Summary and synthesis of G-PST's Resource Adequacy Webinars and In-Person Workshop

G-PST organized three workshops in 2023 to share international experiences, especially European and North American, about lessons and challenges with ensuring system-wide resource adequacy (RA) for both market and non-market perspectives. Two virtual webinars–one focused on resource adequacy modeling and studies and the other focused on the connection with wholesale market design–were arranged to help establish a foundation for background concepts and challenges. A subsequent in-person event in Washington, D.C. gathered 59 participants with diverse backgrounds, including academic researchers, industry professionals, system operators, regulators, and policymakers, for a more in-depth discussion on modern RA assessment and market design. The goal of this event was to stimulate participants to think critically about the important RA challenges: what they are, what to prioritize, and how to address them. This summary synthesizes the discussions of all three workshops, especially the in-person event, with a focus on the two main dimensions of the broader RA discussion: RA assessment and market design.

Topic 1: RA ASSESSMENT

Across the various discussions, the group consensus of modern RA assessment includes (i) the use of multiple RA metrics to characterize loss of load events and the need to standardize them with cost-benefit tradeoffs; (ii) a range of potential operational conditions and resource behavior to reflect realistic dispatch, and (iii) more comprehensive data on resource and load behavior (including temporal/spatial granularity and visibility) as well as modeling techniques to improve accuracy. Based on this consensus, the discussion identified **three strategic drivers** and related strategies and approaches to support system RA in rapidly evolving power systems with growing demand and inverter-based resources:

Uncertainty and risks: Consider the uncertainty from changing climate patterns, extreme events, and tail risks, specifically the gray swans in weather (e.g., heatwaves, hurricanes, snowstorms, and low wind and/or solar periods sometimes called "dunkelflaute" events), as well as policy and regulatory changes, and geopolitical dynamics.

Resource attributes: Evaluate different resource portfolios, including generation and transmission, firm resource availability for capacity adequacy, instantaneous balancing capability for energy adequacy, and flexibility over time and across space.

Evolving demand behavior: Ensure the engagement with energy storage, load flexibility, and distributed energy operations, especially their performance response to real-time pricing within the lookahead period.

Participants also developed and prioritized a list of unresolved RA questions related to planning, operation, and implementation. The top two questions related to "*uncertainty,*" specifically uncertainty in the assessment approach and in the market design:

1. ***How do we identify uncertainties correctly within RA assessments, including the correlation of different uncertainties?***
2. ***How do we design electricity markets to support reliability against large uncertainties and ensure resilience to different pathways, thus providing more predictability to investors?***

To address the first unresolved question, the group identified different types of uncertainty. Through the brainstorming of workshop participants, uncertainty that affects the quality of RA assessment and modeling can be generally categorized into five types: (i) **physical uncertainty** from the impact of changing climate patterns on power systems in both the supply (resources availability, stability) side and demand (load flexibility) side; (ii) **societal uncertainty** from cross-country geopolitics, policy environment, socio-economic structure, and some other future uncertainties (including unknowns unknowns) on fuel supply and electricity load; (iii) **investment uncertainty** from project timeline and costs of emerging technology development; (iv) **operational uncertainty** from the accreditation of inverter-based resources, transmission networks, generator performance, and load forecasting; and (v) **implementation uncertainty** from policy effectiveness and market efficiency between policymakers, regulators, generators, and consumers. Capturing the characteristics of these uncertainties through statistical analysis is sometimes challenging, as data can be very limited in rare events or even hard to quantify in some circumstances. In addition, common mode, correlated uncertainty, and dependent failures in power grids further complicate the uncertainties.

The group identified three approaches to assess and manage these uncertainties. First, regarding **modeling practices** to consider uncertainty, system operators can better utilize existing tools with detailed chronological data, adopt risk-aware planning through dynamic adaptive planning, or perform scenario analysis with different risk metrics. Other advanced methodologies include robust optimization and distributionally robust optimization, lead-time consideration, and joint probabilities to capture the underlying uncertainty correlation. Second, system operators and planners can focus on the scenarios and dimensions that reveal a significant **directional impact from uncertainty**, and place less focus on the cases exhibiting marginal impact, for more effective implementation results. Third, system operators and grid planners can further **mitigate the uncertainty** of deploying resources to meet RA needs by better identifying which resources contribute significantly to RA and which also have a high degree of uncertainty associated with their deployment.

Topic 2: MARKET DESIGN

Market design for reliability was the second unresolved question to participants. Specifically, *how can market design support reliability against large uncertainties and ensure resilience to different pathways, thus providing more predictability to investors?*

The end goal of an effective market design is to economically ensure system adequacy, regardless of different design alternatives (energy only market, capacity market, or reliability reserves). An adequate power system also requires flexibility to accommodate condition changes and provide sufficient reliability services when necessary. To achieve this target, some key problems will need to be answered at the market design and implementation level:

- How should profits be allocated between spot markets and a capacity mechanism?
- Facing uncertainties from emerging technologies, expanding transmission network, as well as response in the load and distribution side, how would different market alternatives perform and impact the investment outcomes of future systems?
- How can different market products differentiate and reflect the physics and reliability needs of the grid, in terms of (i) **geographical and temporal granularity** (including interactions with

locational marginal prices, storage management, and storage and lookahead issues); (ii) **market roles** (e.g., flexibility, ramping, and baseload), and (iii) in case of capacity accreditation, **performance-based incentives** (or alternatively, non-performance penalties)?

To help address the top-level unresolved question, which focused on market design, the group focused their discussion on three broad design alternatives: **capacity procurement mechanisms, energy market with forward contracts, and reliability reserves**. Each of these are described in more detail below.

To support RA, the participants agreed that market-based **capacity procurement mechanisms** not only need "capacity" but also other services such as "flexibility", which can bring additional revenue for all resources. Yet, there is no consensus on how to operationalize this, with three types of conceptual market ideas identified by the group: (i) include flexibility in resource accreditation (with effective load carrying capability, or ELCC, as the recommended approach for calculating capacity accreditation) as implemented in a capacity market or contract construct, (ii) add a capacity requirement for flexible RA separate from a "base" RA product, and (iii) place more emphasis on energy spot prices. Apart from the market structure, debates also persist over whether a capacity mechanism should be mandatory in a centralized manner or voluntary through bilateral agreements. Regardless of the market structure, it is also noteworthy that, as a critical component, resource accreditation is dynamic. The marginal ELCC is dependent on the final portfolio, but the portfolio is unknown until the market is cleared. Like variable renewable energy (VRE) resources, gas units also have dynamic accreditation depending on fuel availability, which can be impacted by weather conditions, i.e., correlated outages.

Participants also discussed whether a **centrally operated energy market with forward contracts** can supplement or function as a capacity mechanism, which offers liquidity for trade among load serving entities (LSEs). The group did not come to a clear consensus. Forward contracts in the energy market are agreements to lock in a predetermined price for future energy delivery to manage price risks, with a proposed compliance period within 1–3 years. The forward contracts can be physical (for actual delivery) or financial (settled against spot prices), involving a variety of market participants like traders, not just LSEs and generators. The main drawback of implementing these forward contracts is that they require accurate predictions of future resource availability and load in order to forecast future revenue streams and, therefore, determine an appropriate predetermined price. Despite this challenge, other alternative capacity procurement options, such as a forward capacity market, present other significant challenges, such as the uncertainty of future resource capacity eligibility defined through resource performance criteria, e.g., capacity accreditation using ELCC. Capacity accreditation is pre-determined by system operators as a way to estimate a resource's contribution to RA and is used to define the portion of nameplate capacity eligible to participate in capacity markets. However, these capacity credit values are dependent on many system conditions and can change from year-to-year, as noted in the previous paragraph. Forward energy contracts potentially sidestep this inherent problem of RA accreditation, by covering 100% of realized energy demand in the system through energy delivery obligations. Power generators can adjust commitments in auctions after energy delivery in each compliance period to trade the unused contracts or purchase additional ones. Thus, risks are internalized by generators via market-based settlement during scarcity events, as any shortfalls in the contracted output must be covered by purchases at higher spot prices. In addition, there are also some arguments about what should be included in the forward market: VRE only, VRE plus load flexibility, or something else? Increased forward contracting can also improve market efficiency by enabling a price-responsive demand side, e.g., by creating incentives for peak load management among large loads and aggregators. Fixed-price forward energy contracts protect the demand side from price spikes, while high price gaps create incentives to sell unused contracted energy in the market. It is also essential to ensure that the implementation of forward energy contracts does not create opportunities for market power.

The group also discussed reliability reserve products that could help to address any identified reliability gaps. These include **strategic reliability reserves** and **scarcity pricing** with more traditional operating reserves (e.g., regulation, spinning, etc.). Many of the European attendees highlighted the value of a strategic reliability reserve product, which is currently used in European markets as an emergency capacity mechanism. These reserves could, with a clearly defined strike price, maintain sufficient price spreads for investment and use of flexibility. For scarcity pricing of operating reserves, which is used in U.S.-based markets, system operators pointed out that infrequent and highly variable scarcity pricing might be an insufficient mechanism for promoting required investment. Regardless of the market mechanism, a reliability assessment is still needed to identify any potential future shortages that would inform the structure of the desired mechanism.

Finally, one additional discussion topic focused on the importance of demand. The group agreed that demand growth uncertainty and demand side participation are critical components for RA and market design. The most-debatable questions related to this dimension were (i) how to incentivize or control the seasonal flexible demand via demand response, and (ii) how to enable the demand side to be more resilient during extreme events (e.g., develop proactive mechanisms for the demand side to ride through time of high grid stress when prices are often very high, or when the grid has an outage).