

Energy Storage Capacity Value on the CAISO System

Final Report

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PREPARED FOR

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PREPARED BY

Kevin Carden
Nick Wintermantel
Astrapé Consulting

INTRODUCTION

To inform the CPUC’s development of the 2019-2020 Reference System Portfolio for its Integrated Resource Planning process (currently R.16-02-007), Astrapé Consulting was contracted by the CPUC to examine the capacity value of energy storage resources on the CAISO system under the high renewables penetration scenarios being contemplated in the IRP process. The CPUC uses the RESOLVE capacity expansion model as a core analytical tool to develop a Reference System Portfolio. RESOLVE’s optimization methodology requires a representation of the marginal capacity contribution of different resource types, including wind, solar, and energy storage, to identify a least-cost portfolio of resources that meets resource adequacy requirements. This report discusses how marginal capacity contribution assumptions were derived for energy storage.

The objective of this study is to produce Effective Load Carrying Capability (ELCC)¹ curves for battery storage for use in the RESOLVE capacity expansion model in the CPUC’s Integrated Resource Planning Proceeding. While suitable for use in developing a 2030 Reference System Plan, the analysis conducted herein is limited in its applicability, specifically in the context of the CPUC’s Resource Adequacy proceeding:

- This study evaluates the marginal ELCC provided by battery storage resources in the context of the future 2022 and 2030 CAISO systems with significant penetrations of solar resources—a total of nearly 50 GW in 2030, including both utility-scale and behind-the-meter resources.
- The marginal capacity value of storage is highly dependent upon the underlying load and resource mix; accordingly the resulting ELCC curves are not applicable in a system with a substantially different load and resource mix—for example, today’s CAISO system—and therefore do not represent values that should be used in today’s Resource Adequacy proceeding.
- Additionally, while the convention used in this analysis—which quantifies the marginal value of battery storage to a portfolio of resources and therefore attributes the impacts of interactive effects between storage and other resources in the portfolio (often referred to as a “diversity benefit”) to storage resources—is useful when optimizing least-cost portfolios in RESOLVE, it may not reflect the methods and conventions used in the Resource Adequacy proceeding in practice to allocate diversity benefits to individual resources or groups of resources.

At the same time, this analysis does highlight important dynamics and considerations that the CPUC’s Resource Adequacy proceeding will eventually have to confront as deployment of energy storage resources continues—namely, the declining marginal ELCC of energy storage at increasing levels of penetration—so while the specific numeric analysis may not be applicable in today’s system, many of the implications highlighted by this analysis will hold true.

¹ Although there is a technical difference between ELCC and Capacity Value, they are often used interchangeably in the industry. This paper uses the terms interchangeably as well.

METHODOLOGY

Astrapé performed the simulations to calculate the marginal ELCC of energy storage at different storage penetration levels in a high renewables CAISO system using the Strategic Energy and Risk Valuation Model (SERVM). To examine the capacity value of the energy storage resources, a “base” case of the system is first established. This involves calibrating CAISO to an industry standard of reliability of 0.1 Loss of Load Expectation (LOLE). Once the “base” case has been established, the energy storage resources are added to the system which improves reliability. Then, perfect conventional capacity is removed until the LOLE returns to 0.1. Figure 1 illustrates the methodology utilized. The ratio of the capacity of energy storage added to the capacity of perfect conventional resources removed is deemed to be the capacity value of the energy storage resource. It should be noted that for this study, Astrapé considered the energy storage resources to be 4-hour resources without any charging constraints that would be imposed on batteries to meet Investment Tax Credit requirements.

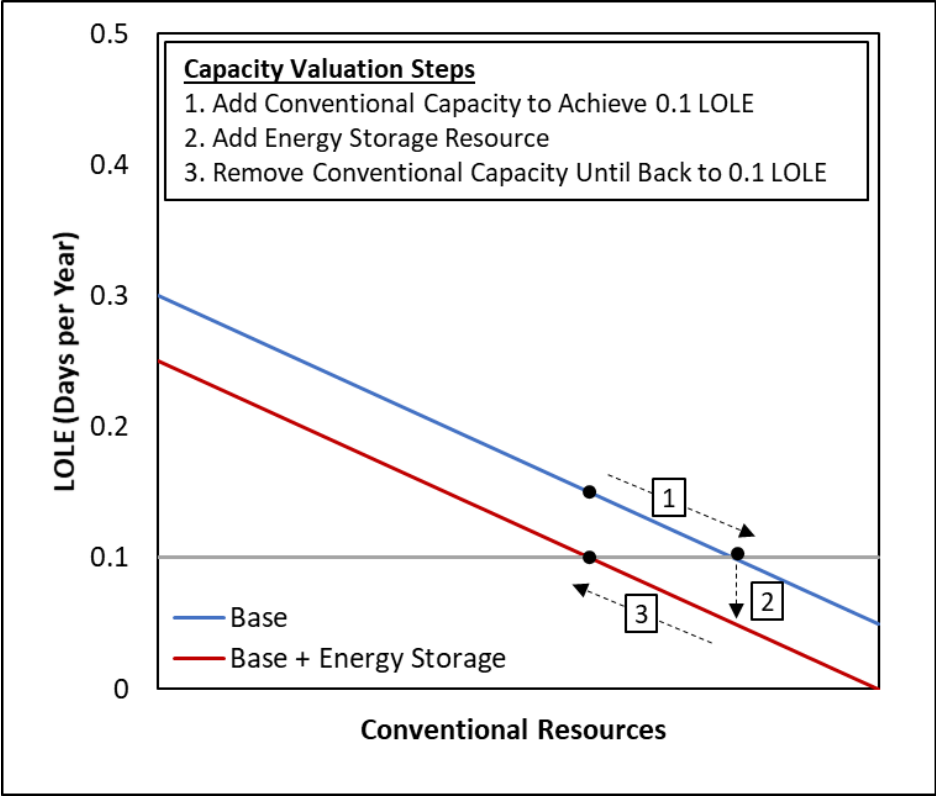


Figure 1: Capacity Value Approach using SERVM

The SERVM commitment logic optimizes decisions for the particular conditions being addressed. During emergency events, SERVM will optimally preserve storage resources while considering all other system resources and their constraints as well as purchase opportunities from zones outside of the study region. This allows the system to take advantage of load and generator outage diversity to preserve the capacity value of energy storage.

SERVM allows energy storage resources to provide ancillary services during emergency conditions. Since assumptions used in SERVM simulations by the CPUC include operating reserves of 4.5%

of hourly gross load to be protected even during firm load shed events, a commensurate quantity of energy storage resources are able to serve ancillary services and provide full reliability during emergency events without discharging energy.

DATA SOURCES

Astrapé utilized the SERVM dataset constructed by the CPUC as of August 2019. This includes all zones in WECC aggregated according to the topology in Figure 2 below.

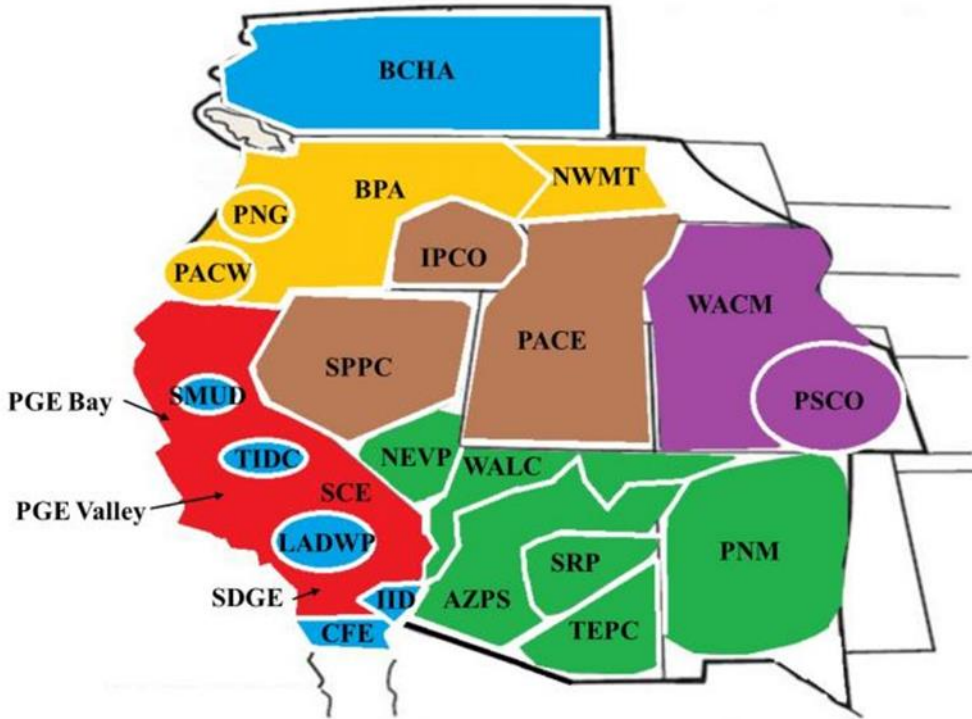


Figure 2: WECC Topology

The capacity value of energy storage is dependent on the volume of renewable capacity in the system. The following tables summarize the projected wind and solar capacity and energy in the CAISO system in 2022. These amounts were derived from resource portfolios being developed in the CPUC’s IRP process as of November 2019.

Table 1: Renewable Capacities and Energies 2022²

Type of Resource	Capacity (GW)	Energy (TWh)
Wind	9.4	17.55
Utility Scale Solar	18.94	47.10
BTM Solar	8.87	14.91

² The underlying portfolio of resources used to derive marginal ELCC curves for energy storage was based on preliminary outputs from RESOLVE in the process of developing the Reference System Portfolio.

The significant renewable capacity results in very steep net load shapes which are illustrated in Figure 3. This provides an opportunity for limited duration storage to provide significant capacity value.

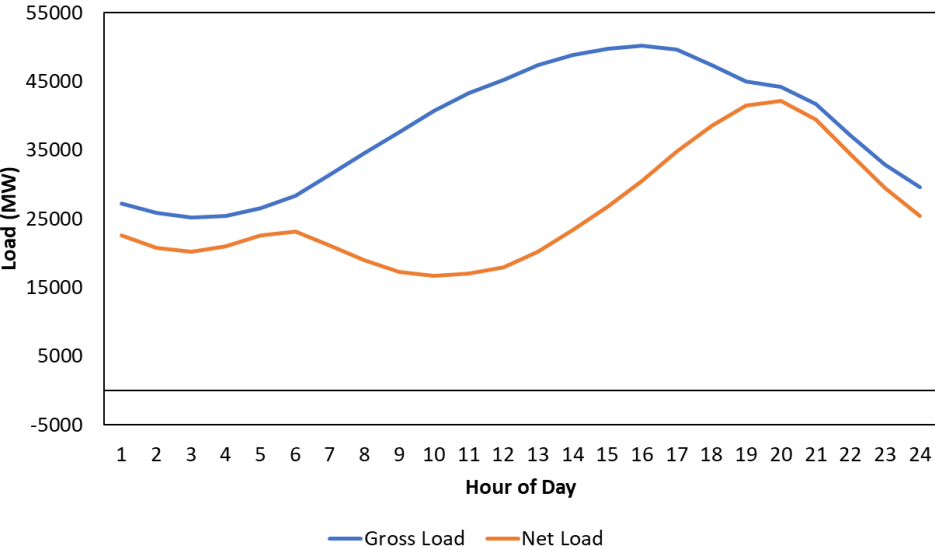


Figure 3: Average Summer Load Shapes 2022 Solar

As shown in Figure 4, solar resources have a more pronounced impact on the average CAISO net load shape than wind resources. This effect means that the level of solar generation on the system can strongly impact the opportunity for limited duration energy storage resources to provide capacity, whereas the impact of wind penetration on storage capacity value will be more limited.

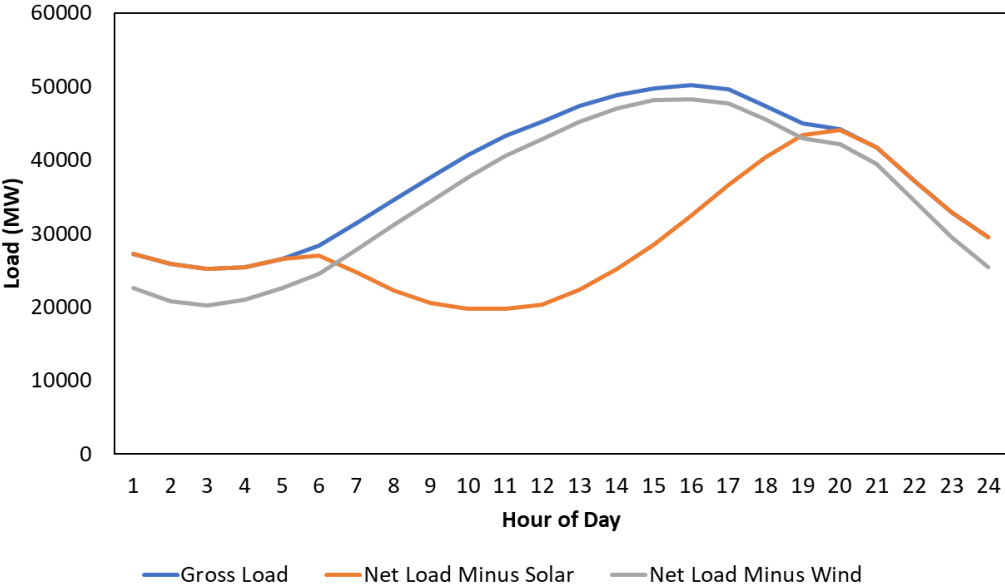


Figure 4: Average Summer Load Shapes

Finally, the CAISO system was modeled with a 5 GW import limit during the summer from 5:00 PM-10:00 PM.

RESULTS-BASE CASE

Astrapé performed the methodology outlined above for the 2022 study year for many different levels of storage deployment. The results are displayed in Table 3.ⁱ

Table 2: Energy Storage Capacity Value 2022

Battery Capacity (MW)	Average Capacity Value	Incremental Capacity Value	Marginal Capacity Value
5,265	100.2%	100.2%	100.0%
7,674	99.5%	98.1%	88.8%
10,530	94.2%	80.1%	76.2%
13,034	90.2%	73.0%	66.4%
15,795	84.8%	59.7%	54.2%
18,426	79.8%	49.6%	44.8%
21,060	74.8%	40.0%	33.9%
23,960	69.2%	28.4%	24.1%
26,325	64.9%	21.7%	21.7%

Astrapé’s findings demonstrate that around 7,500 MW of 4-hour energy storage resources can receive close to 100% capacity value on the 2022 CAISO system – a system that has significantly higher levels of solar generation than present day.³ After the initial 7,500 MWs of energy storage, the remaining energy storage amounts receive diminishing incremental capacity values. For example, energy storage added between 13,034 MWs and 15,795 MWs receives an average of only 59.7% capacity value. At precisely 15,795 MW, marginal battery capacity provides capacity value of 54.2%.

The first 7,500 MWs of the 4-hour resources on the 2022 system are able to serve the shorter periods of elevated load but as the amount of energy storage resources on CAISO’s system is increased, the net load shape flattens. The incremental energy storage resources are then expected to serve longer periods leading to a diminished capacity value. Figure 5 illustrates the effect of increasing amounts of storage on the net load shape from a typical July day.

³ As discussed in the introduction, the resulting capacity value for storage is highly sensitive to the underlying resource mix, so results from this study should not be used outside of the context of the CPUC’s development of a Reference System Portfolio for its IRP process.

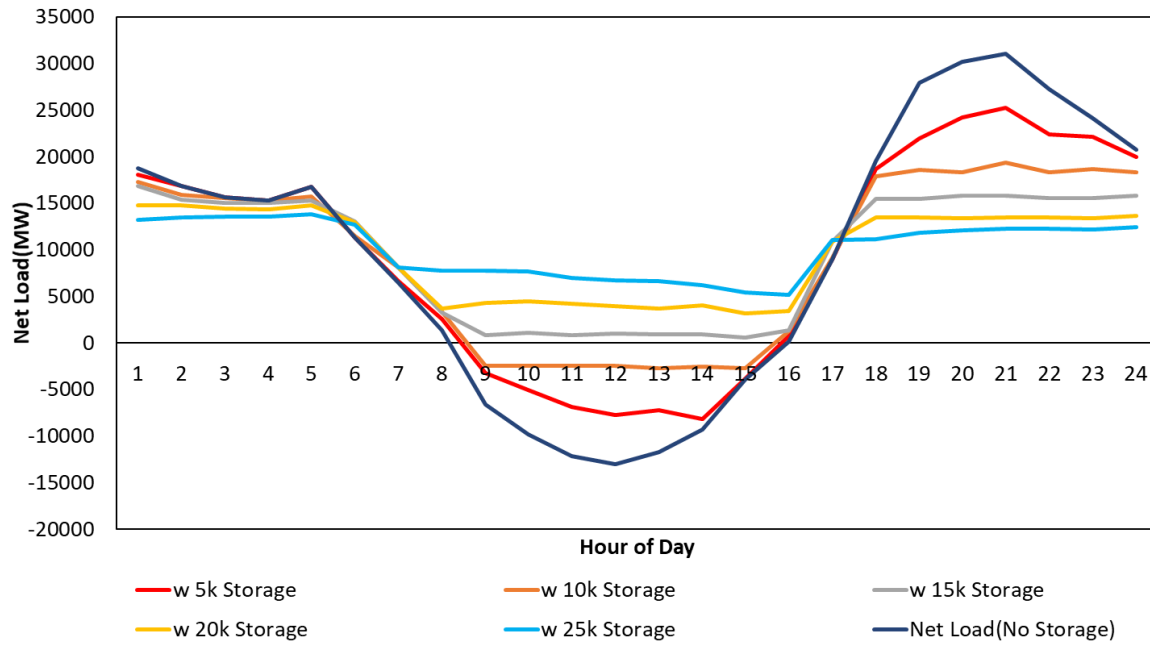


Figure 5: July Net Load Shapes with Various Storage Portfolios

RESULTS-2030 RENEWABLE PORTFOLIO

In an effort to better understand the effects of an increasing renewable portfolio on the CAISO system, Astrapé performed a sensitivity with the same assumptions made in the 2022 Base Case but with the 2030 CAISO renewable portfolio outlined in Table 3.

Table 3: Renewable Capacities and Energies 2030⁴

Type of Resource	Capacity (GW)	Energy (TWh)
Wind	10.30	18.53
Utility Scale Solar	26.71	68.45
BTM Solar	22.15	38.21

Using the same methodology that was used to simulate the 2022 study year, Astrapé simulated many different levels of storage deployment for the 2030 study year. The results are outlined in Table 4.

⁴ The underlying portfolio of resources used to derive marginal ELCC curves for energy storage was based on preliminary outputs from RESOLVE in the process of developing the Reference System Portfolio.

Table 4: Energy Storage Capacity Value 2030

Battery Capacity (MW)	Average Capacity Value	Incremental Capacity Value	Marginal Capacity Value
5,265	100.6%	100.6%	100.0%
7,674	100.0%	98.6%	91.4%
10,530	95.7%	84.2%	79.8%
13,034	92.0%	76.3%	72.1%
15,795	87.9%	68.4%	65.5%
18,426	84.3%	62.8%	59.1%
21,060	80.7%	55.2%	50.8%
23,960	76.6%	47.0%	44.1%
26,325	73.5%	42.3%	42.3%

As Figure 6 and 7 show, the net load shape steepens in 2030 compared to the net load shape in 2022 which gives more 4-hour energy storage resources the opportunity to receive capacity value.

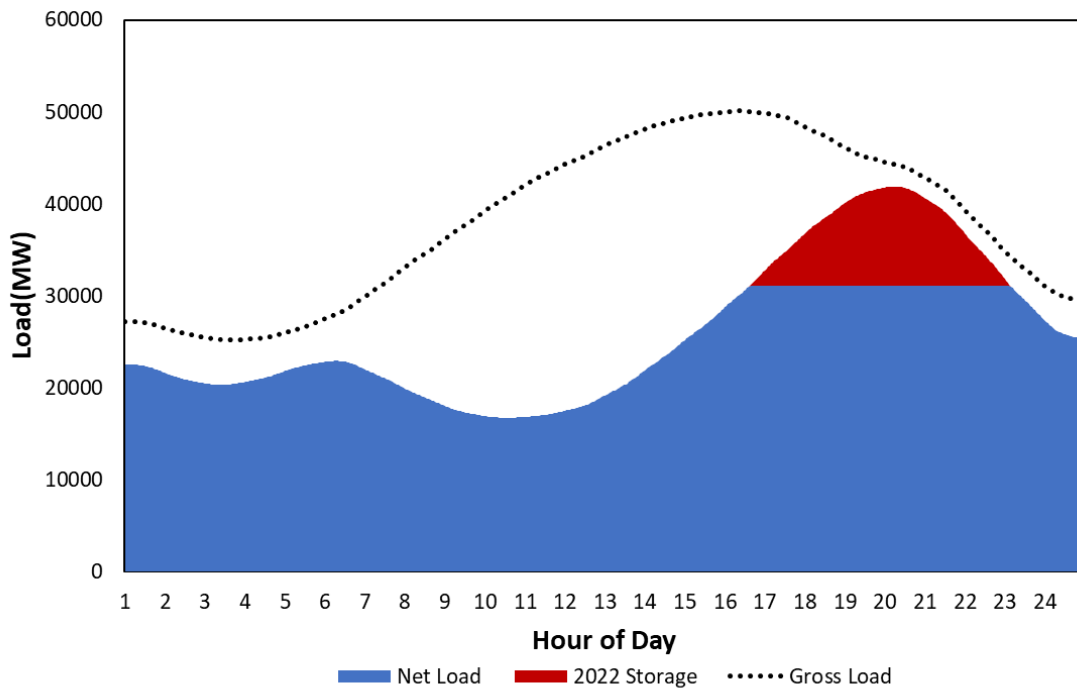


Figure 6: 2022 Net Load Shapes

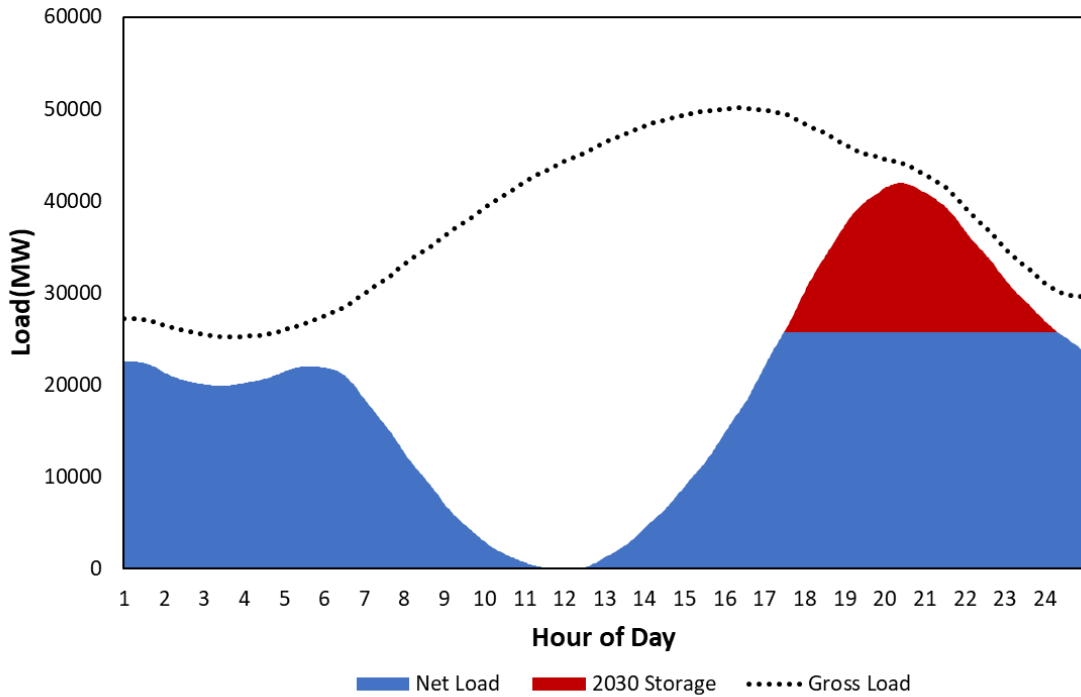


Figure 7: 2030 Net Load Shapes

Table 6 shows the effect of the increasing renewable portfolio on the marginal capacity value of each storage tranche.

Table 5: Marginal Capacity Values

Battery Capacity (MW)	2022 Marginal Capacity Value	2030 Marginal Capacity Value
5,265	100.0%	100.0%
7,674	88.8%	91.4%
10,530	76.2%	79.8%
13,034	66.4%	72.1%
15,795	54.2%	65.5%
18,426	44.8%	59.1%
21,060	33.9%	50.8%
23,960	24.1%	44.1%
26,325	21.7%	42.3%

COMPARISON TO PREVIOUS STUDIES

Differences in resource portfolios between storage ELCC studies can significantly impact ELCC values. Storage ELCC curves are derived by holding a resource portfolio constant and varying the capacity of storage. The Astrapé study ELCC curve shows a greater capacity value for storage for most penetration levels compared to what has been previously indicated by studies done in California and across the country, but also assumes higher levels of renewable (especially

solar) generation than other studies. Figure 8 illustrates the difference in results by showing the relationship between the percentage of system peak served by energy storage and then the marginal capacity value provided by the 4-hour energy storage resources. The first four series come from data from resource adequacy analysis, using E3's RECAP capacity planning model, of the following power systems and timeframes: Xcel Minnesota (2030), Pacific Northwest (2050), Small Northeast Utility (2018), and California (2018). Part of the difference in results for the California analyses is due to the difference in resource mixes assumed for the different study years.

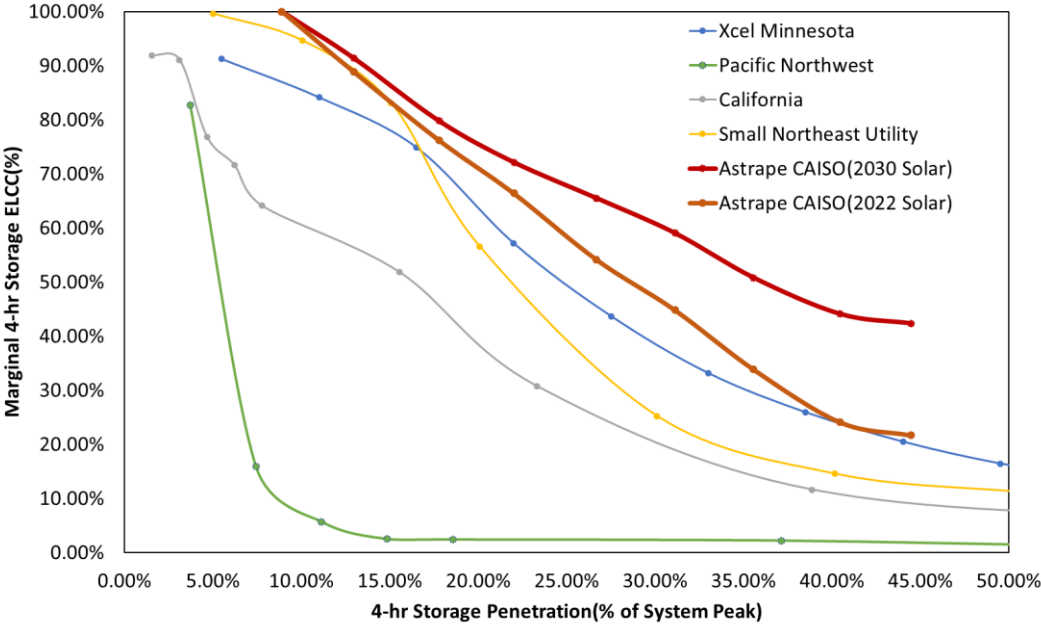


Figure 8: Energy Storage Capacity Value Results, Including Previous E3 studies⁵

Energy storage resources will behave differently on each system, which leads to varying capacity values. For example, the Pacific Northwest relies heavily on a portfolio of flexible hydroelectric resource that effectively provide the system with a substantial amount of storage capability. The existence of the storage capability implicit in the rivers and reservoirs of the Northwest results in lower capacity value for energy storage because it is effectively farther along the saturation curve than any of the other systems.

Still, the results of this analysis are notable for the large amount of capacity value implied for energy storage in contrast to previous work. The single largest driver of this result is the large underlying penetration of solar resources in the underlying portfolio against which storage was modeled. The storage ELCC curves presented in the previous work include significantly less solar generation than the portfolio used to generate the ELCC curves in the Astrapé study. More solar generation compresses the period of net peak to a shorter number of hours, which increases the capacity value of 4-hr storage at higher battery penetrations relative to a system with less solar generation. This interplay between solar capacity and battery ELCC has been referred to as a

⁵ <https://www.utilitydive.com/news/moving-beyond-rules-of-thumb-for-smart-cost-effective-storage-deployment/553674/>

“diversity benefit” in previous work.⁶ By adding battery capacity to a system that already has abundant solar generation, the Astrapé ELCC curve implicitly assigns the “diversity benefit” portion of the total solar and battery ELCC to the battery storage resources. While this convention may not mimic how the diversity benefit is allocated to individual resources in practice, it is suitable for use in the least-cost optimization of the portfolio in RESOLVE. RESOLVE’s solar and wind ELCC curves do *not* include any solar-storage diversity benefit, so the diversity benefit must be assigned to battery storage to arrive at the correct total ELCC for variable resources and battery storage.

A recent study published by the National Renewable Energy Laboratory (NREL) provides a second useful benchmark. NREL’s study, *The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States*, examined the potential for four-hour energy storage resources to reduce peak demand based on a “peak reduction credit” methodology—intended to represent a simplified proxy for more rigorously defined ELCCs. For each region in the United States, the study identifies the amount of four-hour storage capacity that would provide a “full” peak reduction credit (comparable to 100% ELCC). The results for California, shown in Figure 9, indicate that between 2,000 – 8,000 MW of energy storage could provide “full peak reduction credit” depending on the underlying mix of renewable resources.

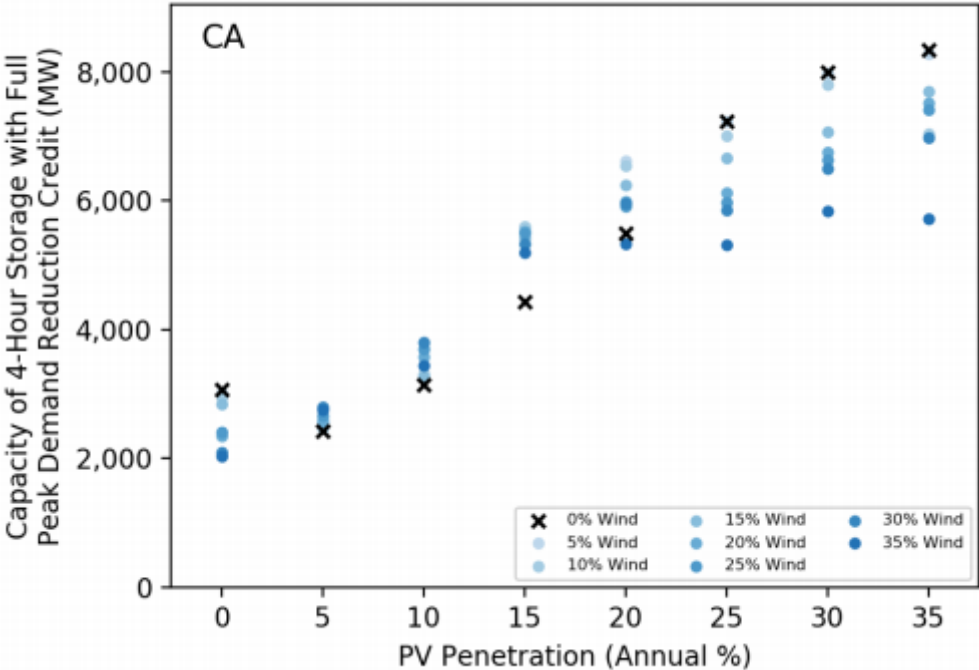


Figure 9: Capacity of Energy Storage with Full “Peak Demand Reduction Credit” as a Function of Wind and Solar Penetration⁷

⁶ https://www.ethree.com/wp-content/uploads/2019/06/E3_Long_Run_Resource_Adequacy_CA_Deep-Decarbonization_Final.pdf, p.38.

⁷ Figure from *The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States* (NREL, 2019), available at: <https://www.nrel.gov/docs/fy19osti/74184.pdf>

As in other cases, these results are not directly comparable to the curve derived in this analysis, but NREL’s study does support the general results of this analysis. Namely:

- 1) There is a strong positive relationship between the penetration of solar resources and the capacity value of energy storage. At low penetrations of solar, capacity contributions from storage are relatively low (2,000 – 4,000 MW) but at high penetrations, the capacity value grows substantially (6,000 – 8,000 MW). Note that the level of solar penetration analyzed in Astrape’s analysis exceeds the highest solar penetration examined in NREL’s study.
- 2) The scale of storage resources attributed “full” capacity credit in NREL’s study at high penetrations is generally consistent with the results of this study. While the geographic scope and underlying penetrations differ, the amount of capacity assigned full value is relatively similar between the two efforts.

CONCLUSION

The results of this analysis highlight several important findings:

- In the context of a highly-renewable portfolio in 2030, the potential for energy storage resources to meet resource adequacy needs is significant: up to approximately 10 GW of energy storage resources could effectively serve as substitutes for perfectly reliable capacity.
- Beyond that level of penetration, the capacity value of additional storage resources will decline, as constraints on the duration of discharge and state of charge begin to limit the effectiveness of energy storage as a substitute for perfect capacity.
- As discussed elsewhere in this study, the specific results obtained in this analysis cannot be easily transferred or generalized to other electricity systems and therefore should not be used directly to estimate the potential contribution of battery storage outside of the context of the 2030 Reference System Plan.
- Nonetheless, the analysis does highlight general trends that will be crucial to consider in resource adequacy planning in the future: namely, the interactive effects between renewables and storage, and the declining marginal capacity value of energy storage.

ⁱ The energy storage capacity values shown in Table 3 are a result of an updated analysis by Astrapé and are not identical to those used in the RESOLVE model for the proposed Reference System Plan analysis. The table below represents the values used in RESOLVE for the proposed Reference System Plan analysis, which was released in November 2019.

Battery Capacity (MW)	Normalized Capacity Value	Incremental Capacity Value
5,265	100.0%	100.0%
10,530	100.0%	100.0%
15,795	88.3%	64.5%
21,060	75.6%	37.6%
26,325	63.3%	14.1%
31,590	53.8%	6.3%