2015-2016 TRANSMISSION PLAN

California ISO

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BOARD APPROVED

Forward to Board-Approved 2015-2016 Transmission Plan

At the March 25, 2016 ISO Board of Governors meeting, the ISO Board of Governors approved the 2015-2016 Transmission Plan.

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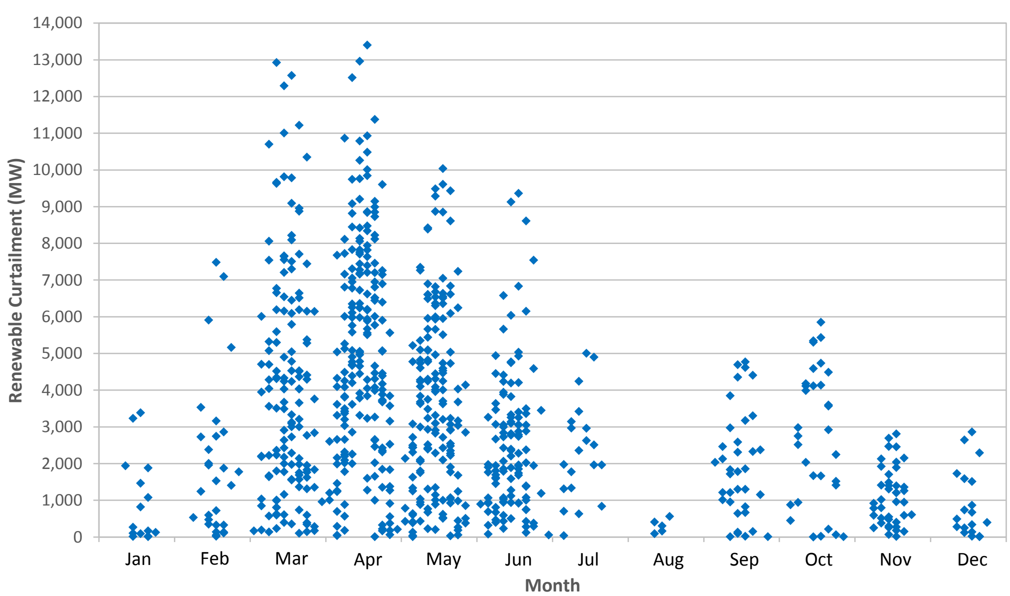
3.5 Bulk Energy Storage Resources Study with 40% RPS in 2024

3.5.1 Introduction

The ISO faces challenges – and potential opportunities – resulting from higher renewable generation development in California as the state moves to reach 33 percent renewable portfolio standard (RPS) target in 2020 and 50 percent in 2030. These include the potential for oversupply during periods of high solar generation output and the potential for much more severe ramping requirements on the rest of the conventional fleet. The ISO needs to manage ramping events and maintaining supply/demand balance while minimizing the curtailment of renewable generation. This special study explored the possible benefits of one resource type – large scale bulk energy storage - that may play a role in helping mitigate the challenges. This provides insights into the effectiveness of the particular resource type, and also helps clarify the scope of the issue itself. The study was provided on an information-only basis and the results are dependent on the assumptions made in the study.

In the studies prepared for the California Public Utilities Commission (CPUC) 2014 Long Term Procurement Plan (LTPP) proceeding the ISO found significant volumes of renewable generation being curtailed in order to maintain the reliability of the grid. The studies found renewable generation curtailment in 822 hours totaling 2,825 GWh in the 40% RPS scenario developed for that proceeding, as shown in figure 3.5-1. The maximum hourly curtailment was 13,402 MW.[131] Due to the amount of curtailment, the actual renewable generation did not meet the state's 40% Renewable Portfolio Standard (RPS) goal in that scenario.

Figure 3.5-1: Curtailment of Renewable Generation in the 2014 LTPP 40% RPS Scenario



[131] For more information, see the 2014 LTPP Phase 1.A. Direct Testimony of Shucheng Liu at http://www.caiso.com/Documents/Aug13_2014_InitialTestimony_ShuchengLiu_Phase1A_LTPP_R13‐12‐010.pdf.

The benefits were studied considering bulk energy storage that can absorb large volume of excess energy during the oversupply hours and make use of the stored energy in other hours that additional generation is needed otherwise. The shift of energy can displace generation from other conventional generation resources and reduce the cost of generation and the emission of greenhouse gas (GHG).

The study assessed the benefits in reduction of renewable generation curtailment, CO2 emission and production cost as well as the financial costs to achieve the benefits. The methodology, assumptions, and results of the study are set out in this section.

3.5.2 Study Approach

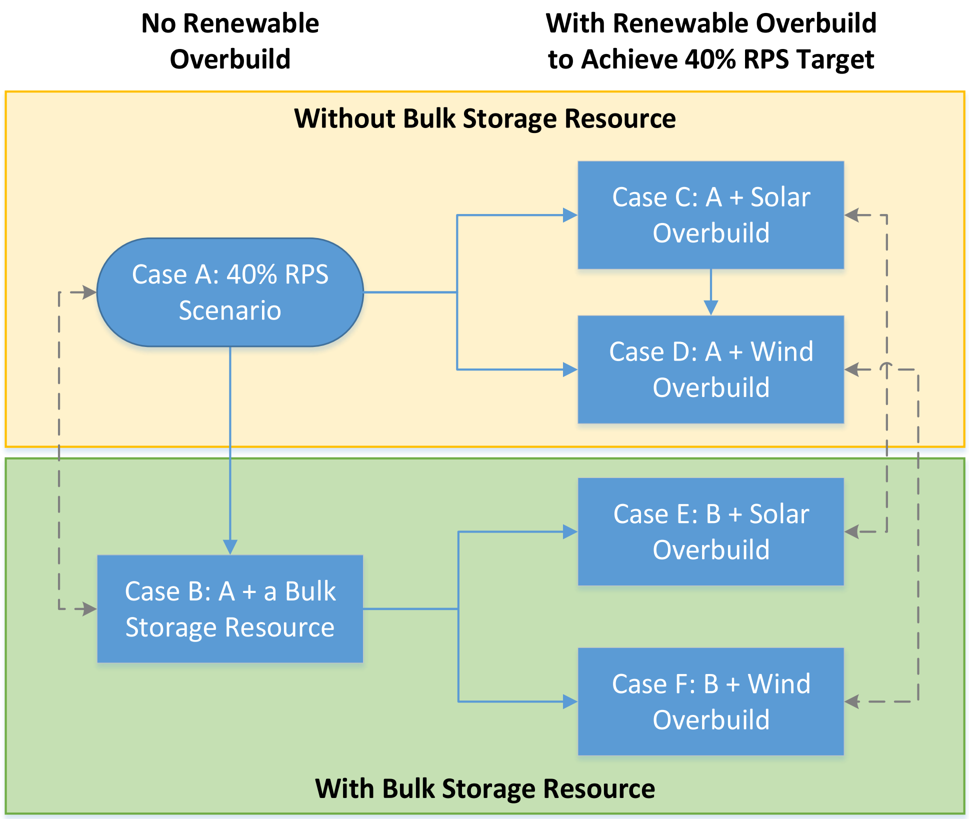
This study was conducted based on the CPUC 2014 LTPP 40% RPS in 2024 Scenario (the "40% RPS Scenario"). A new bulk energy storage resource was added to the 40% RPS Scenario production simulation model to evaluate its contribution to reduction of renewable curtailment, CO2 emission, and production cost.

A simple comparison of two production cost simulations – with and without the bulk energy storage resource – does not determine the full benefits the resource may provide, however, as the presence of the storage resource may lead to different levels of success of various resource mixes in achieving the 40 percent RPS target.

The study was therefore based on production simulations of the original case and five new cases, as shown in Figure 2. The five cases are all derived from the 40% RPS Scenario, which was designated as case **A** in this study. In all cases, renewable curtailment remains unlimited, as in the 40% RPS Scenario. Case **B** is case **A** with the new bulk energy storage resource added. As noted earlier, the actual renewable generation did not meet the state's 40% Renewable Portfolio Standard (RPS) goal in the production simulations due to the amount of curtailment. In case **B** the 40% RPS target was still not achieved due to curtailment. In the other four cases (case **C**, **D**, **E** and **F**), additional renewable generation resources were added to the renewables portfolio of case **A** and case **B** until the actual renewable generation met the 40% RPS requirement despite the curtailment. The additional renewable resources are in effect the renewable overbuild needed to achieve the 40% RPS target and overcome the curtailment impacts on total renewable energy production.

In this study the renewable overbuilds used two alternative resources; solar and wind. Solar and wind have very different generation patterns (hourly profiles). In the 40% RPS Scenario (case **A**), installed solar capacity was 52% of the total RPS portfolio and wind was 29%. Solar generation peaks in the midday. Solar overbuild further increased the solar dominance in the RPS portfolio and added more generation in the hours already having curtailment in case **A**. That portion of solar generation was then all curtailed. On the other hand, wind generation in California usually spreads over the whole day, with lower output in the midday than solar. Therefore, wind overbuild improved the diversification of the RPS portfolio. It has less generation to be curtailed than solar does. The needed wind overbuild was expected to be less than solar overbuild. Also the capital cost (per kW) of wind is lower than that of solar. As shown in figure 3.5-2, the four cases with renewable overbuild were constructed to have either solar (case **C** and **E**) or wind (case **D** and **F**) overbuild. The purpose was to establish two bookends in term of quantity (MW) and capital cost of the overbuild. As a solution to renewable curtailment, the actual renewable overbuild should be combinations of solar and wind, as well as other types of renewable resources.

Figure 3.5-2. Definitions of Bulk Energy Storage Study Cases



The results of the six cases provided all the necessary information to assess the benefits of the bulk energy storage resource and to determine the quantities and cost of renewable overbuild needed to achieve the 40% RPS target. From case **A** to **B**, **C** to **E** and **D** to **F**, the benefits of the new bulk energy storage resource under different situations (without overbuild, with solar or wind overbuild) could be identified. Also, the differences between case **C** and **D** and between **E** and **F** showed the effectiveness of using solar and wind overbuild to achieve the 40% RPS target. The cost of the solar and wind overbuilds in case **C**, **D**, **E** and **F** plus the cost of the new bulk energy storage resource in case **E** and **F** are the costs of renewable curtailments under difference situations. The comparison of the cost of the new bulk energy storage resource with its net market revenue from generation and from providing ancillary services and load following revealed the financial viability of the resource based on the study assumptions.

3.5.3 Study Assumptions

Basis of the Study

This study used the 40% RPS Scenario production simulation model in the 2014 LTPP deterministic studies as the basis. In the five new cases of the study (see figure 3.5-2) all assumptions, except the additional solar, wind and the new pumped storage resources, were consistent with the assumptions in the 40% RPS Scenario. It is important to point out that in all the five new cases, renewable generation curtailment was unlimited, as was in the 40% RPS Scenario. This ensured that the results of the five new cases were comparable to the results of the 40% RPS Scenario that were included in the CAISO testimony filed in the CPUC LTPP proceeding on August 13, 2014.[132]

Renewable Overbuild

In the study, additional renewable resources were added to the renewable portfolio of the 40% RPS Scenario (case **A**) such that the actual renewable generation met the state's 40% RPS target, with and without the new bulk energy storage resource. The renewable overbuild was achieved by scaling up the capacity and generation profiles of the ISO new RPS solar (excluding the 150 MW solar thermal with storage) or wind resources, in and out of state, in case **A**. The exact volume (MW) of the solar or wind overbuild that met the 40% RPS target was determined through running a set of experimental production simulations iteratively.

In these new cases transmission upgrades needed by the additional renewable resources were not explicitly modeled. However, the capital cost of renewable overbuild does include a component of transmission upgrade (table 3.5-2).

A New Pumped Storage Resource

The bulk energy storage in this study was represented by a pumped storage resource. In Case **B**, **E** and **F** a new pumped storage resource is added to the generation fleet. Table 3.5-1 shows the assumptions for the pumped storage resource. The ISO made the assumptions based on a review of publically available information.

[132] See footnote 1.

Table 3.5-1. Assumptions of the New Pumped Storage Resource

Item	Assumption
Number of units	2
Max pumping capacity per unit (MW)	300
Minimum pumping capacity per unit (MW)	75
Maximum generation capacity per unit (MW)	250
Minimum generation capacity per unit (MW)	5
Pumping ramp rate (MW/min)	50
Generation ramp rate (MW/min)	250
Round-trip efficiency	83%
VOM Cost ($/MWh)	3.00
Maintenance rate	8.65%
Forced outage rate	6.10%
Upper reservoir maximum capacity (GWh)	8
Upper reservoir minimum capacity (GWh)	2
Interval to restore upper reservoir water level	Monthly
Pump technology	Variable speed
Reserves can provide in generation and pumping modes	Regulation, spinning and load following
Reserves can provide in off-line modes	Non-spinning
Location	SCE zone

Based on the assumptions, the pumped storage resource has a maximum usable storage volume of 8 GWh that can support generation at maximum capacity for up to 12 hours without additional pumping. The resource can ramp from minimum to maximum generation in 1 minute and from minimum to maximum pumping in 5 minutes. It can provide ancillary services and load-following in both pumping and generation modes.

Revenue Requirement Assumptions

In calculation of the revenue requirements of the solar and wind overbuild and the new pumped storage resource, the assumptions in table 2 were used. Revenue requirement included capital cost, taxes, tax credits, insurances, etc. NQC Peak Factor is the percentage of installed capacity that is counted as qualified net capacity (NQC). NQC is the capacity of the resource that can meet the California Resource Adequacy (RA) requirement and receive resource adequacy capacity revenue.

The assumptions come from several sources that are listed in the footnotes of table 3.5-2.

Table 3.5-2. Assumptions of Revenue Requirements and RA Revenue of the New Resources[133]

Item	Revenue Requirement ($/kW-year)		NQC Peak Factor[134]	RA Revenue ($/kW-year)[135]
	Generation Resource[136]	Transmission Upgrade[137]		
Large Solar In-State	327.12	22.00	47%	16.13
Large Solar Out-State	306.26	22.00	47%	16.13
Small Solar In-State	376.99	11.00	47%	16.13
Solar Thermal In-State	601.71	22.00	90%	30.89
Wind In-State	286.62	16.50	17%	5.83
Wind Out-State	261.13	72.00	45%	15.44
Pumped Storage In-State	383.62	16.50	100%	34.32

3.5.4 Study Results

Table 3.5-3 is a summary of the simulation results and the calculated levelized annual revenue requirements of the solar and wind overbuild and the new pumped storage resource. The results are analyzed in more detail in the sections below.

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133 All revenue requirements and RA revenue are in 2014 dollars.

134 References https://www.caiso.com/Documents/2012TACAreaSolar-WindFactors.xls and https://www.wecc.biz/Reliability/2024-Common-Case.zip

135 Reference http://www.cpuc.ca.gov/NR/rdonlyres/2AF422A2-BFE8-4F4F-8C19-827ED4BA8E03/0/2013_14ResourceAdequacyReport.pdf

136 References https://www.wecc.biz/Reliability/2014_TEPPC_GenCapCostCalculator.xlsm and https://www.wecc.biz/Reliability/2014_TEPPC_Generation_CapCost_Report_E3.pdf

137 Reference http://www.transwestexpress.net/scoping/docs/TWE-what.pdf and the CAISO assumptions.

Table 3.5-3. Simulation Results and Calculated Revenue Requirements

	Without Pumped Storage			With Pumped Storage		
Case	**A**	**C**	**D**	**B**	**E**	**F**
Renewable Curtailment (GWh)[138]	2,825	4,249	3,157	2,417	3,457	2,649
CA CO2 Emission (Million Ton)[139]	62.74	61.82	61.68	62.41	61.66	61.54
CA CO2 Emission Cost ($ mil)[140]	1,460	1,438	1,435	1,452	1,435	1,432
Production Cost ($ mil)[141]						
WECC	14,167	14,109	14,068	14,111	14,070	14,037
CA	3,866	3,826	3,795	3,803	3,779	3,751
Renewable Overbuild and Pumped Storage Capacity (MW)						
Solar		1,918			1,569	
Wind			1,129			950
Pumped Storage				500	500	500
Levelized Annual Revenue Requirement of Renewable Overbuild and Pumped Storage ($mil)						
Solar		703			575	
Wind			340			286
Pumped Storage				183	183	183
Pumped Storage Net Market Revenue ($mil)[142]				160	194	170

Renewable Overbuild

The volume (MW) of solar and wind overbuild needed to achieve the 40% RPS target, with and without the pumped storage resource, was the basis of the analysis of other results. The overbuild creates a levelized ground for assessing the benefits of the pumped storage resource under different situations. The capacity of solar and wind overbuild with and without the new pumped storage resources is shown in figure 3.5-3.

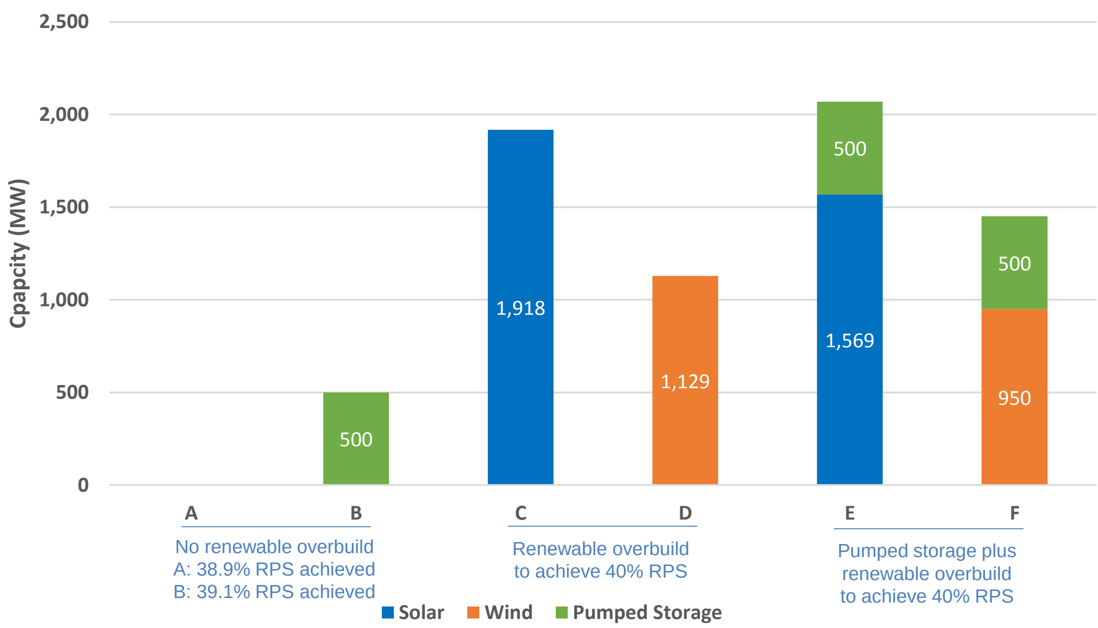
Without the new pumped storage resource, 1,918 MW of solar overbuild or 1,129 MW of wind overbuild was required in order to achieve the 40% RPS target. As expected, wind was more

138 Renewable generation is curtailed at -$300/MWh price (MCP).
139 It includes the CO2 emission from net import. Out-of-state renewable energy is emission free. 25% of the rest of the net import is assumed to be from Northwest, which has only 20% of the ARB average CO2 emission rate for imported electricity (0.435 metric-ton/MWh) according to the ARB rule (http://www.arb.ca.gov/regact/2010/ghg2010/ghgisoratta.pdf on p56 and 59).
140 It is calculated using $23.27/m-ton price.
141 It includes start-up, fuel and VOM cost, but not CO2 cost.
142 Net revenue is revenue of energy and reserves minus cost of energy for pumping and VOM cost.

effective in term of the capacity amount of overbuild needed. Before the overbuild was added, e.g. in case **A**, there were 822 hours with renewable curtailment, mostly in the midday when solar generation was at high output. With solar overbuild in case **C**, the RPS portfolio has even higher solar concentration. As a result, the duration of renewable curtailment increased from 822 to 1,061 hours. The wind overbuild in case **D**, on the other hand, improved the diversification of the RPS portfolio. The additional energy was spread out to almost all the hours, resulting in less curtailment than case **C** (see figure 3.5-3). With case **D**, the duration of renewable curtailment was 888 hours. Therefore, Case **D** needed less overbuild than case **C** to achieve the 40% RPS target.

With the 500 MW new pumped storage resource added to the system, the overbuild needed to achieve the 40% RPS target was reduced. From case **C** to **E**, the solar overbuild was reduced by 349 MW. Similarly, from case **D** to **F**, the wind overbuild was reduced by 179 MW. The reduction of solar overbuild was greater than the reduction in wind overbuild, but both are smaller than the 500 MW capacity of the new pumped storage resource. This can be attributed to the following factors.

Figure 3.5-3 Capacity of the Pumped Storage and Solar and Wind Overbuild



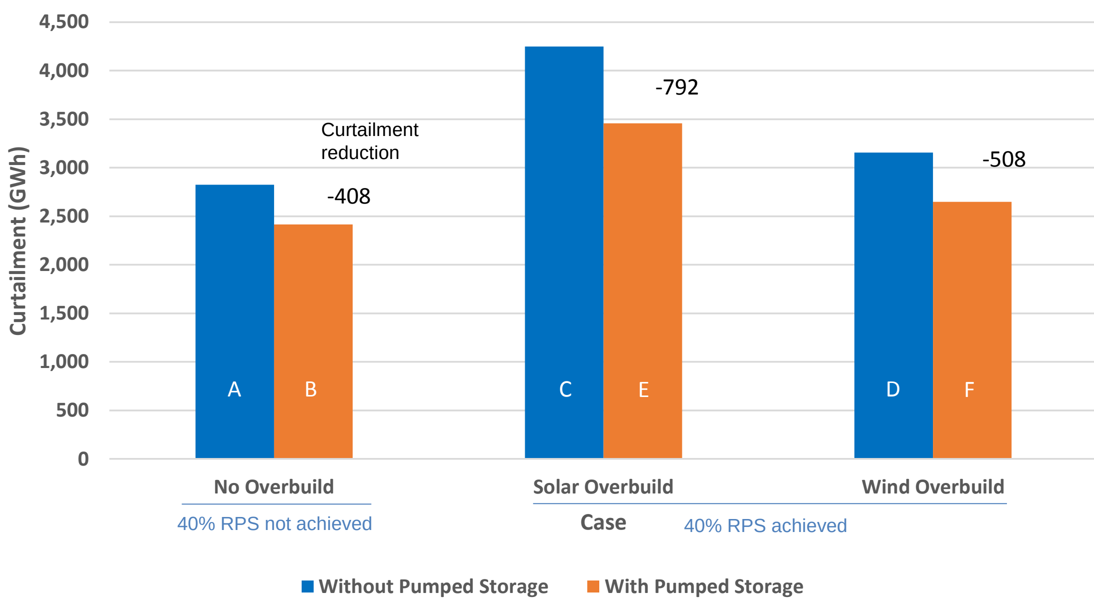
The most effective use of a large pumped storage resource is to move large chunk of energy from the hours with low generation cost to other hours with high generation cost. It matches with the solar generation pattern that concentrates in midday to drive down energy price or even causes curtailment. It has no generation before sunrise and after sunset, during which other higher cost generation is needed to meet the load. It. That is why the new pumped storage resource was more effective with solar overbuild than with wind overbuild to reduce curtailment and therefore the needed overbuild.

On the other hand, the effectiveness of the new pumped storage resource is limited by its maximum capacity in relative to the volume of potential renewable generation curtailment. In this study the new pumped storage resource has 600 MW maximum pumping capacity that converts to 500 MW maximum generation, with an efficiency factor of 83%. When the curtailment from the overbuild in case **C** or **D** is greater than 600 MW, the pumped storage resource in case **E** or **F** cannot store all the energy and use it in later hours. The portion of energy exceeding 600 MW is still curtailed. Also, of the 600 MW of energy stored, 17% is lost due to the round-trip efficiency of the pumped storage resource. As discussed above, 1,918 MW solar or 1,129 MW wind overbuilds in case **C** and **D** caused more curtailment, greater than 600 MW in many of the hours. Therefore the new pumped storage resource was only able to reduced renewable overbuild less than 500 MW from case **C** to **E** or **D** to **F**.

Curtailment

The renewable curtailments of the six cases are shown in figure 3.5-4. In the study the renewable generation was curtailed when the energy price (MCP) dropped to -$300/MWh. The assumption mimics the CAISO market rules about curtailing self-scheduled renewable generation.[143]

Figure 3.5-4. Renewable Curtailment by Case



The overbuild of solar and wind in case **C** and **D** led to more curtailment. Solar overbuild had an increase of 1,424 GWh curtailment, greater than the 333 GWh increase of curtailment with wind overbuild. That is because of the solar overbuild generation pattern closely matched the curtailment pattern in case **A,** as discussed above.

From case **C** to **E**, the reduction of curtailment was 792 GWh, greater that the 508 GWh reduction from case **D** to **F**. It is consistent with the discussion about needed overbuild to meet the 40% RPS target that the new pumped storage resource is more effective with solar overbuild than with wind overbuild in reducing renewable generation curtailment. However, even with the new

[143] The current CAISO curtailing price is -$150/MWh. It is the bid-price floor.

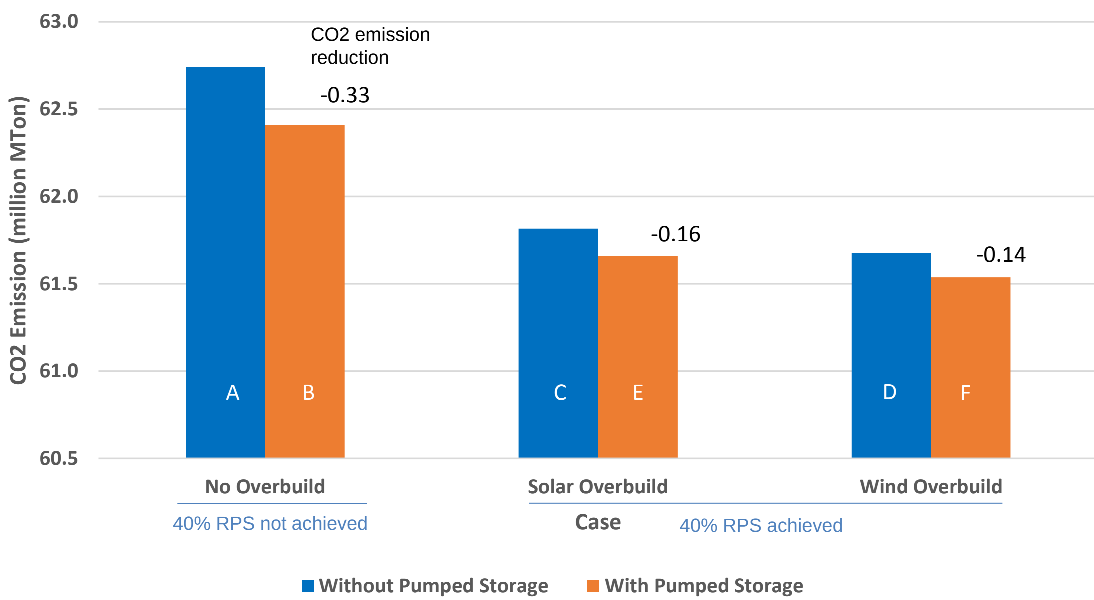
pumped storage resource, the total curtailment with wind overbuild (case **F**) was still 808 GWh lower than that with solar overbuild (case **E**). That is the benefit of a more diversified RPS portfolio.

California CO2 Emission

Figure 3.5-4 and figure 3.5-5 demonstrate that California CO2 emission results were highly correlated to the results of renewable generation curtailment in case **C**, **D**, **E** and **F**, but not in case **A** and **B**.

In case **C**, **D**, **E** and **F** more clean renewable generation was used to meet the load than in case **A** and **B**. It displaced the generation from conventional resources, which resulted in lower CO2 emission.

Figure 3.5-5. California CO2 Emission by Case



The new pumped storage resource was able to reduce curtailment and reduce CO2 emission. The CO2 emission reduction was highest without renewable overbuild. It was higher with solar overbuild than with wind overbuild, consistent with the finding in the discussion of renewable curtailment reduction above.

With and without the new pumped storage resource, wind overbuild resulted in lower emissions than solar overbuild. Solar overbuild made the morning and evening net load ramping processes steeper. This required more support of conventional resources to follow load. The required online conventional resources produced more emissions. The wind overbuild, on the other hand, had a relatively flat generation pattern. It did not steepen the net load ramping and therefore did not require the additional support of conventional resources. Wind overbuild was also able to displace generation of conventional resource in hours when there was no solar generation.

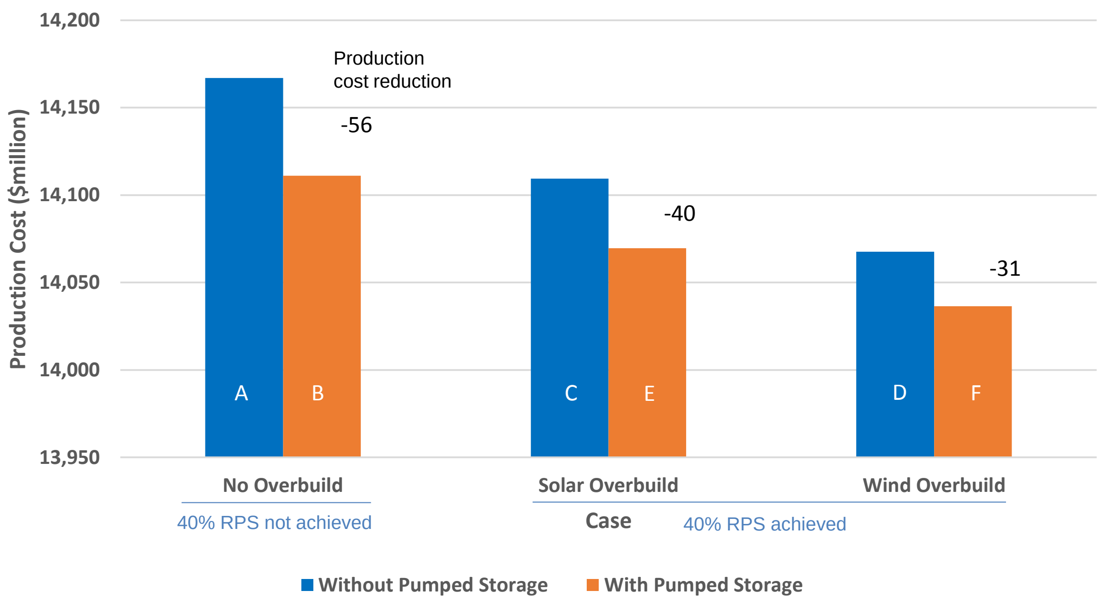
The California CO2 emission costs of the cases can be calculated by multiplying the CO2 emission amount by the CO2 emission price of $23.27/metric-ton.

Production Cost

The figure below shows the annual production cost of the whole western interconnect for all the cases.

The production cost in figure 3.5-6 includes generator start-up cost, variable operation and maintenance (VOM) cost, fuel cost, but not CO2 emission cost. In this study the renewable generation had a curtailment price of -$300/MWh. The production cost of renewable generation is assumed to be $0/MWh. The reported production cost also had the penalty price component from the load following-up and non-spinning shortfalls in a small number of hours removed.[144]

Figure 3.5-6. WECC Annual Production Cost by Case



Even though case **C**, **D**, **E** and **F** had the same amount of renewable generation, production costs were different. Case **D** had lower production cost than case **C** as the latter required more support of conventional resource in the morning and evening ramping processes than the former, as discussed in the CO2 emissions section above. That is the benefit of a more diversified RPS portfolio. That was also true comparing between case **F** and **E**.

The new pumped storage resource helped further reduce production cost because it reduced curtailment and used the stored clean energy to displace higher cost energy in other hours. The new pumped storage resource is very flexible. It can also provide ancillary services and load following to reduce the reliance on higher cost generation resource to stay online to provide these services. The production cost reduction with solar overbuild was higher than with wind overbuild. It further confirms that the new pumped storage resource was more effective with higher solar concentration RPS portfolio.

[144] See footnote 1.

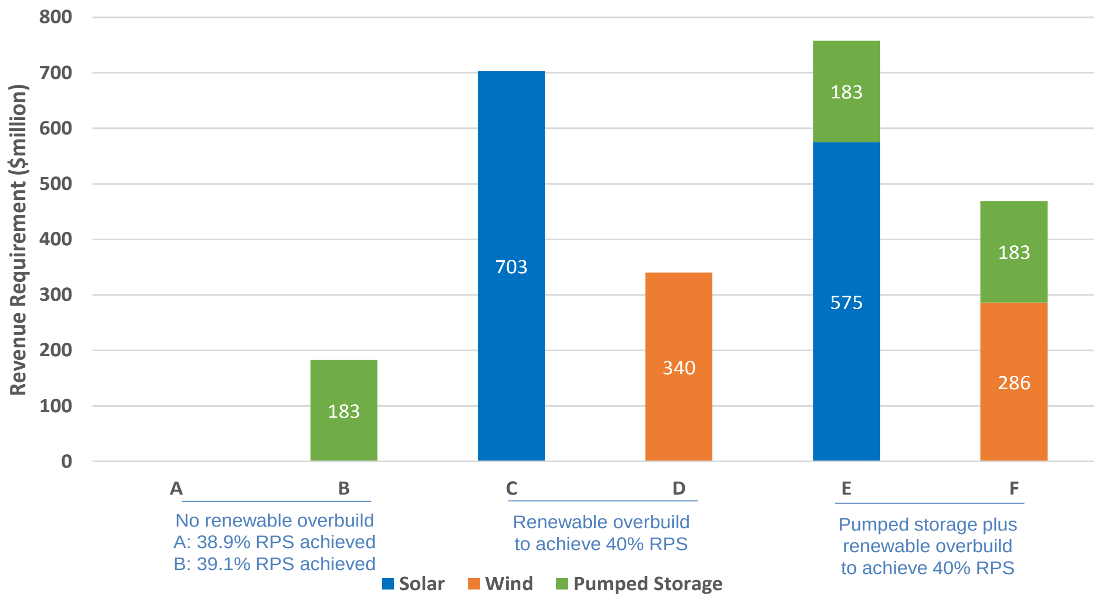
Levelized Annual Revenue Requirement

In figure 3.5-7 are the levelized annual revenue requirements of the renewable overbuild and the new pumped storage resource.

The calculated results show that the annual revenue requirement of wind overbuild was considerably lower than that of solar overbuild, even with the new pumped storage resource added. This was because less overbuild with wind was needed to achieve the 40% RPS target than with solar. Wind per unit cost was also lower than solar (see 3.5-2).

Considering its effectiveness in reducing needed overbuild, the new pumped storage was more expensive than the solar or wind overbuild it replaced. The analyses above show that the new pumped storage brought benefits to the system in reducing overbuild requirements, CO_2 emissions, and production costs. These benefits should be considered in assessing the cost of the new pumped storage resource.

Figure 3.5-7. Levelized Annual Revenue Requirement



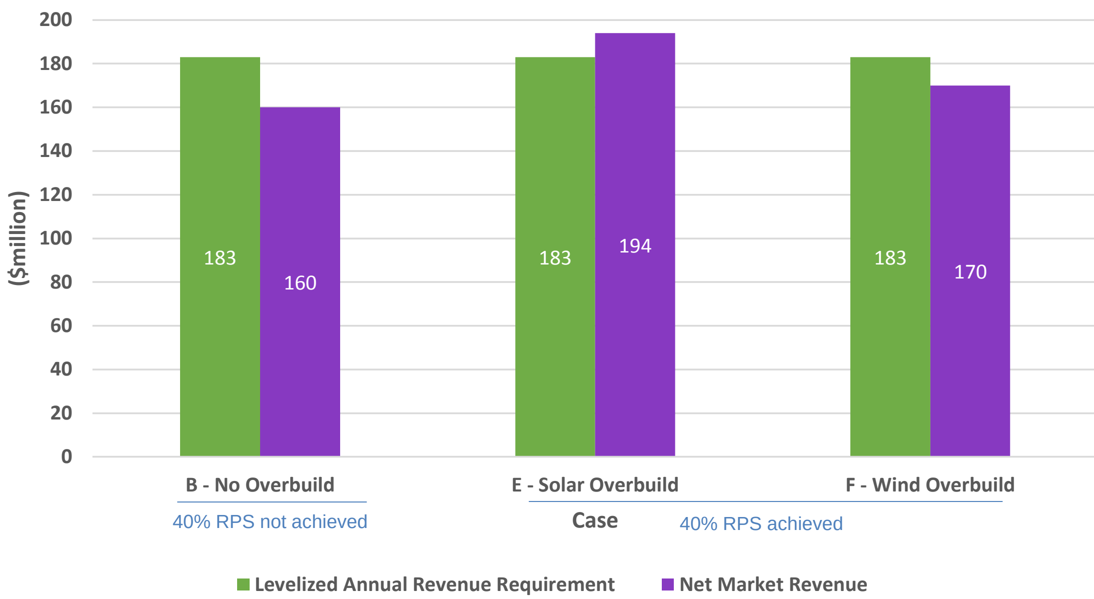
Revenue Requirement and Net Market Revenue of the New Pumped Storage Resource

Assuming the new pumped storage resource would be operated by an Independent Power Producer (IPP), the IPP would need to meet its revenue requirement with the net revenue from the market barring other revenue streams. Figure 8 shows the comparison of levelized annual revenue requirement with the net market revenue of the new pumped storage resource.

The net market revenue is the total revenue of the resource from generation and provision of ancillary services and load-following minus the cost on pumped energy and the resources VOM cost. The pumped storage resource was most profitable when it moved energy from hours with renewable curtailment to the hours the with higher energy prices. Therefore the net revenue of the pumped storage resource was highly dependent on the renewable generation curtailment price.

With the assumptions in this study, the new pumped storage resource should meet its revenue requirement with net market revenue only in case **E** with solar overbuild. It was $13 million short with wind overbuild and $23 million short without renewable overbuild.

Figure 3.5-8. Levelized Annual Revenue Requirement and Net Market Revenue of the New Pumped Storage Resource in 2024



The net revenue from the market would not reasonably be the only revenue stream – consideration should also be given to how the storage resource would be compensated for the benefits it brings to the system.

3.5.5 Conclusions

Based on the results of the study, it can be concluded that:

1) The new pumped storage resource brought significant benefits to the system, including
    - reduced renewable curtailment and reduced renewable overbuild needed to meet the 40% RPS target;
    - lower CO2 emissions, emission costs and production costs; and
    - the flexibility to provide ancillary services and load-following and to help follow the load in the morning and evening ramping processes.
2) Pumped storage was more effective with a high solar concentration renewables portfolio than with a more diversified renewables portfolios. However a more diversified renewables portfolio has more system benefits, resulting in overall lower costs through lower curtailment, CO2 emission, production cost and revenue requirement.

3) At 40% RPS, the new pumped storage has a higher levelized revenue requirement than that of the overbuild of solar or wind it replaces, but that might change with 50% RPS.
4) Assuming the new pumped storage resource was operated by an IPP, its net market revenue met the levelized annual revenue requirement only in the case with solar overbuild.
5) The benefits the new pumped storage resource brought to the system should be considered in assessing the financial viability of the resource.
6) The RPS portfolio in case **A** had high solar share. Wind overbuild made the portfolio more diversified than solar overbuild. So the wind overbuild was preferred over solar overbuild with all factors considered.