

Evaluation of Sub-Annual Designs for PJM's RPM

Preliminary Assessment of Sub-Annual Capacity Market Design

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Agenda

- Preliminary evaluation of design options
- Overview of quantitative analysis

Preliminary Evaluation of Design Options

Today's Presentation

Preliminary assessment of design considerations and tradeoffs in sub-annual markets

- Today's presentation provides a *preliminary* assessment of tradeoffs including certain recommendations
- December presentation and report will reflect further assessment, including the quantitative analysis, and feedback received
- On balance, we recommend that PJM pursue the development of a sub-annual market
- We provide recommendations about certain market design features – *for example*:
 - Two periods (summer, winter)
 - Sub-annual features should be accounted for in market design: demand, supply quantities, supply costs, system features
 - The use of MRI-based demand curves is more accurate and less administratively burdensome with sub-annual market
- We identify tradeoffs for other market design features and identify features requiring further investigation/deliberation – *for example*:
 - Auction structure: co-optimization vs. independent auctions
 - Demand curve caps/scarcity prices

Assessment Reflects Potential Benefits and Costs of Sub-Annual Markets

Sub-annual markets can potentially provide many benefits to PJM

More accurate price
signals

Better alignment of
resource compensation
with services provided

More accurate accounting
of resource and system
features across sub-
periods

RPM that flexibly adapts
to on-going changes in RA
risks across sub-periods

Better alignment of
resource contributions
with cost and risks

While providing benefits, the adoption of a sub-annual market would involve additional costs (to PJM and stakeholders) in the form of one-time implementation costs and on-going costs of managing a potentially more complex market

Design Options

We consider the many dimensions to sub-annual capacity market design

- Market structure
 - Auction structure
 - Offer structure
 - Number of periods
- Supply
 - Resource accreditation
 - Offer caps
 - Obligations
 - Fixed Resource Requirement
- Demand curve
 - Reliability requirement
 - Transmission constraints
 - Curve shape
 - Price caps
- Cost allocation

Sub-period granularity could be applied to all or just some market features, with implications for whether the market provides sub-annual price discovery and accurate accounting of resource supplies

Principle: All else equal, a market that accounts for sub-annual variation along all dimensions will increase both short-term and long-term efficiency by most accurately representing demand and resource/system capabilities

Market Structure

Multiple options for the structure of sub-annual auctions

	Sequential	Simultaneous
Independent	NYISO ISO-NE (proposed)	MISO
Co-optimized (Offer Selection)	Not Feasible	

Independent: Offers are cleared independently in each sub-annual auction

Sequential: Sub-annual auctions are cleared at different points in time, one after the other

Co-optimized: Offers for sub-annual products are cleared jointly within the same auction/optimization

Simultaneous: Multiple sub-annual products are cleared in auction(s) occurring at one point in time

Market Structure

Tradeoffs between auction structures

- Co-optimized, simultaneous
 - Procurement of supply is optimized across sub-periods
 - In principle, increases in efficiency achieved by integration of supply and/or demand in optimization problem
 - Supply – accounting for fixed and variable costs
 - Demand – determining demand within market-clearing, rather than prior to market clearing
 - Magnitude of potential gains from optimization uncertain relative to costs
 - Feasibility of developing optimization software is uncertain – creates uncertainty regarding costs and timing
 - Increases feasibility of annual price caps (discussed in next slides)
 - Further evaluation may be needed to investigate feasibility and timing, with separate evaluations for supply and demand
- Independent, sequential
 - Comparatively easier/lower cost to implement
 - Likely achieves majority of benefits of a sub-annual market
 - Potential inefficiencies due to lack of co-optimization
 - Implications for structure of offer prices (next slide)
- Independent, simultaneous
 - Similar pros/cons as independent, sequential auction compared to co-optimized approach
 - Some differences relative to sequential, independent approach:
 - Greater market uncertainty, since market clears and Capacity Supply Obligations (“CSOs”) awarded further in advance of delivery period
 - Increases feasibility of annual price caps (discussed in next slides)

Supply Offers – Structure of Offer Prices

Options for accounting for fixed costs

- Within a sub-annual market, resources have two types of costs:
 - Fixed costs – incurred regardless of the number of periods supplying; cannot be avoided if supplying in one but not all periods
 - Variable costs – incurred in each period; can be avoided if not supplying in a period
- Relationship between fixed and variable costs may depend on sub-period duration
- The options for accounting for each type of cost differ with auction structure

Co-optimized

- Offer prices could reflect, separately:
 - Annual component (fixed, non-divisible)
 - Period-specific component (avoidable costs for the period)

Independent Markets

- Offer prices reflect a single cost component that incorporates both fixed annual and period-specific costs
- Complicates offer cap rules
- May not achieve optimal selection of capacity supply resources

Market Structure

Independent market may be more feasible in the short-term with minimal loss of efficiency

- If PJM opts to pursue a sub-annual market and wants to pursue a co-optimized market, further evaluation may be needed to assess the scope of the optimization to be pursued (supply? demand?), feasibility, cost, timing and value (i.e., comparison of improved efficiencies to costs, any timing delays and other complications)
- If PJM initially develops an independent sub-annual auction (sequential or simultaneous), it retains the option to co-optimize at a later date
 - Given the scope of market changes needed to move from an annual to sub-annual capacity market, this option may allow PJM to develop sub-annual markets in a more timely way with fewer complications
- The market structure should be evaluated within a broader framework of potential RPM reforms and a long-run targeted design for the RPM (e.g., MRI-based demand curves, prompt auction structure, etc.)
 - Tradeoffs between making reforms all at once versus sequentially
 - Potential sequencing of reforms toward a long-run design
 - Potential consequences of making certain reforms without targeted long-term design

Number of Periods

Tradeoffs of greater temporal granularity

- Greater granularity of periods (seasonal, intra-day) creates tradeoffs
- Pros of greater temporal granularity:
 - Accounts for relevant differences in the value of capacity in different periods and resources' ability to deliver resource adequacy contributions
 - Benefits materialize to the extent there is meaningful risk in sub-periods or there are meaningful differences between sub-period conditions (seasonal risk, resource/system capabilities, etc.)
 - Shoulder seasons
 - Sub-period risk may be low, but defined shoulder seasons may improve incentives for scheduling and limiting planned maintenance outages
 - Intra-day differentiation
 - Intraday period may better align capacity market awards and obligations for certain resources (e.g., solar)

Number of Periods (cont.)

Tradeoffs of greater temporal granularity

- Cons of greater temporal granularity:
 - Low prices
 - Periods with low expected risk would likely lead to low prices, raising (at least) two concerns:
 - *First*, supplier bidding incentives may be misaligned with low prices given CP risks and opportunity costs
 - *Second*, capacity resources may provide other reliability benefits (given must-offer obligation, outage scheduling, etc.) – if supply is reduced due to low prices, may have reliability consequences
 - Greater granularity complicates development of price caps (discussed later)
 - Intraday sub-periods
 - With intra-day sub-periods, market-clearing would be complex and potentially infeasible because accreditation of certain resource types (e.g., storage) would reflect inter-dependent accreditation and market clearing across sub-periods
 - May exacerbate inefficiencies in market clearing when using independent auctions
 - Alignment with energy market incentives
 - With a very granular (e.g., hourly) market or market with intra-day sub-periods, capacity market incentives for performance could conflict with energy market incentives

Number of Periods (cont.)

We recommend a two-season winter/summer market

- Given these considerations, our preliminary recommendation is a two-season market
 - In the PJM region, the summer and winter seasons account for most of the risk and the greatest differences between seasons
 - Variation in demand and resource performance within the winter and within the summer season is not large
 - Gains from specifying shoulder seasons are limited to the impact on maintenance outages, which may not be material and can be addressed through other means
 - A more granular market introduces other complications
- Sub-period/seasons should reasonably bound expected periods of RA risk
 - Summer period: May 1 to October 31
 - Winter period: November 1 to April 30

Preliminary recommendation: Two-season market, including summer (May 1 to October 31) and winter (November 1 to April 30) season

Offer Quantities

Resource offers can reflect capability in each sub-annual period

- Resource capability can account for factors that affect sub-period capability:



Ambient air conditions



Resource deliverability



Performance reflecting
historical forced outage
risk



Contribution to RA given
intermittency/correlated
supplies

Preliminary recommendation: We recommend that market rules account for sub-annual supply offer quantities that reflect resource capability (to the extent feasible)

- Allow capacity to reflect sub-period ambient air capability (resulting in greater winter supply)
- Allow resource deliverability to reflect sub-period capability

Offer Prices

Offer price rules vary with market structure

- In a sub-annual market, offer price mitigation (offers caps, reference prices) will need to be modified depending on the auction structure adopted

Co-optimized, Simultaneous Market

- Two offer price components
 - Period-specific variable component
 - Annual component (fixed, non-divisible)
- Offer caps/reference prices:
 - Same cost elements as present
 - Need to determine how annual and variable components are specified

Sequential, Independent Market

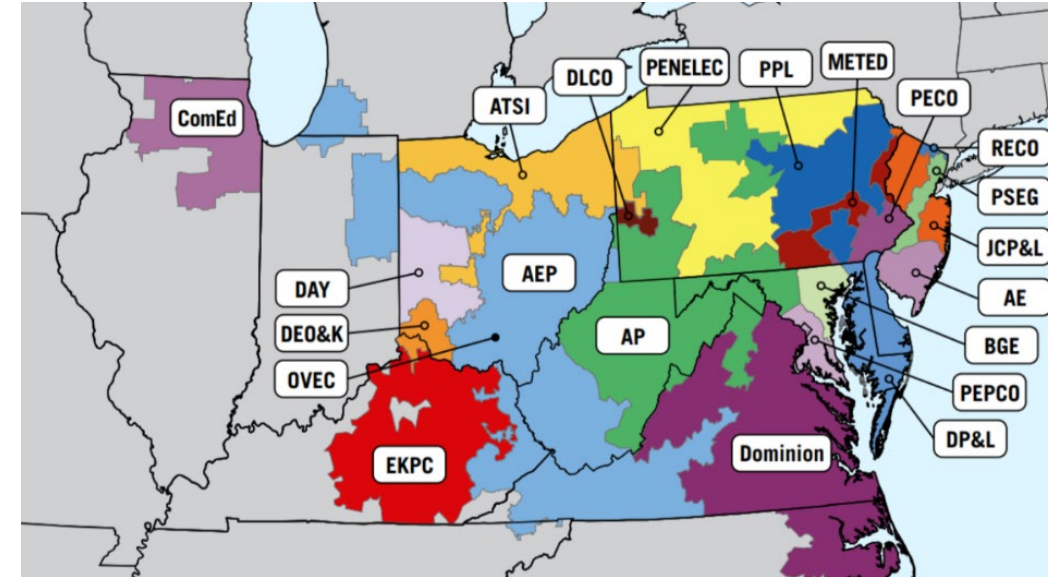
- Single cost component, incorporating annual and period-specific fixed costs
- Offer caps/reference prices
 - Same cost elements as present
 - Need to determine how resource costs can be spread across sub-annual offers
 - Design questions include whether owners have flexibility to (1) vary offer prices across sub-periods or (2) set offer prices to achieve full cost recovery over one or a sub-set of periods
 - Offer caps that allow recovery of all costs in one period (or a subset of periods) increases risk of excess cost recovery and disorderly bidding (resulting in inefficient clearing of resources)

Demand Curves

Sub-annual curves would be constructed for the RTO and LDAs

- A sub-annual market requires that demand for capacity resources reflects the value of marginal capacity for mitigating RA risks
- Demand curves would be constructed for the RTO and Locational Deliverability Areas (“LDAs”) that face potential import constraints under emergency conditions
- Construction of sub-annual demand curves (Variable Resource Requirements, VRRs) could follow the same principles as the current approach, but would require updating
 - Updated approaches to determine sub-period capacity requirements and (allocated) net CONE across sub-periods
 - Updated approaches to account for sub-period RA risk that should inform relevant VRR curve slope and shape

PJM LDAs



Source: PJM, available at <https://www.pjm.com/-/media/DotCom/about-pjm/pjm-zones.pdf>.

Demand Curves

Adoption of MRI curves beneficial to achieving benefits of sub-annual markets

- Marginal Reliability Impact (“MRI”) curves provide information on RA risks in each sub-period
- Two approaches to developing sub-period demand curves that account for sub-period variation in RA risk:

VRR Demand Curve (informed by MRI)

- Accounting for sub-annual variation requires use of RA/MRI analysis
- Sub-period requirement and allocated net CONE
 - With MRI data, requirements and net CONE allocation can reflect RA risk in each sub-period
- Slope/shape can be informed by MRI curves
 - VRRs can reflect relative sub-annual RA risks
 - Requires new administrative process

MRI Demand Curves

- Demand curves derived from MRI curves and economic principles (e.g., equal cost per EUE across seasons)
- Demand curve anchor points, shape and slope directly derived from RA model outputs
 - More accurate
 - Can simplify process of constructing demand curves and lower administrative and stakeholder costs
- Well-developed methods (relied on in MISO and ISO-NE)



Preliminary recommendation: Adopt MRI curves as more accurate and less technically burdensome approach to developing sub-period demand curves

Price Caps

Sub-annual markets would require an assessment of the criteria and formulas for price caps

- Price caps establish a scarcity price for capacity under shortage conditions
- Sub-annual price caps introduce new considerations to establishing price caps
- Tensions between considerations increase with the number of sub-periods

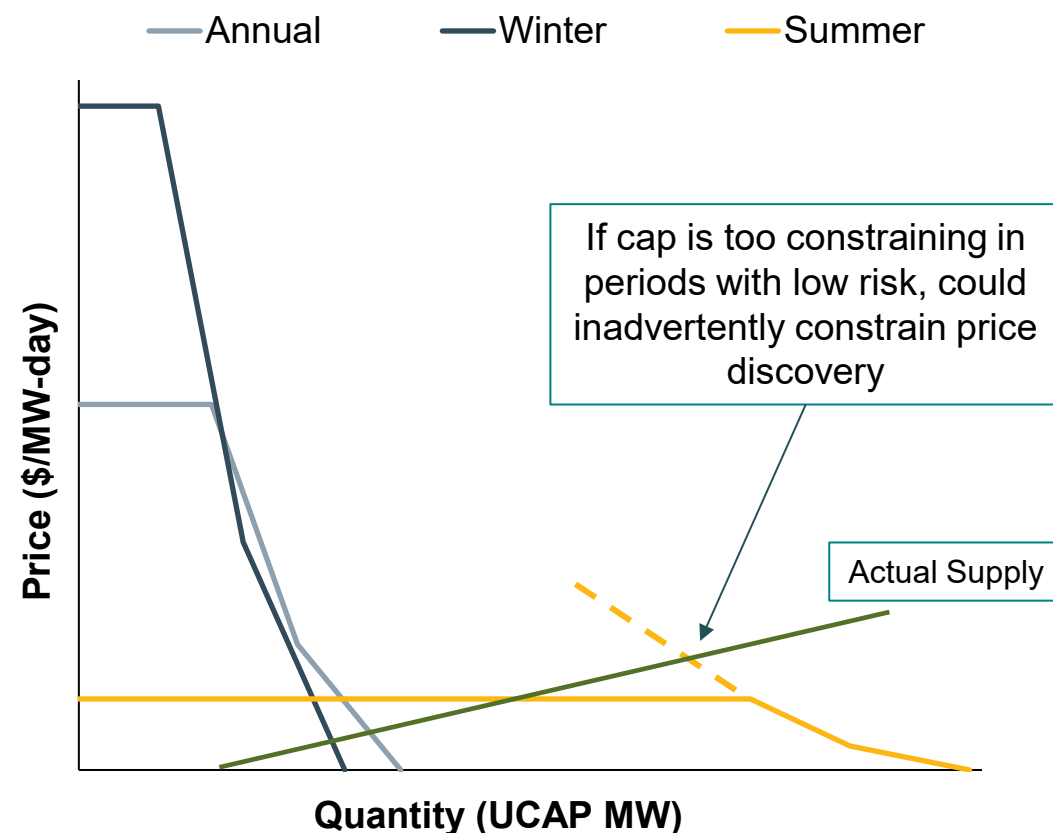
Price Cap Consideration	Issues
Sub-period and annual scarcity prices	• Sub-period demand curves include price caps to reflect sub-period scarcity (potentially reflecting allocated net CONE by season) • A tighter price cap, all else equal, reduces risk of “excess” recovery across seasons • “Excess” recovery across seasons may prompt desire for “annual” cap reflecting pricing across sub-periods
Risks of constraining price discovery	• A tighter price cap, all else equal, constrains price discovery • With a sub-annual market, potentially greater risk that a cap constrains under otherwise “normal” market conditions (especially when caps set relative to net CONE)
Impact of cost recovery	• Overly stringent price caps may inadvertently limit cost recovery when resources clear in some but not all seasons

Price Caps

Development of sub-annual caps

- At present, price caps are set relative to the cost of new entry (gross or net CONE)
- Within a sub-annual market, gross/net CONE needs to be allocated across sub-periods
 - More efficient to allocate more gross/net CONE to high-risk periods, and less to low-risk periods
 - Given the current approach to setting caps, this implies lower price cap in low-risk periods and higher price cap in high-risk periods
 - However, low price caps in periods with low assumed risk potentially constrains price discovery if less supply than expected is offered
 - Economic principles suggests equal scarcity value across sub-periods, reflecting customer willingness to pay (“WTP”)

Illustration: VRR Annual and Seasonal Demand Curves



Overview of Quantitative Analysis

Overview of Quantitative Model

Analysis designed to compare annual and sub-annual designs

- Our market simulation model will illustrate and quantify the potential impacts of moving from an annual to a sub-annual capacity market
 - The model utilizes an optimization algorithm consistent with PJM's RPM BRA algorithm, maximizing welfare given supply, demand, and CETL transmission constraints consistent with 2027/2028 BRA parameters
- We make simplifying assumptions to maintain tractability of the model, without meaningful loss of information about the differences between sub-annual and annual
- Intended to illustrate the *differences between annual and sub-annual designs*
- The model is *not a prediction* of clearing prices or total customer payments under the current annual construct or a possible sub-annual design

Model Design Assumptions

Assessment to reflect current market conditions

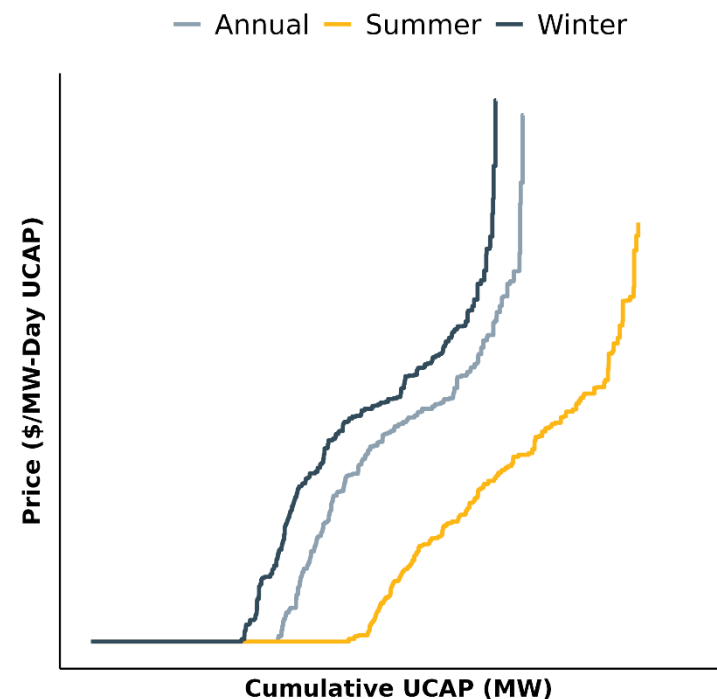
- We model RTO and a subset of the constrained LDAs consistent with PJM Manual 18:
 - Modeled LDAs: MAAC, EMAAC, and SWMAAC (always modeled) and DOM, since its Capacity Emergency Transfer Limit (“CETL”) is less than 1.15 times its Capacity Emergency Transfer Objective (“CETO”)
- Number of periods:
 - Two sub-annual periods, reflecting summer (May 1 through October 31) and winter (November 1 through April 30)
 - The two sub-annual periods are solved independently
- Demand:
 - VRR demand curves are used in the base case, with sensitivities considering MRI curves
 - Sub-period price caps are set consistent with existing market rules, with sensitivities considering alternatives

Modeling Supply

Supply curves rely on parameters associated with 2027/2028 RPM BRA

- Resource mix (and its associated capacity accreditation) is consistent with that used by PJM to derive IRM and FPR for 2027/2028 BRA
- For each period, we construct supply curves reflecting that period's offer quantities and prices
- Offer quantities reflect the period-specific accredited capacity
 - Modeled in MW (UCAP) = ICAP (or effective nameplate for renewables) × ELCC class rating
- Resource bids reflect period-specific costs
 - Modeled in \$/MW-day UCAP = Gross ACR – Net E&AS revenues
 - Gross ACR split equally across seasons
 - Net E&AS estimated specific to each season

Illustration: Annual and Seasonal Supply Curves



Supply Differences Between Annual and Sub-Annual

Sub-annual differences in capacity accreditation and net revenues drive supply differences between periods

- Capacity accreditation – i.e., ELCC ratings – reflects the reliability value in each sub-annual period
 - Leads to differences in sub-annual offer quantities
 - Leads to differences in sub-annual offer prices by affecting costs per MW (e.g., a reduction in offered capacity translates to higher bids)
- Net E&AS revenue estimated specific to each period
 - Leads to differences in sub-annual offer prices by affecting costs per MW (e.g., a reduction in net revenues translates to higher bids)

Annual and Assumed Seasonal ELCC
Top 10 Class Types by ICAP

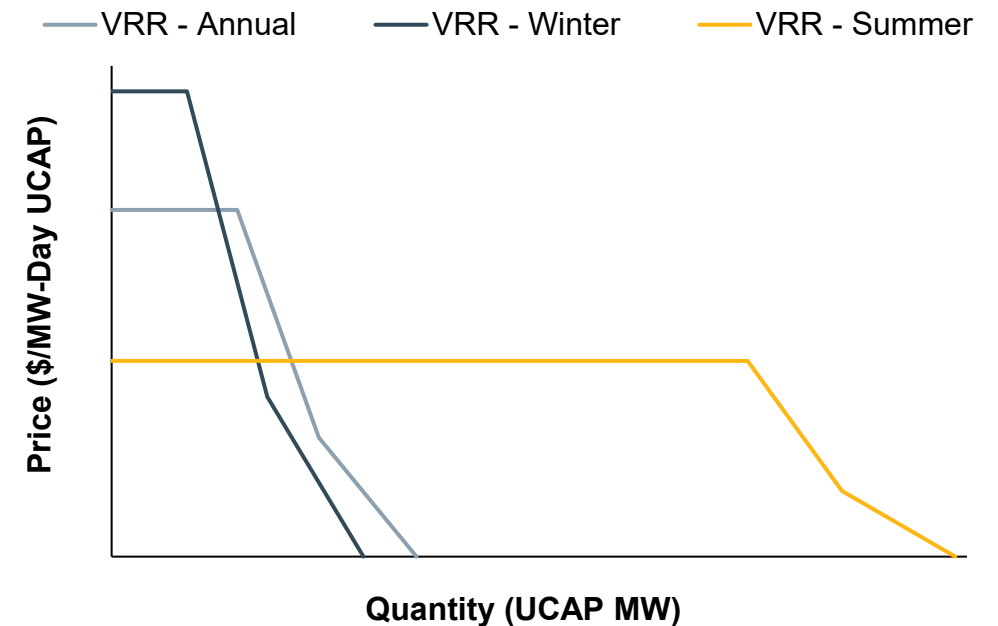
Class Type	ELCC		
	Annual	Summer	Winter
Gas Combined Cycle	0.74	0.96	0.72
Coal	0.83	0.87	0.83
Nuclear	0.95	0.96	0.95
Gas Combustion Turbine Dual	0.77	0.96	0.75
Gas Combustion Turbine	0.61	0.97	0.56
Steam	0.72	0.89	0.70
Demand Resource	0.92	1.09	0.90
Solar Tracking	0.08	0.28	0.06
Onshore Wind	0.41	0.09	0.44
8-hr Storage	0.70	0.93	0.67

Demand Differences Between Annual and Sub-Annual

Sub-annual differences in contributions to RA risk drive demand differences between periods

- VRR demand curves rely on parameters from 2027/2028 RPM BRA, excluding the temporary price floor and price cap
- RTO reliability requirements (“RRs”) differ between sub-annual periods due to differences in sub-annual risk (i.e., share of expected unserved energy)
- LDA reliability requirements differ between annual and sub-annual periods due to differences in internal UCAP
 - This is a consequence of period differences in ELCC ratings
 - CETO values assumed the same in annual and sub-annual periods
- Net CONE anchoring differs between annual and sub-annual periods based on period differences in the ELCC rating of the reference resource and share of reliability risk

Illustration: VRR Annual and Seasonal Demand Curves



Limitations of the Quantitative Modeling

Results are short-term and sensitive to current system conditions

- Does not account for general equilibrium effects of a sub-annual model – i.e., increased efficiency due to entry/exit accounting for sub-annual differences that will be achieved over a longer time horizon
- Does not account for possible future changes in capacity mix, parameters (e.g., CETLs or ICAP ratings), reliability requirements, or evolving allocation of resource adequacy risk across periods
- Results are potentially sensitive to underlying supply and demand conditions due to the current system-wide capacity shortfall and steep VRR demand curves

Potential Sensitivities

Alternative assumptions to test under what conditions base case differences are generalizable

- Potential differences in parameters between sub-annual and annual due to differences between summer and winter ambient conditions
 - Higher CETL values in winter
 - Higher winter ICAP ratings for thermal generation resources
- Alternative demand formulations
 - MRI-based demand curves
 - Alternative VRR formulations
 - Alternative price caps
- Alternative parameters reflecting different market conditions
 - Alternative reliability requirements
 - Alternative CETL values

Next Steps

Next Steps

- Stakeholder presentation in December
- Final Report posted on December 19, 2025
- Stakeholder presentation (report review) following the report release in January

Thank You

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