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London Economics International LLC

Economic considerations for setting reliability standards for the wholesale power market in Texas

prepared for filing in Project No. 54584 at the Public Utilities Commission of Texas

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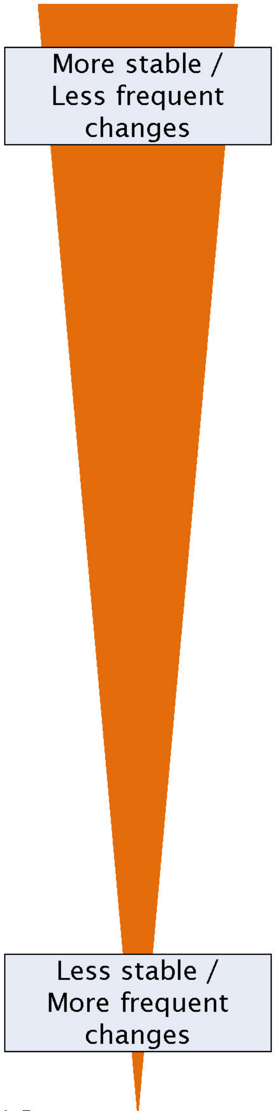
Julia Frayer
Victor Chung
Barbara Porto
Javier Maquieyra
Chinmayee Atre
Lorenzo Perez

For clarity and consistency, LEI identified common terms necessary for understanding key concepts

Reliability metric	▪ The system or method used to measure reliability ▪ Examples of reliability metric includes LOLP, LOLE, LOLH, EUE, CVaR (more details in later slides)
Reliability standard	▪ A numerical value of the reliability metric ▪ The regulator sets the reliability standard and develops a mechanism for the system to achieve this standard ▪ For example, under a LOLH as reliability metric, the reliability standard could be 3 hours per year, 8 hours per year, or other values
Market mechanism to achieve reliability standard	▪ The method to incentivize development of resources to meet the reliability standard ▪ Examples of market mechanism include reliability services such as PCM
Requirement necessary to meet the reliability standard	▪ For a market mechanism to achieve its goals, the market designer sets the parameters required for the mechanism to meet the reliability standard ▪ These parameters include the shape of the demand curve in a capacity market, or the required reserve margin in capacity contract auction mechanism



Note: LOLP (Loss of Load Probability), LOLE (Loss of Load Expectation), LOLH (Loss of Load Hours), EUE (Expected Unserved Energy, (CVaR (Conditional Value at Risk), PCM (Performance Credit Mechanism)

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LEI proposes the following common definitions for reliability metrics *(although we found that jurisdictions may use the same term to describe different concepts)*

▸ **Terms listed below are related to reliability metrics:**

Expected Unserved Energy	▪ MWh of expected unserved load in a year ▪ While EUE is measured in MWhs, when it is used as a reliability standard, it is sometimes defined as a % of the annual load ▪ In some jurisdictions (Australia), "USE" instead or "EUE" is used as the acronym instead

- Different markets have used the same terminology but with different intended meanings
- For example, UK uses the term LOLE which has the same mathematical meaning as LOLH in Singapore; both define it on hours/year
- On the other hand, California, MISO, PJM and SPP use the term LOLE, which they define based on the number of days with unserved load events/year
- For consistency, we use the following definitions in this presentation:

Loss of Load Hours	▪ Expected number of hours with unserved load in a year
Loss of Load Expectation	▪ Expected number of days with unserved load event(s) in a year ▪ It does not matter the duration of the unserved load event or how many times an unserved load happened in a day
Loss of Load Probability	▪ Probability of system daily peak or hourly demand exceeding the available generating capacity during a given period

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Given dynamics in Texas and advances in reliability analysis in other jurisdictions, the Commission should consider LOLH or EUE as well as a metric that focuses on risk posed by extreme events or "tail" risk (CVaR)

<table>
<tr><th></th><th>Questions asked by PUCT</th><th colspan="2">LEI's response</th></tr>
<tr><td>1</td><td>Which reliability metrics should the Commission consider in establishing a reliability standard for the ERCOT power region?</td><td colspan="2">The Commission should consider two types of metrics:
▪ Metrics that focus on the expected (or average) outage risk, including LOLH and EUE
▪ Metrics that focus on tail risk (or outage risk under extreme weather conditions), such as Conditional Value at Risk ("CVaR") (explained in detail in slide 11)</td></tr>
<tr><td>2</td><td>Which reliability metric, or combination of reliability metrics, should the Commission adopt for the reliability standard in ERCOT?</td><td colspan="2">The Commission should not only focus on a single metric, but should use a combination of an expected outage metric such as EUE or LOLH and a tail risk-based metric such as CVaR
The reliability metric could be a hybrid (i.e., weighted average of EUE and CVaR) or multiple standards that have to be complied with simultaneously</td></tr>
<tr><td>3</td><td>What are the advantages of your chosen reliability metrics, and what are the disadvantages of alternative approaches?</td><td>Advantages of a combined EUE and CVaR
▪ EUE is a more granular understanding of reliability risk and can be used in conjuncture with VOLL to understand the trade-offs between reliability and total cost
▪ CVaR focuses on understanding the magnitude of low probability events and is useful in systems with increasing intermittent generation
▪ Using EUE and CVaR metrics together can capture both the average reliability risk and risk under extreme conditions</td><td>Disadvantages of alternative approaches
▪ EUE reflects the average MWh of unserved load; EUE alone cannot capture risks under extreme conditions
▪ Using CVaR alone as a reliability standard may not be sufficient to develop a market mechanism for reliability
▪ LOLE does not distinguish the depth and duration of loss of load events, which is not suitable for systems with growing intermittent generation as there will be more weather-driven risks that can have loss of load events with different magnitudes</td></tr>
</table>

The reliability metric and standard should be system-wide; locational and seasonal requirements, if warranted, should be implemented through the market mechanism

	Questions asked by PUCT	LEI's response
4	What is the most effective way that the Commission can include deliverability in the reliability standard?	Deliverability refers to resources' performance during scarcity events. Low deliverability of resources leads to higher reliability risk. Whether the reliability standard captures these risks depends on the quality of the modeling; If the simulation model captures enough granular detail about resources' performance during different types of situations (e.g., weather-related availability, correlation of weather and intermittent generation, transmission constraints), then the modeled reliability risk would capture risk of low deliverability of resources, and the reliability standard set based on this analysis would also include deliverability risk.
5	Should the reliability standard include a locational requirement?	The goal of the reliability standard should be to ensure overall system-wide reliability. Therefore, the reliability standard should be system-wide. The market mechanism, to achieve the reliability (e.g. PCM), can have different locational requirements under the same reliability standard. This does not necessarily mean the PCM should have individual demand curves for each transmission zone – this depends on whether transmission constraints are binding under various system conditions that put reliability at risk, and the tools available to ERCOT to handle transmission-driven reliability risks (e.g. RUC, ancillary services).
6	Should the reliability standard include a seasonal component?	The level of reliability standard (for example, 3 hours of LOLH as used in the UK and Singapore) should be the same year-round unless there is sound evidentiary foundation that differentiates the value of lost load ("VoLL") among seasons. However, the requirement necessary to meet the reliability standard (e.g. shape of the demand curve of the PCM) can be seasonal as the weather variation and demand pattern in each season is different.

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Extreme events can be captured in a reliability standard by metrics that do not only focus on the average events and expected risk, but also on the level of risk from high impact/low probability events

	Questions asked by PUCT	LEI's response
7	How can extreme events be captured in a reliability standard?	Extreme events can be captured by: ▪ making sure the weather conditions used in modeling include a wide enough distribution of low likelihood yet potential weather profiles with the right probabilities assigned to them ▪ not only looking at the average or median reliability risk, but also evaluating the tail risks and the magnitude (depth and duration) of modeled system outage events ▪ Developing a maximum acceptable risk under extreme conditions (e.g. CVaR of 5% or 1%) and setting reliability standard that requires EUE under those conditions to not exceed a certain level The reliability standard should be chosen based on cost-benefit analysis and consideration of trade-offs between reliability, investment costs and energy production costs, and value of lost load. Such analysis is not new to Texas as the *bi-annual Market Equilibrium and Economically Optimal Reserve Margins* report already contains similar calculations.
8	How can the value of distributed energy and load resources be captured in a reliability standard?	If the modeling to determine the reliability metric (for use in the PCM) already considers distributed energy and load resources, then the standard already captures those resources' contribution to system reliability; it will also be important that market rules in the PCM appropriately (and on a level playing field) acknowledge the participation of such resources. How load resources "perform" under normal and extreme conditions is not solely a function of price signals. Studies should be done to analyze how different types of load resources have performed in previous normal and extreme conditions, such that realized performance of load resources can be reasonably captured by the model.

The frequency of updating the calculation of the reliability standard requirement should align with the cadence in the market mechanism that will ensure the reliability standard is achieved

	Questions asked by PUCT	LEI's response
9	How frequently should the Commission update the calculation of the requirement necessary to meet the reliability standard? What criteria should help determine the frequency of the update?	If the PCM is going to be the market mechanism by which ERCOT achieves the reliability standard, then the reliability standard would be used to derive the shape of the demand curve for the PCM. If the EUE and CVaR are used as the reliability standards, the PCM target quantity derived from the reliability standard would change as the resource mix (or forecasted resource mix) in the ERCOT system evolves. Therefore, the requirement necessary to meet the reliability standard should be updated each time there is a new demand forecast and updates on investment and retirement plants. Practically, such calculation should be scheduled regularly to align with the PCM forward auction and ex-post settlement dates. As an additional note, as the market mechanism to achieve the reliability is linked to the level of reliability standard, some form of policy stability is needed to incentivize investment, which means the level of reliability standard should not be updated too frequently. One reasonable approach is to have a periodic review once every 3-5 years, but the standard should only be changed if the review finds that there is material benefit to changing the standard.

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LEI reviewed developments with respect to reliability standards across 11 jurisdictions around the world

Jurisdiction	Peak demand	Market structure	Why we studied this jurisdiction
Australia NEM	32,761 MW (2021-22)	Energy-only, transitioning to a capacity mechanism	recently conducted a reliability review and transitioning to a capacity mechanism
Brazil	89,107 MW (2022)	Capacity procured via long-term contracts through centralized auctions	large share of legacy renewables resulting in high weather-driven risks
CAISO (US)	52,061 MW (2022)	Energy plus bilateral resource adequacy mechanism	a major US electricity market, reliability challenged by weather and high levels of renewables
Colombia	10,864 MW (2021)	Energy plus scarcity pricing mechanism and Firm Energy Obligation auctions	has large share of legacy renewables resulting in high weather-driven risks
ISO-NE (US)	24,233 MW (2022)	Energy and annual Forward Capacity Market	uses non-linear (Marginal Reliability Impact-based) demand curve
Mexico	49,000 MW (2022)	Energy and a PCM-like mechanism	has a PCM-like resource adequacy mechanism implemented a few years ago
MISO (US)	119,900 MW (2021)	Energy with seasonal Planning Resource requirement and auctions	a major US electricity market, with increasing levels of renewables
PJM (US)	144,356 MW (2022)	Energy and forward capacity market	a major US electricity market, looking to reform its capacity market
Singapore	7,789 MW (2022)	Energy-only, considered transitioning to a capacity mechanism recently	recently studied system reliability and appropriateness of the reliability metric
SPP (US)	53,243 MW (2022)	Requires Load Responsibility Entity to maintain adequate capacity based on the Planning Reserve Margin	a major US electricity market, with increasing levels of renewables and a LSE-based requirement
United Kingdom	46,000 MW (2022)	Energy and forward capacity market	managing increasing renewable energy penetration (wind provided ~27% of energy in 2022)

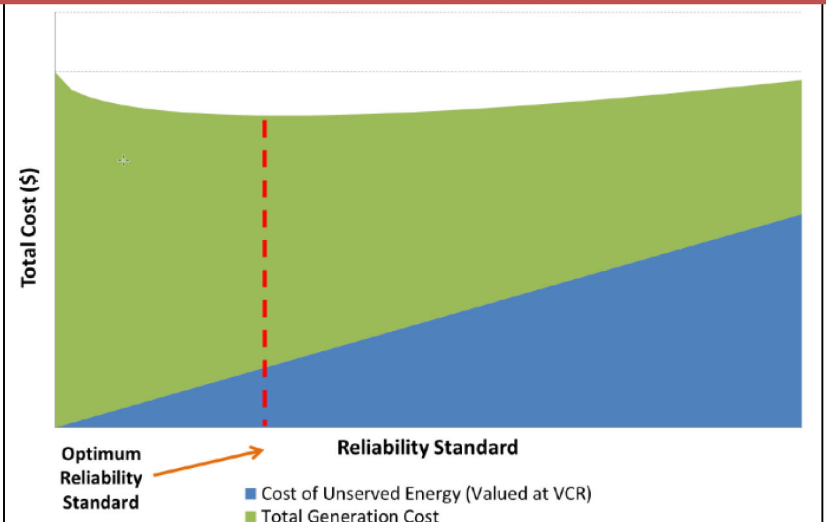
In some markets, the reliability standard is a result of a economic optimization problem – what level of reliability results in the optimal trade-off between cost of capacity and cost of unserved load

Theoretically, the reliability standard should be set at the point where the total cost of (EUE x VOLL) + energy market costs + cost of other markets are minimized

Unserved energy is a cost (i.e. Value of Loss Load, VOLL)

Installing more generating capacity has a cost (i.e. Cost of New Entry)

There is diminishing return in reliability improvement as installed capacity increases (marginal reliability impact)



Source: ROAM, Reliability Standard and Settings Review, Final report, 21 May 2014

Some markets explicitly use this logic to determine their reliability standard:

(1) Determine VOLL

(2) Model total cost under different reliability standards

(3) Determine reliability standard based on economics

LOLE or LOLP (in days/year) is not as useful for setting reliability standard as EUE and LOLH, especially when reliability standards are determined based on economic modeling

Loss of Load Expectation	▪ Expected number of days with unserved load event(s) in a year ▪ Duration of the unserved load event or how many times an unserved load happened in a day does not matter
Loss of Load Probability	▪ Probability of system daily peak or hourly demand exceeding the available generating capacity during a given period

Not enough granularity for calculating cost of unserved energy (which needs the EUE)

- **In jurisdictions worried about rising levels of intermittent generation, and especially in jurisdictions undertaking a recent review of their reliability standard, hourly metrics such as LOLH or EUE appear to be preferred over LOLE/LOLP metrics**
  - Studies that review the choice of reliability metric all concluded that as intermittent generation penetration increase, hours of unserved load per year or EUE metric is better in reflecting reliability risk as compared to traditional LOLP or LOLE metric (expected days/year with unserved load)
  - Systems with higher intermittent generation penetration has larger tail risk – events with low probability but high impact
  - Traditional LOLP or LOLE metric does not distinguish a high impact event from a low impact one
- **NERC BAL-502-RF-03 reliability standard requires "one day in ten year" LOLE**
  - LOLE is defined as "probabilities for loss of load for the integrated peak hour for all days of each planning year"
  - Most US markets follow this standard, but it is not an absolute requirement: SPP decided to report not only LOLE, but also EUE at a seasonal level in its next study (2023); ISO-NE also uses EUE to derive its capacity market demand curve (MRI) shape, instead of procuring capacity solely based on LOLE

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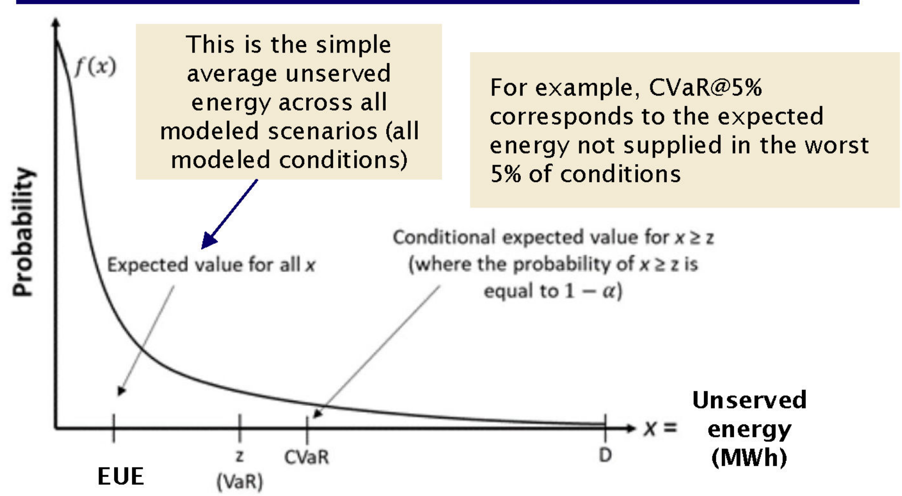
Brazil has adopted, while Australia and Colombia are considering, a Conditional Value at Risk ("CVaR") metric to target tail risk

- **Reliability metrics such as LOLH and EUE are based on the average of unserved load out of the scenarios (conditions) modeled**
- **These metrics are therefore risk neutral, meaning that they value every unit of unserved energy or hour with unserved energy in the probability distribution equally,**
  - Under EUE, a system with 1% unserved load per year in all modeled scenarios is considered the same as a system with 50% unserved load per year in 2% of modeled scenarios
- **In reality, consumers are not risk neutral; consumers purchase insurance against impact of severe events and pay premiums over the risk-neutral value of an insurance product**
- **CVaR describes the fatness of the tail of reliability events defined as the mean value of the α% worst cases**
  - VaR has long been used in financial risk management to understand the maximum dollar amount expected to be lost at a pre-defined confidence level

- After the 2015 drought, Brazil adopted a reliability standard in December 2019 based on multiple criteria related to CVaR
- The regulator procures new supply based on the following criteria
  - CVaR10%: if the monthly marginal operating cost under a 10% worst case scenario exceeds a threshold value, new supply is needed
  - CVaR 5%: on a monthly basis, the EUE under the 5% worst case scenario cannot exceed 5% of monthly peak demand
  - CVaR 1%: on an annual basis, the EUE under the 1% worst case scenario cannot exceed 5% of energy demanded
  - LOLP: If more than 5% of modeled scenarios has unserved load of any magnitude

Probability of unserved energy, EUE, and CVaR



Sources:
AEMC Reliability Panel AEMC. Final Report – 2022 Review of the Reliability Standard and Settings. 1 September 2022
R. Moreno et al., "From Reliability to Resilience: Planning the Grid Against the Extremes", IEEE Power and Energy Magazine, July-August 2020

EUE and CVaR can be used together as standalone binding metrics, or in combination as a hybrid or composite metric that places different weights on EUE and CVaR

Two standalone binding metrics

- Both EUE and CVaR are used as the reliability standards
- The market mechanism to procure resources to meet the reliability standards will be set to meet both standards
- The more constraining reliability standards will therefore set the procurement target

Using CVaR to set requirements

- The EUE-based reliability standard can be used to set target procurement quantity for the market mechanism, while the CVaR values can be used to adjust the shape of the demand curve
- A “budget” can be set to insure against tail risk, and the shape of the demand curve can be adjusted to fit this budget

Composite metric using EUE and CVaR

- The Australia Energy Market Commission Reliability Panel proposed a multi-metric reliability standard that includes a “tail risk metric” to be implemented in 2028
- The straw-person combined composite reliability metric (R) uses a linear combination of the expected metric (EUE) and tail metric (CVaR)

$$R = w * EUE + (1\text{-}w)*CVaR@\alpha\%$$

Where:

w: weight of the expected metric in the composite
α: level of worst case to be captured by CVaR

- The level of risk aversion can be controlled by two parameters, w and α
  - When w=1, the metric is fully risk neutral; when w=0, the metric is fully risk averse
  - The choice of α affect the worst-case scenario that the metric wants to capture
- Problems to be addressed before implementing composite metric:
  - **How to identify efficient levels of overall risk that should be accepted?** Proposed approach includes allocating specific % of budget for investments to address tail risk (i.e. insurance allowance)
  - **How to select the value of w?** Proposed approach includes testing incremental values of w to develop a Pareto-efficient frontier
  - **How to link the market mechanism with the composite metric?** One approach is to have two sets of price caps under different conditions (e.g. “expected” events vs “tail” events)

Sources: AEMC Reliability Panel AEMC. Final Report – 2022 Review of the Reliability Standard and Settings. 1 September 2022
Mancarella. “Considerations in support of the 2022 Reliability Standards and Settings Review”. August 2022.

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Some markets have implicit seasonal and locational reliability requirements, but the reliability standard itself does not vary seasonally or locationally

- **When markets have seasonal load serving requirements or capacity mechanisms with locational deliverability requirements, they implicitly have seasonal and locational reliability requirements**
- **But none of the jurisdictions surveyed has different or specific reliability standard based on season or location; for example, there are no markets that require 1-in-10 LOLE in summer but 1-in-5 LOLE in spring**

Seasonal requirement

- Brazil's CVaR is calculated on a monthly and annual basis
- SPP decided to report EUE at a seasonal level in its next scheduled study of LOLE
- Any market mechanism that has multiple clearing prices per year implies a seasonal reliability standard (such as NYISO and MISO)
  - ✓ ISO-NE is also considering moving from an annual capacity supply obligation to multiple capacity supply obligation periods per year

Locational requirement

- Any market mechanism that has separate zonal / regional clearing price implies a locational reliability requirements – these include PJM, ISO-NE, MISO, NYISO, and CAISO
  - ✓ Some markets have fixed zones, but markets such as ISO-NE have different zonal configurations in each auction depending on level of capacity installed within each zone, local demand, and transmission system constraints
- Australia's reliability standard explicitly stated that unserved energy is measured regionally and includes inter-regional transmission elements

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Once the reliability metric(s) is selected, the associated values (like the required reserve margins or PC procurement target) are estimated on a periodic basis, typically annually

- **Forecasting tools are required; the tool needs to be able to produce an accurate simulation of real-time conditions and economic dispatch, taking into account generation operating constraints, network constraints, demand response/load resource performance**
  - Astrape's SERVM has been used elsewhere, but there are also other modeling tools that can do the job
  - If locational distinction is key, the model should have the capability to account for transmission limits*
  - If seasonal dimensions are important, then the model needs to also consider how seasonal factors impact reliability, like the rules (or lack thereof) around central coordination of planned outages
- **Modeling analysis must be set on a forward basis, taking into account existing and planned additions and retirements, load growth, and various weather conditions**
  - It may be useful to test the model with different quantities of generic new resources to better understand how changes in the supply mix impact market costs and reliability
  - In addition, to the extent that demand growth, distributed resources, and flexible load resources are critical element of the future, scenario testing around these drivers is also useful – especially if there is large uncertainties surrounding their presence and growth in Texas
- **Weather-based Monte Carlo (stochastic) analysis can create stable "expected" values, but are unlikely to provide 100% coverage over all possible conditions**
  - Are extreme conditions in the future different from those experienced in the past?
- **Testing of different metrics is recommended – but ultimately, the Commission may need to decide which metric to give more weight**
  - There are markets that use a combined metric based on weighted sum of multiple metrics, and there are also markets with multiple standards that must be met simultaneously

** Based on LEI's review of ERCOT's Market Equilibrium and Economically Optimal Reserve Margins report, ERCOT internal transmission constraints are not modeled by SERVM. However, SERVM should have such capability as the California Public Utilities Commission has used SERVM to model California on a regional basis*

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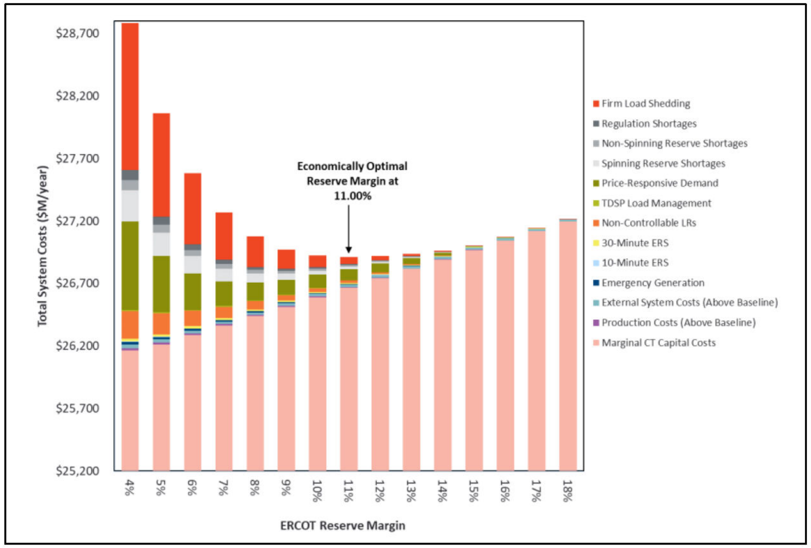
Existing modeling tools like Astrape's SERVM can be leveraged by ERCOT to develop metrics, but selection of a specific reliability standard may also require setting an appropriate VOLL

- **Using modeling results from ERCOT's Market Equilibrium and Economically Optimal Reserve Margins report from January 2021, setting a reliability standard using the economic approach based on LOLH would be similar to that of UK and Singapore (both having LOLH reliability standard of 3 hours per year)**
  - The January 2021 Astrape report was based on a VOLL of $9,000/MWh, which is lower than the values for VoLL used in Australia (~ US$20,000/MWh) and UK (~$12,000/MWh)
  - Moreover, the 40 weather years used in the January 2021 Astrape report excluded events in the last 2 years, including more recent weather conditions and changes to the supply mix - recent and future renewable additions may result in larger LOLH/EUE under the same reserve margin
- **In the first "generation" of setting the reliability standard, ERCOT may want to have multiple models running in parallel analysis as well as multiple models testing and reporting the metrics to assess the logic of each model**

Reserve Margin (%)	Total Annual Loss of Load			Average Outage Event		
	LOLE (events/yr)	LOLH (hours/yr)	EUE (MWh)	Duration (hours)	Energy Lost (MWh)	Depth (MW)
4%	17.61	79.45	209,338	4.51	11,890	2,635
5%	11.41	48.76	120,154	4.27	10,532	2,464
6%	7.39	29.93	68,964	4.05	9,329	2,304
7%	4.79	18.37	39,583	3.83	8,264	2,155
8%	3.10	11.27	22,720	3.63	7,320	2,015
9%	2.01	6.92	13,040	3.44	6,484	1,885
10%	1.30	4.25	7,485	3.26	5,744	1,762
11%	0.84	2.61	4,296	3.09	5,088	1,648
12%	0.55	1.60	2,466	2.92	4,507	1,541
13%	0.35	0.98	1,415	2.77	3,992	1,441
14%	0.23	0.60	812	2.62	3,536	1,348
15%	0.15	0.37	466	2.49	3,132	1,260
16%	0.09	0.23	268	2.35	2,775	1,179
17%	0.06	0.14	154	2.23	2,458	1,102
18%	0.04	0.09	88	2.11	2,177	1,031



Sources: Astrape Consulting, "Estimation of the Market Equilibrium and Economically Optimal Reserve Margins for the ERCOT Region for 2024" 15 January 2021. Table 8 and Figure ES-10

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Some markets are moving from LOLE-based reliability metrics to EUE, LOLH and CVaR to better measure reliability risk driven by increasing levels of intermittent generation and tail risk

Market	Reliability metric	Reliability standard	Why the metric was chosen	Purpose of the reliability standard
Australia NEM	EUE	0.002% of actual annual operational demand	LOLP and LOLE do not sufficiently capture a changing reliability risk profile in high VRE market	Sets price floor and price cap in the energy-only market
Brazil	CVaR	CVaR(5%) ≤ 5% of demand on a monthly basis CVaR(1%) ≤ 5% of demand on an annual basis	CVaR improves over previous metric by modeling a longer-term horizon (5 years instead of 2) using more hydrology scenarios (2000 scenarios)	Capacity contract procurement triggered when forecasted reliability metric falls below the reliability requirement
CAISO (US)	LOLE	0.1 days/year	NERC standard following FERC Order 693	Sets the resource adequacy procurement target
Colombia	EUE & CVaR (Proposed)	EUE < 0.002% (Proposed) CVaR (5%) < 0.005%	Prior procurement target based on de-rating factors is economically inefficient	Sets the central capacity procurement target
ISO-NE (US)	LOLE and EUE	0.1 days/year, EUE used to derive capacity market demand curve	NERC standard following FERC Order 693, EUE used for capacity demand curve after capacity market reform to move away from a vertical demand curve	Sets the forward capacity market demand curve
Mexico	Maximum and efficient LOLP	Maximum LOLP : 0.2178% Efficient LOLP: 0.0315%.	Maximum LOLP is set based on the government's reliability policy. Efficient LOLP is developed to reflects a "comprehensive metric adjusted for the Mexican context"	Sets the Efficient Planning Reserve Margin' and are used to calculate the Annual Power Requirements for Market Participants in the resource adequacy mechanism
MISO (US)	LOLE	0.1 days/year	NERC standard following FERC Order 693	Sets the parameters for the capacity market
PJM (US)	LOLE	0.1 days/year	NERC standard following FERC Order 693	Sets the parameters for the capacity market
Singapore	LOLH	3 hours/year	In 2018, Singapore move from LOLP to LOLH because to better measure the hourly impact of intermittent generation resources	Information purpose only as the market has excess reserve
SPP (US)	LOLE	0.1 days/year	NERC standard following FERC Order 693 SPP decided to report on the next study (2023) not only LOLE, but EUE at a seasonal level	LSE must maintain adequate capacity based on Planning Reserve Margin which is derived from the reliability standard
United Kingdom	LOLE	3 hours/year	Used by interconnected neighbours. Increasing wind penetration makes seasonal and hourly variation more important which favors LOLE	Sets the parameters for the capacity market

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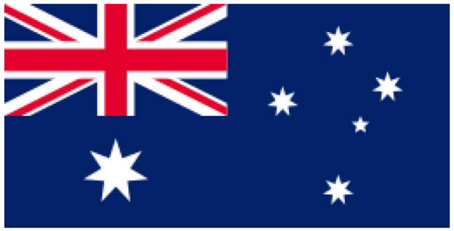
Appendix

Australia's National Electricity Market ("NEM") uses expected unserved energy as its reliability metric, and the reliability standard has a locational requirement

Australia NEM



Market Summary

Peak MW	32,716 MW
Total GWh	188,042
Peaking System	Summer
% Wind	14%
% Solar	6%
% Hydro	9%
Structure	Energy-only, transitioning to a capacity mechanism

What is the metric used to set the reliability standard?

Expected unserved energy ("USE"), expressed as a percentage of expected unserved energy (MWh of EUE / MWh of load)

How is the metric defined

Maximum expected unserved energy as a percent of the total demand in a region for a given financial year

- Principle #1: An event should be included to measure USE if
  - additional investments would have avoided the event from occurring, or
  - the market should have planned for such an event
- Principle #2: Market participants are expected to meet the reliability standard without the need for interventions
- Reliability standard is relevant for generation and inter-regional transmission planning– the reliability panel reviews reliability on a regional basis
- Demand is defined as actual annual operational demand, i.e. it excludes non-scheduled wind/solar generation with a capacity of < 30 MW, such as solar PV

What is the reliability standard in the market

0.002% expected USE in a region over a year

the reliability requirement is used to derive key market settings such as price cap and price floors, and will be used in the future for capacity market demand curve

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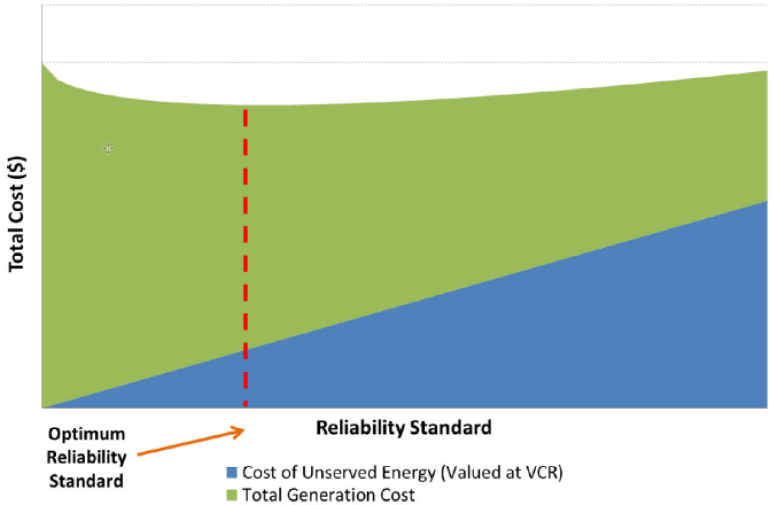
Australia's reliability standard is set by balancing the trade-off between reliability and affordability

- **The Australia National Electricity Rules requires the Reliability Review Panel to review the potential impact of change to the reliability setting on spot prices, investments in the market, reliability, and market participants**
- **The efficient level of the standard, which balances the economic trade-off between reliability and affordability, is the level of USE that minimizes total costs**
- **Uses PLEXOS with a Monte-Carlo approach, with variables for forced outage, weather-sensitive peak demand, and demand shapes. The model then finds the distribution of USE under a central base case, scenarios, and sensitivities**
  - The scenarios and sensitivities were modelled to account for uncertainty given the transition of the power system to higher penetrations of variable renewable generation
- **The theoretical optimal reliability standard at the level where the total cost (EUE x VOLL + capacity + generation) is minimized**
  - Different VOLL sensitivities are used, the regional average of low case VOLL values used in the 2022 review is ~US$21,700/MWh
  - The actual reliability standard is only changed if analysis shows a material benefit from moving away from the existing reliability standard

How reliability standard is chosen



Source: ROAM, Reliability Standard and Settings Review, Final report, 21 May 2014

VOLL used to analyze total cost in 2022

VCR ($/MWH)	NSW & ACT	VIC	QLD	SA	TAS
Base Case	43,526	42,586	41,366	44,673	33,234
Low case	34,202	30,581	32,617	38,338	26,685
High case	100,626	99,056	101,229	94,383	97,267

Source: AER VCR final report, re-weighted by Panel RSS review project team. Details on the re-weighting approach are provided in Appendix A1.

Source: IES, Reliability Standard and Settings Review - modelling report, Fig. 5.1

The Reliability Review Panel recommended adding a tail risk metric in the next review to better reflect the risk faced by Australia in a more intermittent-heavy system

- **The Reliability Review Panel concluded that reliability risk will need to be characterized differently as the electricity system is transitioning from a primarily capacity-limited thermal power system to an energy-limited power system**
- **This transition shifts the distribution of unserved energy towards greater "tail risk" events**
- **Tail risk represents low probability events that would have a high impact on reliability outcomes**
- **A single "expected value unserved energy" metric provides insufficient information on the distribution of USE in a high variable renewable energy ("VRE") power system and may not effectively reflect changes in the NEM's reliability risk profile by 2028**
- **The Reliability Review Panel also concluded that LOLP and LOLE based reliability standards do not sufficiently capture a changing reliability risk profile in an increasingly high VRE NEM**
- **A hybrid standard tail risk metric will capture willingness to pay to address tail risk**
- **The review also considered tightening levels of USE (0.0015% and 0.001%), but decided against it:**
  - the benefits of changing the level of the reliability standard from 0.002% USE to 0.0015% USE were deemed to not be sufficiently material to justify a change

Appendix

Brazil uses CVaR and LOLP concepts in setting its reliability standard

What is the metric used to set the reliability standard?	Conditional Value at Risk ("CVaR"), and Loss of Load Probability ("LOLP")
How is the metric defined	CVaR is the expected value of insufficient power supply, and; LOLP is defined as the % of modeled scenarios that has any instances of unserved load events

- CVaR allows for the expression of risk aversion to outages:
  - 2,000 hydrological conditions are modeled for each month to help understand the distribution of outage risks
  - The EUE in 1%, 5%, and 10% worst case conditions are calculated for capacity planning and guide thermal dispatch orders
- CVaR is used in planning and real-time market operations:
  - capacity planning: power generation capacity expansion is assured by the requirement of regulated market auctions
  - dispatch orders: thermal dispatch in order to conserve reservoir levels
- Requirements calculated by the two metrics (CVaR and LOLP) are compared to identify the different monthly and annual needs

What is the reliability standard in the market	Monthly $CVaR_{5\%}$ of unserved power $\leq$ 5% of monthly peak demand; LOLP $\leq$ 5% on an annual basis

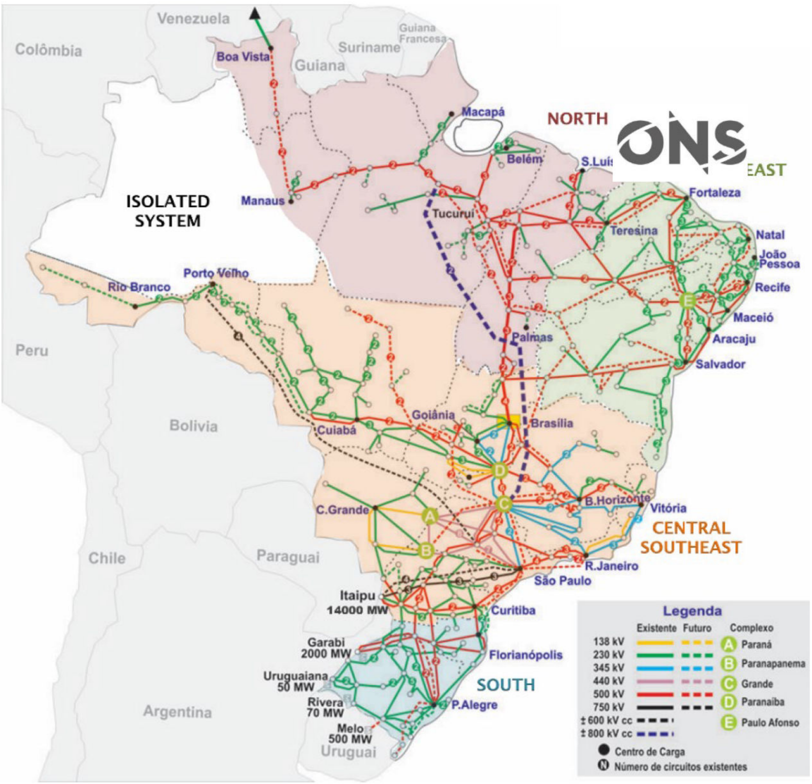
Given the dominance of hydroelectric resources in the supply mix, Brazil's reliability metric naturally focuses on hydrological risk for energy adequacy

- **The assessment of the adequacy of energy and power supply for the base case considers 2,000 hydrological scenarios simulated using the NEWAVE model (medium-term planning up to 5 years)**

- **In addition to the power supply metrics ($CVaR_{5\%}$ and LOLP), the assessment of the adequacy of energy and power supply also considers the following criterion:**
  - $CVaR_{1\%}$ of Unserved Energy ≤ 5% of Demand
    - Risk and its unserved energy depth: on an annual basis, the 1% worst scenarios for meeting energy demand are assessed, where the average load shedding in these scenarios cannot exceed 5% of the demand of the SIN and for each subsystem
  - $CVaR_{10\%}$ CMO ≤ 800 [BRL/MWh]
    - Energy-economic criterion: on a monthly basis, the 10% scenarios with the highest marginal operating costs ("CMO") are assessed, where the average of these scenarios cannot exceed BRL 800/MWh in any subsystem assessed

- **Supply to be procured based on these criteria:**
  - CVaR10%: if the monthly marginal operating cost under a 10% worst case scenario exceeds a threshold value, new supply is needed
  - CVaR 5%: on a monthly basis, the EUE under the 5% worst case scenario cannot exceed 5% of monthly peak demand
  - CVaR 1%: on an annual basis, the EUE under the 1% worst case scenario cannot exceed 5% of energy demanded
  - LOLP: If more than 5% of modeled scenarios has unserved load of any magnitude

Brazilian Interconnected System ("SIN")



Peak demand (2022)	89,107 MW (summer)
Total energy (2022)	589,366 GWh
Intermittent generation share (2022)	Hydro: 72% Wind: 13% Solar: 2%

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Appendix

CAISO relies on LOLE-based target and 0.1 days/year requirement for informing planning as well as California's RA product (capacity)

What is the metric used to set the reliability standard?	Loss of load expectation ("LOLE")
How is the metric defined	LOLE equals the expected number of loss-of-load days with events, regardless of event length, in a given year

- A day with unserved energy means a single day with any length of outage
- The LOLE approach considers the probability of a wide range of distributions of key variables and relies on thousands of simulations drawing randomly from different combinations of demand, solar, and wind profiles as well as unexpected plant outages to arrive at the LOLE metrics
- Procurement orders and integrated resource planning is typically assessed through LOLE studies to indicate system reliability

What is the reliability standard in the market	0.1 days/year

- The 0.1 LOLE target is the NERC standard. FERC Order 693 mandates RTOs to use this NERC standard. CPUC uses this as its basis for RA and IRP proceedings.

CAISO uses 23 weather years and other forecast error adjustments to estimate the days with unserved energy

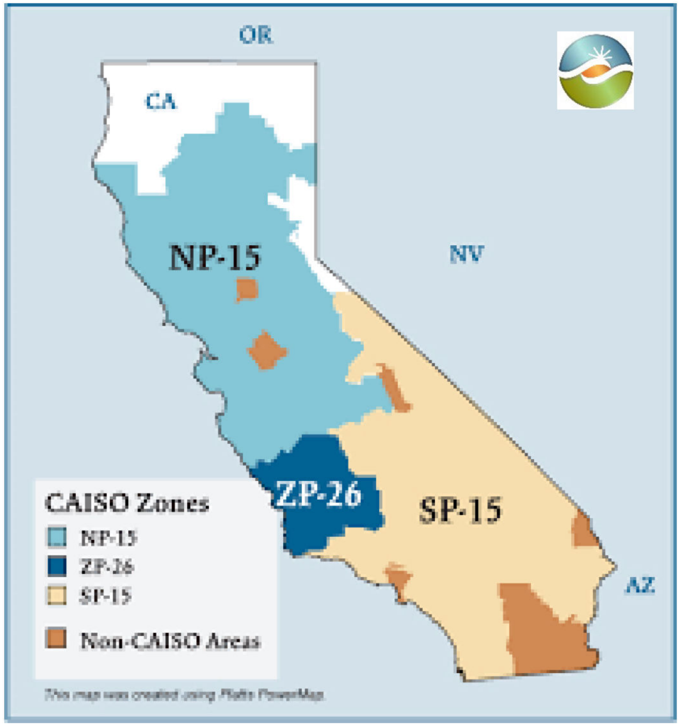
- **For the purpose of long-term planning and procurement, reliability need is typically assessed through LOLE studies, which are stochastic analyses**
  - The model includes future demand profiles, historic wind and solar profiles, and randomized forced outages to determine a probability for a supply shortfall, for a given mix of resources expected to be connected to the grid

- **LOLE modeling utilizes 23 weather years and 5 load forecast error ("LFE") multipliers**
  - The unserved demand for each event is defined as the hour with the highest unserved energy in a day (events are ordered from highest to least unserved demand to determine the shortfall)
  - The LOLE is the number of unserved demand events divided by the number of samples
    - The shortfall capacity is the capacity that would need to be fully available in all hours of the year (perfect capacity) to reduce the LOLE to below 0.1
    - If any shortfall capacity is determined, additional capacity was added to the simulation, until LOLE was less than 0.1

- **Market data:**

Peak demand (2022)	52,061 MW (summer)
Total energy (2021)	220,307 GWh
Intermittent generation share (2021)	Solar: 17% Hydro: 8% Wind: 7%

CAISO System



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Appendix

In 2020, the regulator of Colombia's energy systems began an investigation into a reliability standard

Colombia

Market Summary	
Peak MW	10,864 MW
Peaking System	Nonseasonal
% Wind	0.5%
% Solar	0.6%
% Hydro	70.6%
Structure	Energy plus scarcity pricing mechanism and Firm Energy Obligation auctions

Metric used to set reliability standard	▪ The Regulation Commission of Electricity and Natural Gas ("CREG") started a consultation process in 2020 to adopt a reliability standard ▪ The regulator has expressed interest in using both **Expected Unserved Energy ("EUE")** and **Conditional Value at Risk ("CVaR")** as its standards
How the metric is defined	• CREG proposed that EUE is defined as the percentage of the total energy demand that will be unmet for a given financial year • The proposed definition for CVaR is the expected value of insufficient power supply under a specific probability
Reliability standard	• EUE < 0.002% (Proposed) • CVaR (5%) < 0.005% (Proposed)
Unique features	• Large share of legacy renewables results in high weather-driven risks

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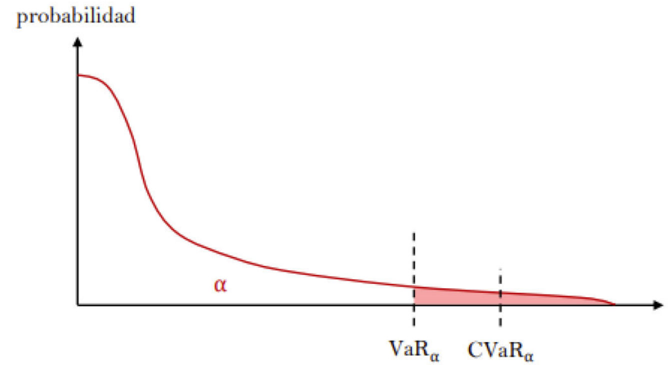
The reliability standard is critical to many elements of Colombia's market design

- **Simulation models are proposed to estimate EUE and CVaR**
  - Because the metric is "continuous", the simulation model can be used to understand contribution of incremental units – in contrast, adding more supply may not impact "discrete measures" such as LOLP
- **CREG acknowledged that simulations should be based on projections on the evolution of demand, the resource mix, hydrology, etc.**
  - CREG stressed the importance of the inclusion of robust hydrology model due to the importance of hydro in the resource mix
- **The proposed CVaR methodology defines CVaR as the mean value of the tail of a probability distribution curve**

Proposed CVaR application



CREG has proposed that the reliability standards be monitored and used in the following reliability mechanisms:

1. Firm Energy Obligations (FEO) auctions to ensure enough generation capacity is available to supply demand; FEOs are allocated and priced using auctions, and winning generators receive stable reliability revenue

2. A call option on the wholesale spot price at the scarcity price, a regulated strike price; the call option allows the system operator to identify hours of tight supply; moreover, generators with FEOs must provide the energy committed in these hours of tight supply

3. A safety net designed to ensure generators can supply the committed FEOs during tight supply; mechanisms in the safety net should also allow market participants to update their positions on FEOs

Source: CREG, Consultoría para definir las métricas para estimar la contribución de confiabilidad al SIN, P 42

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Appendix

ISO-NE uses a LOLE standard for long-term planning, but EUE is also used to derive the shape of the capacity market demand curve

ISO- NE

Market Summary

Peak MW	25,801
Total GWh	124,000
Peaking System	Summer
% Wind	6.5%
% Solar	8.9%
% Hydro	7.8%
Structure	Energy and forward capacity

Metric used to set the reliability standard	Standard Market Rule uses LOLE for long-term planning, but Forward Capacity Market demand curve is derived based on change in EUE per MW of capacity added
Metric definition	LOLE is defined in the ISO-NE tariff as: "the probability of disconnecting non-interruptible customers due to a resource deficiency" EUE (in ISO-NE, referred to as expected energy not served, "EENS") is defined in terms of frequency that an incremental unit of capacity is needed to avoid loss of load (outage)
Reliability metric standard for the market	1 day in 10 years for LOLE
Unique features	• ISO-NE calculates the incremental impact to EUE per MW of capacity, and derives the marginal reliability impact which then informs the shape of the forward capacity demand curve (known as the MRI) • The demand curve is also set such that when the price is at Net Cost of New Entry ("Net CONE"), the LOLE would be 1 day in 10 years, allowing ISO-NE to meet the long-term planning target that meets the NERC reliability standard

ISO-NE uses a probabilistic model from GE to calculate a capacity requirement that satisfies the LOLE reliability criteria

- **ISO-NE's uses probabilistic modeling to determine LOLE called General Electric Multi-Area Reliability Simulation Model ("MARS")**
- **Uses a sequential Monte Carlo simulation to probabilistically compute the resource adequacy of the system by simulating scheduled maintenance, random forced outages of resources, operating reserve requirements, and expected demand**
- **Simulates 8760 hours of the year to measure impact of forced generator outages – only hours of loss calculated not the number of events causing loss**
- **Under Section III.12 of the ISO-NE Tariff, the Installed Capacity Requirement ("ICR") is defined as:**

> *The ISO shall determine the [ICR] such that the probability of disconnecting non-interruptible customers due to resource deficiency, on average, will be no more than once in ten years. Compliance with this resource adequacy planning criterion shall be evaluated probabilistically, such that the Loss of Load Expectation ("LOLE") of disconnecting non-interruptible customers due to resource deficiencies shall be no more than 0.1 day each year. The forecast Installed Capacity Requirement shall meet this resource adequacy planning criterion for each Capacity Commitment Period.*

- **The ICR is then used to set the point of the capacity market demand curve such that when capacity supply is at the ICR (with adjustments for imports), the capacity clearing prices would be at Net CONE**

MARS Output

- Probability of loss of load for the system
- Calculates annual LOLE, LOLH and EENS

Simulation Output

- Calculated LOLE<0.1/year
- Proxy units added to achieve reliability criteria

Simulation Output

- Calculated LOLE >=0.1/year
- ICR calculated and additional load identified such that LOLE = 0.1/year

Appendix

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Mexico relies on LOLP statistics for determining its reliability requirements and setting the reserve margin for its resource adequacy mechanism

Mexico

Market Summary

Peak MW	49,000 MW
Peaking System	Summer
% Wind	5.8%
% Solar	6.3%
% Hydro	11.0%
Structure	Energy Market and a PCM-like resource adequacy mechanism

Metric used to set reliability standard

Two Loss of Load Probability (LOLP) metrics were implemented in 2016 by the Secretariat of Energy:

- The **Maximum LOLP** represents an acceptable technical maximum defined by reliability policies
- The **Efficient LOLP** is defined where the incremental costs of load loss and capacity installation are equal

How the metric is defined

- LOLP is defined as the percentage of time when the system's load will be greater than the generating resources capacity
- Maximum LOLP is a set value that reflects the Secretariat of Energy's policy with respect to acceptable reliability levels
- The Efficient LOLP is the optimal point where the incremental costs of load loss and capacity installation are equal

Reliability standard

- The standards are reviewed and published yearly
- The current Maximum LOLP is set at 0.2178%, and the Efficient LOLP is set at 0.0315%

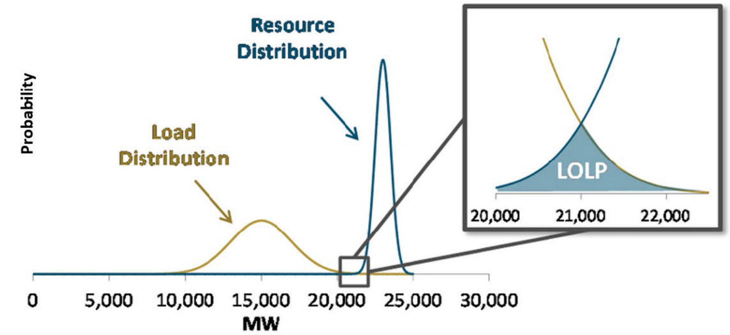
Unique features

- Market has a PCM-like capacity resource adequacy mechanism, implemented a few years ago
- Major market neighboring Texas

The method applied to determining a reserve margin target in Mexico involves policy judgement and economic considerations

- **The Maximum LOLP is a value set, rather than calculated, by the Secretariat of Energy to reflect its reliability policy**
- **A Monte Carlo approach is used to calculate the Efficient LOLP, combining the uncertainty of the demand, random generation outages, and outages due to random transmission failures**

LOLP Modelling Framework



- **The Efficient LOLP is determined using Value of Unserved Energy and the LCOE for generators in Mexico**
  - The Efficient LOLP is that which best balances the value of not losing load against the costs of installing additional capacity to reduce the probability of losing load
  - In other words, the optimum LOLP level is identified at the optimum point where the incremental costs of losing load and installing capacity are equal

- The Maximum LOLP is used to calculate the 'Minimum Planning Reserve Margin', whereas the Efficient LOLP is used to calculate the 'Efficient Planning Reserve Margin' ("EPRM")
- These values are expressed in terms of the reserve margin and are published yearly; more importantly, the EPRMs are used to calculate the Annual Power Requirements for Market Participants in the reliability service market

Source: Secretariat of Energy, Capacity Market Manual

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Appendix

MISO follows the NERC reliability standard, and the LOLE reliability standard is used to set its planning resource auction market parameters

MISO

Market Summary	
Peak MW	119,900
Total GWh	132,028
Peaking System	Summer
% Wind	24.9%
% Solar	2.8%
% Hydro	7.0%
Structure	Energy & voluntary annual capacity auction

Metric used to set the reliability standard	• Loss of Load Expectation ("LOLE") • The 0.1 LOLE target is the NERC standard. FERC Order 693 mandates RTOs to use this NERC standard
Metric definition	The loss of load hours is defined as the number of hours during a given time period where system demand will exceed the generating capacity
Reliability metric standard for the market	0.1 day/year
Unique features	• Adding storage to future supply stack to increase reliability • Also studying capacity market changes to enhance grid reliability

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MISO uses SERVM model to calculate the Planning Reserve Margin in ICAP and UCAP terms in order to comply with 0.1 days/year LOLE

- **MISO uses SERVM to calculate the reserve margin needs to meet the LOLE annually**
- **SERVM uses a sequential Monte Carlo simulation to model a generation system and to assess the system's reliability based on any number of interconnected areas**
  - Capacity is added or removed from the system to achieve target LOLE
- **SERVM calculates the *annual LOLE* for the MISO system and each Local Resource Zone ("LRZ") by stepping through the year chronologically and taking into account generation, load, load modifying and energy efficiency resources, equipment forced outages, planned and maintenance outages, weather and economic uncertainty, and external support**
- **Under a 0.1 days/year LOLE, MISO reached a 17.9% and 8.7% Planning Reserve Margin ("PRM") at ICAP and UCAP levels, respectively for 2022/2023 Planning Year**

Formula used by MISO to calculate PRM values

PRM ICAP = ((Installed Capacity + Firm External Support ICAP + ICAP Adjustment to meet a LOLE of 0.1 days per year) – MISO Coincident Peak Demand)/MISO Coincident Peak Demand

PRM UCAP = (Unforced Capacity + Firm External Support UCAP + UCAP Adjustment to meet a LOLE of 0.1 days per year) – MISO Coincident Peak Demand)/MISO Coincident Peak Demand

Where Unforced Capacity (UCAP) = Installed Capacity (ICAP) x (1 – XEFORd)

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Appendix

Like other US RTOs/ISOs, PJM uses an LOLE standard for reliability, which affects the amount of capacity procured in its Reliability Pricing Model ("RPM") capacity market

PJM

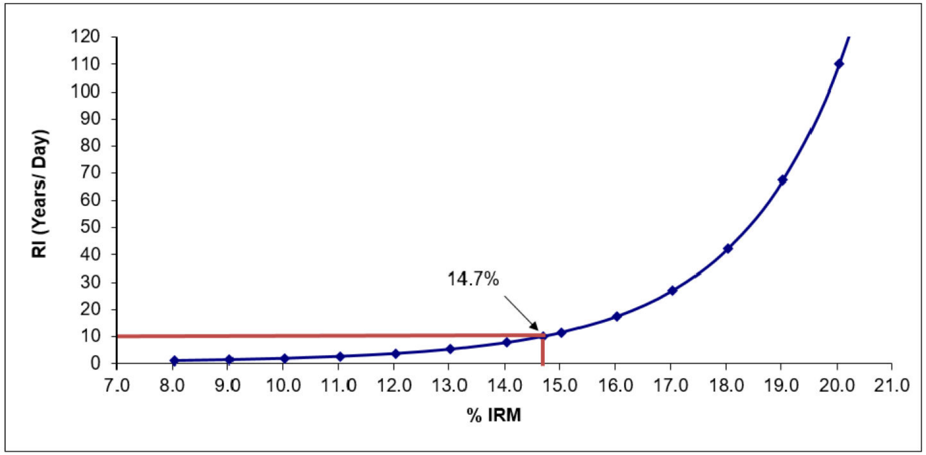
Market Summary	
Peak MWh	144,356
Total GWh	840,027
Peaking System	Summer
% Wind	7.2%
% Solar	5.1%
% Hydro	2.4%
Structure	Energy & forward capacity

Metric used to set the reliability standard	• Loss of Load Expectation ("LOLE") • The 0.1 LOLE target is the NERC standard. FERC Order 693 mandates RTOs to use this NERC standard
Metric definition	Loss-of-load expectation (LOLE) defines the adequacy of capacity for the entire PJM footprint based on load exceeding available capacity, on average, only once in 10 years
Reliability metric standard for the market	1 day in 10 years or 0.1 day/year
Unique features	• Expects lot of offshore wind capacity in the next decade, as well as solar PV (DERs) • Now seeing very low reserve margins in future and working to reform its capacity market

PRISM is the model utilized by PJM to determine the Installed Reserve Margin that meets a LOLE of 0.1 day/year

- **Uses Probabilistic Reliability Index Study Model ("PRISM"), developed by PJM, to calculate LOLE**
  - Forecasts load and future operating capacity
  - Adjusts load such that LOLE is achieved while keeping installed capacity fixed
- **Inputs are set up to produce the necessary installed reserve margin ("IRM")**
  - IRM is defined as the percent of aggregate generating unit capability above the forecasted peak load that is required for adherence to meet a given adequacy level, i.e. meet the PJM criteria for one day, on average, every 10 years
- **Parameters calculated by PRISM are used to determine capacity auction parameters**

Relationship between Reliability Index ("RI")* and IRM



Note: A RI value of 10 indicates that there will be, on average, a loss of load event every ten years.

Source: PJM, "2022 PJM Reserve Requirement Study", October 2022, Figure II-5, Page 38.

PJM's 2022 Reserve Requirement Study - Summary Table

RRS Year	Delivery Year Period	Calculated IRM	Recommended IRM	Average EFORd	Recommended FPR
2022	2023 / 2024	14.87%	**14.9%**	4.87%	**1.0930**
2022	2024 / 2025	14.75%	**14.8%**	4.83%	**1.0926**
2022	2025 / 2026	14.72%	**14.7%**	4.81%	**1.0918**
2022	2026 / 2027	14.70%	**14.7%**	4.81%	**1.0918**

Source: PJM, "2022 PJM Reserve Requirement Study", October 2022, Table I-1, Page 10.

The recommended average IRM for the next 4 planning years that guarantees a 1 day in 10 year criterion is approximately 14.8%

*"Note that the standard does not require "one day in 10 year" as the reliability objective (just the **calculation** of a reserve margin based on "one day in 10 year")"*

Source: PJM, "Education: Current Reliability Metrics in PJM's Resource Adequacy Construct", December 2021

Other sources: PJM Training https://videos.pjm.com/media/0_o62fm8r1

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Appendix

Singapore previously used a 3 day/year LOLP but has recently moved to a LOLH of 3 hours/year

Singapore

Market Summary

Peak MW	7,789
Total GWh	53,500
Peaking System	Summer
% Wind	0%
% Solar	2.8%
% Hydro	0%
Structure	Energy-only

What is the metric used to set the reliability standard?	Loss of Load Hours ("LOLH")
How is the metric defined	Expected number of hours per year when available generating capacity is insufficient to serve the hourly demand across all hours of the year

- Lost load hours are defined as when the available generation is insufficient to serve the demand, as a result of scheduled maintenances, unscheduled/ad hoc repairs and forced outages of generating unit(s)

What is the reliability standard in the market	3-hours of loss of load hours

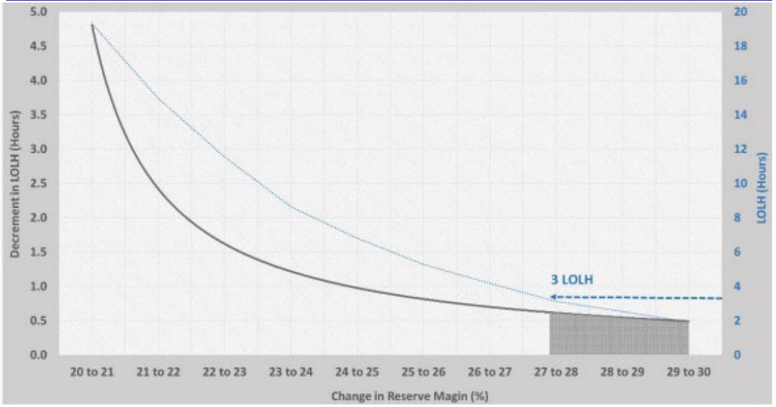
- The reason why 3-hour is chosen is not explicitly stated: the Singapore Energy Market Authority stated that the change from a LOLP of 3 days per year to LOLH of 3-hours per year is based on recommendation from a consultant
- Singapore currently has an energy-only market with excess supply and therefore the reliability standard is for monitoring purpose only

LOLH is calculated based on probability of outage events: as Singapore is a small system relative to the typical size of its generators, a large reserve margin is needed to ensure reliability

Relationship between LOLH and VOLL

- Singapore sets its reliability standard by factoring the trade-off between the value placed by consumers on uninterrupted electricity supply and the cost of adding new capacity to deliver increased reliability
- The key consideration was to minimize the total system cost which comprises the costs of required generation capacity and costs of unserved energy (VOLL is S$5,000/MWh)
- A higher amount (and cost) of generation capacity is required to lower LOLH; however, as LOLH decreases, the cost of unserved energy is correspondingly reduced.

Diminishing returns of LOLH reduction for incremental reserve margin (%)



Illustrative example on how LOLH is calculated by EMA

- The LOLH is the sum of probabilities of all events when load is not fully supplied; the number of events equates to 2N where N is the number of generators in the power system. Hence in this case, the LOLH can be computed through a summation equation
- In an example with 3 generators to serve a 1,000 MW load with varying availabilities (see tables to the right), LOLH (hours) = sum of probabilities with load loss = 0.04165 + 0.13965 + 0.00735 + 0.00085 + 0.00285 + 0.00015 = 0.1925

Generator	Capacity (MW)	Availability (%)
1	500	95
2	600	85
3	300	98

Outages Event	Probability of Occurrence	Amount Load Loss (MW)
None out	(0.95)*(0.85)*(0.98) = 0.79135	0
G1 out	(0.05)*(0.85)*(0.98) = **0.04165**	100
G2 out	(0.95)*(0.15)*(0.98) = **0.13965**	200
G3 out	(0.95)*(0.85)*(0.02) = 0.01615	0
G1 & G2 out	(0.05)*(0.15)*(0.98) = **0.00735**	700
G1 & G3 out	(0.05)*(0.85)*(0.02) = **0.00085**	400
G2 & G3 out	(0.95)*(0.15)*(0.02) = **0.00285**	500
All out	(0.05)*(0.15)*(0.02) = **0.00015**	1000

Singapore was planning to use the LOLH standard of 3 hours/year to set the demand curve for its proposed capacity market

How frequent is the reliability standard being reviewed?	The new standard was set in 2018 when Singapore was also in the process of designing a forward capacity market (the capacity market reform initiative was terminated in 2020)
How is extreme weather condition considered?	The reserve margin derivation was performed through Monte Carlo simulation runs which took into account peak system demand forecast, planned and unplanned outage rates of generating units including intermittent solar PV generation
How is the reliability standard applied to the market design?	Required reserve margin ("RRM)" of 27% was derived from 3-hours of loss of load hours (LOLH) per year. Prior to this, the market had a reliability standard of 3 days/year. The reliability standard would have been used to set the demand curve for the capacity market. Currently, the RRM is only used for reporting and planning purpose. Historically, Singapore's actual reserve margin (50%+) has been well in excess of the RRM.

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Appendix

LOLE is the only criteria used by SPP for reliability purposes currently, but SPP may be considering a change in the future

SPP

Market Summary

Peak MW	51,577
Total GWh	256,574
Peaking System	Summer
% Wind	59.1%
% Solar	0.5%
% Hydro	6.7%
Structure	LSE must maintain adequate capacity based on PRM

Metric used to set the reliability standard	Loss of Load Expectation ("LOLE")
Metric definition	Expected number of days in a year in which available capacity is unable to serve forecasted peak demand
Reliability metric standard for the market	1 in 10 years for LOLE
Unique features	• performs different sensitivities to evaluate the impact of high renewable penetration • adds pre-defined uncertainty patterns and probability distribution to peak demand for each historical weather year

SERVM model coupled with a Monte-Carlo approach is used to determine SPP's Planning Reserve Margins ("PRM") which is designed to achieve the required LOLE threshold

- **SERVM is the software selected by SPP to determine the planning reserve margin that guarantees a 1 day in 10 year reliability metric; SERVM utilizes a Monte-Carlo algorithm that accounts for different variation of forced outages, load forecast uncertainty and wind output**

- **Prioritized resources (based on operational data and age) are removed from SPP system until the reliability threshold is met**

2021 LOLE study – "Base case" outcomes

Method to achieve 0.1 day per year	Study Year	NCP Peak Demand (MW)	Generation Removed to achieve 0.1 day per year (MW)	NCP PRM (%)	NCP Planning Reserves Required (MW)	Total Minimum Capacity Required (MW)
Generator Removal	2023	54,631	5,332	12.78%	6,982	61,613
Generator Removal	2026	56,168	3,466	11.67%	6,555	62,723

Source: SPP, "2021 SPP Loss of Load Expectation Study Report", June 2022, Table 17.1, Page 34.

- **SPP studied 2023 and 2026 conditions in its 2021 LOLE study**
  - The study shows that for 2023, a 12% reserve margin is no longer sufficient to meet a 0.1 day per year LOLE requirement
  - For the 2026 study year, a 12% reserve margin is expected to be sufficient to meet the 0.1 day per year LOLE, but the level of supply in 2021 was not enough to meet this reserve margin due to expected peak demand growth, and new resources is needed
  - For both study years, LOLE occurred in summer during afternoon/evening hours

Based on the results of the high renewable penetration scenarios, SPP decided to report in the next LOLE study (2023) on Expected Unserved Energy ("EUE") at a seasonal level

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Appendix

UK policymakers have determined a reliability requirement, where a maximum of 3 hours/year of mismatch between supply and demand is tolerated – this is based on VoLL of close to US$21,000/MWh

United Kingdom

Market Summary

Peak MW	46,000
Total GWh	283,000
Peaking System	Winter
% Wind	26.8%
% Solar	4.4%
% Hydro	1.8%
Structure	Energy and forward capacity market

What is the metric used to set the reliability standard?

Loss of Load Expectation (LOLE)

How is the metric defined

Number of hours per annum in which, over the long-term, it is statistically expected that supply will not meet demand

- This does not mean 3 hours of blackouts per year; it means that, on average, there may be 3 hours per year when supply would not match demand and exceptional measures would be required to avoid significant effects on customers
- The reliability standard in LOLE is mathematically linked to expected level of unserved energy, the VOLL, and CONE
- Back in 2013, the Department of Energy and Climate Change estimated CONE of a peaking plant was £47,177/MWh, VOLL was £16,940/MWh (~US$ 21,000 using 2023 exchange rate, ~US$27,000 using 2013 exchange rates) and derived the Reliability Standard would be around 2 hours, 47 minutes and 6 seconds, which is rounded to 3 hours per year

What is the reliability standard in the market

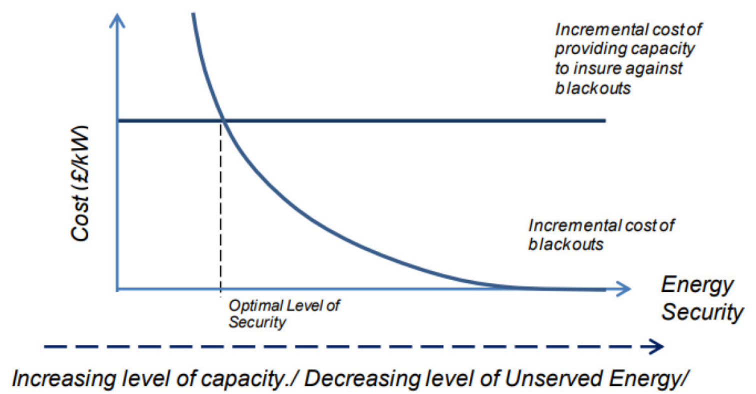
3 hours per year

the reliability standard is used to set the demand curve in the capacity market

UK's LOLH reliability metric relies on a cost of new entry estimate as well as the VoLL value

- The UK Department of Energy and Climate Change ("DECC") (which was recently renamed the Department for Energy Security and Net Zero) took an analytical approach, which takes into account consumers' Value of Lost Load ("VoLL") and the cost of new plant
- The Value of Lost Load represents the value that customers place on security of supply, or alternatively the cost to customers of being disconnected; the optimal level of security of supply trades the cost of providing additional capacity against the associated benefit of a reduced chance of blackouts
- This method has the advantage of choosing a level of capacity that is explicitly linked to the value that consumers place on electricity (VoLL)
- The optimal level of security of supply is found by finding the point at which the incremental cost of insuring customers against blackouts is equal to the incremental cost to customers of blackouts
- Incremental cost of providing capacity is based on CONE of an OCGT

Illustrative optimal level of security of supply



Equilibrium Reliability Standard in LOLE (hrs/yr)		Cost of New Entry (£/kW) LOW £31.89	CENTRAL £47.18	HIGH £66.21
VoLL (£/MWh)	35,490	0.90	1.33	1.87
	16,940	1.88	**2.78**	3.91
	10,290	3.10	4.59	6.43

Appendix

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Bibliography - Australia

- AEMC National Electricity Rules, Clause 3.9.3A - Reliability standard and settings review
- AEMC Reliability Panel AEMC. Definition of Unserved Energy. 1 August 2019
- AEMC Reliability Panel AEMC. Final Report – 2022 Review of the Reliability Standard and Settings. 1 September 2022
- Intelligent Energy System. Reliability Standard Settings Review 2022 – Modelling Report. 31 August 2022
- Pierluigi Mancarella. Considerations in support of the 2022 Reliability Standards and Settings Review – Briefing Note prepared for the Australian Energy Market Commission. August 2022

Bibliography - Brazil

- MME. “2031 Ten-year Energy Expansion Plan.” https://www.gov.br/mme/pt-br/assuntos/secretarias/spe/publicacoes/plano-decenal-de-expansao-de-energia/pde-2031/english-version/relatorio_pde2031_cap03_eus.pdf
- ONS. “Evolution of Processes and Methodological Improvements.” https://www.ons.org.br/sites/multimidia/Documentos%20Compartilhados/relatorios%20anuais/2013/HTML/en/02-11-evolution-processes-methodological-improvements.html?expanddiv=02
- ONS. PEN 2022. https://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/NT-ONS%20DPL%200102-2022_PEN%202022%20-%20Condi%C3%A7%C3%B5es%20de%20Atendimento.pdf
- ONS. “O Planejamento da Operação Energética no Sistema Interligado Nacional - Conceitos, Modelagem Matemática, Previsão de Geração e Carga.” 2020 https://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/Livros-da-Diretoria-de-Planejamento-na-biblioteca-digital-ONS/LIVRO-O-PLANEJAMENTO-DA-OPERA%C3%87%C3%83O-ENERG%C3%89TICA-NO-SISTEMA%20INTERLIGADO-NACIONAL.pdf
- EPE. “Estudos para a Expansao da Geracao” https://www.epe.gov.br/sites-pt/areas-de-atuacao/energia-eletrica/Documents/NT-EPE-DEE-133-2021_Quantifica%C3%A7%C3%A3o%20dos%20Requisitos%20de%20Energia%20e%20Capacidade.pdf

LONDON ECONOMICS

Bibliography - CAISO

- **California Public Utilities Commission. "Staff Report - Midterm Reliability Analysis." September 2021. CEC-200-2021-009. https://www.energy.ca.gov/sites/default/files/2021-09/CEC-200-2021-009.pdf**
- **California Public Utilities Commission. "Loss of Load Expectation and Effective Load Carrying Capability Study Results for 2024." February 18, 2022. Energy Division Study for Proceeding R.21-10-002 https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M452/K750/452750851.PDF**
- **California Energy Commission. "2021 California Reliability Outlook." September 2021. CEC-200-2021-009. https://www.energy.ca.gov/sites/default/files/2021-09/CEC-200-2021-009.pdf**

Bibliography - Colombia

- CREG. Precio Marginal de Escasez. 18 October 2017.
- CREG. Consultoría para definir las métricas para estimar la contribución de confiabilidad al SIN. 25 December 2020.
- Ministry of Mines and Energy. Resolución por la cual se definen criterios de resiliencia, seguridad y confiabilidad para el suministro de energía eléctrica. January 2012
- World Bank Group. Learning from Developing Country Power Market Experiences- The Case of Colombia. March 2019

Bibliography – ISO-NE

- Installed Capacity Requirement Reference Guide, ISO-NE System Planning report
- ISO-NE 2021 Study for the 2025-2026 capacity commitment period FCA 16
- ISO-NE 2022 Study for the 2026-2027 capacity commitment period FCA 17
- FCM Zonal Demand Curve Methodology report
- Operational Impact of Extreme Weather Events Study conducted by ISO-NE with EPRI March 2023

LONDON ECONOMICS

Bibliography - Mexico

- CENACE. Informe de la Tecnología de Generación de Referencia. 10 February 2023.
- Secretariat of Energy. Manual del Mercado para el Balance de Potencia. 23 September 2016
- Secretariat of Energy. AVISO por el que se da a conocer la política de confiablidad, establecida por la Secretaría de Energía. 28 February 2017
- Secretariat of Energy. Manual regulatorio de planeación del sistema eléctrico nacional. 31 December 2021.

Bibliography - MISO

- **Planning Year 2022-2023 Loss of Load Expectation Study Report, MISO Loss of Load Expectation Working Group**

Bibliography - PJM

- PJM Manual 18, 19 and 20
- PJM Glossary
- Current Reliability Metrics in PJM's Resource Adequacy Construct – PJM presentation by PJM Resource Adequacy Task Force
- 2022 PJM Reserve Requirement Study, PJM Resource Adequacy Planning report
- PJM Training videos

LONDON ECONOMICS

Bibliography – Singapore

- EMA. "Determining the Required Reserve Margin to Maintain a Reliable Electricity Supply in Singapore"
- EMA. "Enhancing the Singapore Wholesale Electricity Market for Supply Reliability, Economic Efficiency and Financial Stability" 28 May 2020
- Energy Market Company – "Review of the Value of Loss Load". 12 March 2012

LONDON ECONOMICS

Bibliography - SPP

- SPP, "2021 SPP Loss of Load Expectation Study Report", June 2022
- SPP, "2023 SPP Loss of Load Expectation Scope", January 2023
- SPP, "Open Access Transmission Tariff", Sixth Revised Volume No. 1, Attachment AA Resource Adequacy, July 2018

Bibliography – United Kingdom

- UK Parliament, “The Resilience of the Electricity System - Science and Technology Committee”, Chapter 3: Will the Lights Go Out? https://publications.parliament.uk/pa/ld201415/ldselect/ldsctech/121/12106.htm
- UK Department of Energy and Climate Change. Annex C: Reliability Standard Methodology. July 2013
- UK Department of Energy and Climate Change. Annex G: Modelling Quality Assurance
- UK Department for Business, Energy and Industrial Strategy. “Statutory Security of Supply Report 2022”. December 2022