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Using Long-Duration Storage to Reduce Portfolio Carbon Emissions Risks

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Executive Summary

Future system conditions present risks and opportunities to CAISO market participants

To support California's decarbonization goals, the California Public Utilities Commission (CPUC) requires Load-Serving Entities (LSE) to satisfy CO2 emission reduction targets for 2030 and 2035.

LSE’s demonstrate compliance by submitting their procurement plans using the CPUC’s Clean System Power (CSP) workbook. To facilitate this, the commission pre-defines most inputs in the CSP workbook based on the CPUC’s forecast of system conditions.

This study demonstrates how an alternative forecast of future system conditions presents both risks and opportunities to CAISO market participants.

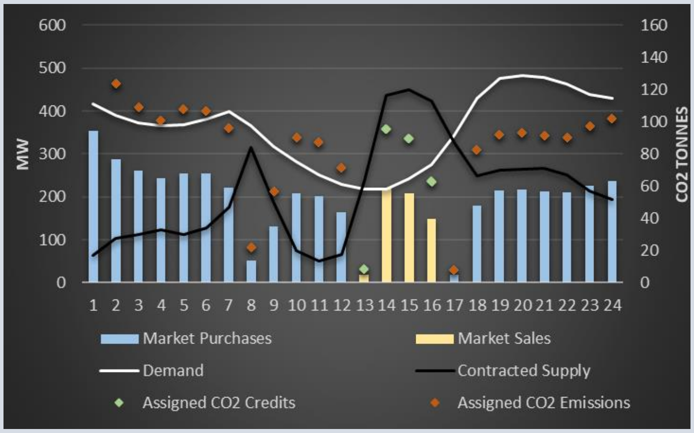

Figure ES-1: 24-Hour Sample Period of Net Market Transactions and CO2 Emissions for a Representative Portfolio

Key Findings

- The *Alternative Case* model built for this study indicates areas where the future system conditions may differ from those in the Commission's *Base Case.*
- In the Alternative Case, a previously compliant LSE’s CO2 emissions are projected to be 20% higher in 2035 compared to the Base Case, exceeding the portfolio's assigned benchmark.
- Adding 115 MWs of 8-hour storage to a sample representative LSE portfolio can reduce emissions sufficiently to bring it back into compliance with the portfolio's assigned benchmark.

Alternative Case

In order to assess the risks of differing future system conditions, the authors define an *Alternative Case* based on their own forecasting models.

The Alternative Case expects that a

a) surge in solar and wind development will result in more curtailments
b) grid operators will require higher minimum thermal generation to ensure resource adequacy.

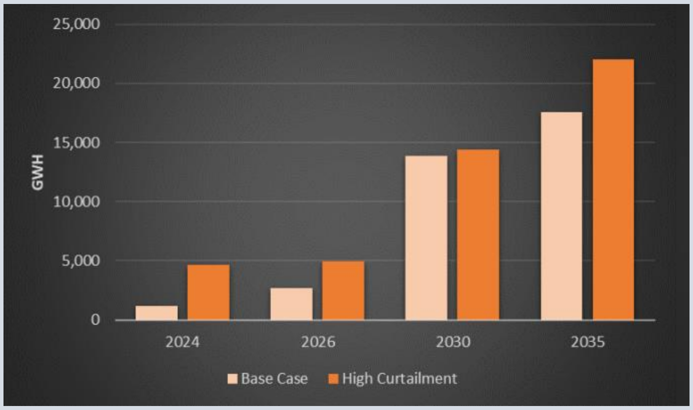

Figure ES-2: Annual Forecasts of System Curtailments. CPUC Base Case vs Authors’ High Curtailment Model

Quantifying Risk to LSEs

Using a representative sample portfolio, this study investigates the changes to projected carbon emissions in the Alternative Case.

LSEs face the risk of elevated curtailment levels in two ways:

1) As system curtailment levels rise, the contracted renewable supply produces less emission-free energy than originally anticipated.
2) With more curtailment hours, LSEs are allocated additional carbon emissions from dispatchable fossil fuel generation, known as "System Power."

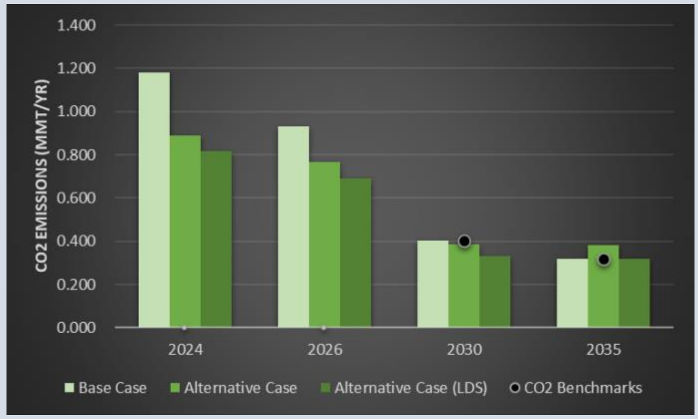

Figure ES-3: CO2 Emissions Footprint of Sample Portfolio

In the Alternative Case, a previously compliant portfolio experiences a 20% increase in its 2035 emissions compared to the Base Case and exceeds its assigned benchmark.

Impact of Long-Duration Storage (LDS) on Emissions Goals

A well-structured portfolio can utilize the excess supply of emission-free energy provided by *other* market participants to reduce *its* CO2 footprint through longer duration storage.

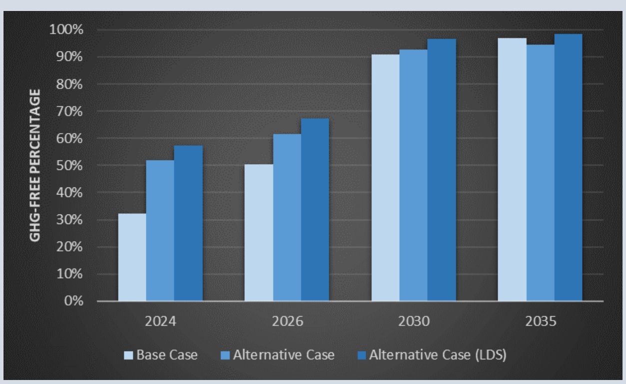

Figure ES-4: Percentage of Sample Portfolio's Retail Demand Served by GHG-Free

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By adding 115 MWs of 8-hour storage to the sample LSE portfolio, CO2 emissions are sufficiently reduced to satisfy the portfolio's assigned benchmark.

LDS allows the portfolio to serve an additional 5% of its retail demand with CO2-free energy in any given year.

Foundational Analytic Framework

To effectively manage the intricacies of LSE portfolios and the changing grid, a comprehensive decision-making framework is needed. This framework should encompass portfolio optimization software, access to various forecasting models (including machine learning and fundamental techniques), and the ability to analyze scenarios and apply probabilistic reasoning.

Introduction

This study analyzes the California Public Utilities Commission's Clean System Power (CSP) workbook to show how changes in future grid conditions can create both risks and opportunities for CAISO market participants. The risk is that if system conditions are different from what is predicted by the CPUC, Load-Serving Entities (LSEs) will displace fewer CO2 emissions on the system by procuring emission-free generation. This can result in a portfolio exceeding its CO2 targets assigned by the CPUC and requiring the LSE to update its procurement plans. On the other hand, a well-structured portfolio can take advantage of the surplus of emission-free energy provided by other market players to reduce its carbon footprint.

Quantifying the risks and opportunities within the CSP workbook is warranted because the Commission's current system modeling is overly optimistic. A scenario analysis that updates the CSP workbook with realistic projections for system curtailments and System Power is necessary to calculate the impact of these changes on the LSE's CO2 emissions. The revised forecasts should reflect recent CAISO system operation data and future trends. Depending on the nature of their supply contracts, LSEs may experience either a reduction or an increase in CO2 emissions. Given their greater dependence on system conditions, portfolios that rely heavily on solar, wind, and 4-hour storage will exhibit greater emission elasticity.

As solar and wind energy become more prevalent in CAISO, organizations may look to stand-alone storage to achieve their carbon reduction goals. Furthermore, for organizations pursuing aggressive decarbonization policies (e.g., 24/7 carbon-free strategy), storage facilities with 8-10 hours of duration are a viable candidate resource. These facilities can absorb more excess power produced by variable energy resources during the day and then discharge that energy later in the evening during times that are challenging to source with emission-free energy.

Although this study primarily focuses on IRP compliance risk for CPUC-jurisdictional entities, the issues and solutions are relevant to any utility or organization that has committed to a carbon reduction plan. And as these decarbonization strategies shift from an annual design to an hourly one, understanding more of the details behind emissions accounting becomes more important.[1] A cost-effective procurement plan that can achieve aggressive emission reduction targets based on a credible accounting methodology requires a robust analytical framework consisting of portfolio optimization software, multi-modal forecast models, and scenario analysis-based decision-making. The authors will describe this framework in more detail in a forthcoming article and its application to other use cases.

[1] If approved, California's SB 1158 will require LSEs to report their hourly emissions to the CEC. https://ww2.arb.ca.gov/2022-senate-bill-1158-becker-josh-retail-electricity-suppliers-emissions-greenhouse-gases-chaptered

Clean System Power Workbook

Overview

As part of the requirements for the CPUC's 2022 IRP process, LSEs were obligated to submit a copy of the Clean System Power workbook to the Commission, demonstrating how their portfolios conform to their assigned CO2 targets. These targets are utilized by the CPUC to confirm that LSEs are obtaining resources in a way that supports CAISO in meeting the greenhouse gas planning goals for the electricity sector defined by the California Air Resources Board (CARB). To account for the uncertainty in the statewide CO2 reduction targets, the CPUC created two versions of the workbook: a 25 MMT (million metric tons) and a 30 MMT scenario.[2]

To simplify the calculation of emissions for LSEs, the Commission pre-defined most inputs in the workbook. LSEs only needed to provide annual inputs related to their demand obligations and supply contracts, along with any customized hourly load or generation profiles. The CSP performs an hourly (i.e., 8760) analysis of emissions for the portfolio for four calendar years: 2024, 2026, 2030, and 2035. To have a "conforming portfolio", an LSE must demonstrate that their emissions do not exceed their CPUC-assigned CO2 benchmarks for 2030 and 2035. These CO2 targets are calculated based on the statewide emissions scenario (e.g., 25 or 30 MMT), the LSE's share of annual system demand, and the LSE's geographic region.[3]

The main purpose of the CSP workbook is to serve as a compliance tool for resource planning activities. It is not intended to enforce any operational decisions for grid operators or market participants. The actual emissions from an LSE's portfolio will be dependent on system conditions as well as the bidding and scheduling strategy of the organization, which is not part of this study's scope.

Accounting Methodology

The CSP workbook calculates a portfolio's CO2 emissions (as well as other emission types and particulate matters) based on a methodology defined by the CPUC. The workbook assigns emissions to a portfolio from one of two sources: the first being any CO2 produced by the LSE's contracted energy supply, and the second being the LSE's reliance on System Power. System Power is defined in the CSP as dispatchable natural gas generation and unspecified imports. Based on the portfolio's demand and contracted supply, the CSP calculates the LSE's hourly net dependency on System Power and assigns a corresponding emission penalty to the portfolio.

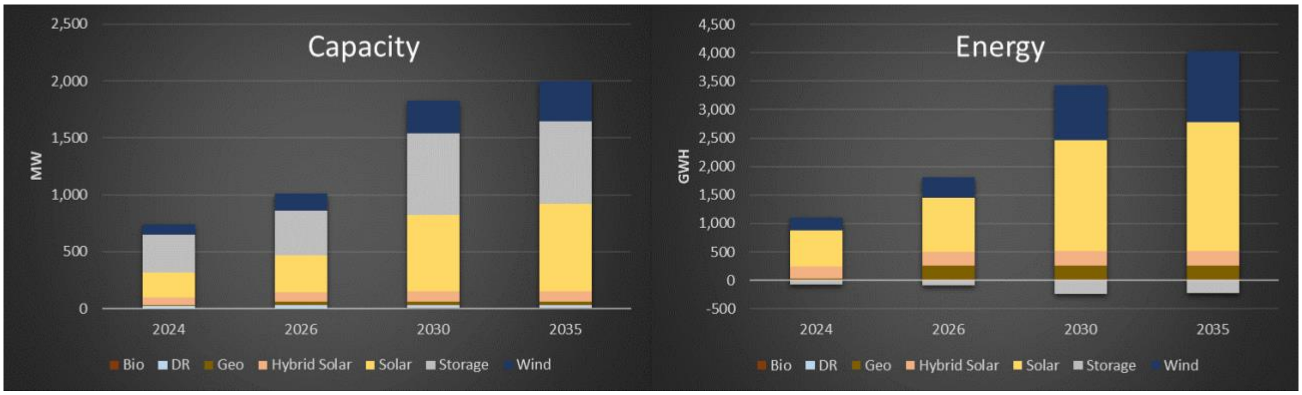
To assist in the explanation of the CO2 accounting methodology defined in the CSP, the authors modeled a sample portfolio in the 25 MMT version of the workbook and provide a series of examples to

[2] A copy of each version of the CSP workbook can be accessed on the CPUC's website: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/2022-irp-cycle-events-and-materials.

[3] Within each PTO region (e.g., PGE, SCE, and SDGE), a fixed GHG intensity ratio (MMT CO2 / MWh) is assumed.

show how emissions are a function of System Power being on the margin.[4] The sample portfolio has an annual demand of 1.75% of the overall CAISO load, and its contracted supply is based on a pro-rata share of the candidate projects selected in the CPUC's June 2022 Preferred System Plan (PSP).[5] The graphs in Figure 1 summarize the sample portfolio modeled for this exercise. Similar to many existing CAISO LSEs that procure resources in-line with the PSP, the portfolio is concentrated in solar, wind, and 4-hour storage.[6]

Figure 1: Installed Capacity (MW) and Annual Production (GWh) of Sample Portfolio



Assignment of CO2 Emissions with System Power

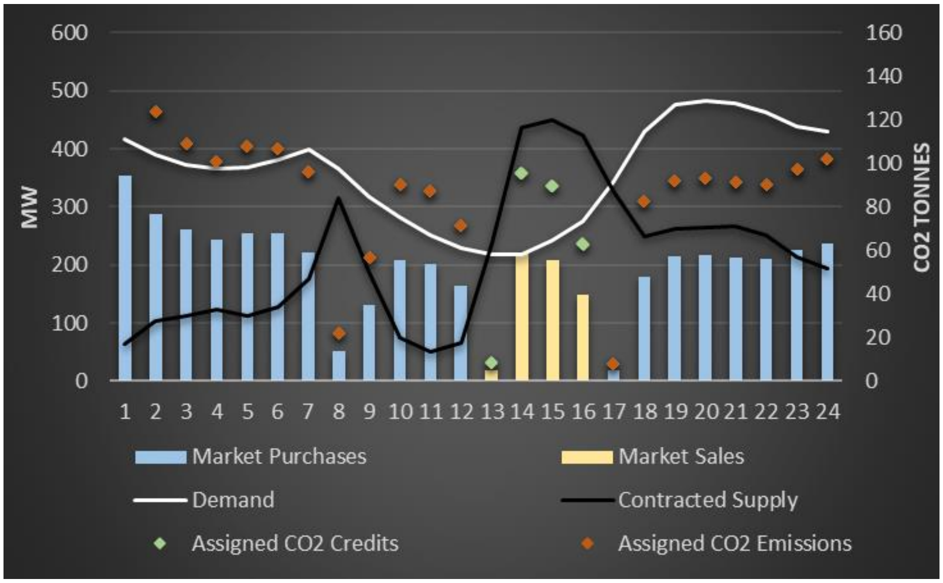
To understand the CSP accounting methodology, it is helpful to examine a 24-hour sample period. Figure 2 displays the hourly demand and portfolio supply for a sample day from March 2026 along with the corresponding market transactions for each hour. In hours 1-12 and 17-24, the portfolio's supply of clean energy is less than its demand, so the LSE is "short" and must purchase energy from the market to meet its demand. The emissions associated with these market purchases are calculated using the following equation:

$$CO2\ Emissions\ from\ Market\ Purchases = Net\ Purchases\ (MWh) * System\ Power\ Hourly\ Emission\ Intensity\ \left(\frac{tCO2}{MWh}\right).$$ [7]

In contrast, during hours 13-16, the portfolio is deemed to be "long" because its supply of clean energy exceeds its demand. During these hours, the excess supply is treated as market sales, and it is assumed that these sales displace System Power that would otherwise serve electric demand from other market participants. As a result, the workbook assigns emission credits to the portfolio that the LSE can use to offset some of its own emissions. The hourly CO2 emissions or emission credits that are assigned to the portfolio are displayed on the secondary y-axis in the figure.

[4] A copy of the CSP workbook used for this study can be accessed here.
[5] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/2019-20-irp-events-and-materials
[6] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/2022-irp-cycle-events-and-materials/lse-2022-integrated-resource-plans
[7] The emission intensity of System Power averages 0.444 tCO2/MWh across all planning years.

Figure 2: 24-Hour Sample Period of Net Market Transactions and CO2 Emissions

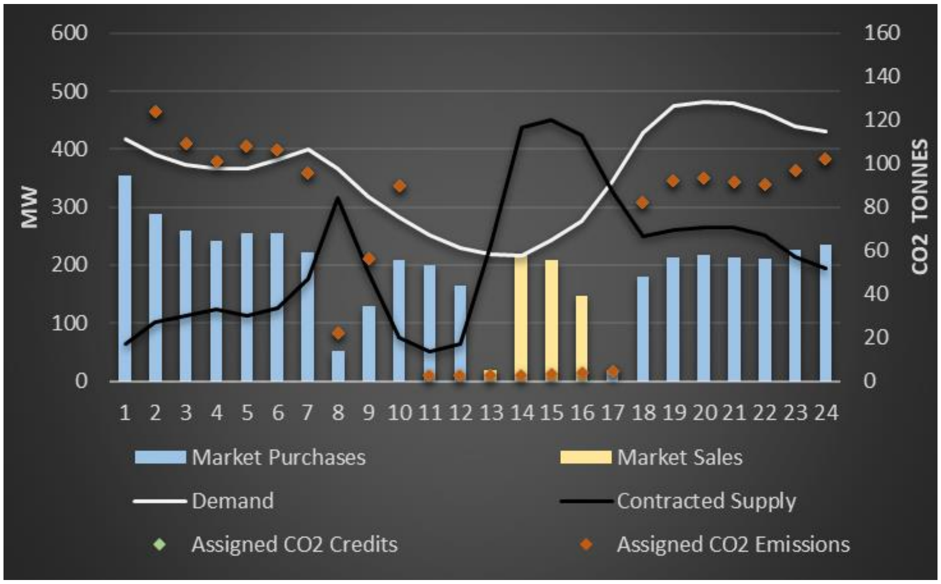


Assignment of CO2 Emissions with System Power not on the Margin

In the previous example, it's assumed that displaceable System Power was on the margin for all hours of the day. This assumption is valid in the workbook as long as system curtailments are below the CPUC-defined threshold.[8] However, if the system curtailments exceed this limit, the CSP treats all System Power for that hour as non-displaceable and adjusts its emissions accounting. During these periods, each LSE is assigned a portion of the non-displaceable System Power based on its *annual* share of system demand rather than its *hourly* market exposure for that specific hour. These emissions are divided equally among all LSEs, regardless of ownership, since these resources provide a benefit to all market participants in the form of resource adequacy. Therefore, portfolios that have a surplus of emission-free energy during these hours will not receive any emission reduction credits because the CSP assumes that no additional System Power can be displaced. Figure 3 displays the same operating day from the example above but it's now assumes System Power is not on the margin for hours ending 11-17. Unlike the previous example, the LSE receives no emission credits for providing excess power to the system during hours 13-16 and is assigned a small amount of CO2 emissions according to its pro rata share of System Power.

[8] The curtailment threshold assumed in the 2022 CSP workbook is 100 MW.

Figure 3: 24-Hour Sample Period of Net Market Transactions and CO2 Emissions (System Power Not on Margin HE 11-17)



Zero Emissions Power from System

Despite being allocated emissions from its proportional share of non-displaceable System Power, an LSE can still lower its emissions under these conditions with a coincident large short position. If the portfolio's short position exceeds its share of non-displaceable System Power, the amount of CO2 emissions assigned to the portfolio will be less than if displaceable System Power was on the margin. The CSP labels this benefit "Zero Emissions Power from System" and defines it as follows:

$$\begin{aligned} &Zero\ Emissions\ Power\ from\ System \\ &\quad = \max\left(Net\ Purchases\ (pre\ curtailment\ and\ exports)\right. \\ &\quad \left. - Share\ of\ NonDisplaceable\ System\ Power, 0\right). \end{aligned}$$

Sample Portfolio Summary Statistics

The CSP workbook calculates annual summary statistics for the portfolio for each modeled year based on the results of the hourly accounting. Table 1 shows the results of the sample portfolio using the default CPUC-defined input values. These portfolio statistics will be used as a comparison point for alternative scenarios that assume different values for system conditions.

Table 1: Sample Portfolio Summary Statistics for Base Case Scenario

Clean System Power Workbook Summary	***Unit***	**2024**	**2026**	**2030**	**2035**
Retail Sales	GWh	3,579	3,637	3,742	3,876
Net Market Purchases (pre curtailments)	% of retail sales	74%	55%	18%	7%
Share of Non-Displaceable System Power	*GWh*	2	2	7	10
Zero Emissions Power From System	*GWh*	54	27	152	52
Net Market Purchases (incurs emissions)	*GWh*	2,591	2,004	739	629
RPS-Eligible Delivered Renewable	GWh	1,098	1,809	3,253	3,699
GHG free	GWh	1,152	1,836	3,405	3,752
RPS-Eligible Delivered Renewable Percentage	*% of retail sales*	31%	50%	87%	95%
GHG-free Percentage	*% of retail sales*	32%	50%	91%	97%

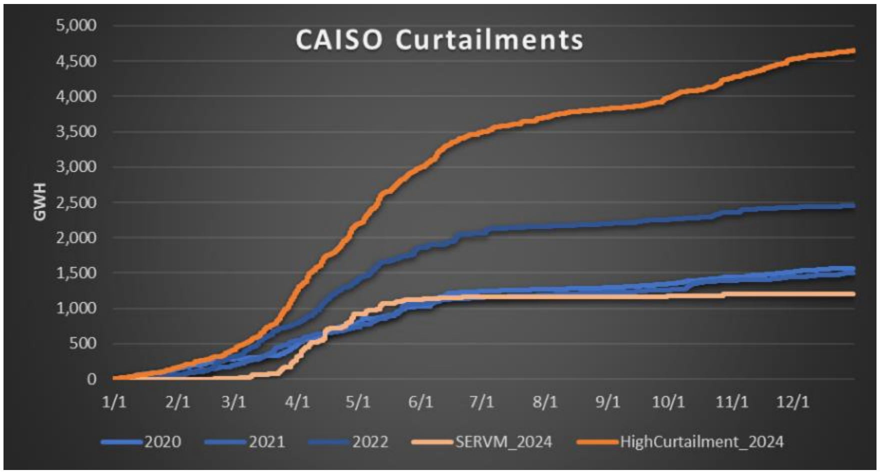
Scenario Analysis of Alternative Assumptions for System Conditions

As mentioned previously, the CPUC defines the inputs in the CSP workbook that characterize overall grid conditions to facilitate the emission calculations for each of the individual LSE portfolios. The two primary inputs that describe system conditions are the System Power and system curtailment hourly profiles, which are established through SERVM modeling exercises conducted by the CPUC as part of the IRP. By centralizing these key assumptions, the Commission makes it easier for LSEs to perform their portfolio calculations. However, this simplification may lead to some LSEs not fully considering the risks and opportunities associated with their projected CO2 footprint. In the following sections, the authors will discuss how their forecasts differ from those of the CPUC and their impact on the CSP's emissions calculations.

System Curtailments

As previously mentioned, system curtailments play a pivotal role in the CSP because they determine whether System Power is on the margin. Thus, it's important to understand not only the representativeness of the default profile but also how responsive a portfolio's emissions are to system curtailments. Curtailments are most common in the workbook during peak solar hours in the middle of the day. In comparing the CPUC's recent SERVM modeling results with CAISO historical market operations data, there is a risk that the Commission is underestimating curtailments of future variable energy resources (VER).[9] Figure 4 compares the cumulative CAISO curtailments from 2020 to 2022 along with the 2024 forecast defined in the workbook. As shown, the forecast is less than actuals for each of the past three years. The CPUC's SERVM modeling forecasts 1,200 GWh of annual curtailments in 2024, while CAISO experienced 2,450 GWh of curtailments in 2022 alone. With planned additions of wind and solar outpacing the increase in storage, actual curtailments will likely continue to rise.[10]

Figure 4: Historical and Forecasted Cumulative CAISO Variable Energy Resources (VER) Curtailments

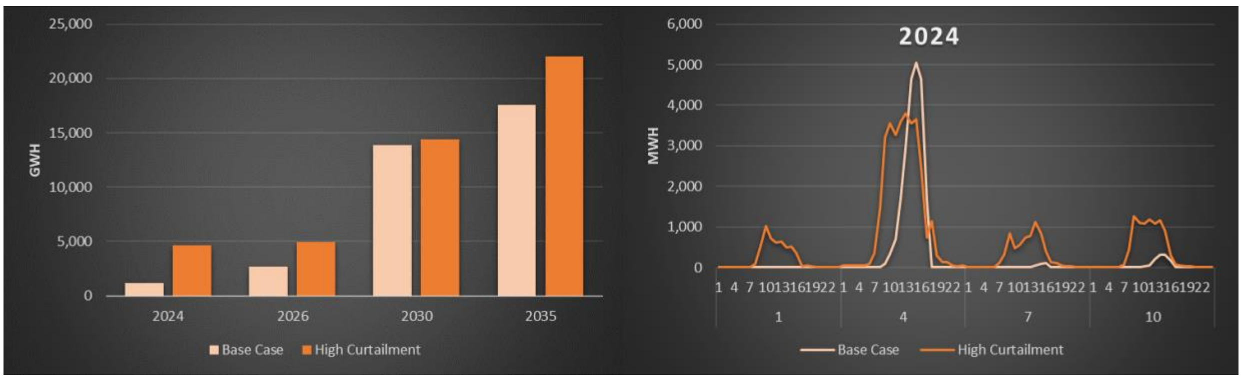


[9] CAISO defines solar and wind facilities as variable energy resources.

[10] Based on recent data provided by the CPUC and CAISO, the authors forecast the addition of approximately 7,250 MW of solar and wind capacity and 4,600 MW of storage over the next two years.

If actual system curtailments continue to exceed the CPUC's forecast, the Commission will need to revise their modeling methodology to reflect more realistic forward projections. To see the impact of higher curtailments on the sample portfolio's emission footprint, the authors modeled a "High Curtailment" scenario by updating the workbook with their own forecast for system curtailments.[11] Figure 5 shows the difference in the curtailment profiles between the CSP default values (the "Base Case") and the High Curtailment scenario. The graph on the left displays the annual curtailment volume for all the years modeled in the CSP, and the graph on the right shows the month-hour averages in 2024 for January, April, July, and October. The cumulative curtailments from the High Curtailment scenario can also be found in Figure 4 for reference. The outcome of this exercise is discussed in the results section below.

Figure 5: Annual and Month-Hour Forecasts of System Curtailments



With greater levels of system curtailments, there will be a greater number of hours when non-displaceable System Power is on the margin. Figure 6 compares the allocation of non-displaceable System Power to LSEs in the Base Case and High Curtailment scenarios. The graph on the left shows the percentage of hours in the Base Case when non-displaceable System Power is on the margin by time of day and month for each year. In 2024, non-displaceable System Power is present in 4% of the hours but increases to 20% in 2035. The graph on the right shows the same data for the High Curtailment scenario. In 2024, 45% of the hours have non-displaceable System Power on the margin, increasing to 63% in 2035.[12] Although both cases indicate a decreasing opportunity for LSEs to displace System Power by procuring emission-free energy, the Base Case scenario presents a misleading view of the robustness of this accounting feature in the workbook due to its systemic under-forecasting of system curtailments that will likely persist as the penetration of VER resources increases.

[11] First Principles Advisory has partnered with GridStatus.io to produce a suite of machine-learning and fundamental forecasting models. The authors will discuss these models in greater depth in a future paper.
[12] The high percentage of hours in the High Curtailment scenario is partly driven by the current system curtailment threshold defined in the CSP (100 MW). The authors acknowledge additional analysis is warranted to assess the sensitivity of the portfolio's emission elasticity to different threshold values.

Figure 6: Percentage of Hours When Non-Displaceable System Power is on the Margin

Base Case

2024

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1				0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	0%	0%	0%	0%	0%	0%	0%	0%
2				0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	7%	14%	4%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	6%	16%	32%	39%	48%	55%	29%	0%	0%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	0%	3%	3%	17%	30%	40%	67%	77%	83%	87%	73%	0%	0%	0%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	0%	0%	3%	6%	6%	29%	39%	55%	65%	71%	65%	0%	0%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	7%	17%	20%	27%	17%	0%	0%	0%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	6%	6%	6%	3%	0%	0%	0%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	3%	3%	0%	0%	0%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	3%	3%	3%	10%	6%	0%	0%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%				
12	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%				

2026

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1				0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	10%	0%	0%	0%	0%	0%	0%	0%	0%
2				0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	14%	14%	4%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	19%	29%	35%	48%	65%	81%	45%	0%	0%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	0%	0%	3%	27%	33%	50%	70%	83%	83%	87%	77%	0%	0%	0%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	16%	26%	39%	48%	68%	81%	65%	0%	0%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	17%	23%	33%	43%	33%	0%	0%	0%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	6%	13%	16%	16%	10%	0%	0%	0%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	3%	6%	0%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	3%	3%	3%	7%	7%	0%	0%	0%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	3%	6%	10%	13%	29%	23%	0%	0%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%

2030

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1				0%	0%	0%	0%	0%	3%	19%	26%	32%	35%	39%	61%	68%	0%	0%	0%	0%	0%	0%	0%	0%
2				0%	0%	0%	0%	0%	0%	32%	46%	50%	50%	50%	61%	57%	14%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	6%	26%	68%	81%	84%	90%	90%	94%	97%	84%	0%	0%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	0%	27%	73%	90%	97%	97%	97%	97%	97%	97%	87%	0%	0%	0%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	3%	13%	52%	71%	84%	87%	84%	90%	90%	90%	84%	10%	0%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	0%	0%	3%	17%	37%	60%	77%	83%	87%	87%	93%	83%	0%	0%	0%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	0%	6%	10%	16%	29%	35%	45%	52%	61%	58%	39%	0%	0%	0%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	19%	29%	32%	42%	65%	65%	16%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	3%	7%	23%	23%	30%	37%	43%	47%	47%	0%	0%	0%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	0%	3%	10%	32%	42%	52%	55%	58%	84%	65%	0%	0%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	20%	17%	27%	33%	70%	30%	0%	0%	0%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	13%	13%	10%	35%	23%	0%	0%	0%	0%	0%	0%	0%	0%

2035

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1				0%	0%	0%	0%	0%	0%	23%	26%	26%	32%	48%	68%	68%	0%	0%	0%	0%	0%	0%	0%	0%
2				0%	0%	0%	0%	0%	4%	32%	36%	43%	46%	43%	61%	61%	18%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	23%	45%	77%	81%	87%	94%	94%	97%	97%	94%	0%	0%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	3%	47%	80%	97%	97%	97%	97%	97%	97%	100%	93%	13%	0%	0%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	6%	29%	71%	74%	81%	84%	84%	94%	94%	97%	87%	23%	0%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	0%	0%	7%	23%	37%	60%	77%	83%	90%	93%	97%	83%	0%	0%	0%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	0%	6%	13%	26%	26%	45%	61%	84%	84%	87%	52%	0%	0%	0%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	32%	35%	58%	81%	77%	68%	32%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	3%	13%	23%	27%	37%	53%	70%	67%	60%	3%	0%	0%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	0%	6%	19%	39%	42%	48%	61%	71%	90%	81%	6%	0%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	13%	20%	30%	50%	80%	50%	0%	0%	0%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	10%	6%	10%	16%	35%	29%	0%	0%	0%	0%	0%	0%	0%	0%

High Curtailment Case

2024

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0%	0%	0%	0%	0%	0%	0%	32%	100%	100%	100%	100%	100%	100%	100%	100%	3%	13%	3%	3%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%	0%	0%	68%	100%	100%	100%	100%	100%	100%	100%	100%	68%	43%	18%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	6%	35%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	94%	26%	23%	0%	0%	0%
4	7%	10%	10%	10%	10%	37%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	70%	63%	13%	0%	7%
5	3%	10%	16%	6%	10%	29%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	94%	94%	90%	81%	39%	10%	3%	3%
6	0%	0%	0%	0%	13%	17%	87%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	80%	70%	57%	10%	3%	0%	0%
7	0%	0%	0%	0%	0%	0%	48%	100%	90%	90%	94%	90%	97%	100%	100%	100%	55%	39%	16%	13%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	13%	100%	74%	94%	94%	94%	97%	94%	94%	100%	48%	6%	3%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	13%	100%	90%	100%	100%	100%	100%	93%	97%	97%	17%	17%	3%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	13%	100%	100%	100%	100%	100%	100%	100%	100%	100%	19%	23%	13%	3%	0%	0%	0%	0%
11	0%	0%	0%	0%	3%	3%	3%	100%	100%	100%	100%	100%	100%	100%	100%	97%	23%							
12	0%	0%	0%	0%	0%	0%	0%	26%	97%	100%	100%	100%	97%	97%	97%	84%	0%							

2026

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0%	0%	0%	0%	0%	0%	0%	58%	100%	100%	100%	100%	100%	100%	100%	100%	6%	6%	3%	0%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%	0%	0%	82%	100%	100%	100%	100%	100%	100%	100%	100%	82%	39%	39%	0%	0%	0%	0%	0%
3	0%	0%	3%	0%	0%	10%	26%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	32%	32%	0%	0%	0%
4	0%	0%	3%	3%	13%	20%	97%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	93%	73%	37%	3%	0%	0%
5	0%	0%	0%	0%	3%	6%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	90%	45%	19%	3%	3%
6	0%	0%	0%	0%	3%	7%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	83%	80%	70%	53%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	55%	97%	97%	94%	100%	90%	90%	97%	100%	100%	65%	42%	19%	13%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	42%	100%	87%	97%	90%	97%	97%	94%	97%	100%	42%	10%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	30%	97%	90%	100%	100%	90%	87%	87%	93%	100%	27%	10%	0%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	13%	100%	100%	100%	100%	100%	100%	100%	97%	97%	16%	32%	13%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	3%	93%	100%	100%	100%	100%	100%	100%	93%	87%	17%	20%	10%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	0%	0%	0%	32%	100%	100%	100%	100%	100%	100%	100%	84%	3%	6%	0%	0%	0%	0%	0%	0%

2030

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0%	0%	0%	0%	0%	0%	6%	81%	100%	100%	100%	100%	100%	100%	100%	100%	35%	94%	68%	42%	26%	6%	0%	0%
2	0%	4%	0%	0%	0%	0%	32%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	82%	68%	14%	4%	7%
3	6%	16%	19%	13%	6%	61%	97%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	94%	55%	26%	23%
4	10%	13%	20%	17%	13%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	77%	50%	27%
5	16%	23%	29%	23%	58%	84%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	84%	55%	26%
6	0%	0%	7%	3%	57%	53%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	97%	97%	80%	37%	23%	7%
7	0%	0%	0%	0%	0%	3%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%	94%	94%	81%	74%	23%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	77%	100%	100%	100%	100%	100%	100%	100%	100%	100%	87%	81%	71%	55%	13%	0%	0%	0%
9	0%	0%	0%	0%	0%	3%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%	47%	67%	47%	13%	7%	0%	0%	0%
10	0%	0%	0%	0%	0%	16%	52%	100%	100%	100%	100%	100%	100%	100%	100%	100%	65%	87%	77%	42%	3%	0%	0%	0%
11	0%	0%	0%	0%	3%	3%	27%	100%	100%	100%	100%	100%	100%	100%	100%	100%	77%	93%	50%	47%	27%	7%	0%	0%
12	0%	0%	0%	0%	0%	0%	3%	71%	100%	100%	100%	100%	100%	100%	100%	100%	42%	87%	35%	23%	13%	0%	0%	0%

2035

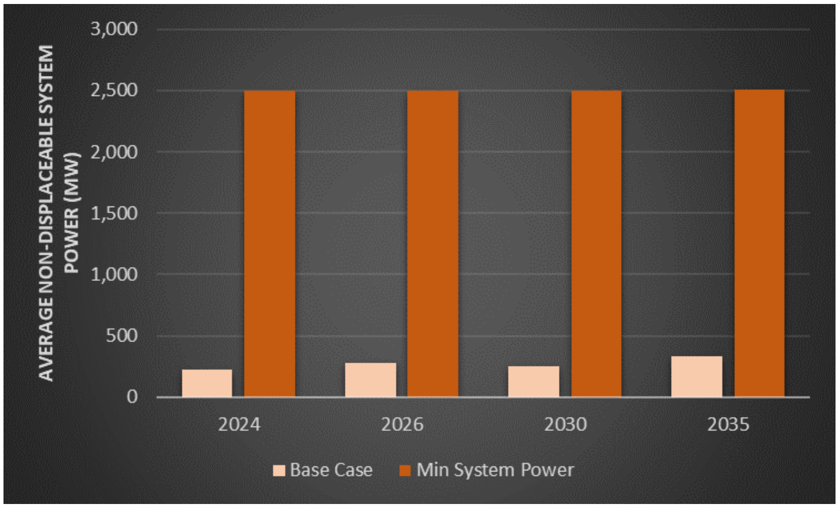
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0%	0%	0%	0%	0%	0%	13%	71%	100%	100%	100%	100%	100%	100%	100%	100%	39%	100%	94%	45%	39%	3%	3%	3%
2	0%	0%	0%	0%	0%	0%	46%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	89%	61%	29%	11%	7%
3	0%	3%	0%	6%	0%	52%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	97%	100%	74%	58%	42%
4	20%	37%	37%	33%	40%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	97%	57%	50%
5	10%	29%	35%	26%	65%	87%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	94%	74%	26%
6	0%	10%	17%	20%	60%	80%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	100%	100%	93%	73%	43%	23%
7	0%	0%	0%	0%	13%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	100%	97%	90%	26%	0%	10%
8	0%	0%	0%	0%	0%	6%	77%	100%	100%	100%	100%	100%	100%	100%	100%	100%	97%	84%	81%	84%	39%	6%	0%	0%
9	0%	0%	0%	0%	0%	3%	57%	100%	100%	100%	100%	100%	100%	100%	100%	100%	77%	90%	73%	43%	33%	0%	0%	3%
10	0%	0%	0%	0%	3%	45%	58%	100%	100%	100%	100%	100%	100%	100%	100%	100%	71%	94%	94%	55%	42%	0%	0%	0%
11	0%	0%	0%	3%	0%	0%	40%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90%	100%	57%	60%	43%	13%	0%	3%
12	0%	0%	0%	0%	0%	0%	39%	84%	100%	100%	100%	100%	100%	100%	100%	100%	77%	94%	39%	16%	16%	3%	0%	0%

Non-Displaceable System Power

In addition to the risk of higher system curtailments, an LSE may be assigned additional emissions if the workbook's assumptions for System Power are also too optimistic. For example, if CAISO's actual net import capabilities are less than what's predicted by the Commission's modeling, grid operators will require more thermal generation to be online for system reliability. As a result, more System Power will need to be allocated across all the LSEs during high curtailment periods, and the emissions associated with these facilities will make it more difficult for an LSE to achieve its stated emission reduction targets.

Similar to the process taken for system curtailments, the authors proposed a new schedule for System Power in the CSP to see its effect on the sample portfolio's CO2 emissions. In the "Min System Power" scenario, the authors inserted a floor on the original SERVM System Power profile to ensure that a minimum of 2,500 MW of thermal generation is online in any hour.[13] This can be seen in Figure 7, which compares the average hourly amount of non-displaceable System Power allocated to the sample portfolio for both scenarios. With an average of 272 MW of System Power allocated during high curtailment periods, the Base Case is more optimistic than the Min System Power scenario in predicting the ability of grid operators to displace System Power. The authors discuss the outcome of this exercise below.

Figure 7: Average Hourly Volume of Allocated System Power Assigned to LSE Portfolios



Portfolio Emissions Elasticity to System Conditions

The authors evaluated the impact of changing system conditions on the sample portfolio's CO2 emissions by modeling alternative scenarios in the CSP workbook. To measure the portfolio's emission sensitivity, the authors tracked two metrics:

1) The emissions from the LSE's share of non-displaceable System Power

[13] This is a conservative measure assumed by the authors based on a recent analysis of historical CAISO operational data from 2020-2022. First Principles Advisory and GridStatus.io are conducting ongoing studies and performing additional model enhancements to improve their internal forecast of non-displaceable System Power.

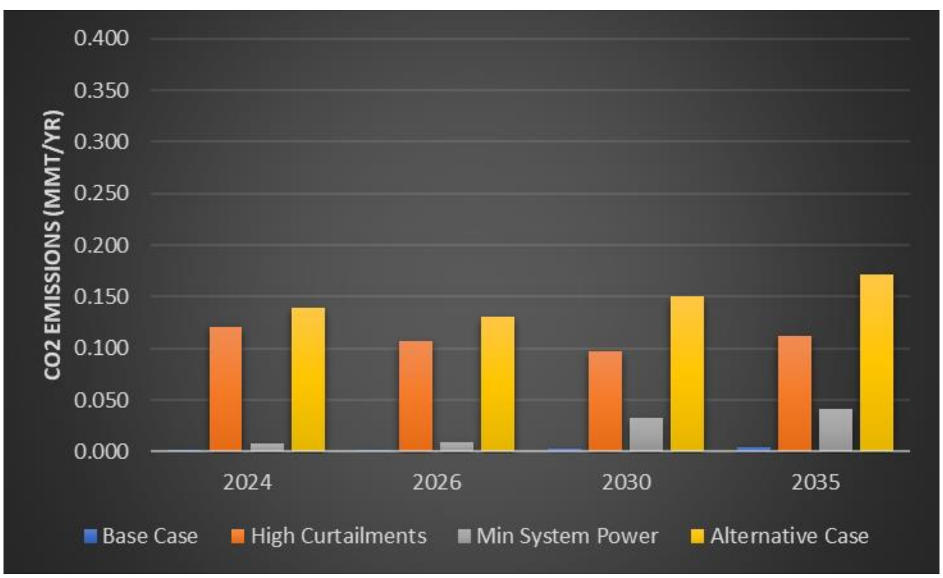
2) The emission reduction credits from awarded Zero Emissions Power from System.

A brief description of each scenario is provided below:

- Base Case: The CSP workbook uses the original CPUC inputs for system curtailments and System Power.
- High Curtailments: The authors use their own forecast for system curtailments instead of the CPUC's forecast.
- Min System Power: The original System Power profile defined by the CPUC is modified to require a minimum of 2,500 MW of System Power in every hour.
- Alternative Case: The CSP workbook uses both the High Curtailments and Min System Power scenarios.

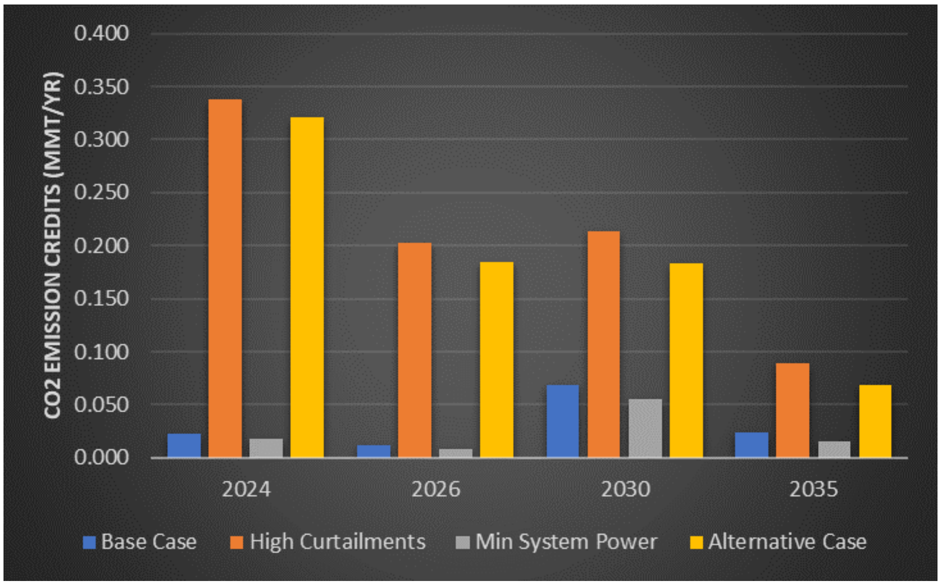
Figure 8 shows the impact of non-displaceable System Power on the sample portfolio's CO2 emissions for each of the four scenarios. In the Base Case, the sample portfolio's share of non-displaceable System Power is low, meaning there's little risk of increased emissions. However, in the High Curtailment scenario, emissions increase each year as a result of less displaceable System Power on the margin. Interestingly, the Min System Power scenario shows that elevated System Power levels alone don't appear to meaningfully impact emissions until 2030. The sample portfolio shows the greatest sensitivity in its emissions when both high curtailments and non-displaceable System Power are assumed. These changes are material. For example, in 2030 (2035), the 0.150 MMT (0.175 MMT) of additional emissions assigned to the portfolio equals 35% (50%) of the CPUC's CO2 benchmark for that year.

Figure 8: Share of Non-Displaceable System Power Assigned CO2 Emissions



Similar to Figure 8, Figure 9 illustrates the impact of Zero Emissions Power from System on the emissions profile of the sample portfolio for each scenario. In the Base Case scenario, the sample portfolio shows limited sensitivity until 2030 but then trails off again in 2035. System curtailments have the greatest impact in the near-term but then gradually decline over time. The reduction in the opportunity to benefit from this surplus of VER energy is mainly due to a decrease in the portfolio's net open market position, which is shown in the "Net Market Purchases (pre curtailments)" line item in Table 1. As expected, elevated levels of non-displaceable System Power reduce the number of emission credits but is less impactful than elevated system curtailments. It's important to mention that, regardless of the scenario modeled, emissions assigned by the CSP mostly increase over time, while the benefits from Zero Emissions Power from System mostly decrease. This highlights the growing challenges an LSE will face as their portfolio become more impacted by the portfolios of others.

Figure 9: CO2 Emission Credits from Zero Emissions Power from System



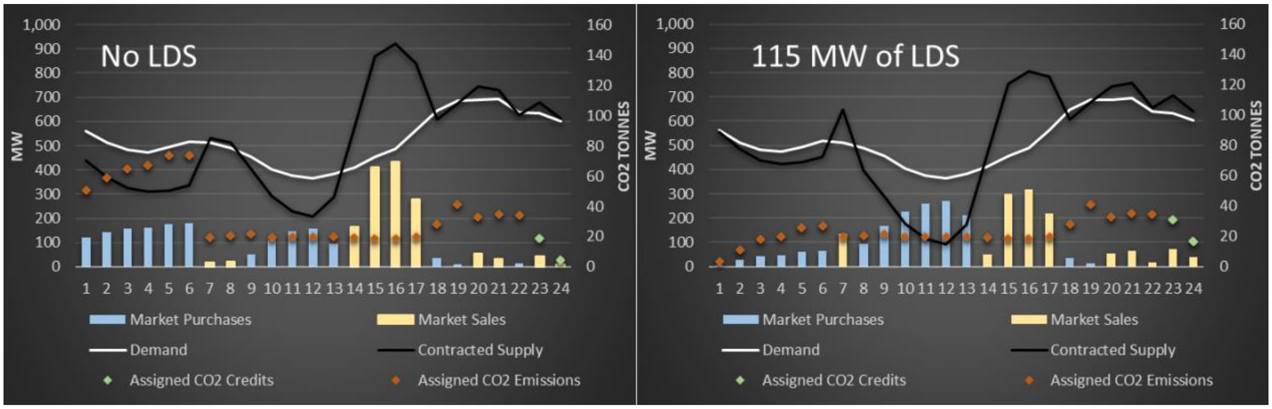
Impact of Long-Duration Storage on Portfolio Emission Targets

While the impact of a single portfolio on the overall system may be limited, an LSE can still manage its own emissions footprint effectively by mindfully formulating a procurement strategy. One way to do this is by incorporating additional storage into the portfolio because it offers multiple benefits. First, it minimizes excess power delivery to the grid during oversupply conditions, reducing the risk of curtailments to the portfolio's supply contracts. Second, it increases the portfolio's demand for grid power during high curtailment periods, taking advantage of excess emission-free power provided by other market participants.

These benefits are not limited to 4-hour storage. As Figure 6 demonstrates, the number of hours with renewable energy on the margin is expected to increase, putting storage projects with duration of 8-10 hours in a favorable position. An LDS facility can shift additional excess emission-free power generated during the day to later in the evening and early morning, which makes these resources a good option for LSEs pursuing a 24/7 carbon-free policy.

Figure 10 illustrates the potential of long-duration storage to reduce an LSE's emissions footprint. The graph on the left shows a sample dispatch for a 24-hour period in July 2035 for the original portfolio, while the graph on the right includes 115 MW of 8-hour storage. Adding the LDS facility increases the portfolio's mid-day market purchases, as it primarily charges from emission-free energy. By discharging the battery from midnight to the early morning, the storage facility reduces the portfolio's reliance on System Power during hours that are typically challenging to supply with clean electricity. The results section further explores the potential of long-duration storage to reduce a portfolio's emissions.

Figure 10: 24-Hour Period of Demand, Contracted Supply, and Market Transactions with and without LDS



Model Results

Alternative Case (No Long-Duration Storage)

This section illustrates how variations in system conditions can impact a load-serving entity's ability to meet their assigned CO2 benchmarks and file a compliant IRP portfolio with the Commission. The authors updated the CSP workbook to reflect the system conditions described in the Alternative Case scenario and then calculated the results. Table 2 displays the summary statistics of the sample portfolio without long-duration storage. The impact of elevated system curtailments and System Power can be measured by comparing these results to the values from the Base Case scenario listed in Table 1.

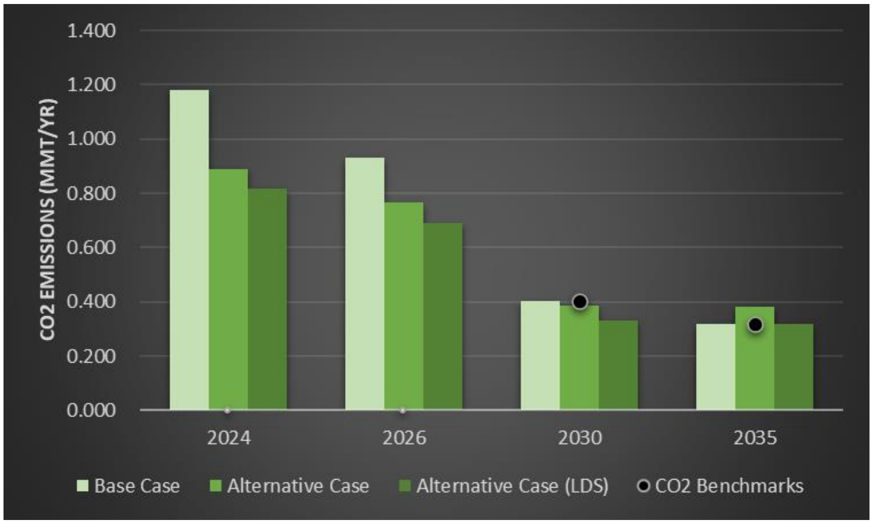
Table 2: Sample Portfolio Summary Statistics for Alternative Case Scenario without Long-Duration Storage

Clean System Power Workbook Summary	***Unit***	**2024**	**2026**	**2030**	**2035**
Retail Sales	GWh	3,579	3,637	3,742	3,876
Net Market Purchases (pre curtailments)	% of retail sales	74%	55%	18%	7%
Share of Non-Displaceable System Power	*GWh*	332	309	332	369
Zero Emissions Power From System	*GWh*	757	434	403	145
Net Market Purchases (incurs emissions)	*GWh*	1,891	1,607	692	746
RPS-Eligible Delivered Renewable	GWh	1,097	1,802	3,063	3,519
GHG free	GWh	1,854	2,236	3,465	3,665
RPS-Eligible Delivered Renewable Percentage	*% of retail sales*	31%	50%	82%	91%
GHG-free Percentage	*% of retail sales*	52%	61%	93%	95%

The portfolio experiences an increase in Zero Emissions Power from System starting in 2024, followed by a steady decrease in the years to follow. However, this increase is partially offset by a coincident increase in the portfolio's share of non-displaceable System Power. Through 2030, the portfolio sees a net emission benefit relative to the Base Case, but this relationship reverses itself in 2035. These offsetting variables, along with the sample portfolio's native market exposure prior to any curtailments or exports taking effect, are captured in the "Net Market Purchases (incurs emissions)" line item in Table 2. It is these net purchases that ultimately decide the portfolio's CO2 emissions. Figure 11 displays the CO2 emissions of the sample portfolio for each calendar year, along with the CPUC-assigned CO2 benchmarks for 2030 and 2035.[14] Whereas in the Base Case, the portfolio meets its CPUC benchmarks for both compliance years, the results in the Alternative Case are mixed. Although the CO2 emissions slightly decrease in 2030, they increase by 20% in 2035 and now exceed the portfolio's assigned benchmark. This is primarily the result of a poor alignment between when the sample portfolio can provide emission-free power to the grid and when the system has an actual marginal need for that electricity. This example highlights the potential risks to LSEs in meeting mandatory decarbonization targets.

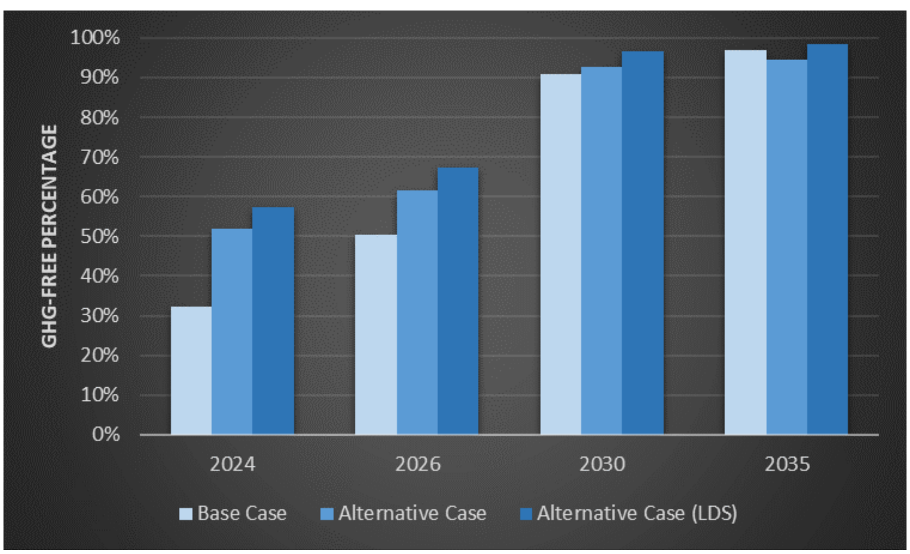
[14] The assigned CPUC benchmarks for this sample portfolio are 0.402 MMT in 2030 and 0.320 MMT in 2035.

Figure 11: CO2 Emissions Footprint of Sample Portfolio



The authors also examine the percentage of the sample portfolio's annual retail load that can be served by CO2-free energy, as shown in Figure 12. With fewer supply contracts in the early years, the portfolio can claim a greater effective supply of emission-free energy in the presence of elevated system curtailments. In 2024, the CSP credits the sample portfolio with an additional 20% of CO2-free energy, thanks to the surplus of clean power on the system. However, as the number of supply contracts in the sample portfolio increases, the amount of Zero Emissions Power from System decreases. In the later years, the revised forecasts for system conditions have less impact on the sample portfolio's effective supply of emission-free energy. In 2030, the CSP awards a slight increase in the number of carbon credits to the portfolio, which is then followed by a slight decrease in 2035.

Figure 12: Percentage of Sample Portfolio's Retail Demand Served by GHG-Free



Alternative Case (With Long-Duration Storage)

As shown in Figure 11, the Alternative Case with long-duration storage reduces the sample portfolio's CO2 emissions in each year relative to the Alternative Case without the LDS facility. More importantly, thanks to the addition of the 115 MW; 8-hour storage facility, the sample portfolio reduces its CO2 emissions in 2035 below its assigned benchmark, bringing it back into compliance with the Commission. Figure 11 illustrates how the LDS facility enables the LSE to benefit from the actions of other market participants by serving an additional 5% of its retail demand with CO2-free energy in any given year. Table 3 provides summary statistics for the sample portfolio after the addition of the long-duration storage asset.

Table 3: Sample Portfolio Summary Statistics for Alternative Case Scenario with Long-Duration Storage

Clean System Power Workbook Summary	***Unit***	**2024**	**2026**	**2030**	**2035**
Retail Sales	GWh	3,579	3,637	3,742	3,876
Net Market Purchases (pre curtailments)	% of retail sales	75%	56%	19%	8%
Share of Non-Displaceable System Power	*GWh*	332	309	332	369
Zero Emissions Power From System	*GWh*	956	640	594	307
Net Market Purchases (incurs emissions)	*GWh*	1,727	1,429	569	606
RPS-Eligible Delivered Renewable	GWh	1,097	1,807	3,020	3,511
GHG free	GWh	2,054	2,448	3,614	3,819
RPS-Eligible Delivered Renewable Percentage	*% of retail sales*	31%	50%	81%	91%
GHG-free Percentage	*% of retail sales*	57%	67%	97%	99%

Applications Beyond the IRP

In addition to the mandatory emission reduction requirements set by the CPUC's IRP process, organizations can elect to use the CSP workbook to also support voluntary emission reduction programs. With its detailed hourly emissions accounting framework that is both comprehensive and flexible, the workbook can serve as a suitable emissions planning tool for all CAISO market participants. By taking a system-wide approach that accounts for the system's hourly interaction with a given portfolio, organizations can credibly estimate the total impact of their portfolio to reduce CO2 emissions for the broader electric sector. Moreover, by also calculating the percentage of annual demand that is served with emission-free power, the workbook is useful for organizations with or without mandatory CPUC CO2 targets. As demonstrated in this study, it is important for all organizations with environmental commitments to factor in hourly curtailment risks into their procurement plans to increase their chances of achieving their decarbonization goals cost-effectively.

It is challenging for organizations to plan and implement a portfolio that balances deep reductions in emissions with affordability for customers. Moreover, the relationship between the portfolio and the broader system is complex, and there is a lot of uncertainty about how the grid will change. This is why organizations need a robust framework for decision making. This framework should include portfolio optimization software, access to a variety of forecasting models, and a design that supports scenario analysis and probabilistic reasoning. The authors plan to provide more information on the framework they are developing in future studies.

Conclusion

The authors of this study have analyzed the CPUC's Clean System Power workbook to show how the changing bulk electric power grid can affect an organization's environmental policies. Because the CSP is overly-optimistic in its assumptions for system conditions, organizations can benefit by considering the impact on their emissions footprint due to different forecasts for system curtailments and System Power. This exercise can help organizations identify risks and benefits related to compliance with carbon reduction plans, particularly for portfolios that focus on solar, wind, and 4-hour storage.

By adding storage to their portfolio, organizations can take advantage of the increasing availability of excess VER energy on the system to reduce their CO_2 emissions. Long-duration storage in particular is a good option for companies aiming for aggressive greenhouse gas reduction targets under a 24/7 carbon free policy. As the grid becomes more saturated with VER energy, storage with 8-10 hour duration can charge more frequently using emission-free energy, which can then be used to offset an organization's dependence on System Power not only during peak demand hours but also in the late evening and early morning.

In closing, the authors highlight the potential for the CSP to assist any CAISO market participant with environmental commitments. The workbook provides a detailed, comprehensive, and flexible emissions accounting framework that provides users with an effective tool for emissions planning. Ideally, this work would be included as part of an advanced analytical platform that consists of suitable forecast and optimization models.

Next Steps

In their next paper, the authors will discuss how their forecast and optimization methodology can help an organization plan a cost-effective hedging strategy.

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