reader with a framework that can be used to perform ERAs. From input assumptions and tools/methods to criteria and corrective action considerations, the audience has a better understanding of how to perform an ERA. With more experience, and as the resource mix continues to evolve away from resources with relatively assured fuels to those with a wider degree of variability, there will be opportunities to develop new methods to perform assessments with new tools, build models to enhance corrective actions, and more clearly define criteria and metrics such that ERAs are meaningful to stakeholders. The assessments described here are not intended to replace existing study work but to supplement that work and address energy-related assessment gaps necessary for understanding power system reliability.

Appendix A: Summary of Available and Suggested Data

This appendix is a summary of all the tables in Chapters 1 through 4 delineating what information may be useful in performing ERAs and where that information might be available to the analyst to retrieve.

Table A.1: Abbreviations for Summary of Potential Information Sources in All ERAs	
Category	**Abbreviation**
Stored Fuels	SF
Natural Gas	NG
Energy Supply Variability	ESV
Electric Storage	ES
Variable Energy Resources	VER
Emissions Constraints on Generator Operations	ECGO
Energy Supply Outages	ESO
Distributed Energy Resources	DER
Demand	D
Transmission	T

Table A.2: Summary of Potential Information Sources in All ERAs

Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
X	X	X	SF	Specific, usable[45] inventory of each generation station	Generator surveys Assumptions based on historical performance	Inventory is often shared for a group of generators located at a single station. Surveys should be performed as often as necessary to initialize an assessment with accurate information. It is recommended to start each iteration of an assessment with updated data. Hydroelectric resources may need to consider the availability of water as a fuel input – change over the course of the year or vary by year. Environmental limitations: water flows/rights priority, dissolved oxygen (DO) limitations, etc.

[45] Usable inventory is the amount of fuel that is held in inventory after subtracting minimum tank levels that are required for quality control and fuel transfer equipment limitations.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
						Stored fuels may be used for unit start-up with a portion embargoed for blackstart service provision.
X	X	X	SF	Minimum consumption requirements of fuels that have shelf-life limitations	Surveys of Generator Owners or Operators Assumptions based on historical performance	May result in a fuel being consumed at a time when it is less than optimal.
X	X	X	SF	Replenishment assumptions	Generator surveys Assumptions based on historical performance	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA.
X	X	X	SF	Shared resources	Generator surveys or registration data	Modeling the sharing of fuel between multiple resources allows for precise modeling of fuel availability.
X	X	X	SF	Global shipping constraints	Industry news reports	Stored fuel supply is often impacted by world events that cause supply chain disruptions, including port congestion, international conflict, shipping embargoes, and confiscation.
X	X	X	SF	Localized shipping constraints	Weather forecasts or assumptions, direct communication with local transportation providers, emergency declarations[46]	Considerations for local trailer transportation of fuels over wet/snow-covered roads, rail route disruptions due to weather or debris, as well as seaport weather when docking ships or river transportation route restrictions for barge movements.
X	X	X	NG	Pipeline transportation capacity	Pipeline Electronic Bulletin Boards (EBB), open season postings, firm transportation contracts	Interstate pipeline information is readily available through public sources, usually directly from the pipeline company itself.
X	X	X	NG	Gas pipeline constraints	EBB postings of operationally available capacity and planned service outages, pipeline maps	Starting with pipeline maps or one-line diagrams, pinpointing the location of specific constraint points requires research. Communication with pipeline operators is helpful when specific locations are in question or difficult to find.

[46] https://www.fmcsa.dot.gov/emergency-declarations

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	**Seasonal**	**Planning**	**Topic**	**Data**	**Potential Sources**	**Notes / Additional Considerations**
X	X	X	NG	Generator location on pipelines	Pipeline maps, generator surveys, registration data	Research is required to properly place generators on pipelines in the correct location.
X	X	X	NG	Non-generation demand estimates	Historical scheduled gas to city gates and end users, historic weather data, weather assumptions based on historic weather and climatology	Similar to load forecasting on the electric system, gas estimates play a crucial role in developing a holistic energy solution. Assuming that more gas is available than physically possible could lead to inaccurate study results.
X	X	X	NG	Heating and end-user demand assumptions	Filings with state regulators, historical demand data	Regulated utilities will file their expected needs for natural gas with their respective state regulators.
X	X	X	NG	Contractual arrangements	EBB index of customers, generator surveys, FERC Form 549B	Some information can be obtained via the EBB Index of Customers; however, nuanced data would need to be queried directly from generators. Non-public information includes generator arrangements with gas marketers and participation in capacity release agreements.
X	X	X	NG	Generator heat rates	Registration data, generator surveys	Converting electric energy to fuel consumption and vice versa requires the heat rate of a generator, typically expressed in Btu/kWh or MMBtu/MWh.
X	X	X	ESV	VER assumptions	VER forecasts as described in the VER sections of this document	VER production drives the need for flexible generation to be available or online. Additionally, the ability to curtail VER production should be considered as a mitigating option.
X	X	X	ESV	Generation ramping capability	Registration data, market offers	Balancing resources would be used to maintain system frequency from moment to moment.
X	X	X	ESV	Fuel supply dynamic capabilities	Fuel supply network models, market-based models to determine volumes delivered to specific sectors or historic observations	The key to including ramping capability in an ERA is focusing on the capabilities of the fuel delivery network (e.g., gas pipelines, fuel oil or coal delivery systems at specific generators) and how that network responds to the ramping needs of the system.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	**Seasonal**	**Planning**	**Topic**	**Data**	**Potential Sources**	**Notes / Additional Considerations**
X	X	X	ECGO	Output limitations for a set of generators	Generator surveys	Each Generator Owner/Operator may know their own operational information, but when determining when a collection of generators will reach a limit would require gathering information that each owner/operator has but not as a collective. The analyst performing the ERA would be the centralized collection point of the information required to accurately model the limit.
X	X	X	ESO	Forced-outage rates	NERC GADS, assumptions based on historical performance	NERC requires outages and reductions to be reported with associated cause codes and makes that information available to registered entities. Alternatively, analysts can observe historical unplanned outage information to determine similar assumptions.
X	X	X	ES	Maximum charge/discharge rates (in MW or kW) and total storage capability (in MWh or kWh)	Registration data	These two parameters combined define the primary characteristics of a storage device.
X	X	X	ES	Usable Capacity	Registration data, operational data	Battery storage may not operate well above and below a specific charged percentage. For example, batteries charged above 80% or below 20% may underperform. Therefore, the storage capacity may be less than intended.
X	X	X	ES	Transition time between charge and discharge cycles	Registration data, operational data, market offers	
X	X	X	ES	Cycling efficiency	Operational data	Calculating the cycling efficiency of storage can be done using operational data, dividing the sum of output energy by the sum of input energy over some period. A longer duration will yield a more accurate efficiency value. All storage requires more input energy than the output that will be produced.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	**Seasonal**	**Planning**	**Topic**	**Data**	**Potential Sources**	**Notes / Additional Considerations**
X	X	X	ES	Co-located/hybrid or standalone configuration. Charging source – primary and secondary	Registration data	Scenario studies may remove a generation type (e.g., solar), which may eliminate the energy supply source.
X	X	X	ES	Ambient temperature limits	Registration data, operational data	This refers to the ambient temperature limitations at the storage facility, which are part of the formula for calculating cell temperature limitations. There are high- and low-temperature requirements for charging and discharging batteries at a normal rate. Outside that band, the rate of charge could be reduced, potentially to 0.
X	X	X	ES	No-load losses	Registration data, operational data	Electric storage facilities may experience a loss of energy even when not delivering energy to the grid.
X	X	X	ES	Emergency limits		Can the storage resource run below the P-Min or above the P-Max, and if so, for how long?
X	X	X	T	Planned outages and Maintenance	Transmission Operators (TOP), Transmission Planners (TP), or other transmission planning entities	
X	X	X	T	Import/export transfer limits	Engineering studies	
X	X	X	T	Import/export resource limits	Coordinated ERA with neighboring areas	Aligning input assumptions between areas would be necessary for ensuring that energy is not ignored or double counted in multiple areas.
X	X	X	T	Transmission topology and characteristics	Transmission and distribution models	Potentially, using a simplified or dc-equivalent circuit for probabilistic or similar analysis. Considerations for including planned transmission expansion projects.

Table A.2: Summary of Potential Information Sources in All ERAs

Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
X	X	X	T	Transmission outage rates	NERC TADS	Ideally, weather-dependent and facility-specific outage rates could be used to reflect energy scenarios.
X			SF	Current inventory, inventory management plans, and replenishment assumptions	Generator surveys, assumptions based on historic performance, or annually variable conditions specific to the resource type	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA. Performance expectations for hydroelectric resources may be informed by seasonal runoff conditions.
X			NG	Natural gas scheduling timelines	Pipeline tariffs, NAESB	Timelines may differ between pipelines. The NAESB sets five standard cycles that are to be followed by Federal Energy Regulatory Commission (FERC) jurisdictional entities (which generally excludes intrastate pipelines and local distribution networks).
X			NG	Natural gas commodity pricing and availability	Intercontinental Exchange (ICE),[47] Platts[48]	Natural gas commodity pricing is an indicator of its availability. Continuously monitoring pricing will allow an analyst to estimate the availability of natural gas into a near-term ERA.
X			VER	Vendor supplied but could be developed using weather service models In-house models or vendor-supplied data	There could be differences between one or multiple central forecast(s) and the aggregation of independent forecasts. Forecast error analysis of historical data would provide a measure of the performance of available options. Wind/solar profiles can be modified to capture uncertainty associated with rainy, windy, and/or cloudy days.	Vendor supplied but could be developed using weather service models In-house models or vendor-supplied data

[47] https://www.ice.com/index
[48] https://www.spglobal.com/en/

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
					It is important to maintain the correlation between wind, solar, and load in conducting these analyses.	
X			VER	Vendor supplied but could be developed using weather service models	Significant research and development have been done in the last decade to create and improve VER/DER forecasts for use in power system operations and analysis, including ERAs. Hourly or sub-hourly profiles of actual production from VERs can be scaled up or down to fit specific scenarios in an ERA.	Vendor supplied but could be developed using weather service models
X			ECGO	Output limitations by specific generators	Generator surveys	For short-term assessments, generator surveys would be the best source of emissions limitation information. Generator Owner/Operators should be aware of what their limits would be and the plans to abide by those limits.
X			ECGO	Output limitations for a set of generators	Generator surveys	Each Generator Owner/Operator may know their own operational information, but when determining when a collection of generators will reach a limit would require gathering information that each owner/operator has but not as a collective. The analyst performing the ERA would be the centralized collection point of the information required to accurately model the limit.
X			ESO	Planned outages and maintenance	Maintenance schedules and outage coordination tools	ERAs can use planned maintenance as an input but can also be used to advise the shifting of planned maintenance to minimize energy-related risks.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	**Seasonal**	**Planning**	**Topic**	**Data**	**Potential Sources**	**Notes / Additional Considerations**
X			DER	Installation data	Electric utility companies (i.e., Distribution Providers, or DPs), production incentive administrators	DERs are likely to be required to coordinate with the distribution System Operator before interconnecting. Additionally, any DER that is participating in a renewable energy credit program will likely need to register with and provide production information to a program administrator.
X			DER	Forecasted DER production	Vendor supplied but could be developed using weather service models	Significant research and development have been done in the last decade to create and improve DER/VER forecasts for use in power system operations and analysis, including ERAs.
X			DER	Historical performance, observations of net load	Historical patterns of demand compared to a longer history	Comparing a similar-day demand curve from a more recent year to one from a year prior can give a sense of the difference in DER that was installed year-over-year.
X			DER	Estimated performance of DERs	Based on limited samples of a subset of the DER type	Modern DERs may have advanced measurement devices that could be made available through vendor aggregation services. Smaller, evenly distributed samples could be used to scale to the full amount. Testing should be done to validate whether the conceived process is accurate.
X			D	Weather forecasts or projections	Numerical weather prediction (NWP) models, weather forecast vendors	Weather information is the primary variable input to demand forecasts. Near-term assessments can use weather forecasts.
X			D	Actual demand forecasts or projections	Load forecast models using weather information as an input	Historical weather and demand may be useful for projecting future conditions; however, caution should be exercised to ensure that interrelated parameters remain interrelated. Decoupling weather and load could result in implausible outcomes.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
X			D	Demand-response capabilities	Electric utilities or other organizations (e.g., demand-response aggregation service providers) that manage participation in demand-response programs	
X			ES	State of charge	Resource owner	Additional considerations may be given to state of charge in a near-term ERA that reflect the recent operation of the electric storage facility.
X			ES	Ramp Rate (up/down) MW/minutes	Resource owner	Rate that the electric storage resource can discharge or absorb energy when electric demand or supply changes.
X			ES	Cell balancing	Resource owner	This describes the change-out of cells within a storage device. Specifically, this would apply to faulty cells that could limit the capability of a battery plant. Balancing takes a few days to accomplish once cells are replaced.
X			ES	Project-specific incentives (e.g., investment tax credits)	Resource owner	Investment tax credits, either production or investment, may indicate how the electric storage resource will run.
X			ES	Cell temperature limits[49]	Resource owner	This is the ambient temperature at the storage facility. There are high- and low-temperature requirements for charging and discharging batteries at a normal rate. Outside that band, you may reduce the rate of charge, potentially to 0.

[49] Lithium-ion battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 140°F
Lead acid battery: Charge temperature at -4°F to 122°F; Discharge temperature at -4°F to 122°F
Nickel-based battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 149°F

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	**Seasonal**	**Planning**	**Topic**	**Data**	**Potential Sources**	**Notes / Additional Considerations**
	X		SF	Current inventory, inventory management strategies, and replenishment assumptions	Generator surveys, formal or informal generator outreach, assumptions based on historical performance, or annually variable conditions specific to the resource type	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA. Performance expectations for hydroelectric resources may be informed by seasonal runoff conditions. Generator surveys can still be useful just prior to a specific season; however, this information may still introduce some uncertainty at the time that the ERA is being performed. Communication with the entities deciding on replenishment strategies would result in more accurate assumptions for starting inventories.
	X		SF	Availability of overall fuel storage	U.S. Energy Information Administration (EIA) reports	The U.S. EIA reports weekly inventories for five Petroleum Administration for Defense Districts (PADD). This can be an indicator of whether fuel may be available for generator fuel replenishment.
	X		SF	Shipping constraints	Industry news reports	Seasonal ERAs could be impacted by weather patterns and world events that cause supply chain disruptions, including port congestion, international conflict, shipping embargoes, and confiscation.
	X		NG	Pipeline, production, import, and export expansion projects	Pipeline websites, filings with state and federal agencies, advertising for open seasons	This includes new pipelines, compressor enhancements and expansions, and LNG import and export projects that will increase or reduce the amount of natural gas that is available.
	X		NG	Pipeline Planned Service Outages	EBB	Interstate natural gas pipelines are required[50] by FERC to post maintenance plans on their public-facing EBBs.

[50] See U.S. Code of Federal Regulations Chapter I, Subchapter I, Part 284, Subpart A, § 284.13.(d).(1) - https://www.ecfr.gov/current/title-18/chapter-I/subchapter-I/part-284/subpart-A/section-284.13

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
	X		NG	Natural gas commodity futures pricing	Several internet sources that monitor futures pricing	Futures pricing can give a sense of what pricing pressures the commodity is facing in the coming year(s). It may not be a fully accurate picture of what the pricing will be but gives an analyst some direction for a starting point for a seasonal ERA.
	X		VER	Weather outlook	NOAA (for the United States), Environment and Climate Change Canada, historical observations, weather models	Seasonal outlooks can provide a direction on which historical observations to select when performing a seasonal ERA.
	X		VER	VER production assumptions	Historical observations adjusted for weather outlooks	Historical observations can set a starting point for what can be expected in upcoming seasons. This would need to be adjusted for other known factors, such as drought conditions or temperature expectations.
	X		VER	New VER installations	Installation queues	New VERs installed between the time that an ERA is performed, and the start of the upcoming season can be large enough to impact the outcome and should be included as accurately as possible. The seasonal horizon should have more certainty on what will be commissioned or not.
	X		ECGO	Output limitations by specific generators	Generator surveys	For short-term assessments, generator surveys would be the best source of emissions limitation information. Generator Owner/Operators should be aware of what their limits would be and the plans to abide by those limits.
	X		ESO	Weather-dependent outage rates	Surveys, registration information, assumptions based on historic performance	GADS will provide average outage rates. The information from GADS can be combined with weather information to derive correlations with weather conditions that could be modeled in an ERA.
	X		ESO	Outage mechanisms	NERC GADS, operator logs	Outage mechanisms can be used to determine outage duration and impact.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	**Seasonal**	**Planning**	**Topic**	**Data**	**Potential Sources**	**Notes / Additional Considerations**
	X		ESO	Planned outage schedules	Outage coordination records	Planned outages are a good start for modeling the unavailability of resources, but considerations should be given to the accuracy of plans. Not every outage goes according to plan, and they may finish early or overrun.
	X		DER	Installation data coupled with expansion assumptions	Electric utility companies (i.e., DPs), production incentive administrators	Like the information needed for a near-term ERA, DERs are likely to coordinate with distribution System Operators, providing a path to make information available. Future information may also be available through those same channels but may also need to be inferred based on trends, growth forecasts, or legislative goals.
	X		DER	Historical DER production data	Operations data, assumptions based on past performance	The analyst may choose to model DER explicitly as a supply resource or as a demand reduction. Modeling the DER separately and incorporating it to the resource mix will allow the analyst to vary the assumptions without impacting other facets of the ERA.
	X		D	Weather forecasts or projections	Historical data, seasonal weather projections (e.g., the National Weather Service, Climate Prediction Center outlooks)[51], Environment and Climate Change Canada,	Weather information is the primary variable input to demand forecasts. Near-term assessments can use weather forecasts. Longer-term assessments, including seasonal assessments, typically require assumptions or projections of weather due to forecast accuracy.
	X		D	Actual demand forecasts or projections	Load forecast models using weather information as an input	Historical weather and demand may be useful for projecting future conditions; however, caution should be exercised to ensure that interrelated parameters remain interrelated. Decoupling weather and load could result in implausible outcomes.

[51] https://www.cpc.ncep.noaa.gov/products/predictions/long_range/

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
	X		D	DER production forecasts or projections	Weather-based prediction models using the assumed weather as an input, which are available from a variety of vendors	This may or may not be considered in the demand side of the energy balance equation. Correlation with modeled weather conditions should be considered.
	X		D	Demand-response capabilities and expectations	Electric utilities or other organizations (e.g., demand-response aggregation service providers) that manage participation in demand-response programs	Not all demand response operates at the command of the entity responsible for dispatching resources.
	X		ES	Cell temperature limits[52]	Resource owner	This is the ambient temperature at the storage facility. There are high- and low-temperature requirements for charging and discharging batteries at a normal rate. Outside that band, you may reduce the rate of charge, potentially to 0.
	X		ES	Ramp Rate (up/down) MW/minutes	Resource owner	Rate that the electric storage resource can discharge or absorb energy when electric demand or supply changes.
	X		ES	Project-specific incentives (e.g., investment tax credits)	Resource owner	Investment tax credits, either production or investment, may indicate how the electric storage resource will run.
		X	SF	Inventory management and replenishment assumptions	Assumptions based on historical performance and/or commodity market evaluations.	Replenishment is key to modeling inventory at any point during the study period. Replenishment restrictions are also an important aspect of an ERA.

[52] Typically, today's battery technologies are constrained to the following temperature bands:
Lithium-ion battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 140°F;
Lead acid battery: Charge temperature at -4°F to 122°F; Discharge temperature at -4°F to 122°F;
Nickel-based battery: Charge temperature at 32°F to 113°F; Discharge temperature at -4°F to 149°F

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
		X	SF	Availability of overall fuel storage	EIA reports	The U.S. EIA reports weekly inventories for five PADDs. Trending PADD inventories over time may provide insight into how replenishment may occur over longer periods of time.
		X	SF	Intra-annual hydro availability	Historical drought or high-runoff conditions	Since drought and high-runoff hydro forecasts may not cover an extensive enough period to depend on for a planning ERA, assumptions would need to be made based on historical information.
		X	NG	Pipeline, production, import, and export expansion projects	Pipeline websites, filings with state and federal agencies, advertising for open seasons	This includes new pipelines, compressor enhancements and expansions, and LNG import and export projects that will increase or reduce the amount of natural gas that is available.
		X	VER	Expected installed resources	Interconnection queue, economic analysis and forecasts	
		X	VER	Renewable energy goals	State legislature dockets	These goals drive the rate at which renewable (and likely variable energy) resources are built, including target years and amounts.
		X	VER	Production assumptions	Historical observations, weather models, climate trends	Profiling the expanded fleet across some historical dataset, adjusted for expected trends in climate, gives an ERA plausible inputs.
		X	ECGO	Output limitations by specific generators	Generator surveys	For short-term assessments, generator surveys would be the best source of emissions limitation information. Generator Owner/Operators should be aware of what their limits would be and the plans to abide by those limits.
		X	ECGO	Trends in individual state carbon emissions goals	State government or public utility commission (PUC) websites	When assessing the probability of long-term retirements and new construction, emissions goals may provide insight to the analysts to decide whether a specific resource or a subset of the entire fleet may or may not be viable under the expected rules.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
		X	ESO	Forced-outage rates	NERC GADS, assumptions based on historical performance	NERC requires outages and reductions to be reported with associated cause codes and makes that information available to registered entities. Alternatively, analysts can observe historical unplanned outage information to determine similar assumptions.
		X	ESO	Weather-dependent outage rates	Surveys, registration information, assumptions based on historical performance	GADS will provide average outage rates. The information from GADS can be combined with weather information to derive correlations with weather conditions that could be modeled in an ERA.
		X	ESO	Assumed outage rates for newly constructed supply resources	Fleet averages using existing resources, when possible	New construction using existing plans means that there is likely a similar resource somewhere that has some performance data that can be used to estimate the performance of a new resource.
		X	ESO	Outage mechanisms	NERC GADS, operator logs	Outage mechanisms can be used to determine outage duration and impact.
		X	DER	Growth estimates, renewable energy goals	State government and PUCs, directly or via their websites	
		X	D	Weather forecasts or projections	Historical data, adjusted using climate models	Weather information is one of the primary inputs to longer-term demand forecasts. Longer-term assessments typically require assumptions or projections of weather due to forecast accuracy concerns.
		X	D	Actual demand projections	Historical actual demand modified by the expected impact of demand changes, load forecast models using weather information as an input	Historical weather and demand may be useful for projecting future conditions; however, caution should be exercised to ensure that interrelated parameters remain interrelated. Decoupling weather and load could result in implausible outcomes. Performing an energy assessment still requires a profiled demand curve over a period of time. Most legacy long-term forecasts produce a set of seasonal peak values.

Table A.2: Summary of Potential Information Sources in All ERAs						
Near Term	Seasonal	Planning	Topic	Data	Potential Sources	Notes / Additional Considerations
		X	D	Projected changes in actual demand magnitude and profile (e.g., load growth)	Analysis of economic factors, governmental policy, and technical considerations	This should include the impact on demand magnitude as well as changes in demand profiles. This includes energy efficiency and electrification. Electrification of heat is a function of local temperatures. Electrification of transportation will be more linked to commute distances and time of day.
		X	D	DER production forecasts or projections	Historical production data, scaled to future capability	This may or may not be considered in the demand side of the energy balance equation. Correlation with modeled weather conditions should be considered.
		X	D	Demand-response capabilities	Electric utilities or other organizations (e.g., demand-response aggregation service providers) that manage participation in demand-response programs.	

Appendix B: Contributors

Name	Company
Jack Armstrong	Duke Energy
John Brewer	National Energy Technology Laboratory (NETL)
Layne Brown	Western Electricity Coordinating Council (WECC)
Alex Carlson	North American Electric Reliability Corporation (NERC)
Becky Davis	PJM Interconnection
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