ISO 2016-2017 Transmission Planning Process

Supplemental Sensitivity Analysis: Benefits Analysis of Large Energy Storage

January 4, 2018

Contents

1. Introduction

This report summarizes the informational studies conducted by the ISO to assess the benefits large scale energy storage projects may provide to ratepayers in the ISO footprint as the state moves towards higher renewable generation levels and provides the results of the most recent sensitivity results that were conducted in 2017 as an extension of the 2016-2017 planning cycle studies.

As discussed in more detail below, the 2016-2017 Base Case assumptions generally leaned to underestimate the value the large scale storage is reasonably able to provide, leading to the additional sensitivity analysis performed in 2017.

Given the evolution of the analysis over several years, it is necessary to review the background of the past efforts, to put into context the latest results and the observations drawn from those results.

It must also be noted that the planning assumptions included in the additional sensitivity analysis were finalized in early 2017. This analysis does not reflect ongoing evolution of the CPUC's Integrated Resource Planning proceeding, or changes in planning assumptions being made through that process.

2. Background

During the 2016-2017 planning cycle, the ISO undertook further study of the benefits large scale energy storage projects may provide to ratepayers in the ISO footprint as the state moves from the 33 percent RPS to a 50 percent RPS. This analysis began in the 2015-2016 transmission planning cycle with a 40 percent RPS-based analysis that was later updated to a 50 percent RPS-based analysis.[1] The 2016-2017 study used the same methodology as the previous ones and provided a further update using the latest assumptions and load forecasts, and 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 ISO also expanded the study scope to consider potential locational benefits.

The study and results were documented in Section 6.5 of the 2016-2017 Transmission Plan.

The study was provided on an information-only basis and the results are dependent on the assumptions made in the study. The methodology, assumptions, and results of the study are set out in this section.

Initial Base Case in 2016-2017 Analysis

The 2016-2017 special study was conducted based on the 50 percent RPS "in-state portfolio with full capacity deliverability" portfolio the CPUC provided for the ISO 2016-2017 50 percent RPS special studies. The 50 percent RPS Base Case was developed based on the Default Scenario of the CPUC 2016

[1] See http://www.caiso.com/Documents/Board-Approved2015-2016TransmissionPlan.pdf and http://www.caiso.com/Documents/BulkEnergyStorageResource-2015-2016SpecialStudyUpdatedfrom40to50Percent.pdf

LTPP/TPP Assumptions and Scenarios.[2] The assumptions have some major changes compared to that of the last 50 percent RPS based bulk energy storage study in the 2015-2016 transmission planning cycle. The changes are mostly in the following areas:

- The retirement of non-dispatchable generation resources;
- Dispatchability of CHP resources;
- Energy forecast and Additional Achievable Energy Efficiency (AAEE);
- Renewable energy needed to achieve the 50 percent RPS target (not curtailment included); and
- The prices for renewable curtailment.

Table 1 below has the comparison of these changes.

Table 1: Comparison of Assumptions with Major Changes

Assumption	2016-2017 TPP 50% RPS Study	2015-2016 TPP 50% RPS Study
Changes in non-dispatchable generation resources	Diablo Canyon nuclear plant (2,300 MW) is retired 2,786 MW CHP in operation	Diablo Canyon in operation 4,684 MW CHP in operation
Dispatchability of CHP resources	50% of the 2,786 MW CHP is dispatchable	All 4,684 MW CHP is non-dispatchable
California load forecast	64,009 MW 1-in-2 No AAEE non-coincident peak load 301,480 GWh energy	70,763 MW 1-in-2 No AAEE non-coincident peak load 322,218 GWh energy
California AAEE	9,418 MW non-coincident peak impact 39,779 GWh energy CEC provided hourly profiles that usually have higher values in the late afternoon and early evening	5,713 MW non-coincident peak impact 24,535 GWh energy No hourly profile, offsetting load proportionally to the hourly load values
California RPS Portfolio	36,776 MW installed capacity 110,288 GWh energy	40,986 MW installed capacity 125,307 GWh energy
Price of renewable generation curtailment	-$15/MWh for the first 200 GWh, -$25/MWh for additional 12,400 GWh and -$300/MWh thereafter	-$300/MWh for all curtailment
Hydro condition	2005 hydro generation	2005 hydro generation
ISO maximum net export capability	2,000 MW	2,000 MW

[2] See http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M162/K005/162005377.PDF

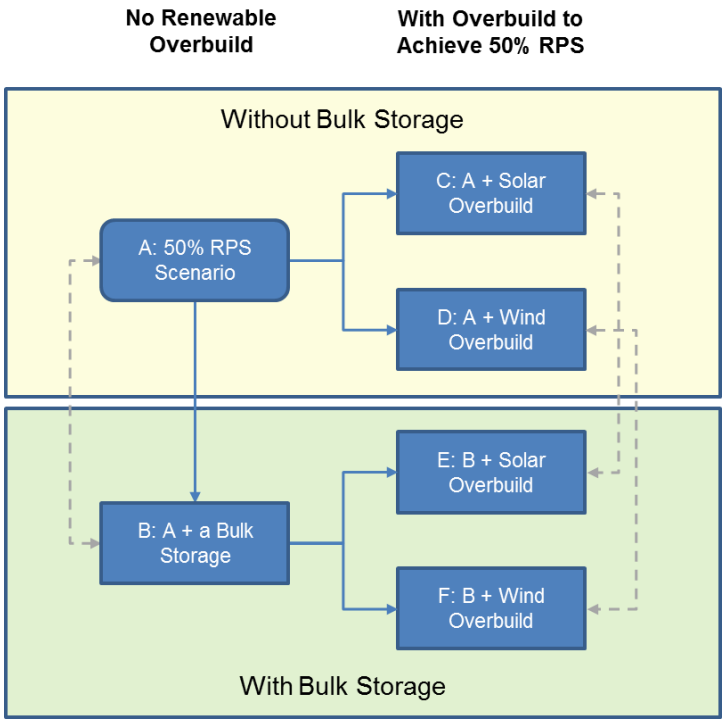
Two new bulk energy storage resources – a 500 MW and a 1400 MW resource – were added in turn to the 50 percent RPS scenario production simulation model to evaluate its contribution to reduction of renewable curtailment, CO2 emission, and production cost.

Initial Study Cases

Consistent with the studies the ISO did in the 2015-2016 transmission planning process, the study was based on production simulations – for each size of resource – of the original case and five new cases, as shown in Figure 1, as 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, as the presence of the storage resource may lead to different levels of success of various renewable resource mixes in achieving the 50 percent RPS target.

The five cases were all derived from the 50 percent RPS scenario Base Case, which was designated as case **A** in this study. In all cases, renewable curtailment remains unlimited. Case **B** is case **A** with the new bulk energy storage resource added. As expected, the actual renewable generation did not initially meet the state's 50 percent renewable portfolio standard (RPS) goal in the production simulations due to the amount of curtailment. In case **B** the 50 percent 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 50 percent RPS requirement despite the curtailment. The additional renewable resources are in effect the renewable overbuild needed to achieve the 50 percent RPS target and overcome the curtailment impacts on total renewable energy production.

Figure 1: Definition of Study Cases



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 50 percent RPS scenario (case **A**), installed solar capacity was 55% of the total RPS portfolio and wind was 32%, excluding the distributed solar PV. Solar generation peaks in the midday and causes curtailment when the generation is more than the system can utilize. 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 (see Table 2). As shown in Figure 1, 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.

Table 2: Assumptions for Revenue Requirements and RA Revenue

Item	Generation & Transmission Costs (2016$/kW-year) [3]	NQC Peak Factor [4]	RA Revenue ($/kW-year)[5]
Large Solar In-State	242.19	47%	16.53
Large Solar Out-State	183.17	47%	16.53
Small Solar In-State	334.80	47%	16.53
Solar Thermal In-State	551.55	90%	31.66
Wind In-State	239.14	17%	5.98
Wind Out-State	223.88	45%	15.83
Pumped Storage In-State	407.91	100%	35.18

Need for additional analysis

The Base Case assumptions generally leaned to underestimate the value the pumped storage is reasonably able to provide. They provided a starting point of the studies, however, to help focus further study. As a result, the ISO committed to analyze additional sensitivity cases to assess the costs and benefits of the bulk energy storage resource in supporting integration of high penetration renewable energy in the ISO market, which is the subject of this addendum. These parameters do not affect the consideration of locational benefits of the various sites considered in the 2016-2017 Transmission Plan analysis; locational benefits did not receive further study in this sensitivity analysis.

3. Objectives of Further Study in 2017

The objective of the further study conducted in 2017 was to address the additional sensitivity analysis identified as needed in the 2016-2017 transmission planning process.

First, the Default Scenario was updated after the initial results were presented to the stakeholders in the 2016-2017 transmission planning process, changing the import from out-of-state RPS resources:

[3] See http://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Electric_Power_Procurement_and_Generation/LTPP/DRAFT_RESOLVE_Inputs_2016-12-21.xlsx,

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

[4] See https://www.caiso.com/Documents/2012TACAreaSolar-WindFactors.xls and https://www.wecc.biz/Reliability/2024-Common-Case.zip

[5] See http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442452221

- The study assumes that 70% of out-of-state RPS generation needs to be imported into the CAISO
- The Default Scenario in 2016-2017 TPP allows the import to be exported back
- This update changes the RPS import into Category 1 and 2 RPS, which has to stay in the CAISO
- The change reduces allowed net export when there is curtailment of renewable generation in the CAISO.

Those additional sensitivity analyses focused on the following assumptions:

- Dispatchability of CHP resource (The updated Default Scenario assumed 50% of CHP resources are dispatchable – this sensitivity assumes all CHP is non-dispatchable.)
- Level of AAEE (The updated Default Scenario assumed the 2015 IEPR Mid-AAEE will be doubled in 2030 – this sensitivity assumes the 2015 IEPR Mid-AAEE forecast for 2026)
- Prices of renewable curtailment (the updated Default Scenario assumed that the first 200 GWh renewable will be curtailed at -$15/MWh, additional 12,400 GWh renewable will be curtailed at -$25/MWh, the rest at -$300/MWh. The curtailment in the Default case did not go beyond 3,000 GWh, so the -$300/MWh curtailment was never triggered.) This sensitivity assumes 4 tiers of curtailment price as noted below:

	Tier 1	**Tier 2**	**Tier 3**	**Tier 4**
Curtailment Price ($/MWh)	-15	-25	-50	-150
Max Curtailment (GWh)	200	1,300	500	All the rest

  So the effective renewable curtailment prices in this sensitivity case is lower than that in the Default Scenario.

The results of both the update to the Default Scenario and the further sensitivities are provided in this report.

4. Summary of Results

The study results from the 2016-2017 analysis and the results of the further sensitivity analysis are set out in the attachment.[6]

Based on the results of the initial study and further analysis, it can be concluded that:

[6] Also see http://www.caiso.com/Documents/Day2_ISO-Presentation_2017-2018TransmissionPlanningProcess_PreliminaryReliabilityResults.pdf

- The new pumped storage resources brought significant benefits to the system, including
    - reducing renewable curtailment and renewable overbuild needed to meet the 50% RPS target;
    - making use of the recovered renewable energy from curtailment as well as low cost out-of-state energy during hours without renewable curtailment;
    - providing lower cost energy during the net peak hours in early evening and flexibility to provide ancillary services and load-following and to help follow the load in the morning and evening ramping processes; and,
    - lowering system production cost to serve the load.
- The new pumped storage resources also took advantage of low cost out-of-state energy during hours without renewable curtailment. They also resulted in higher net import to California and slightly increased CO2 emissions[7] within California footprint.
- 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, production cost and revenue requirement.
- Compared to the study with 50% RPS in 2015-2016 TPP, results of this study show significantly lower renewable curtailment, mainly due to the following assumptions:
    - Retirement of Diablo Canyon and non-dispatchable CHP resources;
    - Dispatchability of 50% of CHP resources; and
    - Lower load forecast together with higher AAEE, and the resulted lower renewable energy needed to achieve the 50% RPS target
- Because of low renewable curtailment, the effectiveness of the pumped storage resources in reducing renewable curtailment, renewable overbuild, and production costs was limited in this study.
- The net market revenue of the pumped storage resources provided only a portion of the levelized annual revenue requirements. Developing pumped storage resources would need other sources of revenue streams, which could be developed through policy decisions.

[7] The slightly increased CO2 emissions result from the assumptions regarding the GHG adder relied upon in the study and the assumption that the pumped storage would pump when low cost energy is available regardless of source. Higher GHG adders or other restrictions on these pumping opportunities would mute this impact, albeit with some corresponding impact on benefits.

- The results of the study are sensitive to the assumptions, especially the dispatchability of the CHP resources, the level and AAEE, and the prices of renewable curtailment. The conclusions about the benefits and costs of the pumped storage resources will change should the assumptions change.

- When all CHP resources are assumed to be non-dispatchable, the renewable curtailment as well as the needed renewable overbuild to meet the 50% RPS target increased significantly, as do the production costs. The pumped storage resources were able to take advantage of the higher curtailment and increased their net market revenue and benefits to the system. However, the sum of net market revenue and system benefits still fell short to meet the levelized revenue requirements of the pumped storage resources.

- With the AAEE reduced to the 2015 IEPR forecasted level (see Table 1), retail sales of electricity increases and more renewable energy is needed to meet the 50% RPS target. Then more solar is added to the RPS portfolio. As a result, more solar generation was curtailed in the simulations and more overbuild was needed. The production cost also increased because more flexible non-renewable resources were utilized to support the renewable generation. The pumped storage resources were able to take advantage of more renewable curtailment to increase their net market revenue and their contribution to the system.

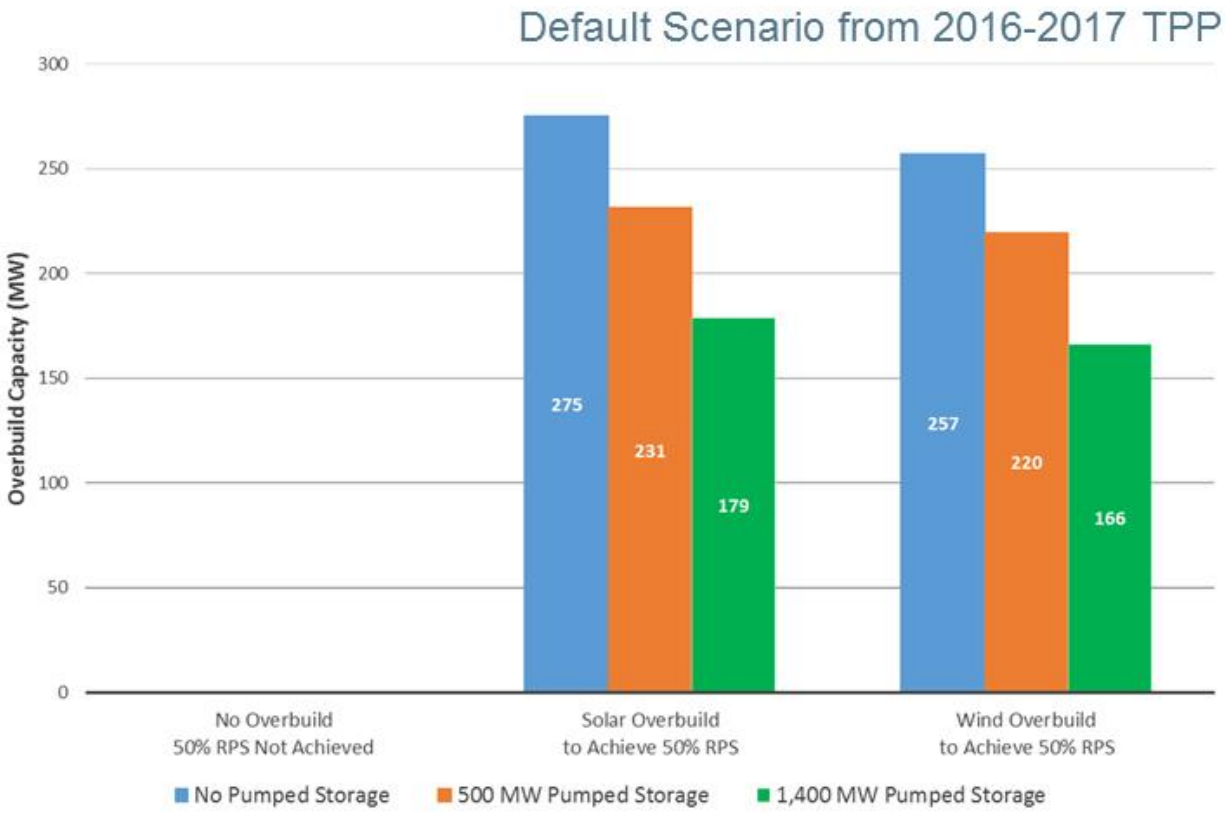
- With lower renewable curtailment prices, renewable curtailment was reduced, so was the needed renewable overbuild, the system production cost, the pumped storage resources' net market revenue and their benefits to the system.

Attachment
Slide Deck – September 20, 2017 (Revised)
Transmission Planning Process
Stakeholder Session

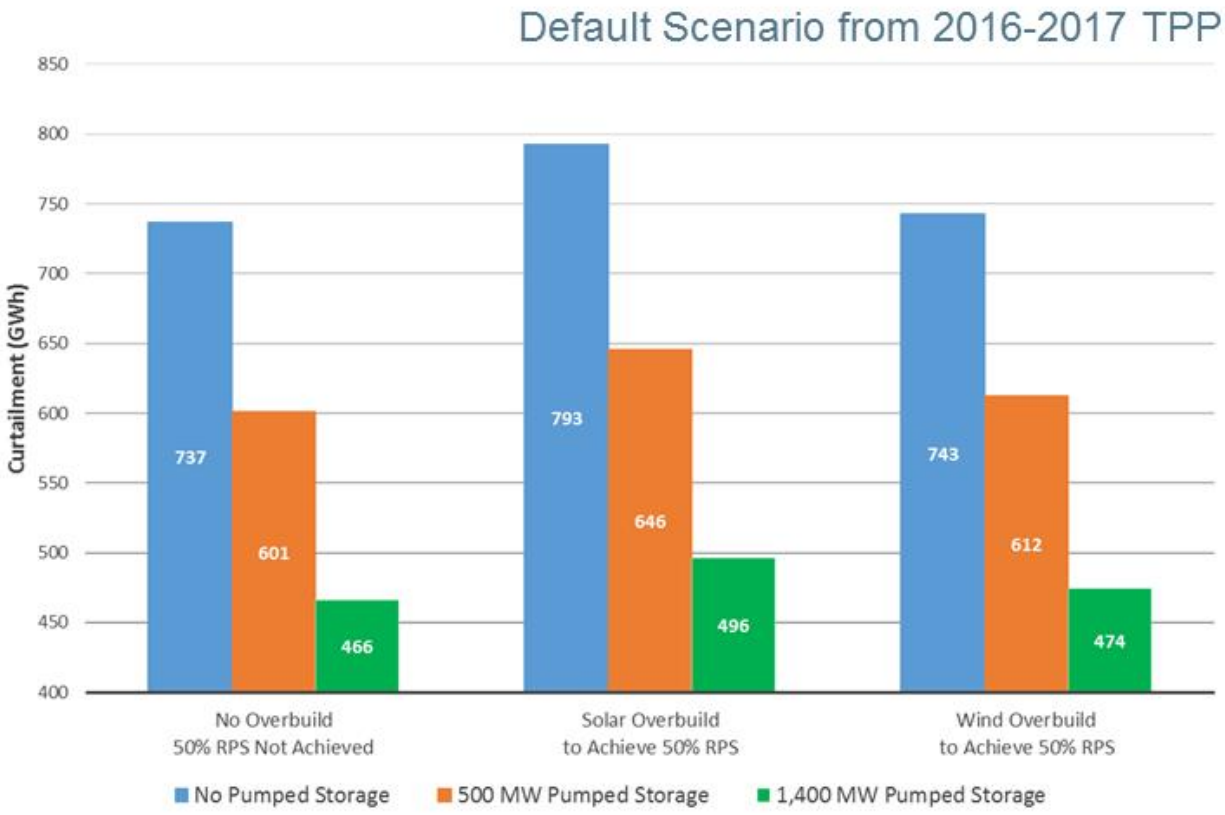
Recap of results from 2016-2017 TPP

– Default Scenario

Capacity of renewable overbuild to achieve the 50% RPS target

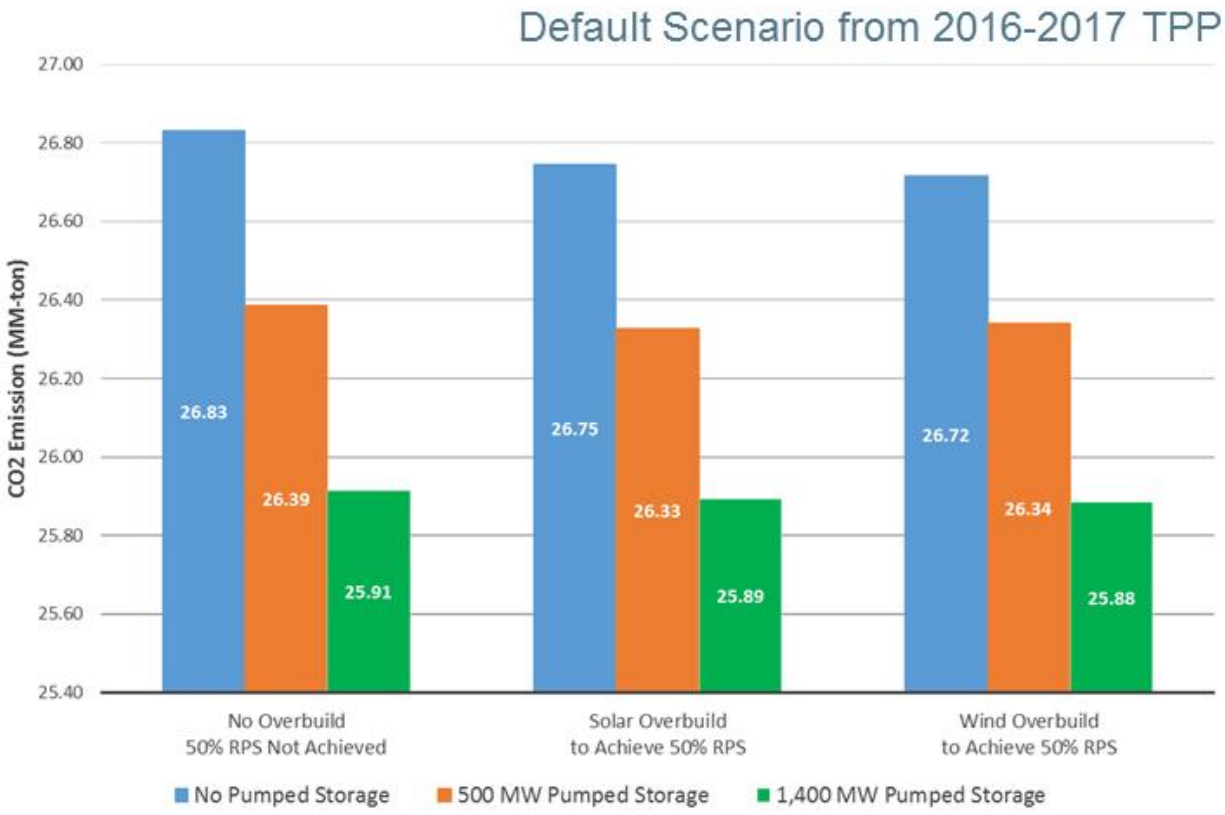


California renewable generation curtailment



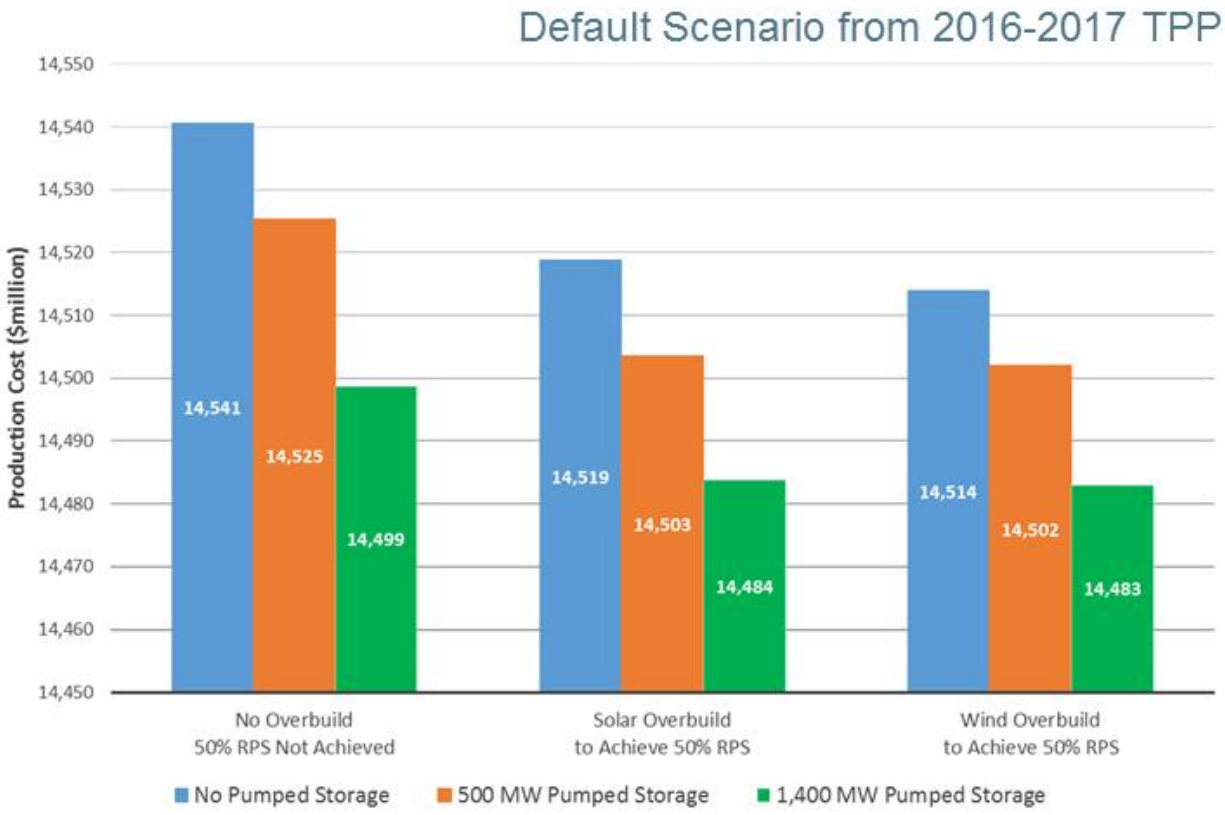
Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.

California CO2 emission



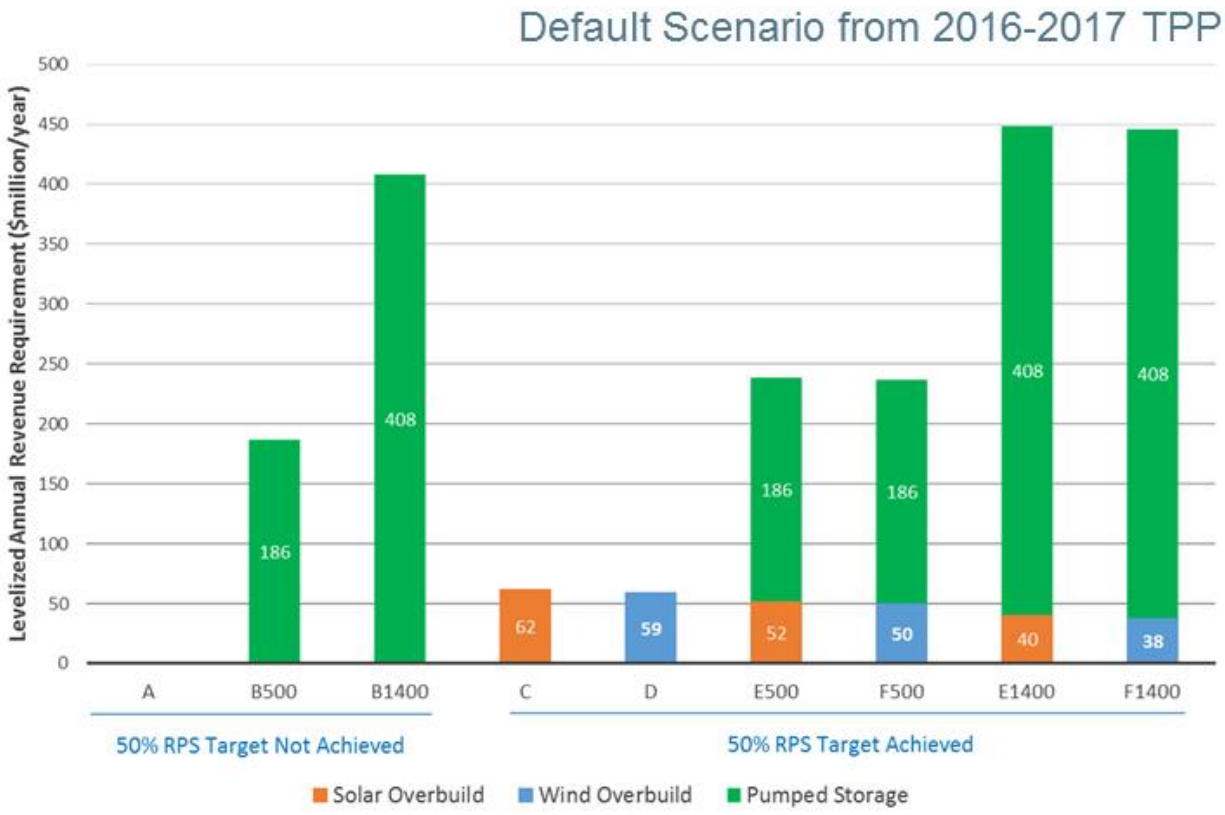
CA CO2 Emission includes the CO2 emission from net import

WECC annual production cost



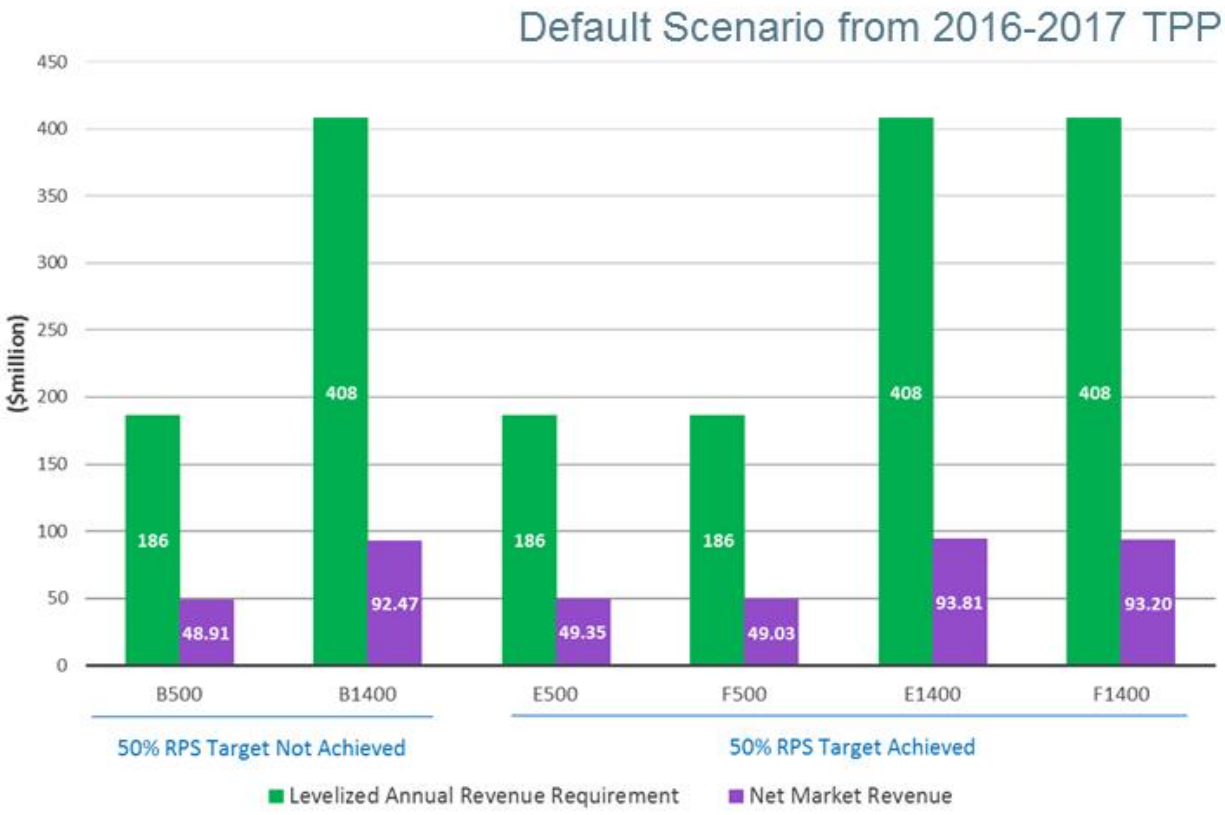
Production cost includes start-up, fuel and VOM cost, but not CO2 cost.

Levelized annual revenue requirements of renewable overbuild and the pumped storage resources



Cost of the 1,400 MW pumped storage is discounted by 20% based on economies of scale assumption

Pumped storage levelized annual revenue requirements and net market revenues of 2026



Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation

Summary of annual results by case

Default Scenario from 2016-2017 TPP

	No Pumped Storage			500 MW Pumped Storage			1,400 MW Pumped Storage		
Case	A	C	D	B500	E500	F500	B1400	E1400	F1400
Renewable Curtailment (GWh)	737	793	743	601	646	612	466	496	474
Curtailment Frequency (hours)	292	320	305	251	268	253	211	219	207
CA CO2 Emission (MM-ton)	26.83	26.75	26.72	26.39	26.33	26.34	25.91	25.89	25.88
CA CO2 Emission ($million)	606	604	604	596	595	595	585	585	585
Production Cost ($million)									
WECC	14,541	14,519	14,514	14,525	14,503	14,502	14,499	14,484	14,483
CA	2,999	2,989	2,986	2,952	2,945	2,946	2,900	2,898	2,897
Renewable Overbuild and Pumped Storage Capacity (MW)									
Solar		275			231			179	
Wind			257			220			166
Pumped Storage				500	500	500	1,400	1,400	1,400
Levelized Annual Revenue Requirement of Renewable Overbuild and Pumped Storage ($million/year)									
Solar		62.11			52.17			40.43	
Wind			58.89			50.41			38.04
Pumped Storage				186.37	186.37	186.37	407.61	407.61	407.61
Sum		*62.11*	*58.89*	*186.37*	*238.54*	*236.78*	*407.61*	*448.04*	*445.65*
Pumped Storage Net Market Revenue ($million)				48.91	49.35	49.03	92.47	93.81	93.20

Notes:

1. Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.
2. CA CO2 Emission includes the CO2 emission from net import.
3. CO2 cost is $22.59/M-ton.
4. Production cost includes start-up, fuel and VOM cost, but not CO2 cost.
5. Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.

Findings of system benefits

- Compared to the study with 50% RPS in 2015-2016 TPP, results of this study show significantly lower renewable curtailment, mainly due to
  - Retirement of Diablo Canyon and non-dispatchable CHP resources
  - Dispatchability of 50% of CHP resources
  - Lower load forecast together with higher AAEE, and the resulted lower renewable energy needed to achieve the 50% RPS target

Findings of system benefits (cont.)

- Because of low renewable curtailment, the effectiveness of the pumped storage resources in reducing renewable curtailment, CO2 emission and production costs is limited
- Besides lower curtailment, the net market revenues of the pumped storages are also affected by the higher renewable curtailment prices

Findings of system benefits (cont.)

- The net market revenue of the pumped storage resources provides only a portion of the levelized annual revenue requirements
- Developing pumped storage resources would need other sources of revenue streams, which could be developed through policy decisions

Findings of system benefits (cont.)

- The following annual system cost reductions (benefits) are not included in the net market revenue, but may be attribute to the pumped storage resources

	500 MW Pumped Storage		1,400 MW Pumped Storage	
Case	E500	F500	E1400	F1400
CA CO2 Emission ($million)	-9.45	-8.50	-19.25	-18.79
Production Cost ($million)				
WECC	-15.30	-11.96	-35.03	-30.96
CA	-44.05	-39.59	-91.49	-89.01
Levelized Annual Revenue Requirement of Renewable Overbuild ($million/year)				
Solar	-9.94		-21.68	
Wind		-8.48		-20.85

Next steps

- The results of the study are sensitive to the assumptions, especially those listed in the tables on slide 6 and 7
- There are uncertainties in some of these assumptions
- The conclusions about the benefits and costs of the pumped storage resources could change should the assumptions change in the future
- The ISO will conduct sensitivity analyses at least on
  - Dispatchability of CHP resource
  - Level of AAEE
  - Prices of renewable curtailment

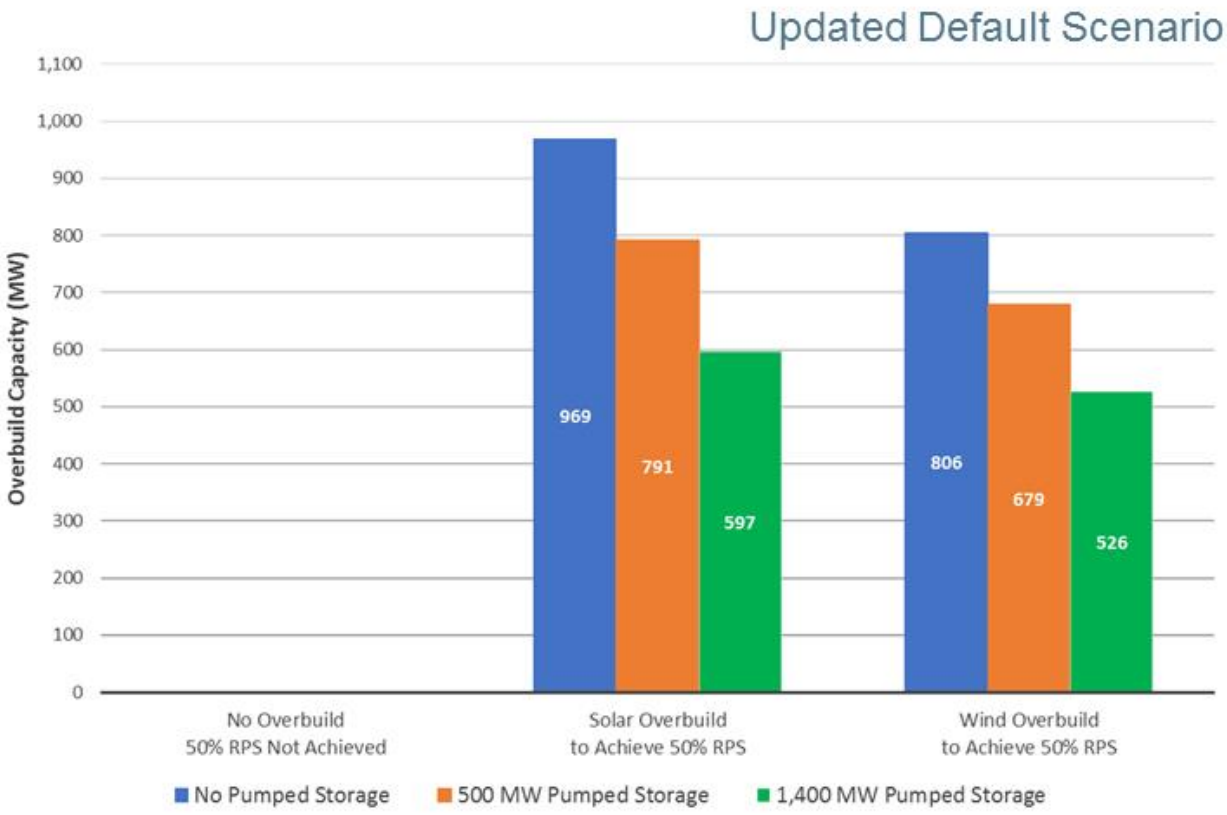
New updates and sensitivities

Update to the Default Scenario

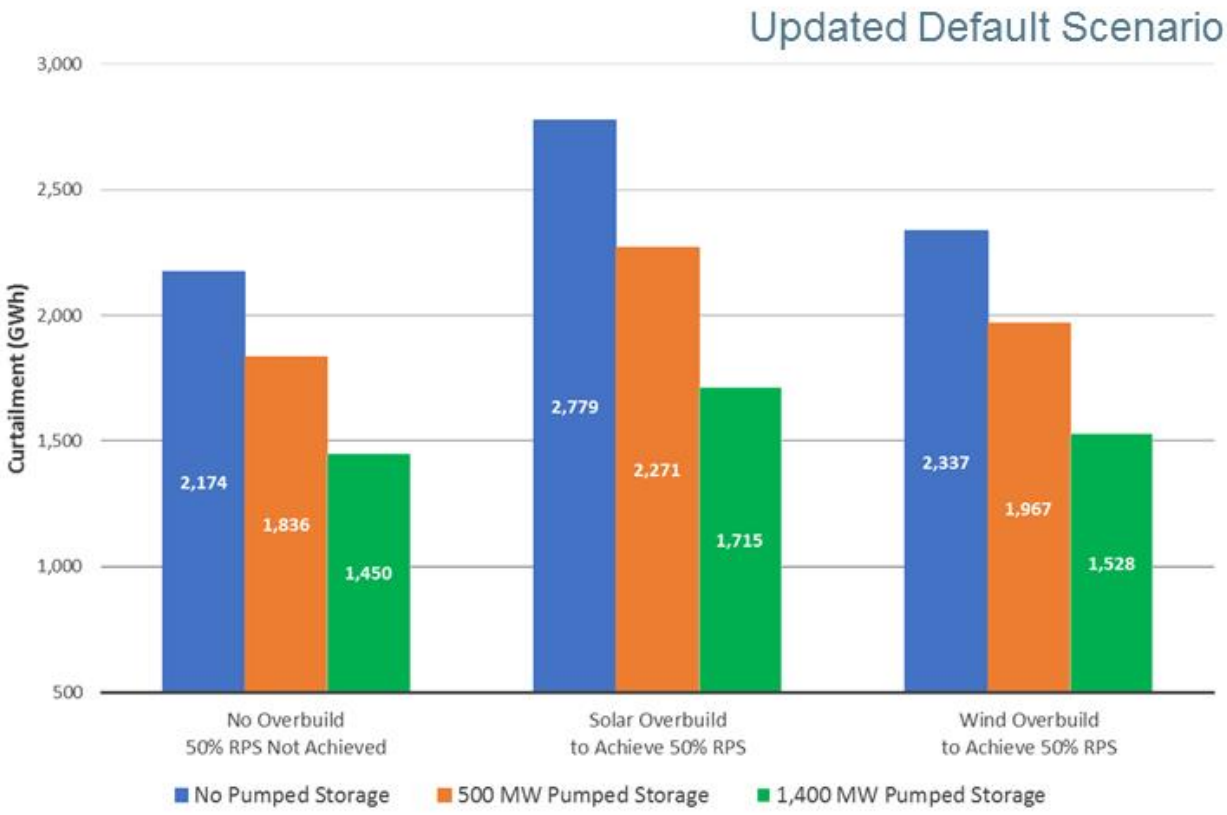
The Default Scenario was updated after the initial results were presented to the stakeholders

- Changing the import from out-of-state RPS resources
  - It assumes that 70% of out-of-state RPS generation needs to be imported into the CAISO
  - The Default Scenario in 2016-2017 TPP allows the import to be exported back
  - This update changes the RPS import into Category 1 and 2 RPS, which has to stay in the CAISO
  - The change reduces allowed net export when there is curtailment of renewable generation in the CAISO

Capacity of renewable overbuild to achieve the 50% RPS target

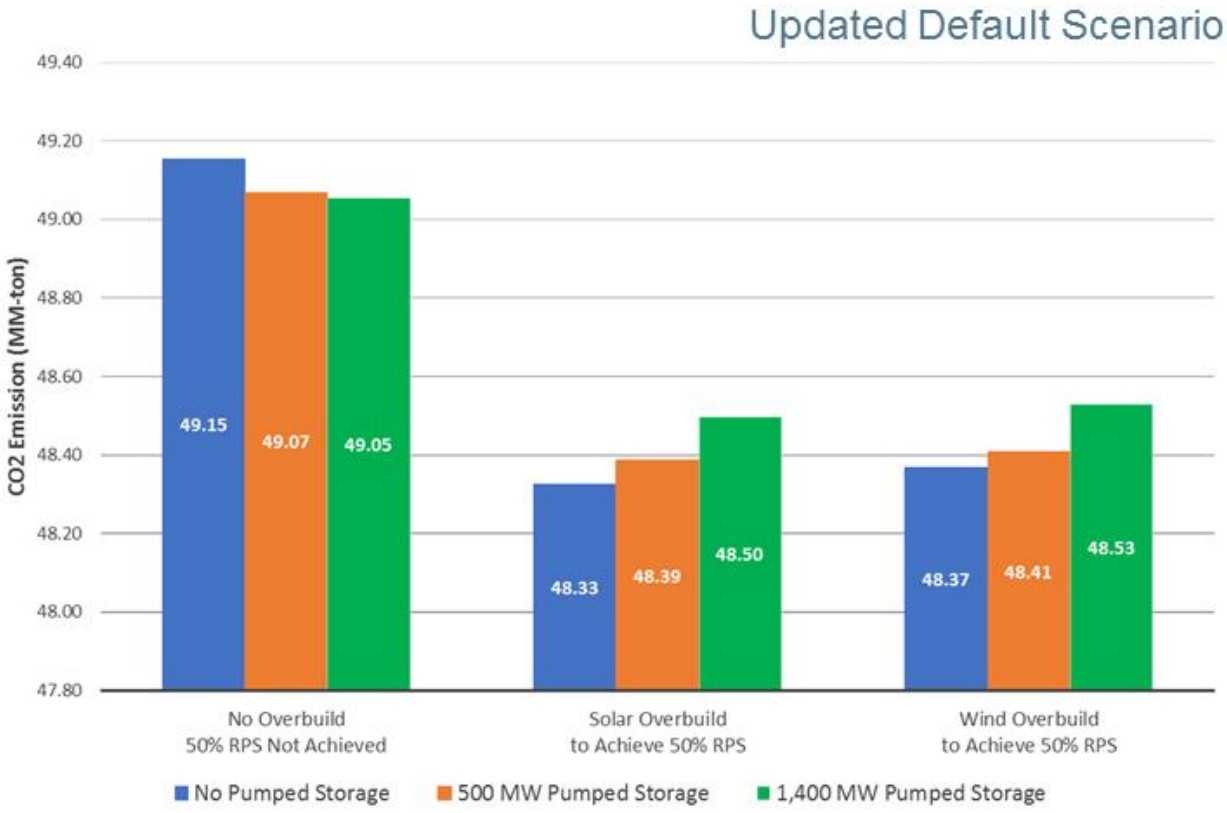


California renewable generation curtailment



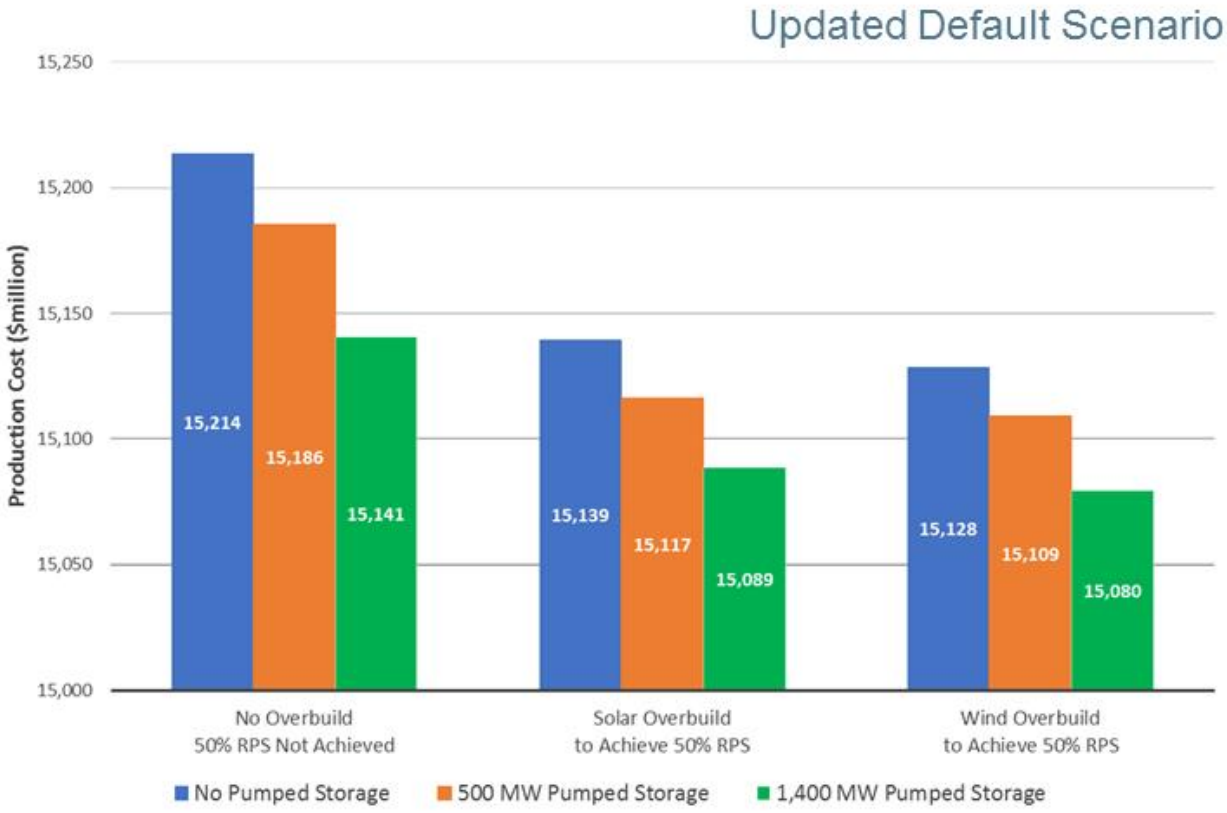
Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.

California CO2 emission



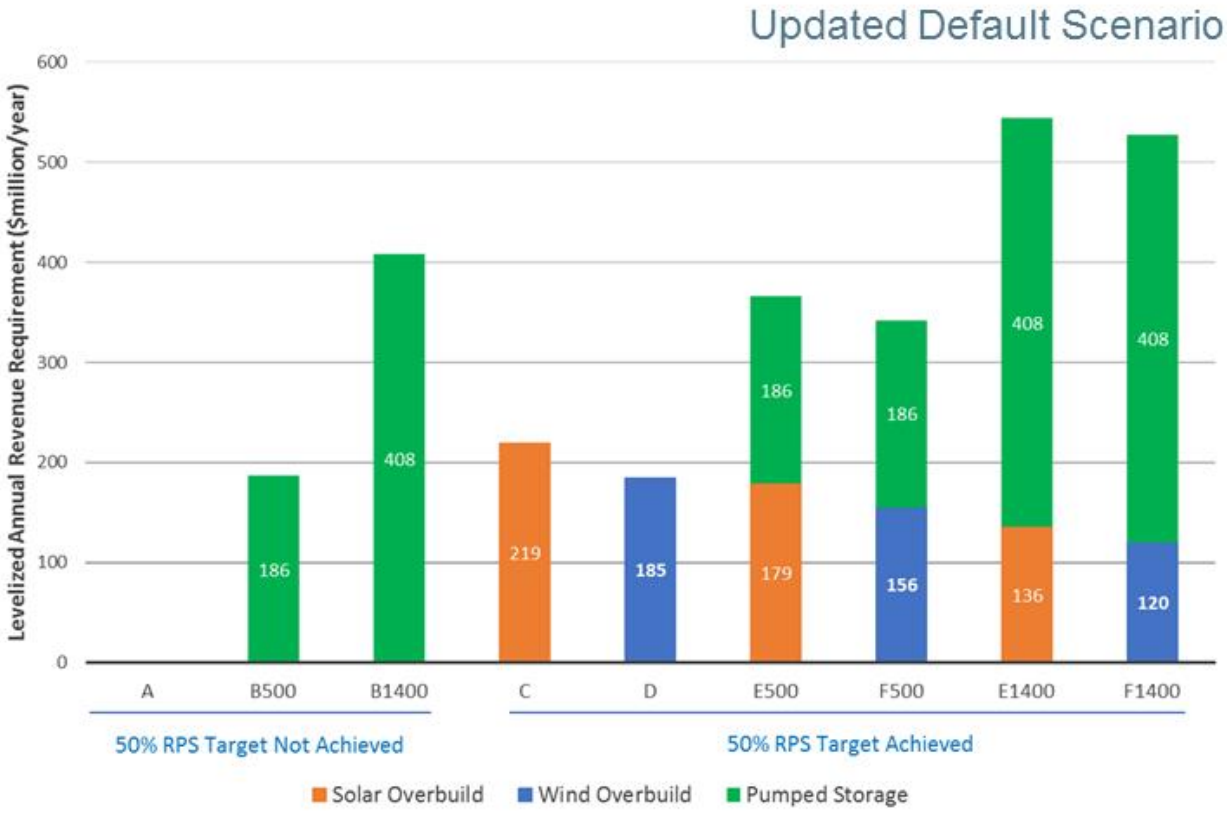
CA CO2 Emission includes the CO2 emission from net import

WECC annual production cost



Production cost includes start-up, fuel and VOM cost, but not CO2 cost.

Levelized annual revenue requirements of renewable overbuild and the pumped storage resources



Cost of the 1,400 MW pumped storage is discounted by 20% based on economies of scale assumption

Pumped storage levelized annual revenue requirements, net market revenues and system benefits of 2026

Updated Default Scenario

Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.
System benefits includes reduction of CO2 emission cost, WECC production cost and renewable overbuild cost

Summary of annual results by case

Updated Default Scenario

	No Pumped Storage			500 MW Pumped Storage			1,400 MW Pumped Storage		
Case	A	C	D	B500	E500	F500	B1400	E1400	F1400
Renewable Curtailment (GWh)	2,174	2,779	2,337	1,836	2,271	1,967	1,450	1,715	1,528
Curtailment Frequency (hours)	672	806	722	601	704	631	487	554	502
CA CO2 Emission (MM-ton)	49.2	48.3	48.4	49.1	48.4	48.4	49.1	48.5	48.5
CA CO2 Emission ($million)	1,110	1,092	1,093	1,108	1,093	1,094	1,108	1,096	1,096
Production Cost ($million)									
WECC	15,214	15,139	15,128	15,186	15,117	15,109	15,141	15,089	15,080
CA	3,583	3,543	3,534	3,543	3,495	3,494	3,465	3,436	3,429
Renewable Overbuild and Pumped Storage Capacity (MW)									
Solar		969			791			597	
Wind			806			679			526
Pumped Storage				500	500	500	1,400	1,400	1,400
Levelized Annual Revenue Requirement of Renewable Overbuild and Pumped Storage ($million/year)									
Solar		219			179			136	
Wind			185			156			120
Pumped Storage				186	186	186	408	408	408
Sum		*219*	*185*	*186*	*365*	*342*	*408*	*544*	*528*
Pumped Storage Net Market Revenue ($million)				58	63	60	118	127	121
System Benefits by the Pumped Storage Resource ($million)				28	63	49	73	134	114

Notes:

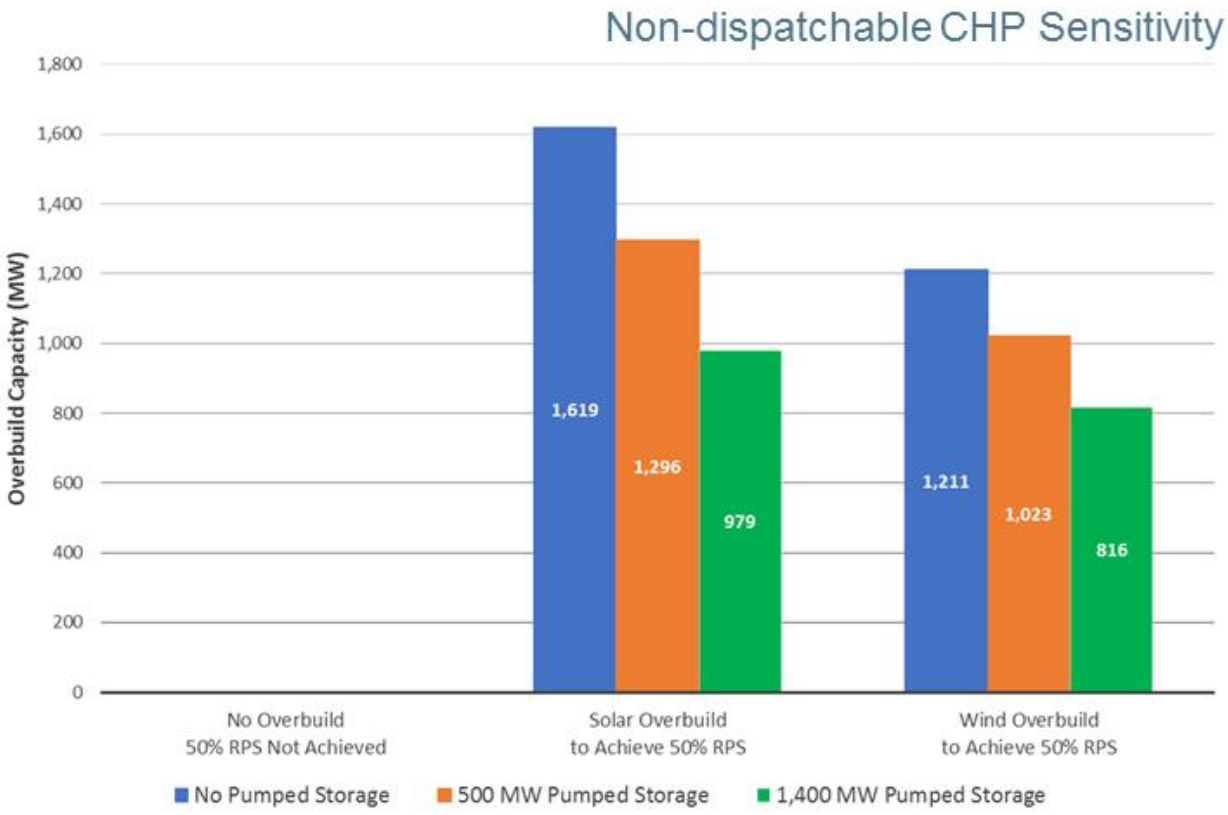
1. Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.
2. CA CO2 Emission includes the CO2 emission from net import.
3. CO2 cost is $22.59/M-ton.
4. Production cost includes start-up, fuel and VOM cost, but not CO2 cost.
5. Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.

Default Scenario with non-disptachable CHP

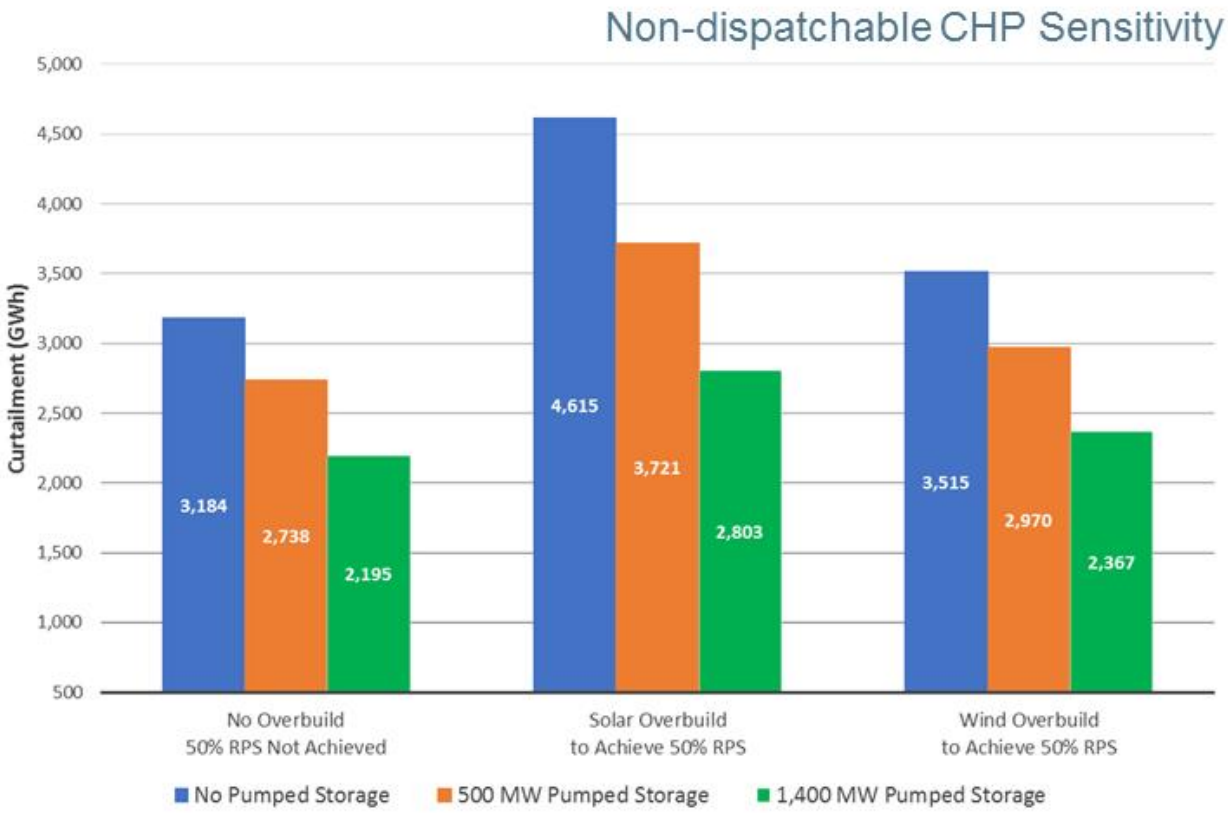
The sensitivity of non-dispatchable CHP

- Based on the updated Default Scenario, which assumes 50% of CHP resources are dispatchable
- In this sensitivity all CHP is assumed to be non-dispatchable

Capacity of renewable overbuild to achieve the 50% RPS target

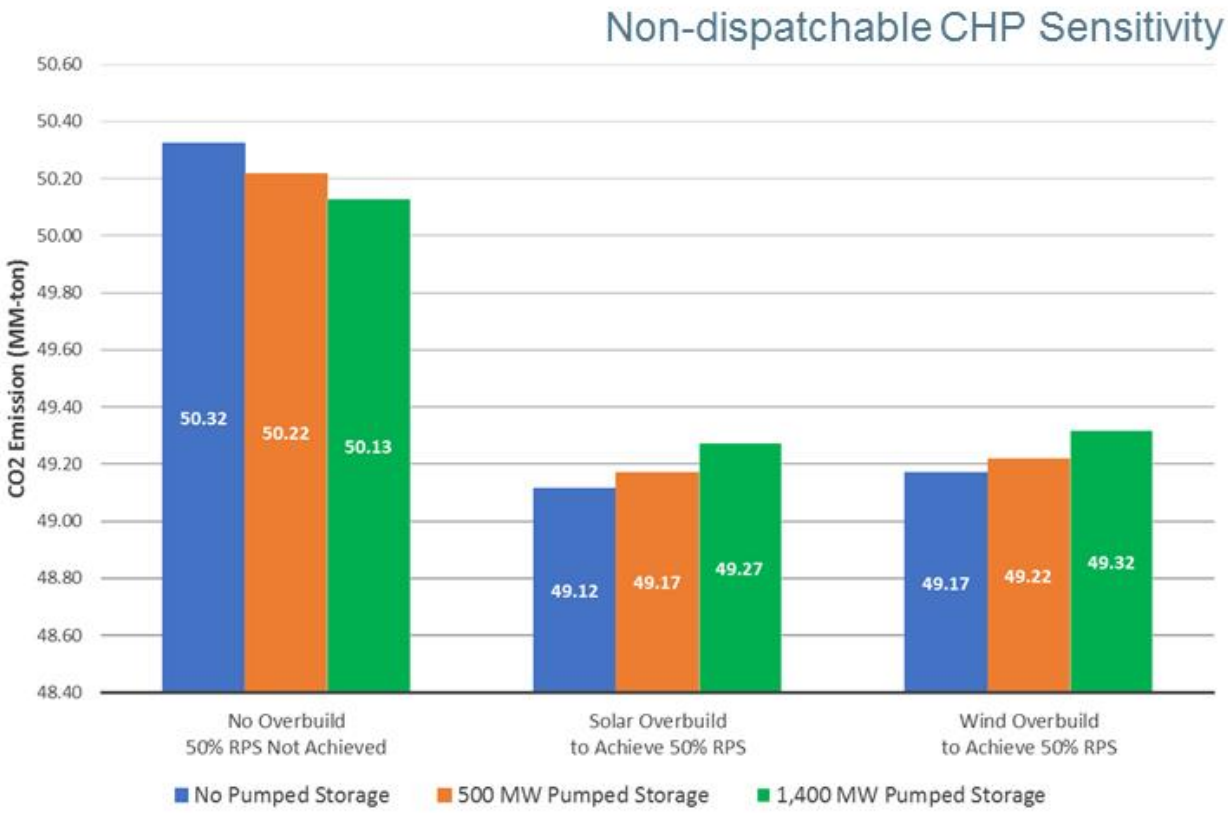


California renewable generation curtailment



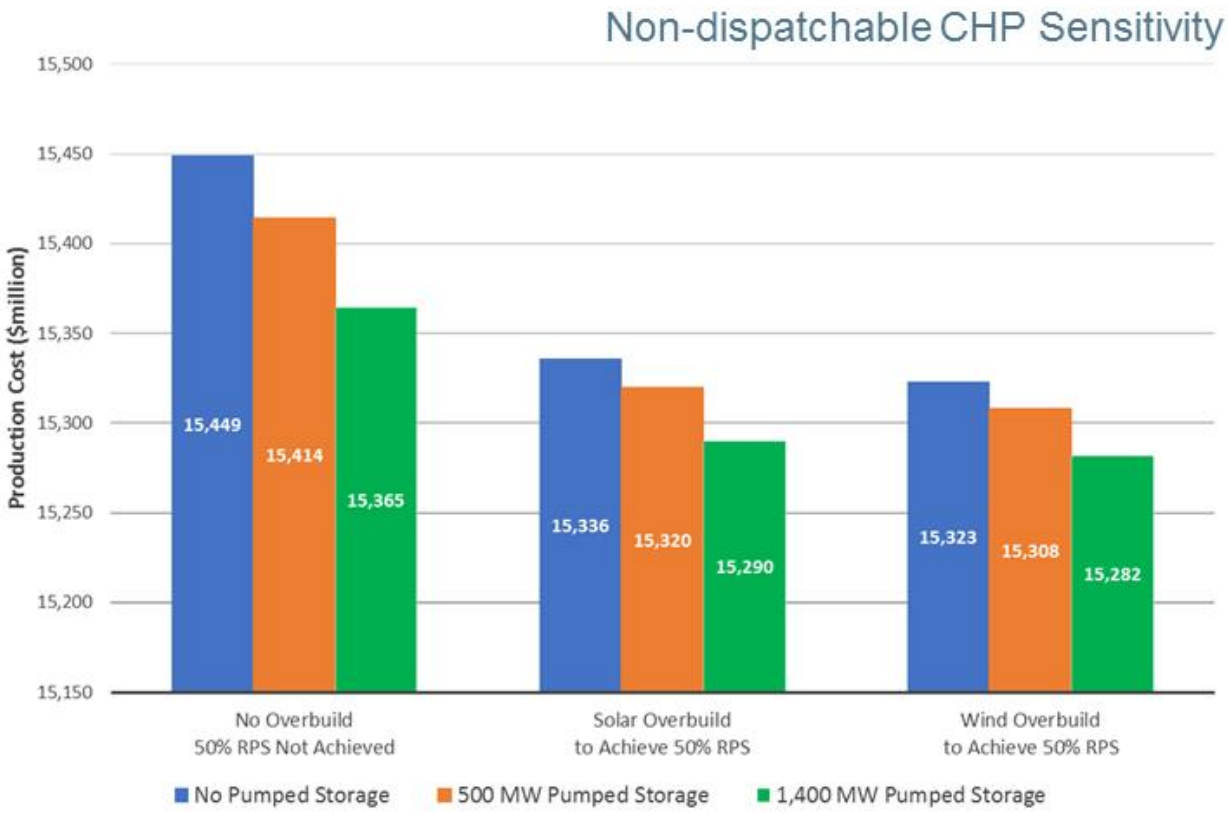
Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.

California CO2 emission



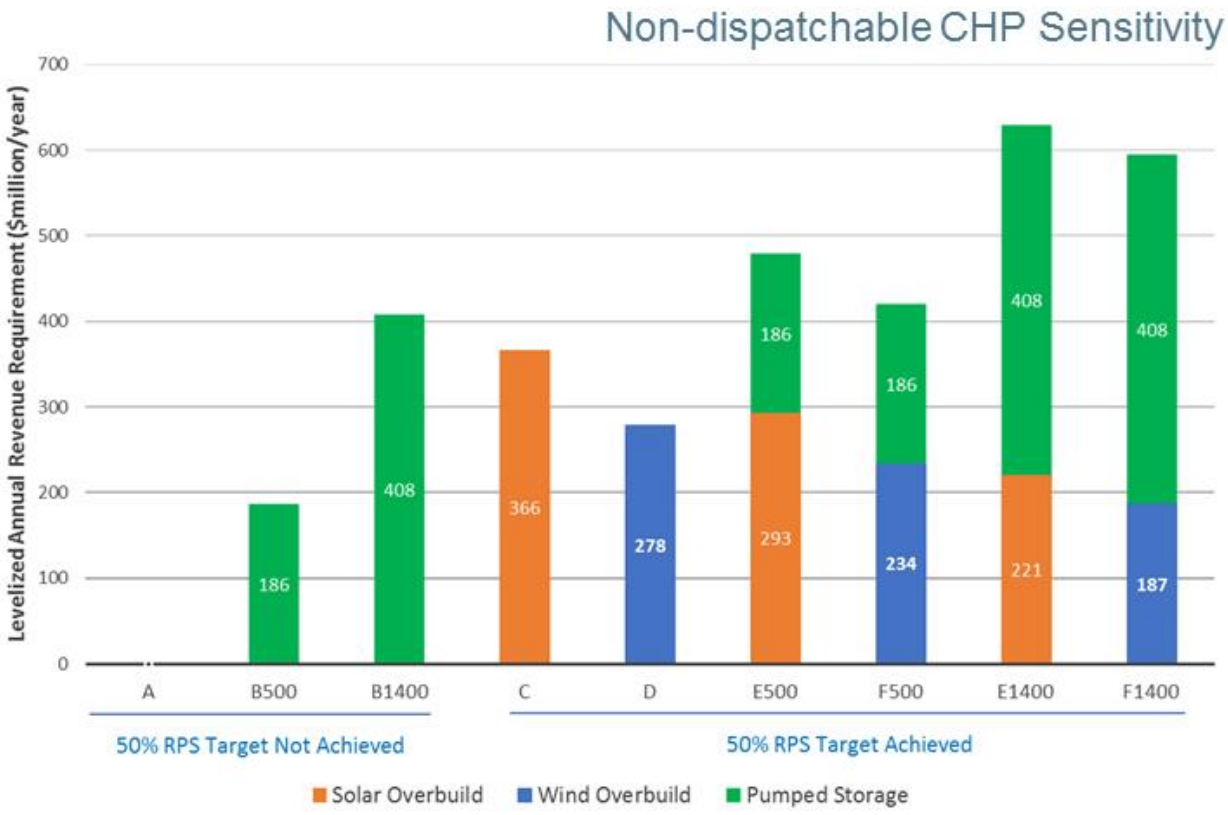
CA CO2 Emission includes the CO2 emission from net import

WECC annual production cost



Production cost includes start-up, fuel and VOM cost, but not CO2 cost.

Levelized annual revenue requirements of renewable overbuild and the pumped storage resources



Cost of the 1,400 MW pumped storage is discounted by 20% based on economies of scale assumption

Pumped storage levelized annual revenue requirements, net market revenues and system benefits of 2026

Non-dispatchable CHP Sensitivity

Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.
System benefits includes reduction of CO2 emission cost, WECC production cost and renewable overbuild cost

Summary of annual results by case

Non-dispatchable CHP Sensitivity

	No Pumped Storage			500 MW Pumped Storage			1,400 MW Pumped Storage		
Case	A	C	D	B500	E500	F500	B1400	E1400	F1400
Renewable Curtailment (GWh)	3,184	4,615	3,515	2,738	3,721	2,970	2,195	2,803	2,367
Curtailment Frequency (hours)	911	1,176	964	787	990	830	672	786	695
CA CO2 Emission (MM-ton)	50.3	49.1	49.2	50.2	49.2	49.2	50.1	49.3	49.3
CA CO2 Emission ($million)	1,137	1,110	1,111	1,134	1,111	1,112	1,132	1,113	1,114
Production Cost ($million)									
WECC	15,449	15,336	15,323	15,414	15,320	15,308	15,365	15,290	15,282
CA	3,929	3,861	3,862	3,882	3,830	3,825	3,808	3,774	3,768
Renewable Overbuild and Pumped Storage Capacity (MW)									
Solar		1,619			1,296			979	
Wind			1,211			1,023			816
Pumped Storage				0	0	0	1,400	1,400	1,400
Levelized Annual Revenue Requirement of Renewable Overbuild and Pumped Storage ($million/year)									
Solar		366			293			221	
Wind			278			234			187
Pumped Storage				186	186	186	408	408	408
Sum		*366*	*278*	*186*	*479*	*420*	*408*	*629*	*595*
Pumped Storage Net Market Revenue ($million)				67	76	69	139	153	143
System Benefits by the Pumped Storage Resource ($million)				34	89	58	84	191	132

Notes:

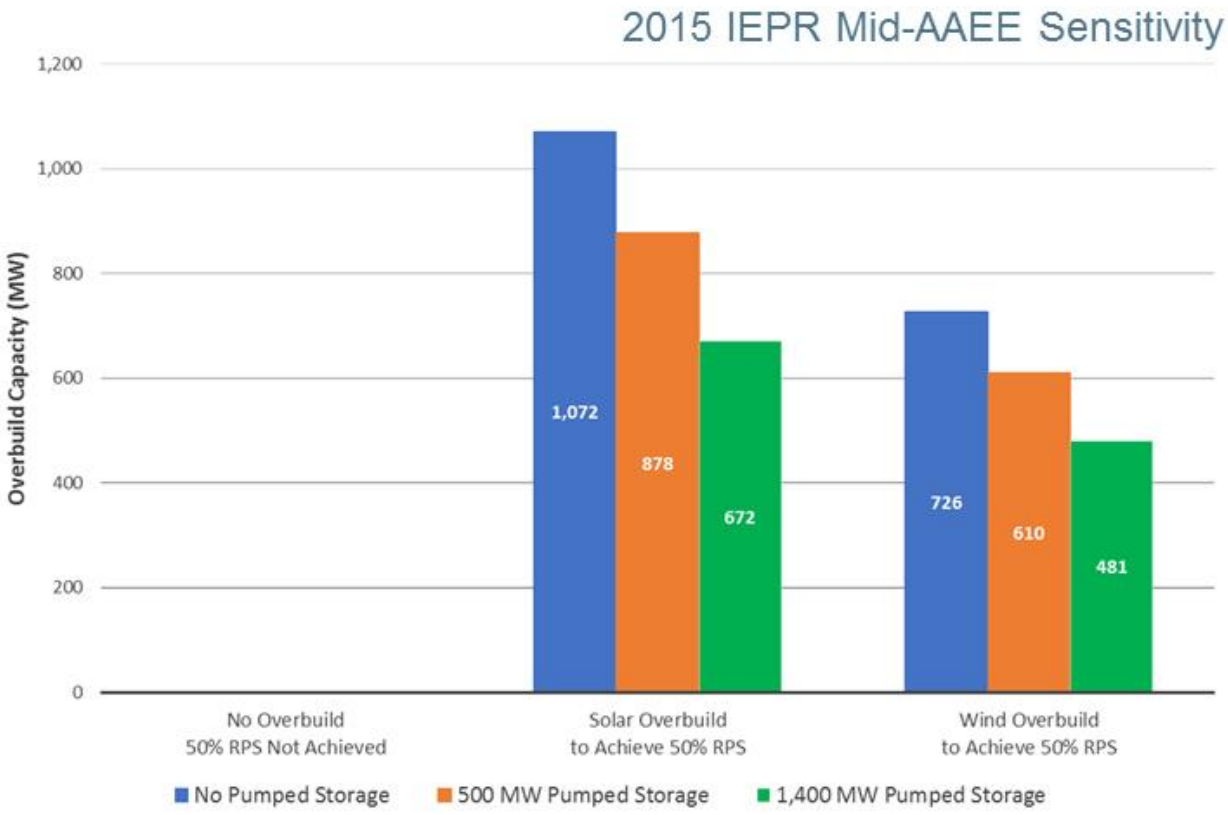
1. Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.
2. CA CO2 Emission includes the CO2 emission from net import.
3. CO2 cost is $22.59/M-ton.
4. Production cost includes start-up, fuel and VOM cost, but not CO2 cost.
5. Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.

Default Scenario with 2015 IEPR Mid-AAEE

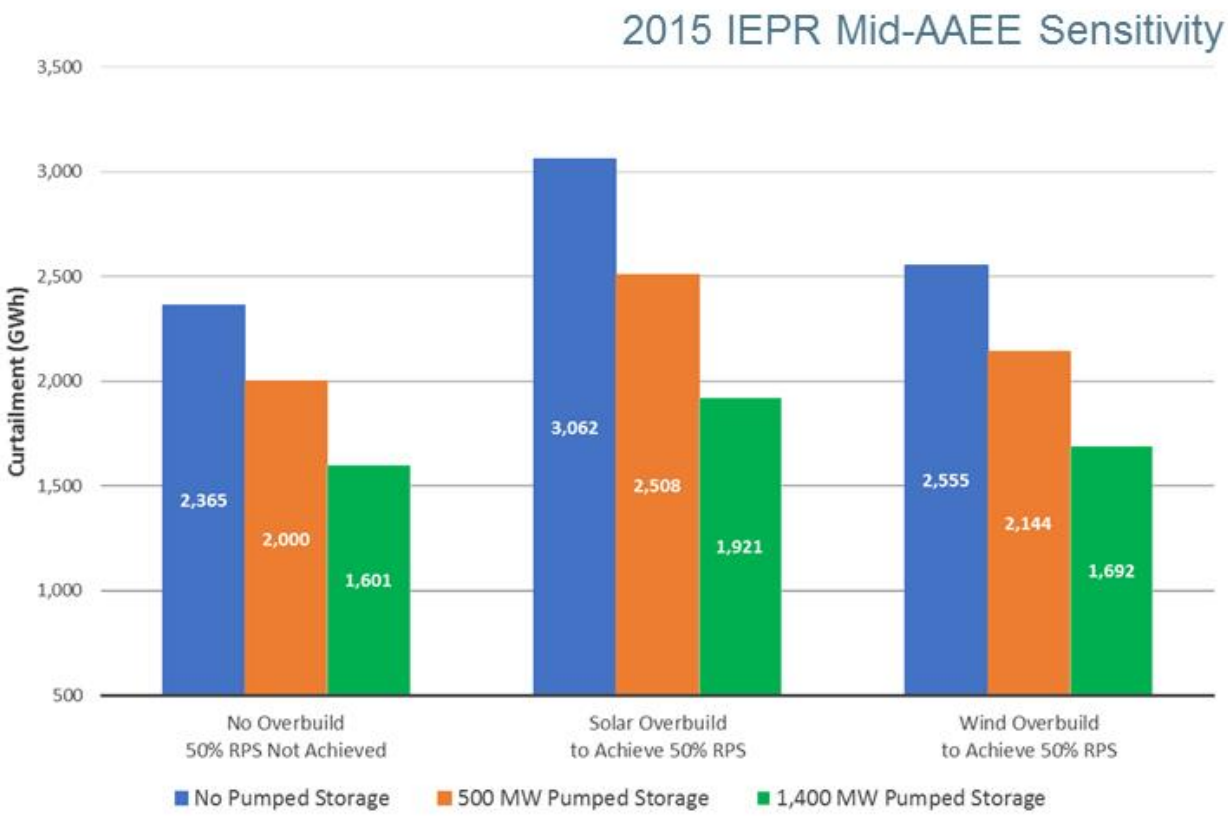
The case of non-dispatchable CHP

- Based on the updated Default Scenario, which assumes the 2015 IEPR Mid-AAEE will be doubled in 2030
- In this case the 2015 IEPR Mid-AAEE forecast for 2026 is used

Capacity of renewable overbuild to achieve the 50% RPS target

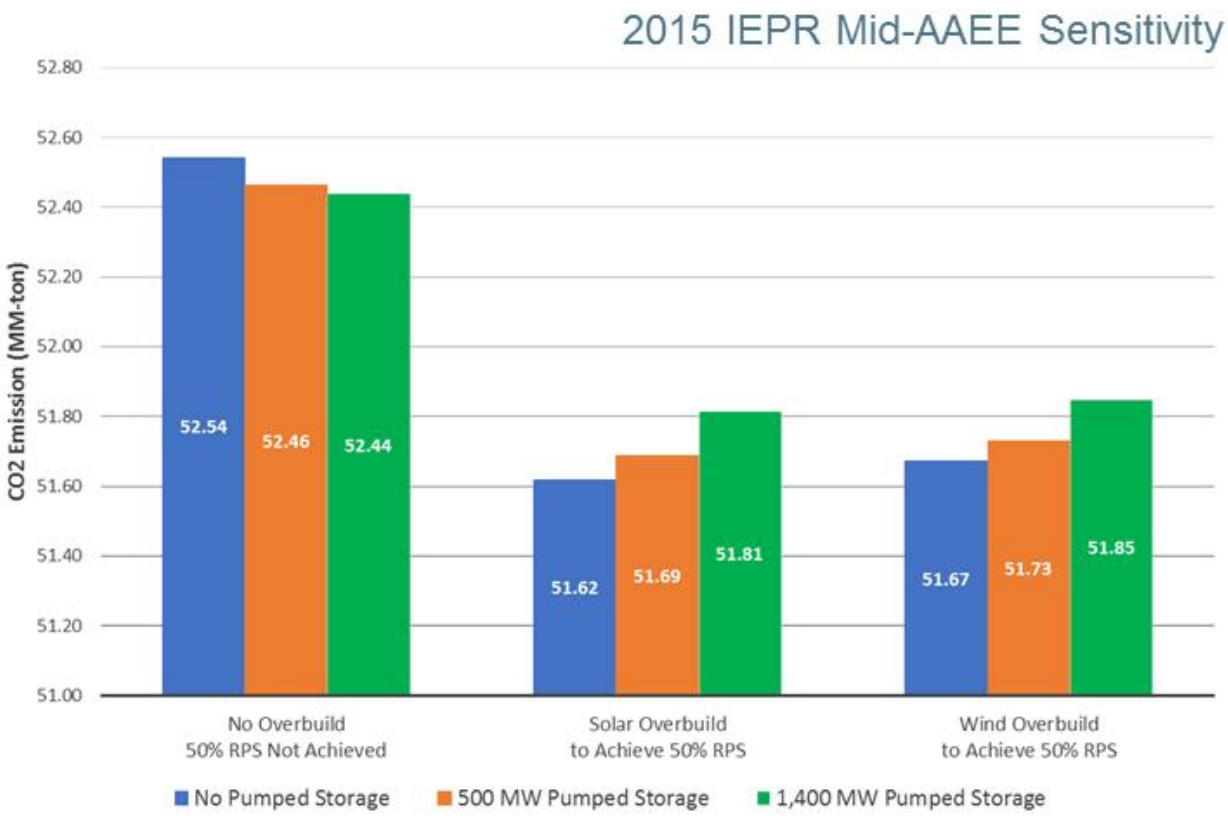


California renewable generation curtailment



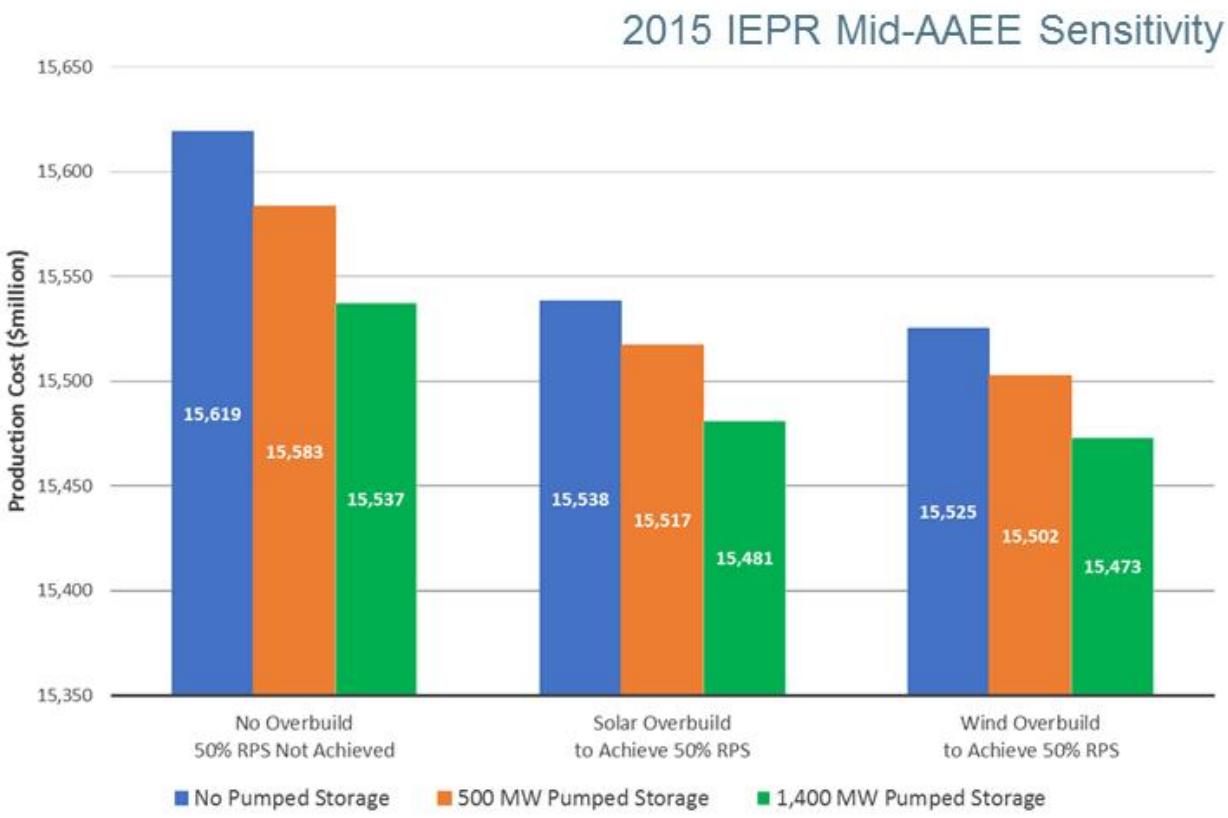
Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.

California CO2 emission



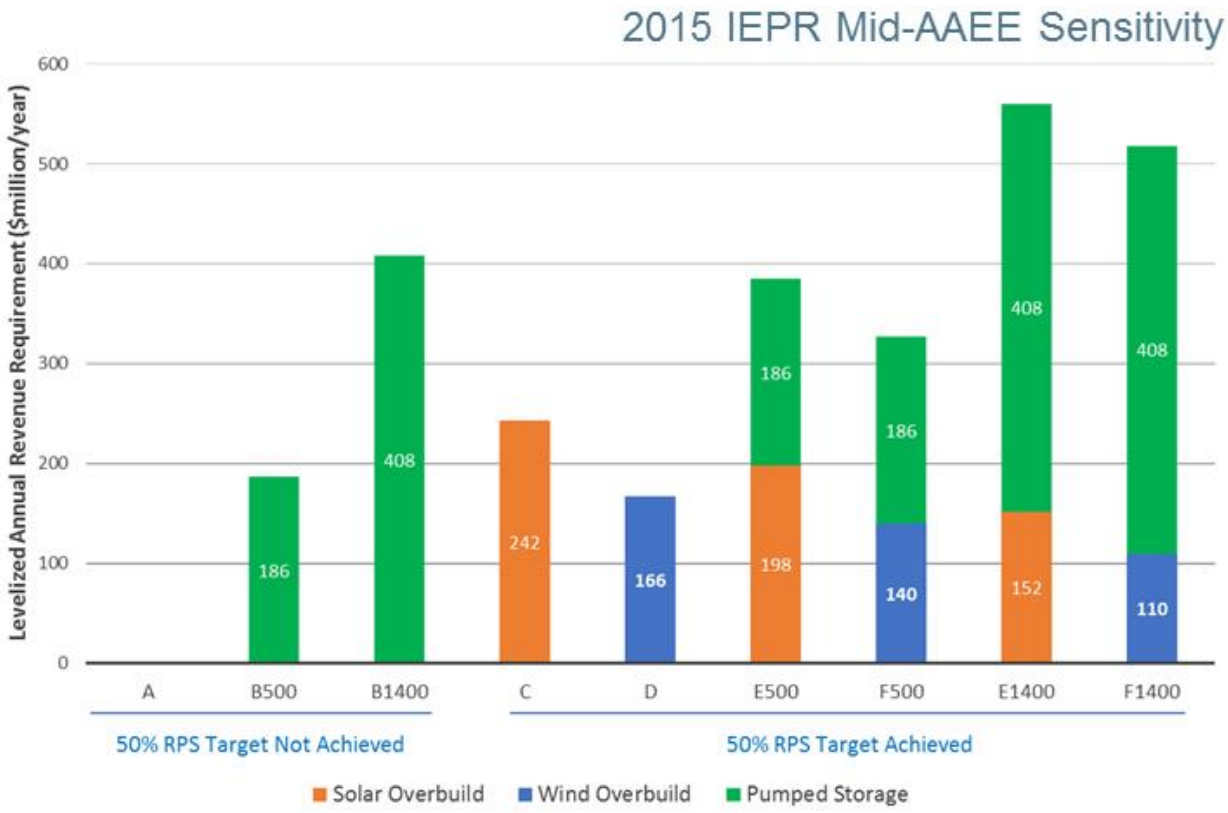
CA CO2 Emission includes the CO2 emission from net import

WECC annual production cost



Production cost includes start-up, fuel and VOM cost, but not CO2 cost.

Levelized annual revenue requirements of renewable overbuild and the pumped storage resources



Cost of the 1,400 MW pumped storage is discounted by 20% based on economies of scale assumption

Pumped storage levelized annual revenue requirements, net market revenues and system benefits of 2026

2015 IEPR Mid-AAEE Sensitivity

Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.
System benefits includes reduction of CO2 emission cost, WECC production cost and renewable overbuild cost

Summary of annual results by case

2015 IEPR Mid-AAEE Sensitivity

	No Pumped Storage			500 MW Pumped Storage			1,400 MW Pumped Storage		
Case	A	C	D	B500	E500	F500	B1400	E1400	F1400
Renewable Curtailment (GWh)	2,365	3,062	2,555	2,000	2,508	2,144	1,601	1,921	1,692
Curtailment Frequency (hours)	708	849	756	635	740	672	505	587	536
CA CO2 Emission (MM-ton)	52.5	51.6	51.7	52.5	51.7	51.7	52.4	51.8	51.8
CA CO2 Emission ($million)	1,187	1,166	1,167	1,185	1,168	1,169	1,185	1,170	1,171
Production Cost ($million)									
WECC	15,619	15,538	15,525	15,583	15,517	15,502	15,537	15,481	15,473
CA	3,899	3,857	3,848	3,846	3,815	3,803	3,770	3,740	3,733
Renewable Overbuild and Pumped Storage Capacity (MW)									
Solar		1,072			878			672	
Wind			726			610			481
Pumped Storage				0	0	0	1,400	1,400	1,400
Levelized Annual Revenue Requirement of Renewable Overbuild and Pumped Storage ($million/year)									
Solar		242			198			152	
Wind			166			140			110
Pumped Storage				186	186	186	408	408	408
Sum		*242*	*166*	*186*	*384*	*326*	*408*	*560*	*518*
Pumped Storage Net Market Revenue ($million)				61	66	61	125	136	129
System Benefits by the Pumped Storage Resource ($million)				36	65	49	82	147	108

Notes:

1. Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.
2. CA CO2 Emission includes the CO2 emission from net import.
3. CO2 cost is $22.59/M-ton.
4. Production cost includes start-up, fuel and VOM cost, but not CO2 cost.
5. Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.

Default Scenario with a 4-tier curtailment prices

The case of non-dispatchable CHP

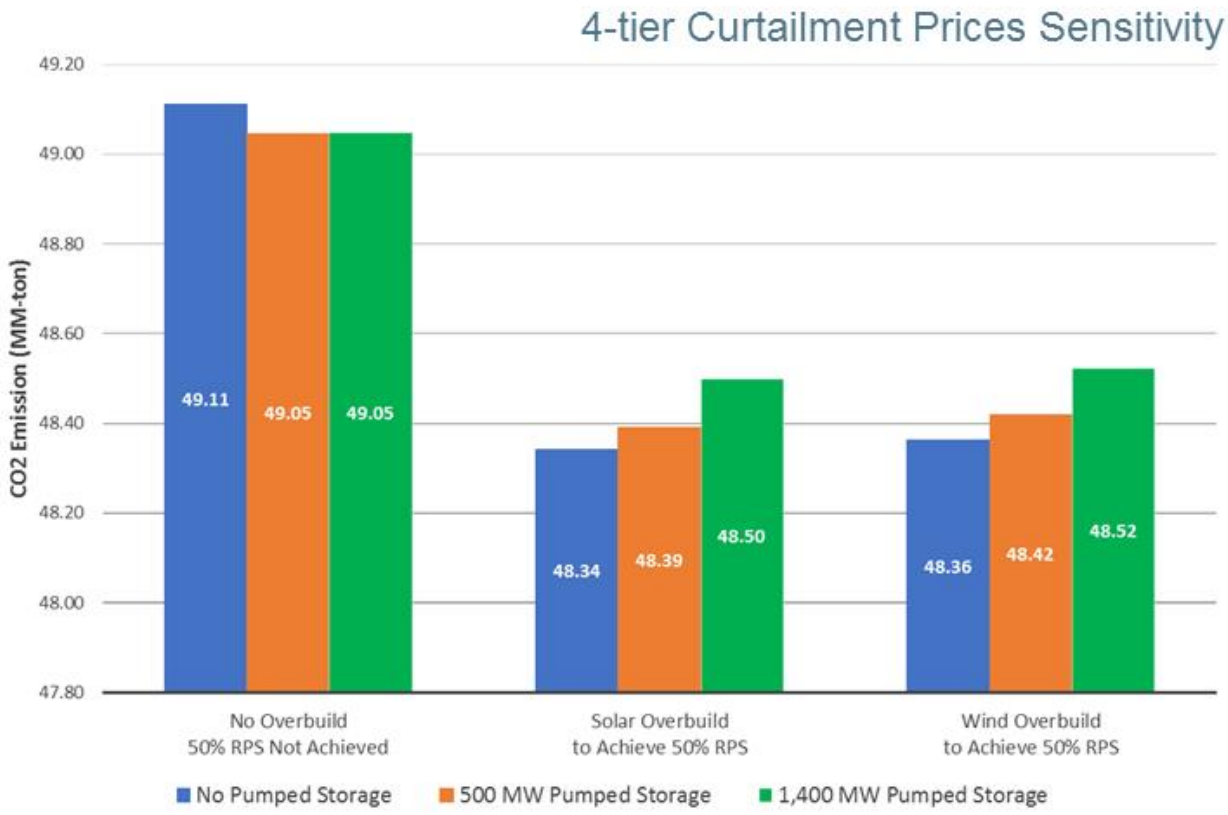
- Based on the updated Default Scenario, which assumes that the fist 200 GWh renewable will be curtailed at -$15/MWh, additional 12,400 GWh renewable will be curtailed at -$25/MWh, the rest at -$300/MWh
- In this case the curtailment prices in 4 tiers in the table below are used

	Tier 1	Tier 2	Tier 3	Tier 4
Curtailment Price ($/MWh)	-15	-25	-50	-150
Max Curtailment (GWh)	200	1,300	500	All the rest

Capacity of renewable overbuild to achieve the 50% RPS target

California renewable generation curtailment

California CO2 emission (50% RPS)



CA CO2 Emission includes the CO2 emission from net import

WECC annual production cost

Production cost includes start-up, fuel and VOM cost, but not CO2 cost.

Levelized annual revenue requirements of renewable overbuild and the pumped storage resources

Cost of the 1,400 MW pumped storage is discounted by 20% based on economies of scale assumption

Pumped storage levelized annual revenue requirements, net market revenues and system benefits of 2026

Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.
System benefits includes reduction of CO2 emission cost, WECC production cost and renewable overbuild cost

Summary of annual results by case

4-tier Curtailment Prices Sensitivity

	No Pumped Storage			500 MW Pumped Storage			1,400 MW Pumped Storage		
Case	A	C	D	B500	E500	F500	B1400	E1400	F1400
Renewable Curtailment (GWh)	2,043	2,521	2,162	1,751	2,097	1,843	1,427	1,614	1,476
Curtailment Frequency (hours)	659	783	707	588	683	608	476	539	487
CA CO2 Emission (MM-ton)	49.1	48.3	48.4	49.0	48.4	48.4	49.0	48.5	48.5
CA CO2 Emission ($million)	1,109	1,092	1,093	1,108	1,093	1,094	1,108	1,096	1,096
Production Cost ($million)									
WECC	15,210	15,138	15,131	15,179	15,118	15,108	15,137	15,087	15,080
CA	3,578	3,534	3,532	3,532	3,498	3,489	3,464	3,438	3,429
Renewable Overbuild and Pumped Storage Capacity (MW)									
Solar		881			733			566	
Wind			750			642			514
Pumped Storage				500	500	500	1,400	1,400	1,400
Levelized Annual Revenue Requirement of Renewable Overbuild and Pumped Storage ($million/year)									
Solar		199			166			128	
Wind			172			147			118
Pumped Storage				186	186	186	408	408	408
Sum		*199*	*172*	*186*	*352*	*333*	*408*	*536*	*526*
Pumped Storage Net Market Revenue ($million)				61	76	69	125	138	128
System Benefits by the Pumped Storage Resource ($million)				30	54	48	73	122	104

Notes:

1. Renewable curtailment price is assumed as -$15/MWh for the first 200 GWh and -$25/MWh for additional 12,400 GWh.
2. CA CO2 Emission includes the CO2 emission from net import.
3. CO2 cost is $22.59/M-ton.
4. Production cost includes start-up, fuel and VOM cost, but not CO2 cost.
5. Net Market Revenue is revenue from energy, reserves and load following minus cost of energy and operation.