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WITNESS: ELAINE K. HART

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

In the Matter of PUGET SOUND ENERGY, INC. 2021 Clean Energy Implementation Plan	**Docket UE-210795**

SEVENTH EXHIBIT TO THE PREFILED RESPONSE TESTIMONY OF

ELAINE K. HART

ON BEHALF OF NW ENERGY COALITION AND FRONT AND CENTERED

OCTOBER 10, 2022

Review of Puget Sound Energy Effective Load Carrying Capability Methodology

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Energy+Environmental Economics

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1 Introduction

1.1 Status of PSE's IRP and All-Source RFP

Puget Sound Energy's (PSE) most recent Integrated Resource Plan (IRP), filed in April 2021, indicated a need for new resources, to meet both peak capacity needs and compliance under the state of Washington's Clean Energy Transformation Act (CETA). In response to this, PSE filed a draft All-Source Request for Proposals (RFP) with the Washington Utilities and Transportation Commission (WUTC) that same month. This draft filing initiated a 45-day public comment period. In June 2021, the Commission approved the All-Source RFP. However, given stakeholder comments on the draft RFP regarding the effective load carrying capability (ELCC) for generic resources, especially battery storage resources, the WUTC required additional information on PSE's methodology for estimating effective load carrying capability (ELCC). Specifically, this included a primer on ELCC and a workshop on the subject in August 2021.

1.2 E3's Review and Scope of Work

To ensure that its ELCC calculations are rigorous and accurate, PSE retained Energy and Environmental Economics, Inc. (E3) through its Independent Evaluator, Bates White, to review PSE's methodology for calculating ELCC values, to provide an opinion on its reasonableness, and to recommend any necessary improvements. E3 has extensive experience with ELCC estimation across different jurisdictions and for different stakeholders, as well as resource adequacy analysis more broadly. In addition to direct ELCC modeling, E3 regularly delivers presentations and expert testimony on ELCC topics including background, application, and ELCC methodology.

E3 reviewed PSE's ELCC methodology and the results of their calculations, which required reviewing modeling methods and available documentation. The goal was to evaluate the reasonableness of PSE's calculations of ELCC for battery storage on its system. To do so, this review aimed to answer the following questions:

1) Does Puget Sound Energy (PSE) use industry-standard methodology for calculating ELCC?
2) Does PSE use reasonable input data in its ELCC modeling?
    a. Does PSE reflect the relevant correlations between data inputs?
    b. Does PSE appropriately capture regional dynamics in its calculation of ELCC?
3) Does PSE's ELCC calculation methodology appropriately capture the interactivity between intermittent and energy-limited resources?

In addition to the review above, E3 participated in PSE's August 2021 ELCC public workshop.

1.3 Summary of Findings

E3 finds that PSE's general approach to ELCC calculation is reasonable. While PSE's treatment of Mid-C does disadvantage battery storage ELCCs, there is no industry standard for how to address the issue of external market equilibrium, and whether it is appropriate to assume an adequate regional system is a real and difficult question. Beyond the question of how to treat the external market, the other topic requiring immediate attention in the current RFP process is the presentation of generic battery storage operating characteristics, which does not require changes in PSE's ELCC calculation methodology. While it would be ideal to address the treatment of Contingency Reserves and PSE's participation in the NWPP Reserve Sharing Program under its battery storage scenarios, this may require continued analysis beyond what is feasible within the current RFP timeline. Moving forward, PSE's treatment of resource correlations, temperature data, and hydropower operations merit additional analysis and potential adjustments, but without additional analysis it is unclear if changes in the treatment of these topics will produce significant changes in battery storage ELCCs; in the case of hydropower operations, updates to the PSE modeling approach could produce a reduction in battery storage ELCCs.

E3 recommends that PSE do the following before conducting the portfolio analysis in the RFP:

1) Conduct an additional GENESYS model run assuming regional capacity additions such that the region meets a 5% LOLP standard before recalculating ELCC;

2) Restate ELCC values for battery storage in a manner more aligned with industry standards, such that storage can discharge at maximum capacity for X hours if the storage is defined as having X hours of duration, and align the presentation of ELCC values with the characterization of minimum, maximum, and nameplate MW values in RFP documentation; and

3) Re-calculate battery storage ELCCs under the assumption that PSE's treatment of its own Contingency Reserves and the NWPP's Reserve Sharing Program is the same as in PSE's Base Case without battery storage, and investigate the significance of the revised results.

E3 recommends that PSE do the following in future IRP cycles:

1) Utilize weather-matched load that is aligned with wind and solar data;

2) Reevaluate its current approach to considering temperatures in developing load shapes based on (1) the use of two different weather stations, and (2) the changing climate;

3) Update modeling to incorporate hydro dispatch capabilities and hydro energy limitations.

E3 expects that even in the context of the recommendations above, battery storage ELCCs are likely to be relatively low in a hydropower-dependent region like the PNW compared to other regions. To confirm this judgment, however, E3 recommends the additional steps above.

2 ELCC Background

2.1 Defining ELCC and Applications

First introduced as a concept in the 1960s, ELCC has gained popularity in recent years as a method to express the capacity contribution of intermittent and energy-limited resources in terms of equivalent “perfect” capacity (capacity that is always available). In this respect, ELCC is technology agnostic: a system with a given quantity of ELCC megawatts will achieve the same level of reliability, regardless of what types of resources are providing those megawatts. The more the construct of ELCC is applied across resources within a resource adequacy program, the more adequately prepared that program will be to accurately capture the effects of future portfolio changes, and the more level a playing field it will create for all resources that can contribute to resource adequacy needs.

The calculation of ELCC relies on sophisticated “loss-of-load-probability” modeling, which simulates the electricity system under many decades of different load and resource conditions. These models, which allow system planners to calculate the expected frequency, duration, and magnitude of reliability events on a system with a given portfolio of resources, can be used to compare the reliability contributions of different resources – including conventional thermal generation, hydro generation, and intermittent and energy-limited resources – to a perfect capacity resource. While ELCC calculations require rigor and complexity in their derivation, ELCC produces capacity value estimates that capture the most significant challenges that will arise with increased penetrations of renewables, storage, and other resources.

The ELCC of a resource depends on the following:

- Coincidence of production with load – A positive correlation with load means higher capacity value.
- Production variability – Statistically, the possibility of low production reduces the value of a resource.
- Reliability target – Effective capacity has a non-linear relationship with system Loss-of-Load Expectation (LOLE), meaning that incremental additions of a given resource do not necessarily translate into constant improvements in reliability.
- Existing quantity of other resources – The same or similar resource shapes have a diversity penalty, while complementary resource shapes have a diversity benefit.
- Sustained peak – The ability to sustain output for longer durations.

Because of the interactions between resources in a portfolio, there is no single value that accurately captures the contribution of an individual resource toward the reliability of a portfolio under all circumstances. Instead, there are two types of ELCC values that can be uniquely defined and calculated, from which all practical applications of ELCC must be derived:

- Portfolio ELCC: the combined capacity contribution of a portfolio of intermittent and energy-limited resources. Because all resources are evaluated together, this method inherently captures all interactive effects and combined capability of the resources. This method is most important for assessing system reliability.

- Marginal ELCC: the incremental capacity contribution of a specific resource (or combination of resources), measured relative to a specified portfolio. This method is most important for procurement and assessing how a new incremental resource will contribute to system capacity needs.

2.2 Importance of ELCC for Assessing Resource Adequacy

Historically, simple and practical heuristic methods have been used to assign capacity credits to individual intermittent or energy-limited resources. These simplifications have been adequate in many places due to the low penetration of renewables and energy storage. However, they do not appropriately capture the reliability dynamics of the system at higher penetrations when the need for accurate representation of their characteristics is most critical.

Specifically, resource adequacy programs across the US regularly employ ELCC for the following reasons:

- It captures how intermittent and energy-limited resources can interact to meet resource adequacy needs.
    - For example, the finite duration limits the ability of energy storage to meet demand across extended periods. This effect can be interpreted in multiple ways: either (1) the marginal ELCC of storage with a fixed duration will continue to decline as more is added to the system, or (2) storage with progressively increasing duration is needed to sustain a high capacity value.

- Its ability to highlight the diminishing marginal returns of a specific resource with increasing scale – that is, continuing to add more and more to an electricity system will produce lower and lower marginal resource adequacy benefits.
- ELCC on a portfolio level exposes synergistic and antagonistic interactions between different resources in a system. Synergistic means that different resources complement each other and, together, have a higher ELCC, than the sum of their parts. Conversely, an antagonistic relationship would produce the opposite effect.
- Its ability to "level the playing field" means the methodology can reasonably be used to compare drastically different capacity portfolios with the same ELCC.

2.3 ELCC Practices and Industry Standards

2.3.1 LACK OF SINGLE NATIONWIDE STANDARD FOR RESOURCE ADEQUACY

Many factors affect resource adequacy, including the characteristics of load (magnitude, seasonal patterns, weather sensitivity, hourly patterns) and resources (size, dispatchability, forced outage rates, and other limitations on availability). There is no unified standard or method for determining resource adequacy across the industry. Rather, each power system defines its own resource adequacy requirements, acting under oversight from state, provincial, or local authorities, based on a variety of factors including, in some cases, evaluations of the costs and benefits of achieving higher or lower reliability standards. If a power system's resources are inadequate to serve its load, North American Electric Reliability Council ("NERC") standards require it to proactively curtail service during a resource shortfall to protect against the possibility of an interconnection-wide reliability event.

Utilities use many metrics to quantify the frequency, magnitude, and duration of loss-of-load events. See Table 1 below for a summary of the reliability metrics. While there is no continent-wide requirement for resource adequacy, many power systems in North America are planned based on a standard of "1-day-in-10-years". This standard requires that there be sufficient generation and transmission resources to serve load during all but one day every ten years. It is frequently implemented as requiring a loss-of-load expectation ("LOLE") of 0.1 days per year. Because directly measuring the LOLE reliability of a system is data-intensive and computationally complex, loss-of-load studies are often used to define a planning reserve margin ("PRM"), measured as the quantity of capacity needed above the median year peak load to meet the LOLE standard, to serve as a simple and intuitive metric that can be utilized broadly in power system planning.

Table 1. Summary of Reliability Metrics[1]

Metric	Units	Description	Examples
Loss of Load Probability ("LOLP")	%	The probability of system demand exceeding the available generating capacity during a given time period	Northwest Power and Conservation Council: 5% loss of load probability
Loss of Load Events ("LOLEV")	Events/year	The average number of loss of load events per year, of any duration or magnitude, due to system demand exceeding available generating capacity	Most U.S. Systems: 1 loss-of-load event per decade, or 0.1 event per year. See below
Loss of Load Expectation ("LOLE")	Days/year	The average number of days per year with loss of load (at least once during the day) due to system demand exceeding available generating capacity	See below
Loss-of-Load Hours ("LOLH")	Hours/year	The average number of hours per year with loss of load due to system demand exceeding available generating capacity	See below
Normalized Expected Unserved Energy ("EUE")	MWh/year	The average total quantity of unserved energy (MWh) over a year due to system demand exceeding available generating capacity	See below

2.3.2 DIVERSITY OF ELCC PRACTICES AMONG UTILITIES

ELCC is a widely used metric throughout the United States. Due to its popular adoption in the 1960s, it has gained significant traction among utilities, utility commissions and Independent System Operators; however, many employ ELCC in different ways. Below are some examples of how ELCC has been implemented:

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[1] NWPP 2019, "Exploring a Resource Adequacy Program for the Pacific Northwest" - https://www.nwpp.org/private-media/documents/2019.11.12_NWPP_RA_Assessment_Review_Final_10-23.2019.pdf.

- The California Public Utilities Commission uses marginal ELCC for RPS program bid ranking and selection, and average ELCC for the RA program;
- The Mid-Continent Independent System Operator (MISO) allocates system-wide ELCC as its capacity credit to ascertain reliability;
- The New York Independent System Operator (NYISO) uses ELCC to quantify the capacity contributions of limited duration resources like storage; and
- Many utilities use marginal ELCC for evaluating the capacity contribution of new resources, including PSE, Avista, Portland General Electric, NorthWestern Energy, NV Energy, Xcel Energy, El Paso Electric, Duke Energy, Southern Company, and others.

2.3.3 NORTHWEST POWER AND CONSERVATION COUNCIL RA COMMITTEE AND MODELING

Under its charter to ensure prudent management of the region’s federal hydro system while balancing environmental and energy needs, the Northwest Power and Conservation Council (“NPCC”), with oversight from its Resource Adequacy Advisory Committee (“RAAC”), conducts regular assessments of the resource adequacy position for the portion of the Northwest region served by the Bonneville Power Administration (consisting of Washington, Oregon, Idaho and the portions of California, Nevada, Utah, and Montana that are in the Columbia River Basin).

In 2011, the NPCC established an informal reliability target for the region of 5% annual LOLP—a metric that determines the capacity needed for the region to experience reliability events in fewer than one in twenty years. The 5% LOLP is unique to the Northwest region and is not widely used throughout the rest of North America.

NPCC uses GENESYS, a stochastic LOLP model with a robust treatment of the region's variable hydroelectric conditions and capabilities, to examine whether regional resources are sufficient to meet this target on a five-year ahead basis. These studies count only existing resources, planned resources that are sited and licensed, and the energy efficiency savings targeted in the NPCC's power plan. The studies provide valuable information referenced by regulators and utilities throughout the region and are meant to be an early warning of potentially insufficient resource development. While the work of NPCC is widely regarded as the most complete regional assessment of resource adequacy for the larger region, ultimately each individual utility must conduct its own resource adequacy planning to determine its need for new capacity.

NPCC's resource adequacy modeling heavily influences PSE's resource adequacy modeling, and ultimately its ELCC analysis. Like the NPCC's own modeling, PSE aims to achieve a 5% LOLP and tunes its reliability model to this standard when beginning its ELCC analysis. It also uses GENESYS to help calculate the overall regional resource adequacy conditions; specifically, its starting point for the 2021 IRP modeling was the GENESYS model from the NPCC power supply adequacy assessment for 2023. That specific version of GENESYS conducts 7040 simulations that consist of permutations of 80 different years of hydro conditions and 88 years of temperature conditions. These 7040 simulations reflect the combinations of load and hydro resource conditions for each separate analysis that ultimately makes up the ELCC calculations.

3 PSE Approach

3.1 PSE Model

PSE uses three models for its ELCC analysis. The primary model is the Resource Adequacy Model (RAM), which uses 7040 individual simulations that consist of combinations of 80 historical hydro years of data and 88 temperature years of data, along with load data, resource operating data, and external market modeling for short-term market purchases. The results of the simulations allow for the calculation of reliability metrics (LOLP, LOLE, EUE, etc.), as well as the quantification of the need for reliability-driven capacity to reach reliability standards and ELCC calculations for intermittent and energy-limited resources. To estimate availability for short-term market purchases, two other models are used: GENESYS and the Wholesale Purchase Curtailment Model ("WPCM"). GENESYS (also described in the section above) is a model of the Pacific Northwest region and shapes regional hydro to minimize regional curtailments and fully utilize California imports. Using the outputs of the GENESYS model, WPCM is used to allocate those regional curtailments to the PSE system.

3.2 Input Data

E3 requested, received, and reviewed the following input data used by PSE for its ELCC calculations:

- 8760 profiles for load, solar, and wind, along with battery storage charging and discharging schedules;
- Nameplate capacity of thermal resources;
- Hydro availability data;
- Mid-C market availability estimates; and
- Generic battery storage operating characteristics.

3.3 Output Data

E3 requested, received, and reviewed the following outputs from PSE's ELCC modeling:

- Hourly energy production estimates by resource type (including the external Mid-C market and its components) and other components used to calculate hourly unserved energy and loss of load events;
- Reliability metric results (e.g., LOLP, EUE, LOLE);
- Outage duration and frequency results for January and February (the months with the most reliability events); and
- ELCC calculation results.

Model input and output data was reviewed for the years 2027 and 2031 in the PSE forecast, each representing 7040 combinations of 80 hydro years and 88 temperature years. While E3 did obtain data from PSE's Temperature Sensitivity case described in its 2021 IRP, E3's review and conclusions are focused on PSE's Base Case, since the ELCC results of this case are reflected in the current RFP.

4 Key Issues

4.1 General LOLP Approach

4.1.1 ISSUE DESCRIPTION

E3 investigated whether PSE’s application of the LOLP standard in its resource adequacy modeling is appropriate, and whether its approach for estimating battery storage ELCCs as an extension of this approach is reasonable.

4.1.2 PSE METHODOLOGY AND INDUSTRY PRACTICE

In alignment with the practice of other entities in the region, PSE tunes its system to meet a 5% LOLP standard, providing the starting point for evaluating the ELCCs of generic resources in future years. For storage and variable resources, an additional step is taken by adding storage capacity to a system that already meets the 5% LOLP standard and then removing perfect capacity until expected unserved energy (EUE) returns to its previous level that is equivalent to the 5% LOLP standard.

While LOLP is a common reliability metric in the Pacific Northwest region, LOLE is the most commonly used loss-of-load reliability metric throughout the industry and specifically a standard of 0.1 days of LOLE per year (see Table 2).

Table 2. Reliability Metrics in Various Jurisdictions[2]

Jurisdiction	Reliability Metric(s)	Standard Value	Notes
AESO	**EUE**	800 MWh/year (0.0014%)	AESO monitors capacity and can take action if modeled EUE exceeds threshold; 34% PRM achieved in 2017 w/o imports
Australia	**EUE**	0.002%	System operator monitors forecasted reliability and can intervene in market if necessary
CAISO	**PRM**	15%	Stipulated, not explicit.
ERCOT	**N/A**	N/A	Tracks PRM for information purposes. PRM of 13.75% achieves 0.1 events/yr.
Florida	**LOLE**	0.1 days/year	15% PRM required in addition to ensuring LOLE is met
Great Britain	**LOLH**	3 hours/year	5% (Target PRM 2021/22) 11.7% (Observed PRM 2018/19)
Ireland	**LOLH**	8 hours/year	LOLH determines total capacity requirement (10% PRM) which is used to determine total payments to generators (Net-CONE * PRM)
ISO-NE	**LOLE**	0.2/0.1/0.01 days/year	Multiple LOLE targets are used to establish demand curve for capacity market
MISO	**LOLE**	0.1 days/year	8.4% UCAP PRM; 17.1% ICAP PRM.
Nova Scotia	**LOLE**	0.1 days/year	20% PRM to meet 0.1 LOLE standard

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[2] For additional examples and context, see: https://irp.nspower.ca/files/key-documents/presentations/20190807-02_-E3-Capacity-Study-Overview.pdf.

NYISO	**LOLE**	0.1 days/year	LOLE is used to set capacity market demand curve; Minimum Installed Reserve Margin (IRM) is 16.8%; Achieved IRM in 2019 is 27.0%
PacifiCorp	**N/A**	N/A	13% PRM selected by balancing cost and reliability; Meets 0.1 LOLE
PJM	**LOLE**	0.1 days/year	LOLE used to set target IRM (16%) which is used in capacity market demand curve
SPP	**LOLE**	0.1 days/year	PRM assigned to all LSEs to achieve LOLE target: 12% non-coincident PRM, 16% coincident PRM.

The NPCC has chosen LOLP as its reliability metric and has used it since 2011, driving its annual resource adequacy assessments in the region and influencing the decision of utilities in the region, including Avista, as well as the NPCC itself.[3] Further, in PSE's 2015 IRP, PSE modified its reliability standard to be driven by the value of loss-of-load to its customers. However, this resulted in an expression of concern from the WUTC, and led to a return to the use of a 5% LOLP reliability standard in PSE's 2017 IRP.

Unlike LOLE, LOLP does not account for event duration and the number of events in a year. This matters because LOLP does not effectively take generator characteristics like production time and duration into account when assessing system reliability. Sizing the system for LOLP reduces the chances of having a

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[3] Avista's 2021 IRP notes that its Aurora capacity expansion "model must also meet a 5 percent LOLP threshold for reliability when selecting new resources." (Avista 2021 IRP, page 2-19. https://www.myavista.com/-/media/myavista/content-documents/about-us/our-company/irp-documents/2021-electric-irp-w-cover-updated.pdf.)
The Northwest Power and Conservation Council (NPCC) stated in its most recent power plan (2016) that "A specific year's power supply extracted from an RPM analysis is deemed to be acceptably adequate if its LOLP ranges between 2 and 5 percent." (NWPCC 2016, pg 11-4. https://www.nwcouncil.org/sites/default/files/7thplanfinal_allchapters_1.pdf.)

single event but it does not necessarily minimize the event duration or magnitude. While LOLE does not account for the magnitude of the event (supply shortfall), it does seek to limit the duration and frequency of events in a year. Although a system may be designed to have a 5% probability of LOL occurrence, when an event does occur, it may be several hours long. Alternatively, LOLE, while possibly having a higher event probability than 5%, would produce a system with limited event durations.

4.1.3 E3 CONCLUSION

E3 finds that PSE's application of the LOLP standard in its resource adequacy modeling, and the 5% standard in particular, is appropriate for two reasons:

1) There is precedent in the region for this standard, with the NPCC's RAAC using it for the last decade to annually assess reliability in the region, as well as its use by other utilities in the region, and PSE's usage following feedback from the WUTC after its 2015 IRP. Given the complexity of LOLP analysis and ELCC calculations, E3 believes there is value in utilizing methodologies that are consistent over time, that are in keeping with common regional practices that stakeholders are familiar with, and that have precedence in application to regulatory proceedings in a given jurisdiction. PSE's current methods are consistent with how the utility has evaluated ELCCs in the past, are in keeping with and indeed explicitly linked to the regional analysis performed by the NPCC, are similar to the methodologies utilized by other utilities, are familiar to PSE stakeholders, and have been previously accepted for use by the WUTC.

2) The LOLE of the Base Case for the two years that were tested for ELCC (2027 and 2031) and were tuned to a 5% LOLP by adding reliability-driven perfect capacity is in the 0.10-0.12 days/year range, which is very close to the 0.1 standard discussed above. Given this, E3 would expect that tuning the system to 0.1 LOLE rather than 5% LOLP would result in very minimal changes to the portfolio, and hence to the resulting ELCC values.

4.2 Treatment of Mid-C Market Availability

4.2.1 ISSUE DESCRIPTION

E3 investigated how PSE's treatment of the availability of market purchases from the Mid-Columbia (Mid-C) trading hub impacts its ELCC calculations in general, and whether it disadvantages battery storage ELCCs in particular.

4.2.2 PSE METHODOLOGY AND INDUSTRY PRACTICE

Utilities rely on a combination of self-owned generation, bilateral contracts, and front-office transactions (FOTs) to satisfy their resource adequacy requirements. FOTs represent short-term firm market purchases for physical power delivery. FOTs are contracted on a month-ahead, day-ahead, and hour-ahead basis. A survey of utility IRPs in the PNW reveals that most utilities expect to meet a significant portion of their peak capacity requirements by using FOTs.[4]

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[4] For additional discussion, see: https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf.

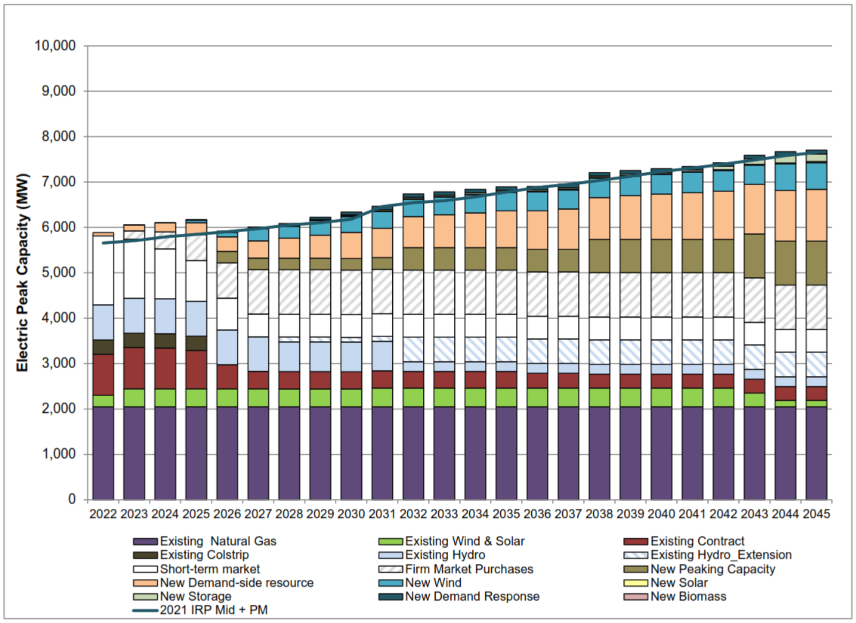
FOTs may be available to utilities for several potential reasons, including regional capacity surplus with some generators uncontracted to a specific utility or natural load diversity between utilities. The use of FOTs in place of designated firm resources can result in lower costs of providing electric service, as the cost of contracting with existing resources is generally lower than the cost of constructing new resources. However, as loads grow in the region and coal generation retires, the region’s capacity surplus is shrinking, and questions are emerging about whether sufficient resources will be available for utilities to contract with for month-ahead and day-ahead capacity products. In a market with tight load-resource balance, extensive reliance on FOTs risks under-investment in the firm capacity resources needed for reliable service.

At the same time, failure to consider the availability of surplus energy in the regional market would result in over-procurement and higher costs for PSE ratepayers. It is reasonable for PSE to assume that some amount of energy would be available in the market due to the nature of the region’s hydroelectric resource base, which produces surplus energy during most years. PSE must therefore strike a careful balance between the potential reliability implications and cost savings associated with reliance on the regional market.

Mid-C market interactions are an important consideration for PSE’s system. As such, PSE includes “short-term wholesale (spot) market purchases up to PSE’s available firm transmission import capability from the Mid-C” as an existing resource in reliability planning.[5] Referring to Figure 1, this is currently roughly a quarter of PSE's peak capacity.

Figure 1. PSE Preferred Portfolio Meeting Electric Peak Capacity[6]

Figure 3-6: Preferred Portfolio Meeting Electric Peak Capacity and Reducing Market Risk



In its ELCC modeling, PSE does not assume that reliability-driven (perfect) capacity additions are made to the broader Pacific Northwest region to achieve a reliability standard. Instead, given that PSE is testing future years 2027 and 2031, PSE assumes, based on NPCC GENESYS cases, that the regional system's reliability degrades below accepted resource adequacy thresholds as load continues to grow and plants retire. However, as mentioned in the section above, PSE adds

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[5] PSE 2021 Final IRP, pg 7-11.
[6] PSE 2021 Final IRP.

reliability-driven capacity to bring its own system up to a 5% LOLP, with more local capacity added as the reliability of the external market degrades.

Mid-C market availability declines over time in PSE's modeling, resulting in increased forecasted curtailment from the Mid-C market for PSE's system. Fluctuations in energy from Mid-C are the largest contributor to outages in PSE's modeling and are the most frequent primary contributor (in MW) to longer duration outages (5+ hours). Table 3 below shows the frequency of outages of different lengths in January 2027 in the Base Case. These longer duration outages reduce the ELCC for the energy-limited battery storage resources.

Table 4 shows statistics for how the median capacity by resource type changes during hours with and without unserved energy and depending on the duration of the outage event.

Table 3. Summary of Outage Events by Duration in PSE Base Case – January 2027[7]

Frequency of loss of load event occurrences					
1 hour	1-2 hour	3-4 hour	5-6 hour	7-8 hour	9+ hour
131	95	155	72	31	82

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[7] E3 analysis of PSE IRP data.

Table 4. Summary of Resource Performance During Outages in PSE Base Case – January 2027[8]

	Median MWh of Energy, by Outage Duration					
Resource	**No Outages**	**All Outages**	**3-4 hr**	**5-6 hr**	**7-8 hrs**	**9+ hr**
Contracts	740	747	747	747	747	740
Hydro	596	515	562	524	502	492
Load	3,344	5,371	5,554	5,375	5,322	5,182
Mid-C	1,415	370	1,307	495	380	190
Solar	0	0	0	0	3	1
Thermal	1,959	1,880	1,880	1,826	1,927	1,899

Given that load growth is assumed in the modeling of the Mid-C external market and no generic capacity is added, the reliability of the Mid-C degrades further between the two ELCC test years, 2027 and 2031. This may result in longer-duration reliability events on the PSE system, since availability of Mid-C imports is the key driver of these events. PSE does add more perfect capacity to its own system in 2031 (1,361 MW) than in 2027 (907 MW). This additional capacity reduces the frequency of loss-of-load events to bring the system up to a 5% LOLP standard, and increases battery storage ELCCs (see Table 5), however it does not change the shape of outages on the system because it is always available.

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[8] E3 analysis of PSE IRP data.

Table 5. Peak Capacity Credit for Battery Storage in 2021 PSE IRP[9]

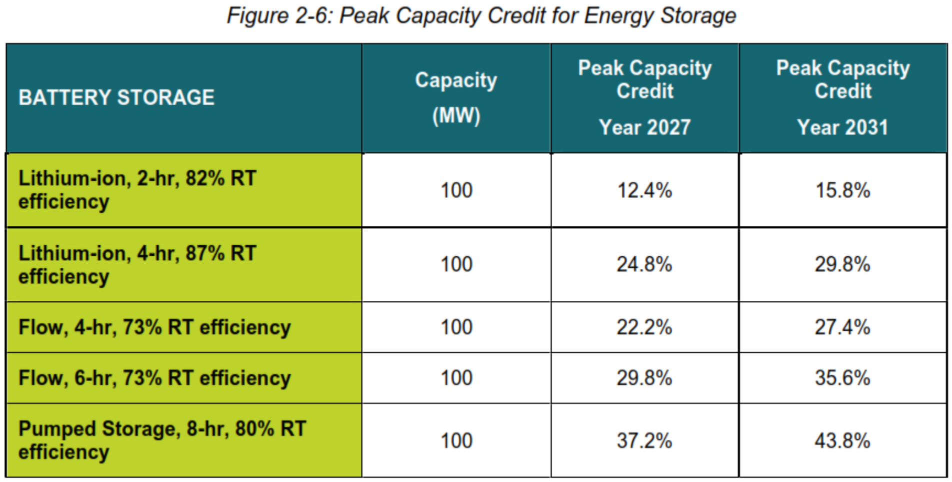

Figure 2-6: Peak Capacity Credit for Energy Storage

BATTERY STORAGE	Capacity (MW)	Peak Capacity Credit Year 2027	Peak Capacity Credit Year 2031
Lithium-ion, 2-hr, 82% RT efficiency	100	12.4%	15.8%
Lithium-ion, 4-hr, 87% RT efficiency	100	24.8%	29.8%
Flow, 4-hr, 73% RT efficiency	100	22.2%	27.4%
Flow, 6-hr, 73% RT efficiency	100	29.8%	35.6%
Pumped Storage, 8-hr, 80% RT efficiency	100	37.2%	43.8%

Typical industry practice assumes that a utility will tune its own system to a specific reliability standard before calculating ELCCs, but will not necessarily also tune the external market. The treatment of the external markets varies across the industry ranging from excluding the market entirely to making simplified assumptions such as a fixed shape based on import limits. For example, Duke Energy has applied a modeling framework that models imports as a dynamic resource on an hourly basis, driven by the estimated relationship between net load and market purchases.[10] By contrast, the California Public Utility Commission (CPUC) assumes a fixed constraint on imports, with an additional constraint applied only during hours where gross electric demand exceeds the 95th percentile.[11] Similarly, the Public Service Company of New Mexico assumes a constant constraint that 50 MW of market purchases will be available during its

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[9] PSE Final 2021 IRP, pg 2-13.

[10] See page 19-20: https://dms.psc.sc.gov/Attachments/Matter/41d424e5-077b-4ff9-8bb3-3c31467b2638.

[11] See pages 22-23: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M331/K772/331772681.PDF.

net peak period.[12] PSE is including the external market but is modeling it as a dynamic resource accounting for hydro energy, outages and other competing transmission needs.

Because the Mid-C market is modeled as a dynamic resource with varied output and outages, a less reliable Mid-C market may result in more long duration events with low import availability, reducing battery storage ELCCs. However, there is no single industry standard for how to address unreliable external markets. Excluding the market altogether is not realistic for PSE. Conversely, determining whether it is appropriate to add reliability-driven capacity to the external market before beginning ELCC calculations is a real and difficult question and has real world implications. PSE does not have control over the reliability of the external system, and how much they would have to contribute to achieve a reliable broader PNW system is an open question. Further, if reliability-driven capacity were added to the Mid-C market that would likely result in less reliability-driven capacity needed for the PSE system. The ultimate impact on storage ELCC calculations cannot be known without further modeling.

To illustrate the impact of potential additions to regional capacity, E3 generated the dispatch plots below from the week of January 25, 2027 in the PSE Base Case. This week was chosen because of a 42-hour outage that occurs in draw 1687 (out of 7040), representing the combination of hydro calendar year 1947 (in which streamflow was the lowest of all 80 hydro years) and temperature calendar year 1943. In Figure 2, PSE's modeled dispatch is shown. In Figure 3, E3 has added 500

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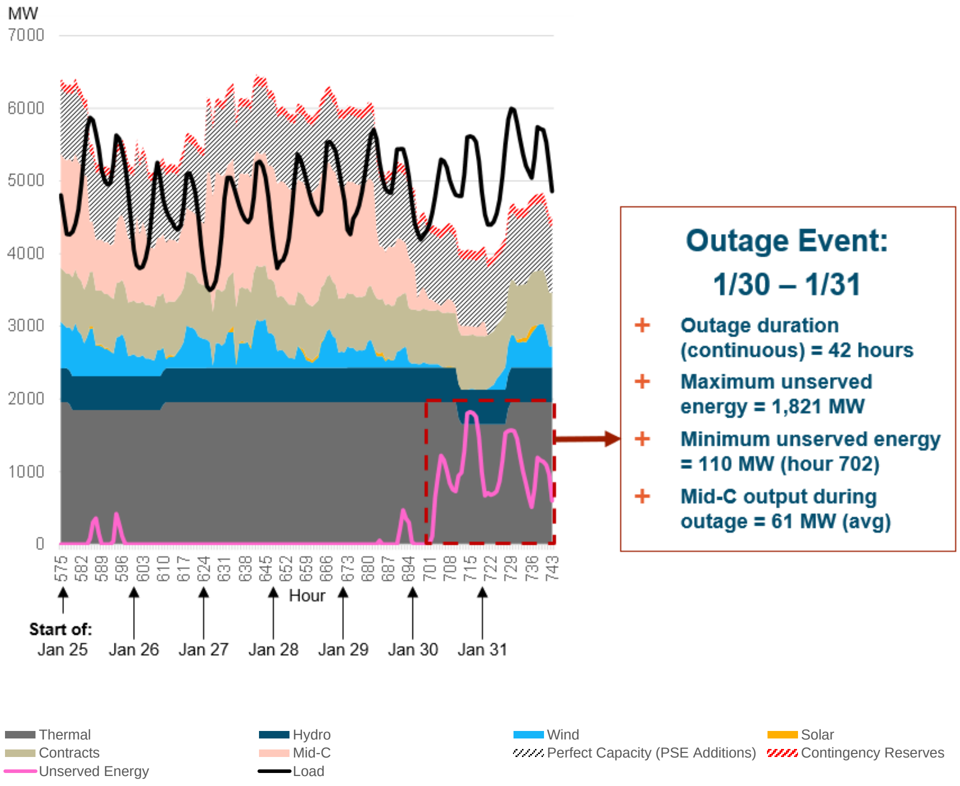
[12] See page 57: **https://www.pnmresources.com/~/media/Files/P/PNM-Resources/rates-and-filings/PVNGS%20Leased%20Capacity/8-2021-04-02-Phillips-Exhibits-Aff.pdf**.

MW of available hourly capacity from Mid-C during the outage events in the Base Case and removed 500 MW of perfect capacity from the PSE system.

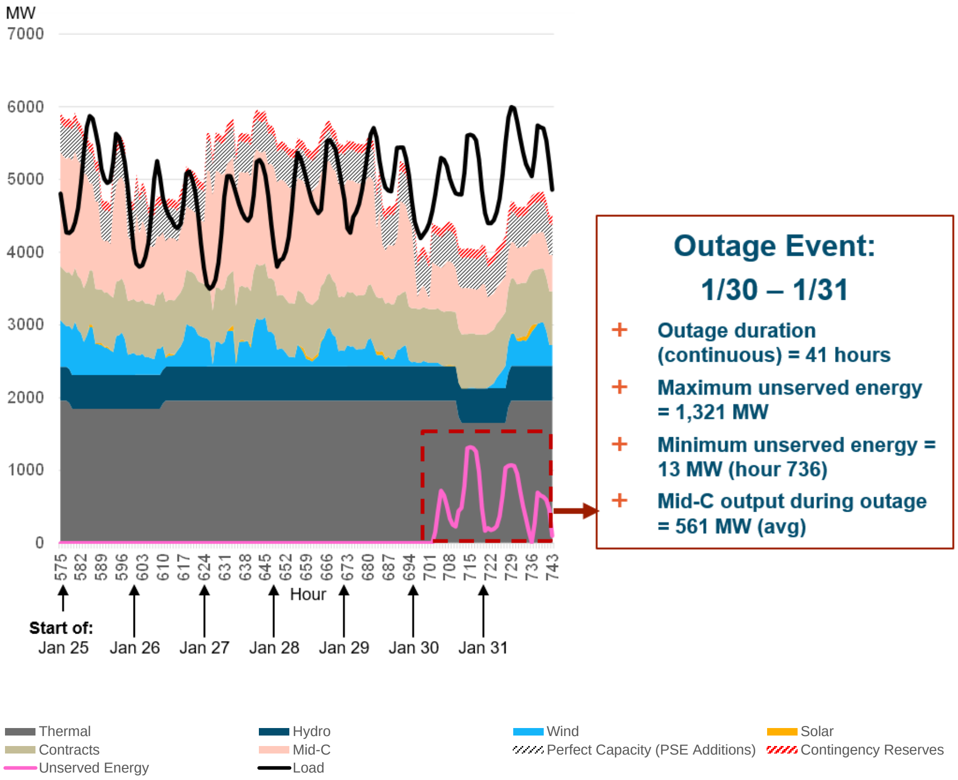
Figure 2. Dispatch Plot, Week of January 25 (2027), PSE IRP Base Case



Outage Event: 1/30 – 1/31

- Outage duration (continuous) = 42 hours
- Maximum unserved energy = 1,821 MW
- Minimum unserved energy = 110 MW (hour 702)
- Mid-C output during outage = 61 MW (avg)

Figure 3. Dispatch Plot, Week of January 25 (2027), PSE IRP Base Case With 500 MW of Additional Mid-C Output and 500 MW Reduction of Perfect Capacity



Outage Event:

1/30 – 1/31

- **Outage duration (continuous) = 41 hours**
- **Maximum unserved energy = 1,321 MW**
- **Minimum unserved energy = 13 MW (hour 736)**
- **Mid-C output during outage = 561 MW (avg)**

As shown above, modifying the PSE Base Case so that Mid-C output is increased by 500 MW during unserved energy events reduces the duration of the 42-hour outage by only 1 hour, illustrating the impact of Mid-C on the outage characteristics against which battery storage is tested. However, it can also be seen that increasing the Mid-C market availability by an additional 500 MW would reduce outage durations substantially by effectively segmenting the long-duration outage shown above into multiple smaller-duration outages.

4.2.3 E3 CONCLUSION

To assess the potential impact of changes in PSE's approach to the external market on ELCC values, E3 recommends an additional GENESYS model run (and subsequent calibration with the WPCM model) where reliability-driven capacity is added to the broader region to achieve a 5% LOLP, as well as the PSE system. PSE should then perform ELCC calculations with a reliable system (to a 5% LOLP standard) where both the Mid-C market and PSE system are in a reliable state. How the battery storage ELCCs change could inform how PSE possibly rethinks its current modeling of the Mid-C market. If the changes to ELCC results are negligible then PSE would be comfortable that its current modeling is sufficient. If the ELCC results change significantly then broader consideration would need to be given to what reliability standard (and relatedly how much added reliability-driven capacity) is reasonable to assume given PSE's expectations for future capacity additions and retirements in the region.

To be clear, E3 is not recommending at this time that PSE make resource planning decisions based on this new GENESYS run, but rather to understand whether this single assumption about reliability in the regional system is a key driver of battery ELCC results.

4.3 Hydro Operations

4.3.1 ISSUE DESCRIPTION

E3 investigated whether PSE's approach to modeling hydropower operations is impacting its ELCC results in general, and battery storage ELCC results in particular.

4.3.2 PSE METHODOLOGY AND INDUSTRY PRACTICE

PSE models the output of its own hydro plants (Baker River Project and Snoqualmie Falls), as well as its hydro contracts with the Chelan, Douglas and Grant PUDs, as a fixed hourly shape rather than a dispatchable (flexible) resource. This shape is aligned with the streamflow data inherent in the 80 hydro draws that are assumed in GENESYS and the hydro in the broader PNW region, and results in a single MW value being modeled in every hour of a single day and draw. This single MW value is the maximum available capacity in any hour within that day within that draw, the implicit assumption being that PSE could rely on its owned and contracted hydro to dispatch up to its maximum available capacity in a given hydro year during any time period in which a resource shortfall is possible.

In typical resource adequacy modeling and ELCC calculations across the industry, hydro is modeled with the extent of its dispatchable (i.e. not run-of-river) capabilities. Further, energy limitations are typically accounted for in modeling of hydro resources.[13] In reality, PSE's hydro resources cannot always dispatch to their maximum capacity to meet a long duration outage event (e.g., the 42 hour event shown above) due to water availability constraints. At the same time, PSE generally has flexibility on a diurnal time scale to dispatch its hydro resources to avoid loss-of-load events. Thus, PSE's approach both overvalues hydro (by assuming it is always available at its max capacity) and does not account for its

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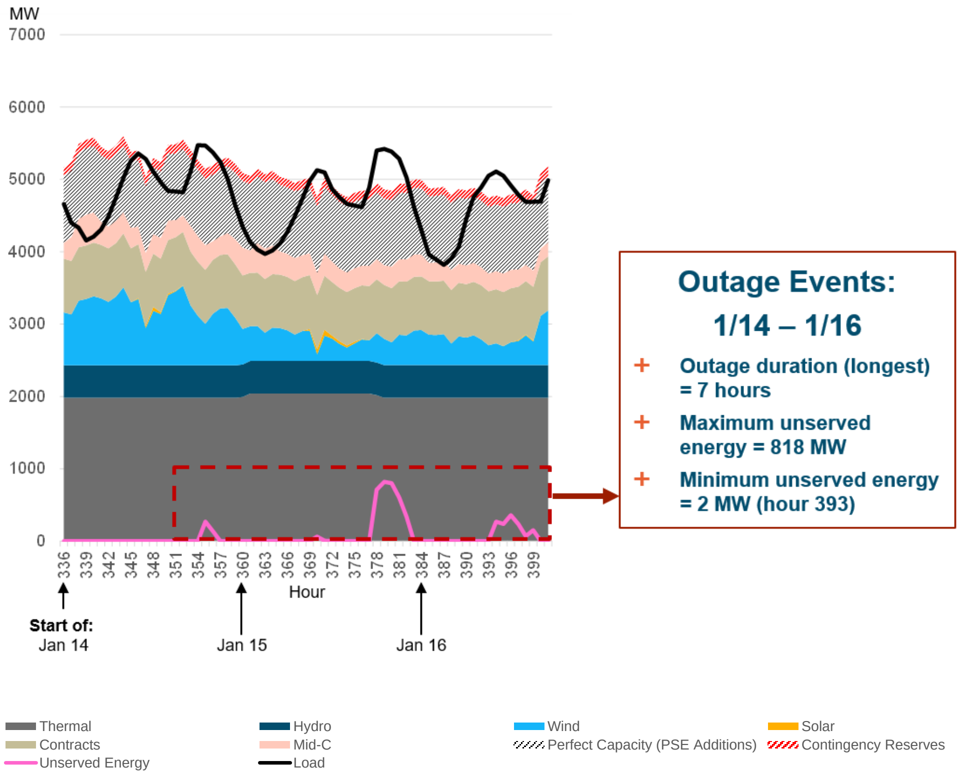
[13] For a more detailed discussion of this in the Pacific Northwest context, see E3's 2019 analysis: https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf.

diurnal flexibility, which would compete with energy storage to fulfill a limited need for short-duration services.

To illustrate the impact of changes in PSE's approach to modeling hydro operations, E3 generated the dispatch plots below from the week of January 14, 2027 in the PSE Base Case. This week was chosen because it contains multiple shorter-duration outages in draw 1687 (out of 7040), representing the combination of hydro calendar year 1947 (in which streamflow was the lowest of all 80 hydro years) and temperature calendar year 1943. In Figure 4, PSE's modeled dispatch is shown. In Figure 5, E3 has modified the capabilities of hydro resources to operate with energy limitations (50% capacity factor, pmin of 25%) and dispatch capabilities (i.e. output can be increased to pmax when there is unserved energy).

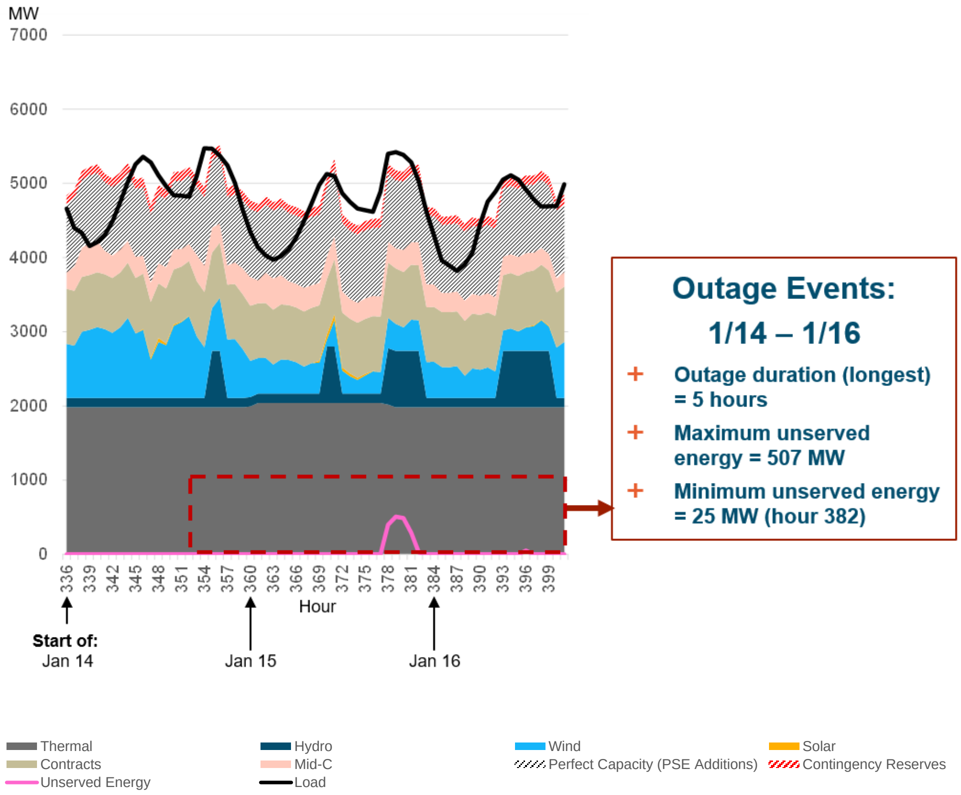
Figure 4. Dispatch Plot, Week of January 14 (2027), PSE IRP Base Case



Outage Events:
1/14 – 1/16

- + **Outage duration (longest) = 7 hours**
- + **Maximum unserved energy = 818 MW**
- + **Minimum unserved energy = 2 MW (hour 393)**

Figure 5. Dispatch Plot, Week of January 14 (2027), PSE IRP Base Case With Dispatchable and Energy-Limited Hydro Resources



Outage Events:
1/14 – 1/16

- **Outage duration (longest) = 5 hours**
- **Maximum unserved energy = 507 MW**
- **Minimum unserved energy = 25 MW (hour 382)**

As shown above, modifying hydro resources so they are energy-limited and dispatchable illustrates the ability of hydro to minimize unserved energy needs over shorter-duration periods (e.g., 4-6 hours).

4.3.3 E3 CONCLUSION

A lack of dispatchability and considerations of energy limitations both lead to an overestimation of storage ELCCs. If the hydro resources were modeled as dispatchable, this would enhance the operational capability of a competing (and likely more robust) energy-limited resource. This would, in turn, reduce the ELCC estimates for battery storage resources. If the modeling were enhanced to add energy limitations this would remove energy from the system, reducing the energy available for battery resources to charge, leading to lower ELCC estimates.

For future IRP cycles, E3 recommends that PSE update its modeling to incorporate hydro dispatch capabilities and hydro energy limitations. E3 recognizes, however, that modeling hydro as flexible is highly complex, as the flexibility depends on water conditions, operational constraints, and other factors that are difficult to quantify in a planning model.

4.4 Resource Correlations

4.4.1 ISSUE DESCRIPTION

E3 investigated whether PSE applies appropriate correlations to different resources, between resources and load, between hydro and regional market purchases and between weather and load in its modeling.

4.4.2 PSE METHODOLOGY AND INDUSTRY PRACTICE

E3 found the following:

+ PSE preserves the correlation between solar and wind generation by using aligned wind speed and solar irradiance data from NREL.
+ PSE preserves the correlation between weather and load by using 88 years of temperature data and correlating this data with historical load. PSE uses several variables to generate its load forecast: population,

unemployment rates, retail rates, personal income, total employment, manufacturing employment, consumer price index (CPI), U.S. Gross Domestic Product (GDP), transmission and distribution losses, and weather data from Sea-Tac Airport.

- PSE preserves the correlation between hydro and regional market purchases through modeling in GENESYS. This captures regional worst-case conditions likely to impact both PSE and external hydro resources and is important given that roughly 30% of PSE's 2022 peak capacity need is expected to be met by the short-term market.
- Through modeling in GENESYS and WPCM, load and hydro are not correlated but rather permutated across 7040 draws (88 temperature years, 80 hydro years). Correlating weather and hydro is likely not appropriate: day-of weather conditions are unlikely to drive hydro resource availability, which is driven by snowpack and not single-day temperature spikes or dips.
- No correlation is being modeled between weather and renewable (solar and wind) output, nor between load and renewable output.
    - The renewable output profiles are determined exogenously by taking samples of NREL data from potential development sites and then taking the median 250 samples. These sets of 250 samples of wind and solar profiles are then randomly applied to the 7040 temperature/hydro draws.

4.4.3 E3 CONCLUSION

The correlations being applied between wind and solar, as well as between weather and load, are reasonable and aligned with industry practice. Further, the permutation of hydro output and weather is also aligned with how other reliability forecasting models approach the same inputs (e.g., SERVM, E3's RECAP model).

Correlations between weather/load and wind/solar output are traditionally used in resource adequacy system modeling, which helps capture conditions which may drive loss-of-load events. In the Pacific Northwest, this would primarily result from intense cold weather driving increased demand and decreased renewable output. For future IRP cycles, E3 recommends utilizing weather-matched load that is aligned with wind and solar data. This will impact the ELCC results for wind and solar resources (see Appendix for additional detail) but should not have a major impact on storage ELCCs, which are largely driven by high load and low hydro events.

4.5 Temperature Data

4.5.1 ISSUE DESCRIPTION

E3 investigated whether the temperature data used by PSE as an input in its resource adequacy modeling is impacting its ELCC results.

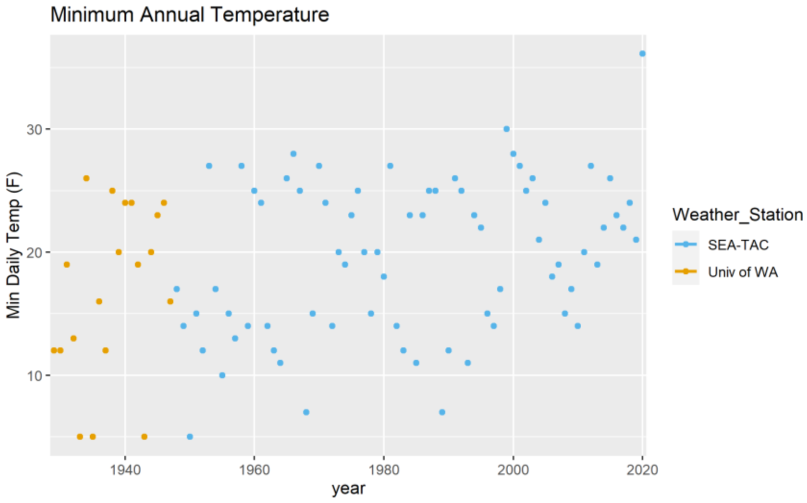
4.5.2 PSE METHODOLOGY AND INDUSTRY PRACTICE

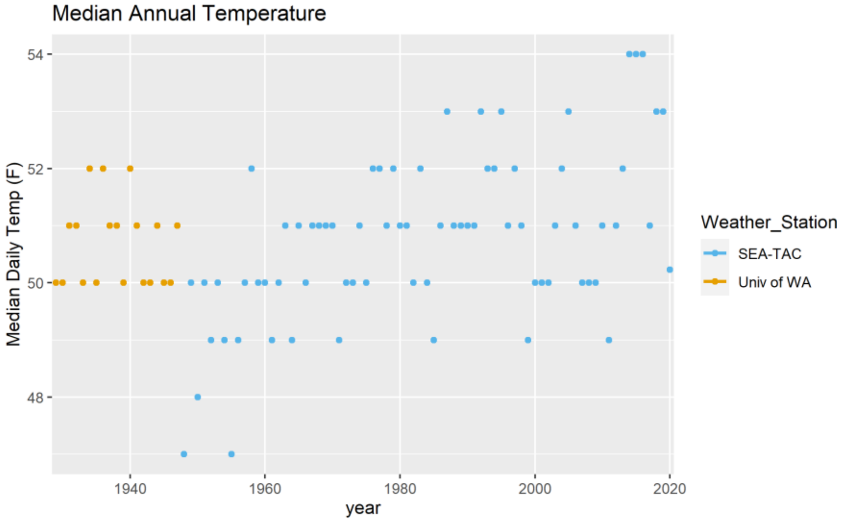
PSE uses 88 years of hourly temperature data (1929-2016) to inform its historical load forecast. Much of this hourly temperature data comes from the Sea-Tac Airport. However, Sea-Tac temperature data is only available from 1948 onward, following its construction, so data prior to 1948 is synthesized using daily high and low temperatures from the University of Washington weather station and hourly shapes from Sea-Tac data.

This brings up important questions regarding whether the synthesized hourly temperature data is having an impact on PSE's modeling and ELCC analysis. Unlike the outage events across hydro input years that are relatively evenly distributed, outage events in PSE's modeling are not evenly distributed across temperature input years. 33% - 35% of the simulated draws that have loss of load events in January 2027 and January 2031 occur in the temperature years prior to 1948, a period representing 21% of all weather years.

However, E3 analyzed this pre-1948 temperature data and found that it is reasonable and does not demonstrate any apparent bias compared to the other temperature years that would unfairly impact ELCC results. The minimum annual temperatures, as well as the median temperatures do not show a clear bias in the data that is formed with the synthesized data.

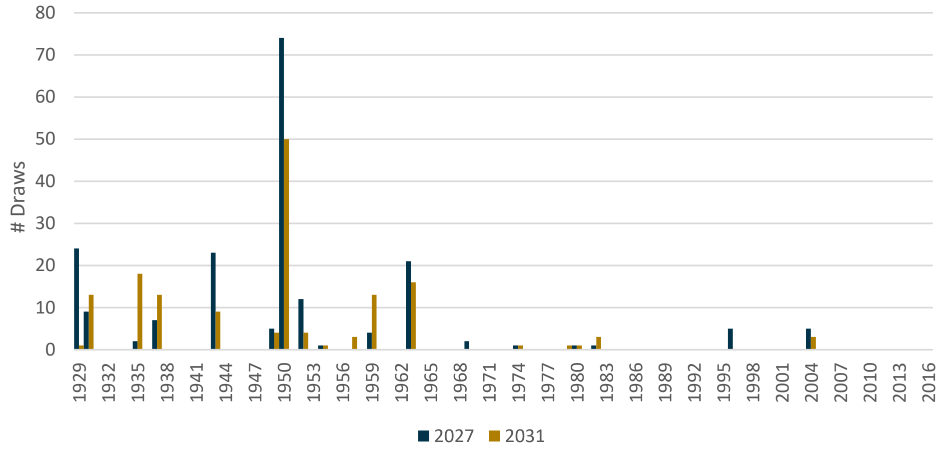
Figure 6. PSE Temperature Year Data, by Source





But looking at the temperature data further reveals that nearly 95% of the simulated draws that have loss-of-load events in January 2027 and January 2031 occur in the first half of the temperature years, prior to 1972 (see Figure 7).

Figure 7. Number of PSE Base Case Draws With Loss of Load Events, by Temperature Year, January 2027 and 2031



This raises important questions regarding whether, given that PSE is a winter-peaking system, there are clear warming trends that make the use of temperature data as far back as 1929 less useful. Moving forward, PSE's winter peaks may be reduced relative to summer peaks based on more recent climate warming trends, which has the potential to impact PSE's resource planning.

Including warming trends in load modeling is an evolving area of research and application and there is no prevailing industry standard. Furthermore, there is precedent in the PNW region for using 88 historical years of temperature data in GENESYS modeling, in line with the modeling by the NPCC.

A Temperature Sensitivity was modeled in PSE's 2021 IRP. Data was taken from three models that the NPCC has been using in its resource adequacy analyses that account for warming trends in the PNW region. This change only impacted the energy demand forecast used in PSE's resource adequacy modeling, but importantly it changed the nature of the demand profile and lowered winter peaks. Given that PSE is a winter-peaking system, this results in less reliability-driven capacity needed to start the ELCC analysis. See Table 6.

Table 6. Peak Capacity Need in PSE 2021 IRP[14]

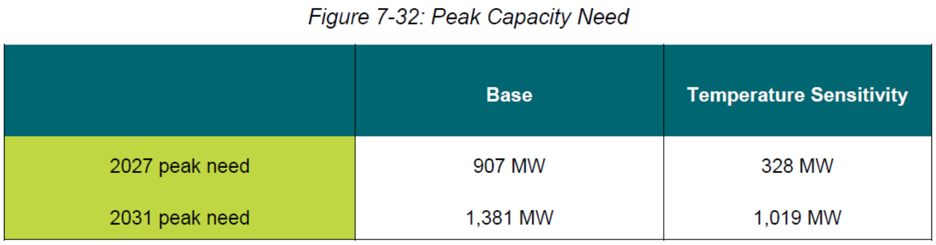


Figure 7-32: Peak Capacity Need

	Base	Temperature Sensitivity
2027 peak need	907 MW	328 MW
2031 peak need	1,381 MW	1,019 MW

Given the change in the demand profiles and the amount of reliability-driven capacity that is added to the system, this then results in much different ELCC results. See Table 10 in Appendix for a comparison of PSE's ELCC results in its Base Case and Temperature Sensitivity.

4.5.3 E3 CONCLUSION

PSE's synthesis of temperature data from the University of Washington appears reasonable based on data E3 has reviewed.

E3 recommends that PSE analyze the impact of the Temperature Sensitivity shown in its IRP on the current RFP and investigate potential modifications of the temperature data set to reflect a changing climate in light of its findings. This is especially relevant to the bid-specific analysis that will be conducted in Phase 2

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[14] PSE Final 2021 IRP, pg 7-45.

of the RFP, but can also inform future IRP cycles. Specifically, PSE should investigate:

(1) Whether the use of two different weather stations to derive temperature data at different times introduces bias into the analysis. This can be done by analyzing the temperature data from the time period when data from both weather stations is available and performing statistical tests to determine whether the two data sources can be considered part of the same data set, or whether there are statistically significant differences in the mean, median, or standard deviations.

(2) Whether PSE should truncate the amount of temperature years used to inform its load data if it believes that earlier temperature years are no longer applicable given a changing climate, and where this truncation might be most reasonable.

4.6 Generic Battery Storage Characteristics

4.6.1 ISSUE DESCRIPTION

E3 investigated whether the generic operating characteristics and capacity contributions of battery storage resources reflected in PSE's ELCC calculations are reasonable.

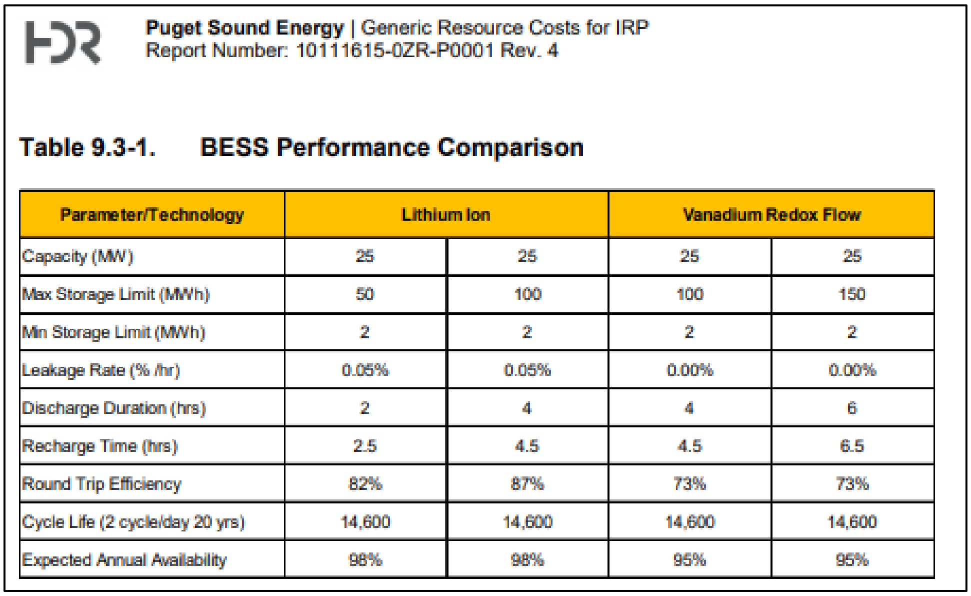
4.6.2 PSE METHODOLOGY AND INDUSTRY PRACTICE

PSE assumes round trip efficiency (RTE) of 82% - 87% for generic Li-ion battery storage resources and calculates one-way efficiency applied to both charging and discharging of the storage. During the charging process, the maximum charging capacity is nameplate capacity and the state of charge (SOC) increase is (Nameplate Capacity) x (1 – One Way Efficiency). During the discharging process, the maximum discharging capacity is nameplate capacity and the SOC decrease is (Nameplate Capacity) x (1 + One Way Efficiency).

Besides RTE, PSE also applies the minimum state of charge (SOC) for battery storage when calculating storage ELCC. Minimum state of charge (SOC) for battery storage is 20% in PSE's modeling.

Both RTE and minimum SOC assumptions in PSE's model will decrease the ELCC of storage. For the RTE assumption, even though the RTE input is reasonable, the duration of the storage is de-rated due to the size of the energy capacity. For example, for a battery with 4 hours duration and 100 MW of nameplate capacity, the energy capacity is assumed to be 400 MWh. However, during the discharging process modeled by PSE, it takes less than 4 hours to deplete the storage, which is different from the common convention of storage duration. A typical practice is to expand the energy capacity by the efficiency losses so that the discharging duration at nameplate capacity can achieve the target duration. In addition, the minimum SOC assumption used in PSE's modeling does not align with the minimum storage limits presented in PSE's HDR report (see Table 7).

Table 7. Battery Specifications in PSE's Generic Resource Cost Report[15]



Puget Sound Energy | Generic Resource Costs for IRP
Report Number: 10111615-0ZR-P0001 Rev. 4

Table 9.3-1. BESS Performance Comparison

Parameter/Technology	Lithium Ion		Vanadium Redox Flow	
Capacity (MW)	25	25	25	25
Max Storage Limit (MWh)	50	100	100	150
Min Storage Limit (MWh)	2	2	2	2
Leakage Rate (% /hr)	0.05%	0.05%	0.00%	0.00%
Discharge Duration (hrs)	2	4	4	6
Recharge Time (hrs)	2.5	4.5	4.5	6.5
Round Trip Efficiency	82%	87%	73%	73%
Cycle Life (2 cycle/day 20 yrs)	14,600	14,600	14,600	14,600
Expected Annual Availability	98%	98%	95%	95%

4.6.3 E3 CONCLUSION

PSE's round-trip efficiency assumptions are reasonable.

PSE's application of minimum SOC and one-way efficiency both impact battery storage's maximum and overall potential ELCC results in the RFP context.

E3 recommends that:

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[15] Page 65: https://oohpseirp.blob.core.windows.net/media/Default/PDFs/HDR_Report_10111615-0ZR-P0001_PSE%20IRP_Rev4%20-%2020190123).pdf.

1) PSE models battery storage in a manner more aligned with industry standards, such that storage can discharge at maximum capacity for X hours if the storage is defined as having X hours of duration; and

2) PSE aligns the presentation of ELCC values with the characterization of minimum, maximum, and nameplate MW values in its RFP documentation.

If these recommendations are reflected, no additional ELCC analysis is required.

4.7 Battery Storage Dispatch

4.7.1 ISSUE DESCRIPTION

E3 investigated whether the dispatch of the generic battery storage resources tested for ELCC calculations is reasonable.

4.7.2 PSE METHODOLOGY AND INDUSTRY PRACTICE

Proper storage dispatch behavior has a direct and significant impact on storage ELCC results. Standard practice is for battery discharge to occur whenever possible during a loss of load event in utility resource adequacy modeling.

In PSE's Base Case, the 4-hour Li-ion battery discharges in 265 of a total of 7040 simulation draws in 2027. In January 2027 in the Base Case, there are 197 simulated draws with loss of load events, with a total of roughly 2,900 hours with unserved energy. Furthermore, each draw in the January 2027 Base Case that has unserved energy in any hour, also has battery discharge at some hour in the draw.

E3 investigated whether storage dispatch within a given draw conforms to our expectation that storage dispatch occurs in response to loss of load events. In general, storage dispatch behavior is reasonable and in line with expectations: when there is an unserved energy event, storage dispatch occurs to the extent allowable by capacity.

As part of this investigation, E3 confirmed that PSE modeling includes the ability to call upon reserves from the Northwest Power Pool (NWPP) Reserve Sharing Program during the first hour of an unserved energy event, to the extent there is energy available in the external market.[16] Furthermore, while 50% of contingency reserves are typically added to load in PSE's resource accounting, this can flip to a subtraction from load in the first hour of a loss of load event, after which PSE must replace these reserves with either imports or increased production from its internal units.

It was beyond the scope of the current engagement for E3 to audit each of the calculations used by PSE to account for the net impact of reducing perfect capacity, adding battery storage capacity, and calling upon the NWPP Reserve Sharing Program on unserved energy events. E3 was able to confirm that PSE's accounting for unserved energy in its Base Case without battery storage reflects all the relevant dynamics as expected, based on data E3 reviewed. In battery storage scenarios, PSE modeling assumes a limit on the ability to call upon Assistance Reserves from the NWPP Reserve Sharing Program in response to the first hour of a loss-of-load event of once per day; this is inconsistent with Base Case modeling. If this assumption is relaxed, the duration of a second (or third, or

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[16] For more information, see: **https://www.nwpp.org/about/workgroups/2**.

fourth, or fifth, etc.) outage within a given day would be reduced by one hour. However, based on data E3 has reviewed from PSE's January 2027 scenarios with battery storage, the impact of relaxing this assumption on ELCCs is likely to be minor, as this only alters the number of hours with unserved energy by roughly 1% (from a base of roughly 2,700 hours under battery storage scenarios). Furthermore, there is a rationale for assuming that multiple outages within a given day are unlikely to be remedied by energy available at Mid-C, since this would likely occur during periods when the region is stressed and Assistance Reserves are less likely to be consistently available. However, this inconsistency between Base Case and battery storage scenarios is a minor disadvantage for battery storage ELCCs.

4.7.3 E3 CONCLUSION

In general, E3 finds that PSE's modeling of storage dispatch is reasonable and reflects the appropriate dynamics for calculating ELCC. As noted above, there is credible rationale for PSE's treatment of the first hour of a loss of load event in the Base Case, given the NWPP Reserve Sharing Program.

E3 recommends that PSE align its treatment of the first hour of loss-of-load events across its Base Case scenarios without battery storage and its scenarios with battery storage to reflect the proper utilization of the NWPP Reserve Sharing Program and consistent treatment of its own Contingency Reserves, as this inconsistency creates a minor disadvantage for battery storage ELCCs.

5 Additional Topics Reviewed

In addition to the key issues covered above, E3 investigated the questions listed below, representing inquiries PSE has received from stakeholders in the RFP process. For each question, E3's response is noted.

5.1.1 GENERAL

Why are PSE's ELCCs lower than those of other utilities, such as PGE and California utilities?

While E3 did not conduct a deep-dive analysis into the ELCC calculations and methodology of other utilities in the western U.S., PSE differs from many other utilities in general, and even from other utilities in the western region. First, PSE is a winter-peaking system, while many other utilities, including PGE, are summer-peaking systems. Secondly, hydro dominates the regional system, which has enabled the Pacific Northwest to build relatively fewer gas-fired peaking resources. This means that during a drought year, the energy deficit becomes the biggest driver of long duration loss of load events, which has a negative impact on battery storage ELCC results.

Are the operating data for different non-storage technologies reasonable?

E3 recommended that PSE utilize output shapes for wind and solar resources that are correlated with temperatures in the PSE service area. E3 did not uncover any other issues with non-storage operating data.

Are the load shapes used in PSE's analysis reasonable?

E3 recommends that PSE investigate (1) Whether the use of two different weather stations to derive temperature data at different times introduces bias into the analysis, and (2) whether it should truncate the amount of temperature years used to inform its load data if it believes that earlier temperature years are no longer applicable given a changing climate, and where this truncation might be most reasonable.

5.1.2 PUMPED STORAGE

Is it unreasonable for PSE to limit pumped storage resources' operating range (or "state of charge") to 70% of the resource's storage capacity?

E3 did not specifically analyze PSE's input assumptions for pumped storage resources. The key issues covered in this report in the context of battery storage are relevant to the discussion of pumped storage, and these issues (e.g., hydropower operations as a supply factor, temperature data as a demand factor) will also impact ELCCs for pumped storage. In general, E3 normally assumes that pumped storage units can be fully dispatched, but also recognizes that sometimes specific characteristics of specific pumped storage plants can require them to hold back a portion of their energy in their respective ponds.

5.1.3 HYBRID RESOURCES

Does PSE unreasonably limit hybrid resources by only allowing them to charge from renewables over the entire lifecycle of the resource?

E3's analysis and review did not specifically focus on the operating parameters of PSE's generic hybrid resources (battery storage paired with another resource). The key issues covered in this report in the context of battery storage are relevant to the discussion of hybrid resources. These key issues (e.g., treatment of Mid-C external market availability) will also impact ELCCs for hybrid resources. In general, E3 recommends that the energy storage component of hybrid resources should be allowed to be charged by the grid after the window for investment tax credit eligibility expires, subject to the combined interconnection limit.

5.1.4 MARKET LIMITATIONS

Does the reduction in availability of market purchases in PSE's IRP artificially constrain the ability of storage resources to meet PSE's capacity needs?

As discussed above, PSE's treatment of the Mid-Columbia (Mid-C) trading hub does impact its ELCC calculations in general and battery storage ELCCs in particular. As detailed above, E3 is recommending additional modeling where the external region is brought up to a 5% LOLP reliability standard and the ELCC analysis is re-run under those conditions. The result of that analysis will inform if any further changes are needed for how PSE models the external market.

Does the IRP impose a market import limitation across the full 24-hour window on all days in January and February instead of only during "super-peak" and "heavy-load" hours?

Based on the data that E3 reviewed, as well as conversations with PSE, the high level import limit did not change based on month or super-peak or heavy-load hours. Market import curtailments are derived from NPCC GENESYS model runs.

How does PSE's analysis reflect transmission constraints?

Transmission constraints are defined by the physical capability to import power into PSE's system, as well as the resources and contracts that have rights on those lines and could therefore potentially reduce the ability for PSE to make short-term market purchases in some hours. These short-term market purchases are then incorporated into PSE's ELCC analysis as a reliability resource and are a key driver of longer duration loss-of-load events and low storage ELCC results.

5.1.5 BATTERY STORAGE

Are the ELCCs for Li-ion (2-hour and 4-hour) overly conservative, considering that the resources are stand-alone and charging and discharging schedules will not be constrained by a co-located renewable generation resource?

The reason for low battery storage ELCCs is not whether they are charged by renewable resources or not, but rather the nature and length of the outages on PSE's system. Many outage events, even after PSE's own system has been brought up to a 5% LOLP standard by adding perfect capacity, are very long in duration. See E3's discussion of PSE's treatment of Mid-C for more details.

Does PSE's IRP portfolio modeling preference for 2-hour battery storage conflict with an industry-standard of 4-hour battery?

PSE calculated ELCC values for multiple generic battery storage resources including a two-hour and four-hour Li-ion battery, as well as a four-hour and six-hour flow battery.

What changed between the cases utilized in 2020 and amended in 2021 that resulted in a decrease in the assessed ELCC of energy storage?

E3 did not analyze the ELCC calculations from the last IRP. However, the first reference year for which ELCC results were shared was updated from 2022 to 2027. Given that reliability-driven capacity is not added to the external market to make up for growing load and hydro shortfalls, an earlier reference year (2022 compared to 2027) would presumably have fewer long duration outages which would benefit battery storage ELCCs.

5.1.6 OTHER

Are PSE's ELCC estimates inclusive of the possibility of forced outages during a peak event?

Yes, forced outage rates are accounted for in the modeling and ELCC analysis.

How did the temperature sensitivity scenario in the 2021 IRP impact PSE's resource plan?

E3's understanding is that the temperature sensitivity was a stand-alone analysis that did not directly inform resource plans resulting from the 2021 IRP. However, as noted in this report, E3 recommends that PSE reevaluate the appropriateness of its current approach to considering temperatures in developing load shapes.

6 Summary

E3 finds that PSE's general approach to ELCC calculation is reasonable. While PSE's treatment of Mid-C does disadvantage battery storage ELCCs, there is no industry standard for how to address the issue of external market equilibrium, and whether it is appropriate to assume an adequate regional system is a real and difficult question. Beyond the question of how to treat the external market, the other topic requiring immediate attention in the current RFP process is the presentation of generic battery storage operating characteristics, which does not require changes in PSE's ELCC calculation methodology. While it would be ideal to address the treatment of Contingency Reserves and PSE's participation in the NWPP Reserve Sharing Program under its battery storage scenarios, this may require continued analysis beyond what is feasible within the current RFP timeline. Moving forward, PSE's treatment of resource correlations, temperature data, and hydropower operations merit additional analysis and potential adjustments, but without additional analysis it is unclear if changes in the treatment of these topics will produce significant changes in battery storage ELCCs; in the case of hydropower operations, updates to the PSE modeling approach could produce a reduction in battery storage ELCCs.

E3 recommends that PSE do the following before conducting the portfolio analysis in the RFP:

4) Conduct an additional GENESYS model run assuming regional capacity additions such that the region meets a 5% LOLP standard before recalculating ELCC;

5) Restate ELCC values for battery storage in a manner more aligned with industry standards, such that storage can discharge at maximum capacity for X hours if the storage is defined as having X hours of duration, and align the presentation of ELCC values with the characterization of minimum, maximum, and nameplate MW values in RFP documentation; and

6) Re-calculate battery storage ELCCs under the assumption that PSE's treatment of its own Contingency Reserves and the NWPP's Reserve Sharing Program is the same as in PSE's Base Case without battery storage, and investigate the significance of the revised results.

E3 recommends that PSE do the following in future IRP cycles:

4) Utilize weather-matched load that is aligned with wind and solar data;

5) Reevaluate its current approach to considering temperatures in developing load shapes based on (1) the use of two different weather stations, and (2) the changing climate;

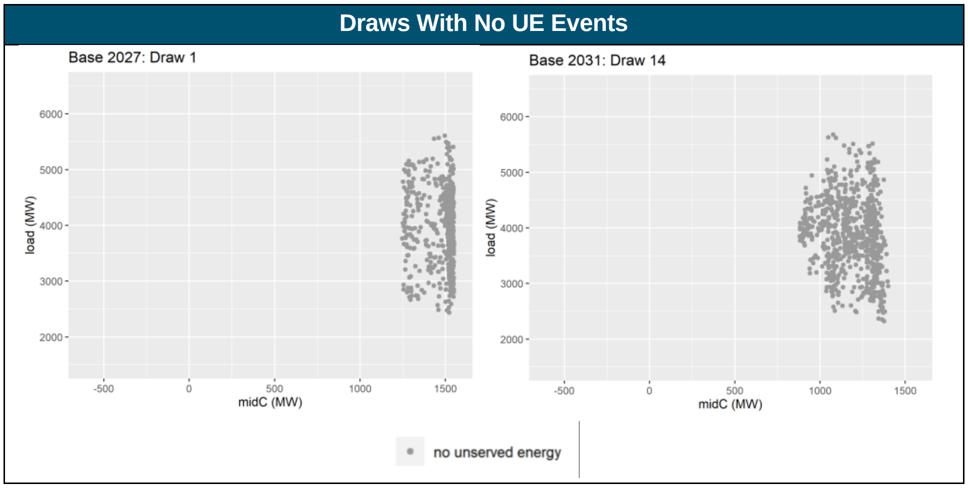
6) Update modeling to incorporate hydro dispatch capabilities and hydro energy limitations.

E3 expects that even in the context of the recommendations above, battery storage ELCCs are likely to be relatively low in a hydropower-dependent region like the PNW compared to other regions. To confirm this judgment, however, E3 recommends the additional steps above.

7 Appendix

7.1 Mid-C Data Visualization

Figure 8. Mid-C Output During Draws With No, Some, and Many Unserved Energy Events[17]



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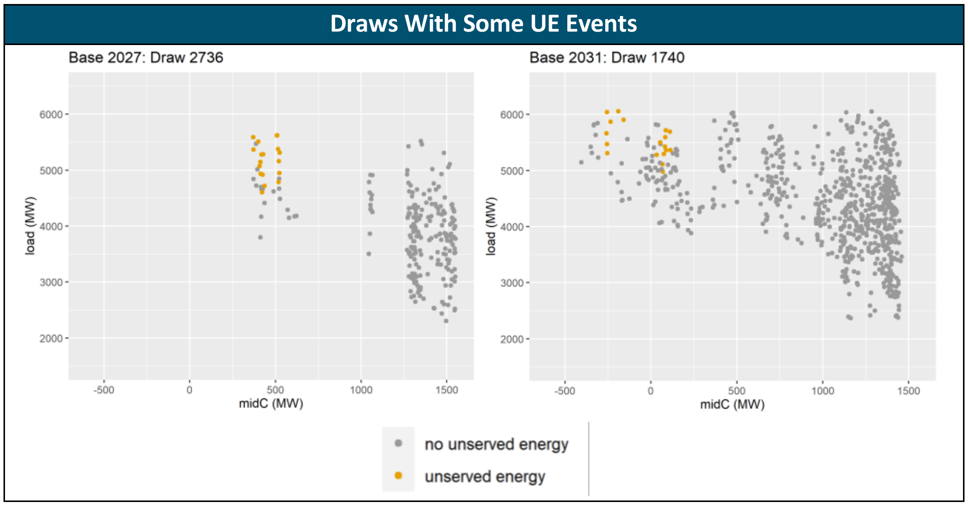
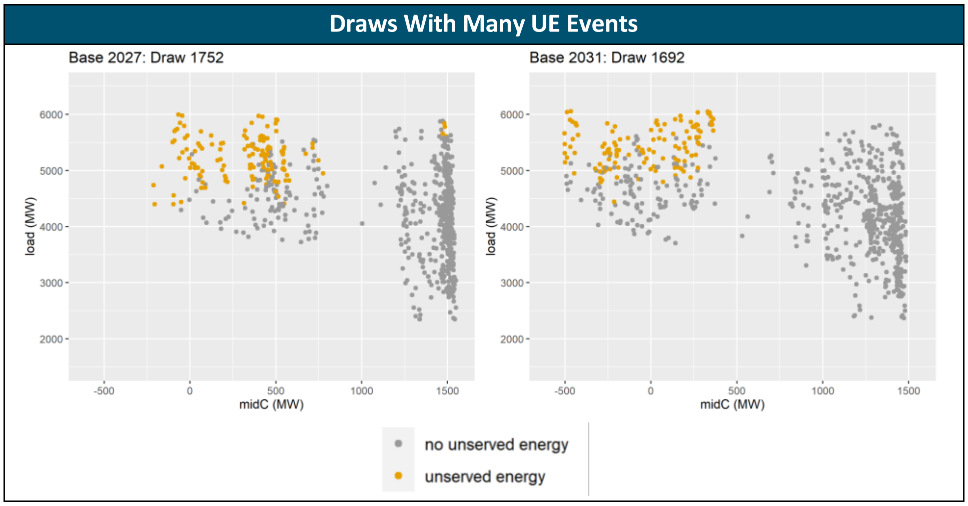
[17] PSE IRP data. E3 analysis.


Draws With Some UE Events
Base 2027: Draw 2736
Base 2031: Draw 1740
load (MW)
6000
5000
4000
3000
2000
-500
0
500
1000
1500
midC (MW)
● no unserved energy
● unserved energy

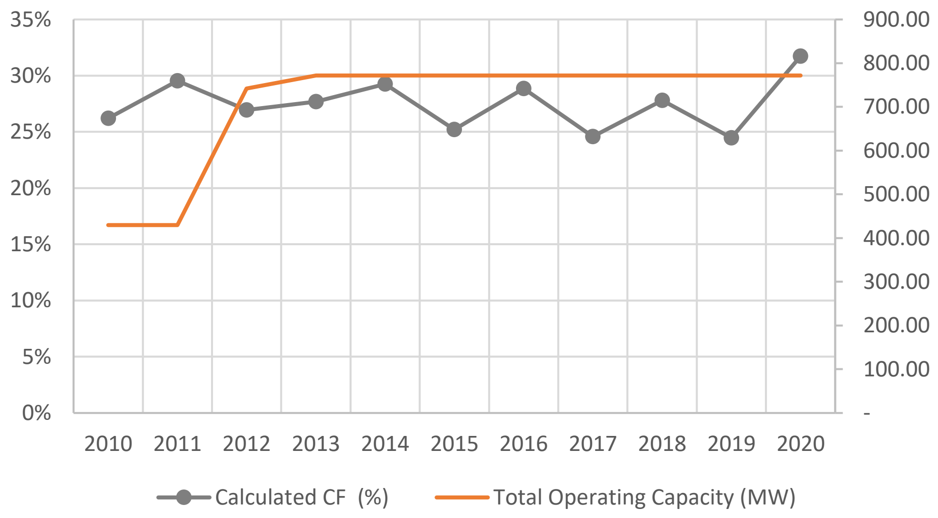

Draws With Many UE Events
Base 2027: Draw 1752
Base 2031: Draw 1692
load (MW)
6000
5000
4000
3000
2000
-500
0
500
1000
1500
midC (MW)
● no unserved energy
● unserved energy

7.2 Resource Correlations

7.2.1 SOLAR AND WIND CAPACITY FACTORS

E3 analyzed PSE's historical wind data to assess the historical correlation of wind production and load. While PSE does have some solar capacity (0.5 MW), the amount was considered too small for inclusion in this analysis. PSE's wind assets displayed an average capacity factor of 27% from 2010-20.

Figure 9. PSE Wind Capacity Factor vs Operating Capacity[18]



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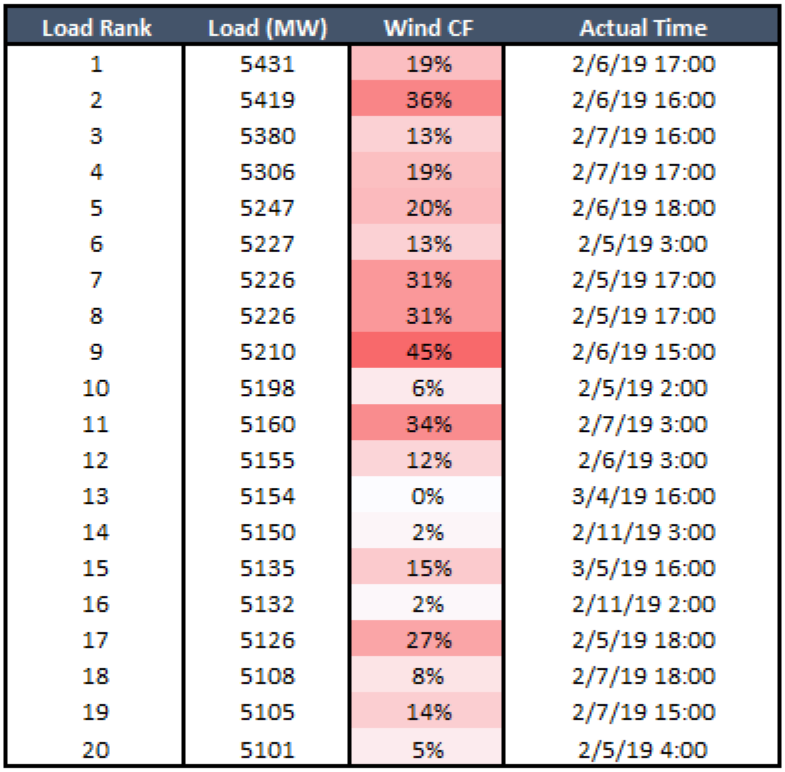
[18] SNL. https://www.capitaliq.spglobal.com/web/client?auth=inherit&overridecdc=1&#company/plantportfoliosummary?ID=4062485.

7.2.2 WIND CORRELATION WITH LOAD

In the highest load hours over the past 4 years, the wind fleet showed an average capacity factor of 18%. There appears to be a negative correlation between average wind fleet output (27% for the years 2010-20) and wind output during the highest load hours (18%).

Table 8. Historical Hourly Load and Wind Capacity Factor for PSE, 2017 – 2020[19]



Load Rank	Load (MW)	Wind CF	Actual Time
1	5431	19%	2/6/19 17:00
2	5419	36%	2/6/19 16:00
3	5380	13%	2/7/19 16:00
4	5306	19%	2/7/19 17:00
5	5247	20%	2/6/19 18:00
6	5227	13%	2/5/19 3:00
7	5226	31%	2/5/19 17:00
8	5226	31%	2/5/19 17:00
9	5210	45%	2/6/19 15:00
10	5198	6%	2/5/19 2:00
11	5160	34%	2/7/19 3:00
12	5155	12%	2/6/19 3:00
13	5154	0%	3/4/19 16:00
14	5150	2%	2/11/19 3:00
15	5135	15%	3/5/19 16:00
16	5132	2%	2/11/19 2:00
17	5126	27%	2/5/19 18:00
18	5108	8%	2/7/19 18:00
19	5105	14%	2/7/19 15:00
20	5101	5%	2/5/19 4:00

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[19] EIA. https://www.eia.gov/opendata/qb.php?category=3390168&sdid=EBA.PSEI-ALL.NG.WND.H.

Figure 10. Plot of Historical Hourly Load and Wind Capacity Factor for PSE for 100 Highest Load Hours, 2017 – 2020[20]

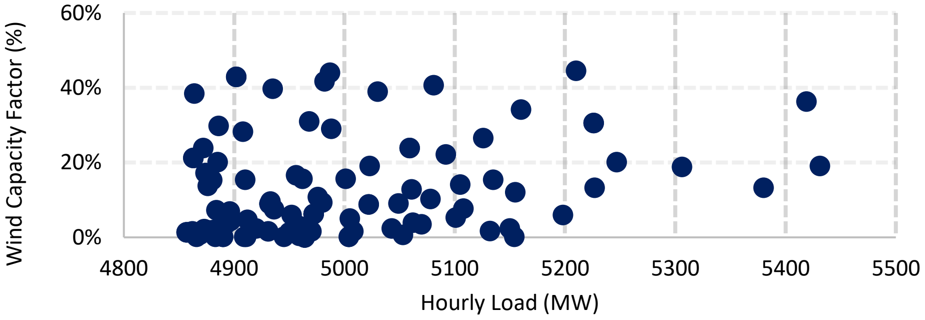
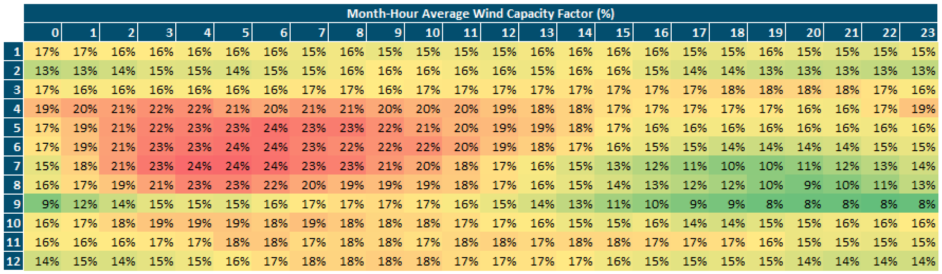
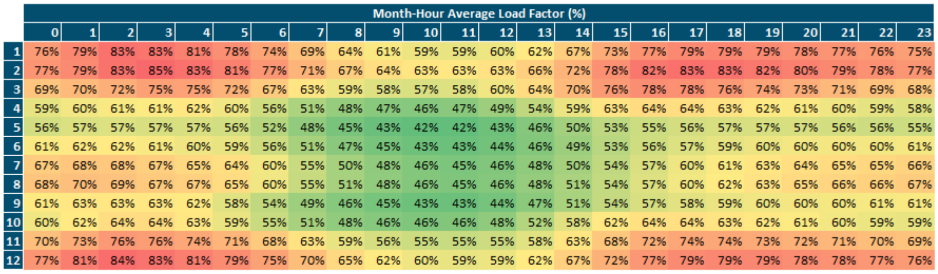


Table 9. Month-Hour Heatmaps of Wind Capacity Factor and Load Factors for PSE, 2017-2020[21]



Month-Hour Average Wind Capacity Factor (%)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	17%	17%	16%	16%	16%	16%	16%	15%	16%	15%	15%	15%	15%	16%	16%	16%	16%	15%	15%	16%	15%	15%	15%	15%
2	13%	13%	14%	15%	15%	14%	15%	15%	16%	16%	16%	16%	16%	15%	16%	16%	15%	14%	14%	13%	13%	13%	13%	13%
3	17%	16%	16%	16%	16%	16%	16%	17%	17%	16%	17%	17%	17%	17%	17%	17%	17%	17%	18%	18%	18%	18%	17%	16%
4	19%	20%	21%	22%	22%	21%	20%	21%	21%	20%	20%	20%	19%	18%	18%	17%	17%	17%	17%	17%	16%	16%	17%	19%
5	17%	19%	21%	22%	23%	23%	24%	23%	23%	22%	21%	20%	19%	19%	18%	17%	16%	16%	16%	16%	16%	16%	16%	16%
6	17%	19%	21%	23%	23%	24%	24%	23%	22%	22%	22%	20%	19%	18%	17%	16%	15%	15%	14%	14%	14%	14%	15%	15%
7	15%	18%	21%	23%	24%	24%	24%	23%	23%	21%	20%	18%	17%	16%	15%	13%	12%	11%	10%	10%	11%	12%	13%	14%
8	16%	17%	19%	21%	23%	23%	22%	20%	19%	19%	19%	18%	17%	16%	15%	14%	13%	12%	12%	10%	9%	10%	11%	13%
9	9%	12%	14%	15%	15%	15%	16%	17%	17%	17%	17%	16%	15%	14%	13%	11%	10%	9%	9%	8%	8%	8%	8%	8%
10	16%	17%	18%	19%	19%	19%	18%	19%	18%	18%	18%	17%	17%	16%	15%	15%	16%	14%	14%	15%	15%	16%	16%	16%
11	16%	16%	16%	17%	17%	18%	18%	17%	18%	18%	17%	18%	18%	17%	18%	18%	17%	17%	17%	16%	15%	15%	15%	15%
12	14%	15%	14%	15%	15%	16%	17%	18%	18%	18%	18%	17%	17%	17%	17%	16%	15%	15%	15%	15%	14%	14%	14%	14%



Month-Hour Average Load Factor (%)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	76%	79%	83%	83%	81%	78%	74%	69%	64%	61%	59%	59%	60%	62%	67%	73%	77%	79%	79%	79%	78%	77%	76%	75%
2	77%	79%	83%	85%	83%	81%	77%	71%	67%	64%	63%	63%	63%	66%	72%	78%	82%	83%	83%	82%	80%	79%	78%	77%
3	69%	70%	72%	75%	75%	72%	67%	63%	59%	58%	57%	58%	60%	64%	70%	76%	78%	78%	76%	74%	73%	71%	69%	68%
4	59%	60%	61%	61%	62%	60%	56%	51%	48%	47%	46%	47%	49%	54%	59%	63%	64%	64%	63%	62%	61%	60%	59%	58%
5	56%	57%	57%	57%	57%	56%	52%	48%	45%	43%	42%	42%	43%	46%	50%	53%	55%	56%	57%	57%	57%	56%	56%	55%
6	61%	62%	62%	61%	60%	59%	56%	51%	47%	45%	43%	43%	44%	46%	49%	53%	56%	57%	59%	60%	60%	60%	60%	61%
7	67%	68%	68%	67%	65%	64%	60%	55%	50%	48%	46%	45%	46%	48%	50%	54%	57%	60%	61%	63%	64%	65%	65%	66%
8	68%	70%	69%	67%	67%	65%	60%	55%	51%	48%	46%	45%	46%	48%	51%	54%	57%	60%	62%	63%	65%	66%	66%	67%
9	61%	63%	63%	63%	62%	58%	54%	49%	46%	45%	43%	43%	44%	47%	51%	54%	57%	58%	59%	60%	60%	60%	61%	61%
10	60%	62%	64%	64%	63%	59%	55%	51%	48%	46%	46%	46%	48%	52%	58%	62%	64%	64%	63%	62%	61%	60%	59%	59%
11	70%	73%	76%	76%	74%	71%	68%	63%	59%	56%	55%	55%	55%	58%	63%	68%	72%	74%	74%	73%	72%	71%	70%	69%
12	77%	81%	84%	83%	81%	79%	75%	70%	65%	62%	60%	59%	59%	62%	67%	72%	77%	79%	79%	79%	78%	78%	77%	76%

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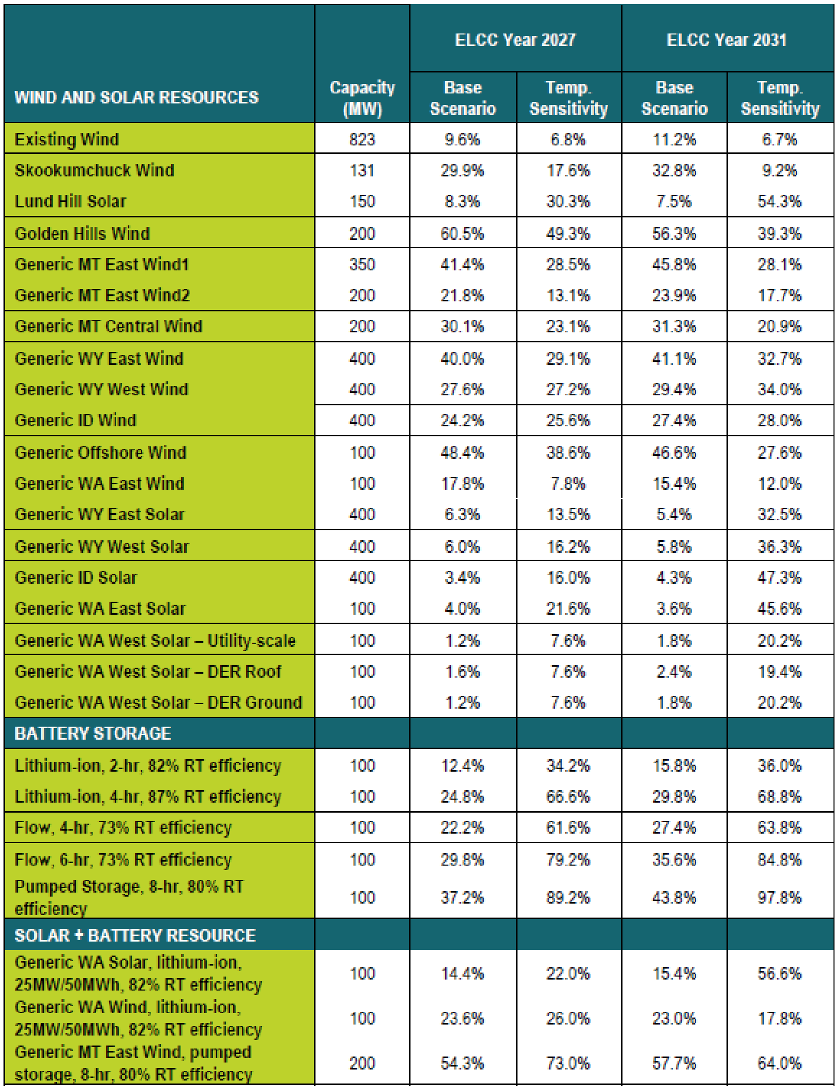
[20] EIA. https://www.eia.gov/opendata/qb.php?category=3390168&sdid=EBA.PSEI-ALL.NG.WND.H.

[21] EIA. https://www.eia.gov/opendata/qb.php?category=3390168&sdid=EBA.PSEI-ALL.NG.WND.H.

7.3 Temperature Data

Table 10. ELCC by Resource and by Sensitivity in PSE 2021 IRP[22]



		ELCC Year 2027		ELCC Year 2031	
WIND AND SOLAR RESOURCES	Capacity (MW)	Base Scenario	Temp. Sensitivity	Base Scenario	Temp. Sensitivity
Existing Wind	823	9.6%	6.8%	11.2%	6.7%
Skookumchuck Wind	131	29.9%	17.6%	32.8%	9.2%
Lund Hill Solar	150	8.3%	30.3%	7.5%	54.3%
Golden Hills Wind	200	60.5%	49.3%	56.3%	39.3%
Generic MT East Wind1	350	41.4%	28.5%	45.8%	28.1%
Generic MT East Wind2	200	21.8%	13.1%	23.9%	17.7%
Generic MT Central Wind	200	30.1%	23.1%	31.3%	20.9%
Generic WY East Wind	400	40.0%	29.1%	41.1%	32.7%
Generic WY West Wind	400	27.6%	27.2%	29.4%	34.0%
Generic ID Wind	400	24.2%	25.6%	27.4%	28.0%
Generic Offshore Wind	100	48.4%	38.6%	46.6%	27.6%
Generic WA East Wind	100	17.8%	7.8%	15.4%	12.0%
Generic WY East Solar	400	6.3%	13.5%	5.4%	32.5%
Generic WY West Solar	400	6.0%	16.2%	5.8%	36.3%
Generic ID Solar	400	3.4%	16.0%	4.3%	47.3%
Generic WA East Solar	100	4.0%	21.6%	3.6%	45.6%
Generic WA West Solar – Utility-scale	100	1.2%	7.6%	1.8%	20.2%
Generic WA West Solar – DER Roof	100	1.6%	7.6%	2.4%	19.4%
Generic WA West Solar – DER Ground	100	1.2%	7.6%	1.8%	20.2%
BATTERY STORAGE					
Lithium-ion, 2-hr, 82% RT efficiency	100	12.4%	34.2%	15.8%	36.0%
Lithium-ion, 4-hr, 87% RT efficiency	100	24.8%	66.6%	29.8%	68.8%
Flow, 4-hr, 73% RT efficiency	100	22.2%	61.6%	27.4%	63.8%
Flow, 6-hr, 73% RT efficiency	100	29.8%	79.2%	35.6%	84.8%
Pumped Storage, 8-hr, 80% RT efficiency	100	37.2%	89.2%	43.8%	97.8%
SOLAR + BATTERY RESOURCE					
Generic WA Solar, lithium-ion, 25MW/50MWh, 82% RT efficiency	100	14.4%	22.0%	15.4%	56.6%
Generic WA Wind, lithium-ion, 25MW/50MWh, 82% RT efficiency	100	23.6%	26.0%	23.0%	17.8%
Generic MT East Wind, pumped storage, 8-hr, 80% RT efficiency	200	54.3%	73.0%	57.7%	64.0%

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[22] PSE Final 2021 IRP, pg 7-47.