Reliability Assessment of the IRP Hybrid Conforming Plan

Shucheng Liu, Ph.D.
Principal, Market Development

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Purposes of the CAISO's assessment

- To conduct an independent reliability assessment by
  - using production cost modeling software with some functions and methodologies different from SERVM, such as unit commitment and economic dispatch;
  - adopting some enhanced modeling assumptions, such as shapes of load, solar and wind profiles, load-following and regulation requirements; and
  - developing models based on the knowledge gained in the past CPUC Long Term Procurement Plan (LTPP) proceedings.

Purposes of the CAISO's assessment (cont.)

- To evaluate whether the Hybrid Conforming Plan (HCP) satisfies CAISO system reliability and operating requirements
- To provide feedback to the CPUC Integrated Resource Plan (IRP) proceeding
- To communicate with all parties in the IRP proceeding regarding the CAISO's view about operability of the HCP

Approaches of the CAISO's assessment

- Using both deterministic and stochastic production cost modeling for the assessment
  - Production cost modeling enforces operational constraints in optimizing generation unit commitment and dispatch
  - Deterministic simulations produce detail results for deep-diving analyses
  - Stochastic simulations examine a wide variety of system conditions and report the likelihood of capacity shortages

Approaches of the CAISO's assessment (cont.)

- Developing IRP models based on the models developed in the past LTPP proceedings that were:
  - discussed thoroughly with the involved parties;
  - made available to the public; and
  - used by many other parties for various studies.

References: CAISO testimonies about production cost modeling filed into the CPUC 2014 LTPP proceeding

1. *http://www.caiso.com/Documents/Aug13_2014_InitialTestimony_ShuchengLiu_Phase1A_LTPP_R13-12-010.pdf*
2. *http://www.caiso.com/Documents/Nov20_2014_Liu_StochasticStudyTestimony_LTPP_R13-12-010.pdf*

Approaches of the CAISO's assessment (cont.)

- Having a zonal model structure similar to the CPUC SERVM model
  - WECC-wide deterministic model and CAISO-wide stochastic model
  - 8 zones in California, 4 in CAISO
  - Transmission constraints between the zones

Approaches of the CAISO's assessment (cont.)

- Implementing the same core inputs as the SERVM model, including
  - Energy Commission (CEC) Integrated Energy Policy Report (IEPR) Mid Demand case load forecast;
  - Resource portfolio specified in the HCP; and
  - WECC ADS PCM dataset for non-CAISO regions.
- Running simulations chronologically in hourly interval for the whole year of 2030
  - Deterministic simulation for one iteration
  - Stochastic simulations for 500 iterations

Deterministic Modeling

From Reference System Plan (RSP) to HCM, the portfolio has changed significantly.

	RESOLVE	CAISO Plexos Model		
Capacity (MW)	RSP	RSP	HCP	Change
Battery	**3,429**	**3,429**	**2,480**	**-949**
1-hour	2,144	2,144	217	-1,927
4-hour	1,285	1,285	2,263	978
BTM PV	**19,992**	**19,295**	**19,295**	**0**
Renewable	**33,084**	**33,381**	**34,094**	**714**
Biomass	725	725	888	163
Geothermal	2,683	2,683	1,487	-1,197
Small Hydro	466	763	763	0
Solar	18,767	18,767	19,658	891
Wind	10,443	10,443	11,299	856
Thermal	**27,562**	**25,770**	**22,543**	**-3,227**
CCGT		15,720	14,642	-1,078
CHP	1,685	2,932	1,078	-1,854
GT		7,108	6,813	-295
ST		10	10	0
Gas	25,877			
Hydro	**7,844**	**6,894**	**6,894**	**0**
Pumped Storage	**1,832**	**1,831**	**1,831**	**0**
Demand Response	**1,752**	**1,752**	**1,752**	**0**
Net Import Limit	**10,068**	**10,341**	**10,341**	**0**

Notes:

- HCP battery has longer duration, but less capacity than RSP
- BTM PV capacity difference from RESOLVE is due to the shapes used to develop the profiles
- HCP has 714 MW more renewable capacity, but 5,649 GWh less renewable energy than RSP
- Geothermal capacity has 100% base load capacity factor
- Plexos thermal is based on Rated Capacity instead of Installed Capacity
- Thermal is after the retirement of all OTC and nuclear resources
- Demand Response availability varies over time

CAISO deterministic simulation case definitions

- Besides the HCP case, CAISO ran 4 sensitivity cases of it to understand the impacts of some key assumptions
  - Lower net export capability in case the 5,000 MW capability is not achievable
  - 20% of the default CO2 intensity rate for Northwest import as California Air Resource Board suggested
  - The combination of the two above
  - Higher CO2 emission price as RSP suggested, which is sum of the default CO2 price and the shadow price of the CO2 emission constraint in RESOLVE for RSP

CAISO deterministic simulation case definitions (cont.)

Case	CO2 Intensity for Import from Northwest (MTon/MWh)	CAISO Net Export Capability (MW)	CO2 Emission Price ($/MTon)
RESOLVE Reference Plan	0.428	5,000	27.37
CAISO Plexos Hybrid Conforming Plan	0.428	5,000	27.37
CAISO Sensitivity 1	0.428	2,000	27.37
CAISO Sensitivity 2	0.086	5,000	27.37
CAISO Sensitivity 3	0.086	2,000	27.37
CAISO Sensitivity 4	0.428	5,000	217.58

More detail CO2 modeling of NW import reflected in optimization

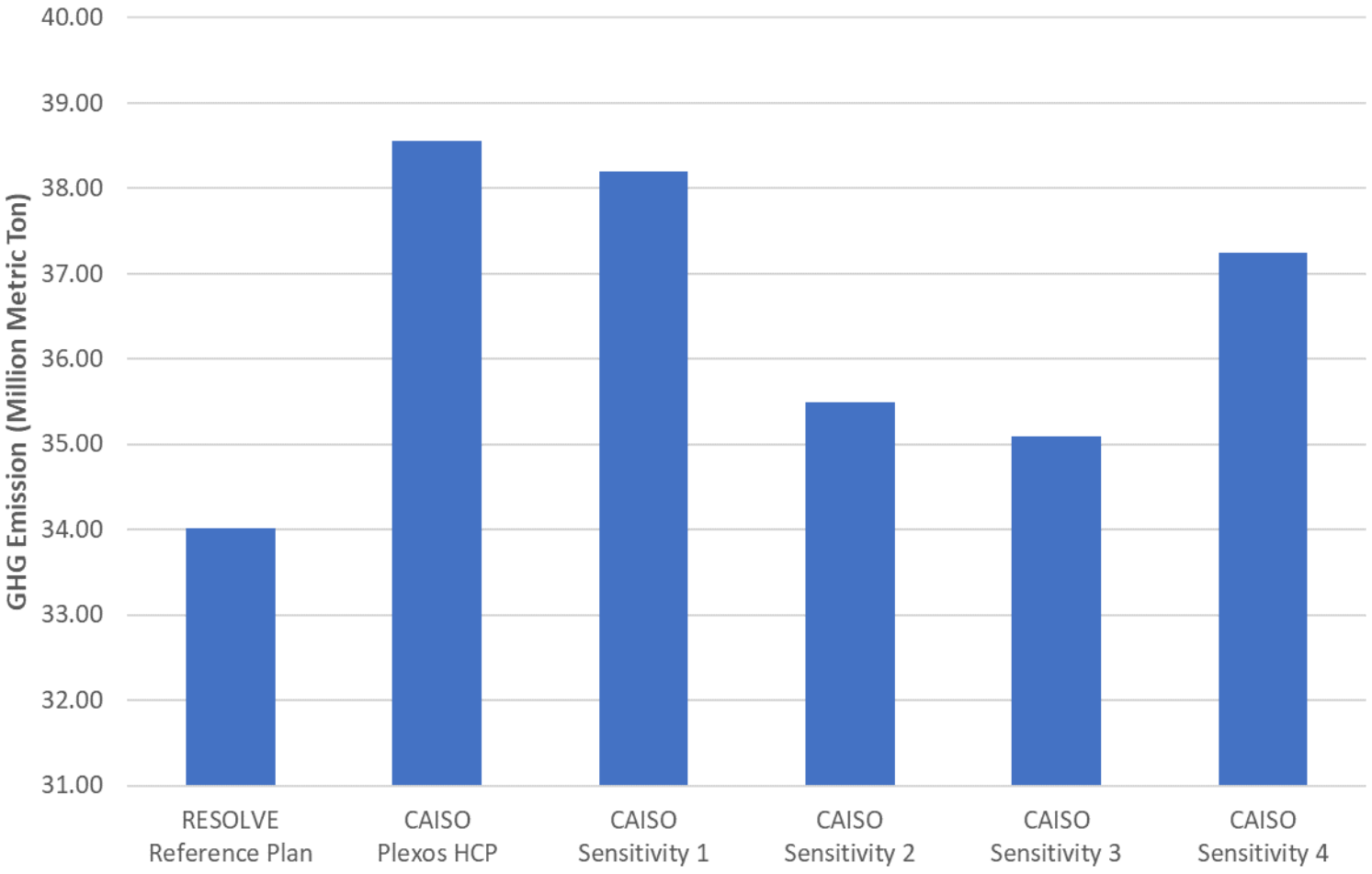
Tests what can be achieved without higher export capability

Tests if CO2 price determined in IRP achieves emission reduction target

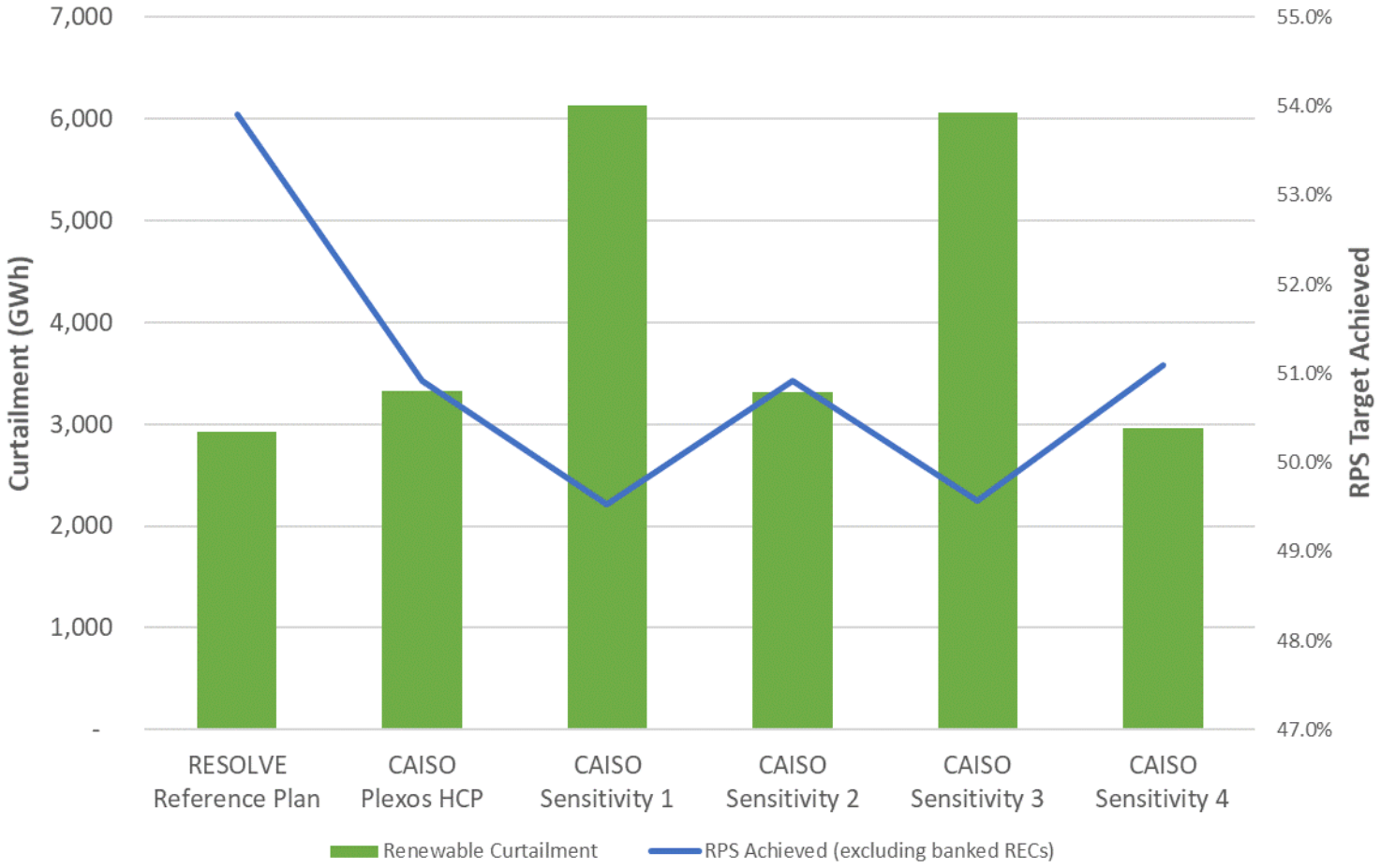
Summary of deterministic simulation annual results of HCP and sensitivity cases

	RESOLVE Reference Plan	CAISO Plexos HCP	CAISO Sensitivity 1	CAISO Sensitivity 2	CAISO Sensitivity 3	CAISO Sensitivity 4
Northwest Import CO2 Intensity (MTon/MWh)	0.428	0.428	0.428	0.086	0.086	0.428
CAISO Net Export Limit (MW)	5,000	5,000	2,000	5,000	2,000	5,000
CO2 Price ($/MTon in 2016 dollars)	27.37	27.37	27.37	27.37	27.37	217.58
CAISO CO2 Emission (MMTon)						
By In-ISO Generation	31.38	23.43	22.88	22.69	22.13	23.62
From Import	5.44	17.92	18.11	12.79	12.96	16.43
Sum	36.82	41.35	41.00	35.49	35.09	40.05
CO2 Emission Offset	-2.80	-2.80	-2.80	0.00	0.00	-2.80
Total Emission	34.02	38.55	38.20	35.49	35.09	37.25
WECC-Wide CO2 Emission		303.67	305.63	304.23	306.18	303.22
CAISO Generation, Import and Export (GWh)						
CAISO Generation	237,407	205,532	201,242	203,488	199,208	207,259
Net Import	17,631	49,009	53,300	51,054	55,334	47,282
Renewable Generation, Curtailment and RPS Achieved						
Renewable Generation (GWh)	109,136	103,088	100,283	103,099	100,348	103,450
RPS Achieved (excluding banked RECs)	54%	51%	50%	51%	50%	51%
Renewable Curtailment (GWh)	2,923	3,322	6,127	3,311	6,062	2,961
Production Cost ($million)						
WECC		13,039	13,094	13,008	13,058	19,223
CAISO		2,866	2,827	2,786	2,744	7,497

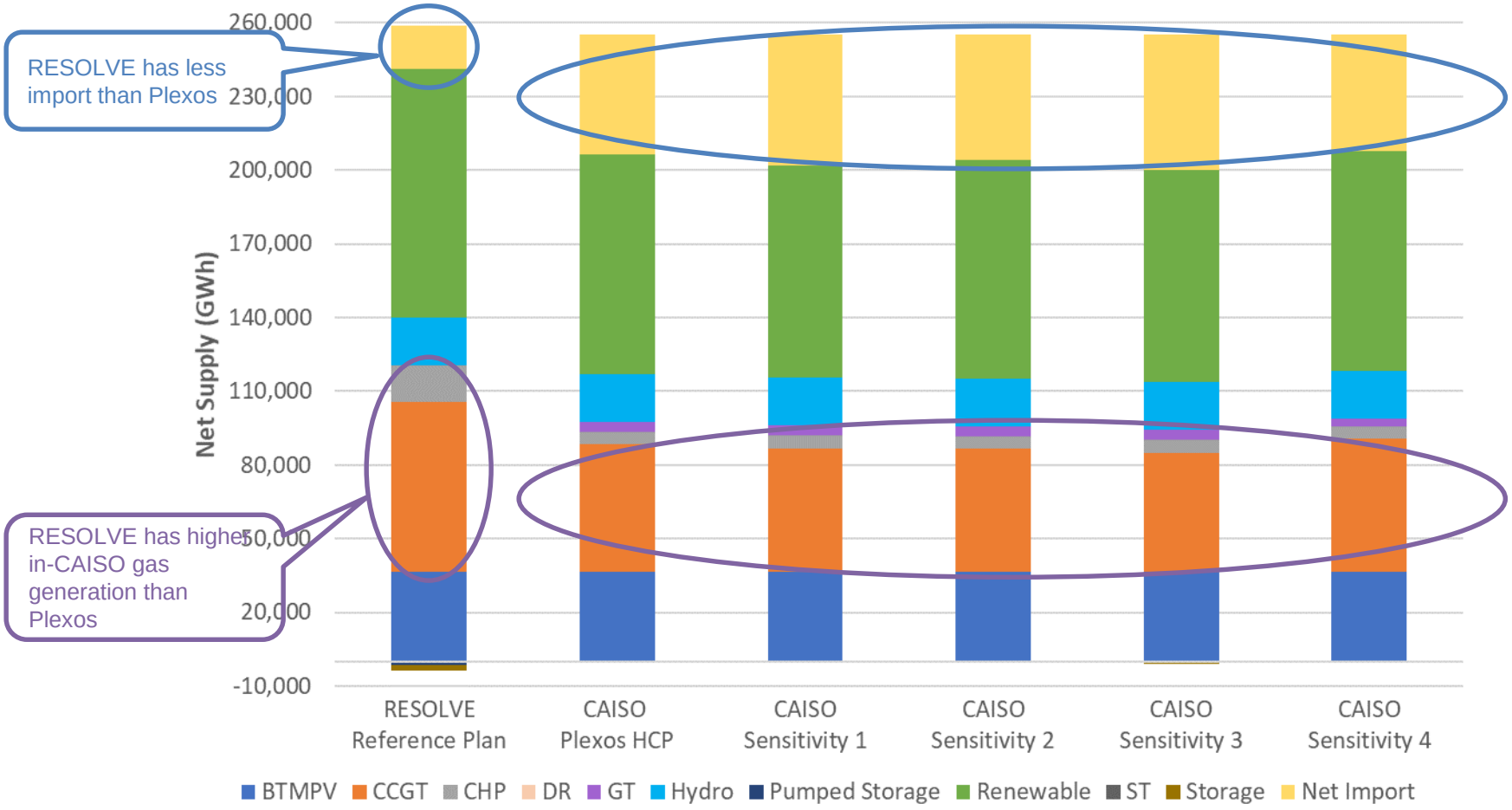
HCP portfolio does not achieve the 34 MMT CAISO CO2 emission target.



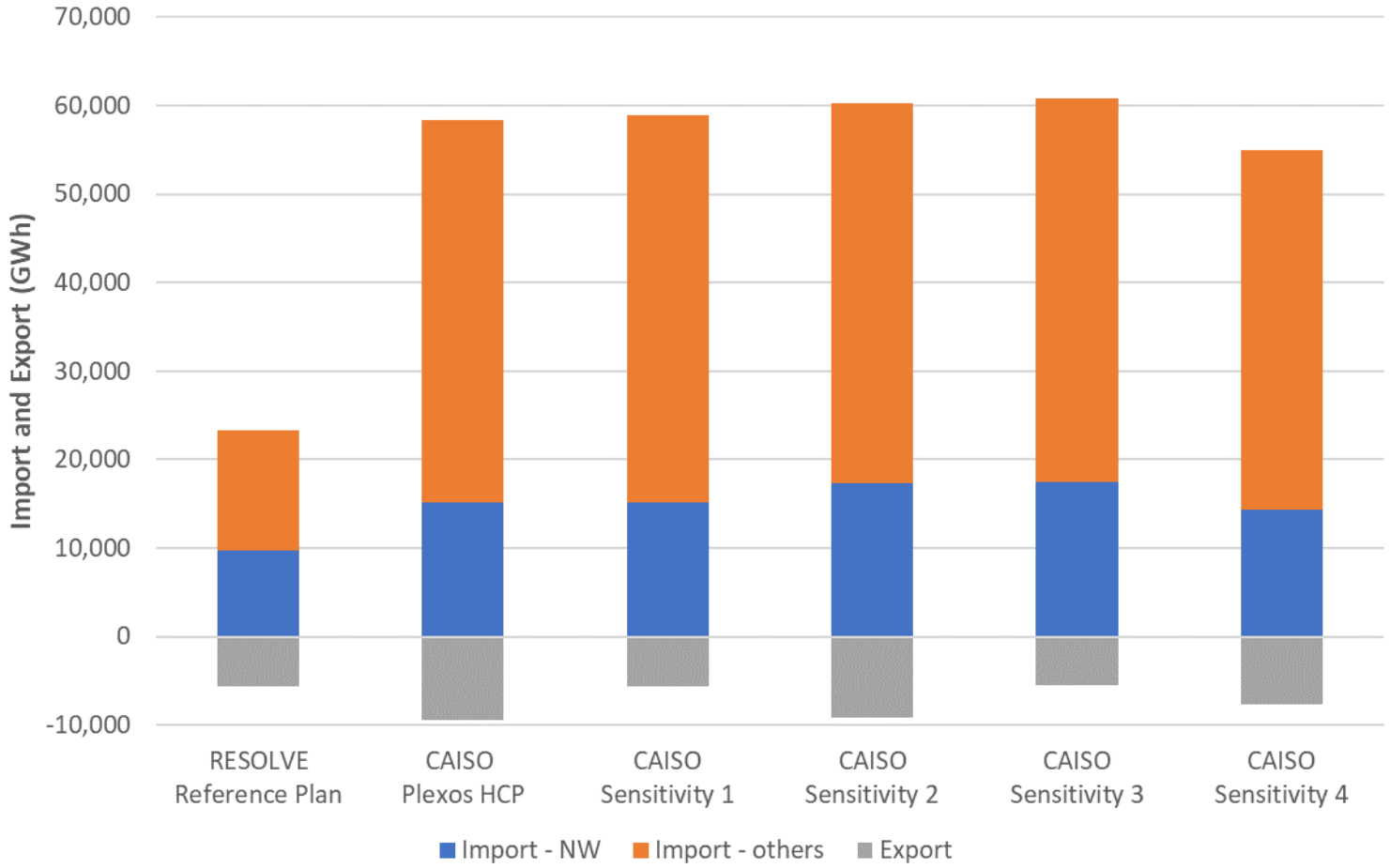
Renewable curtailment is sensitive to net export capability



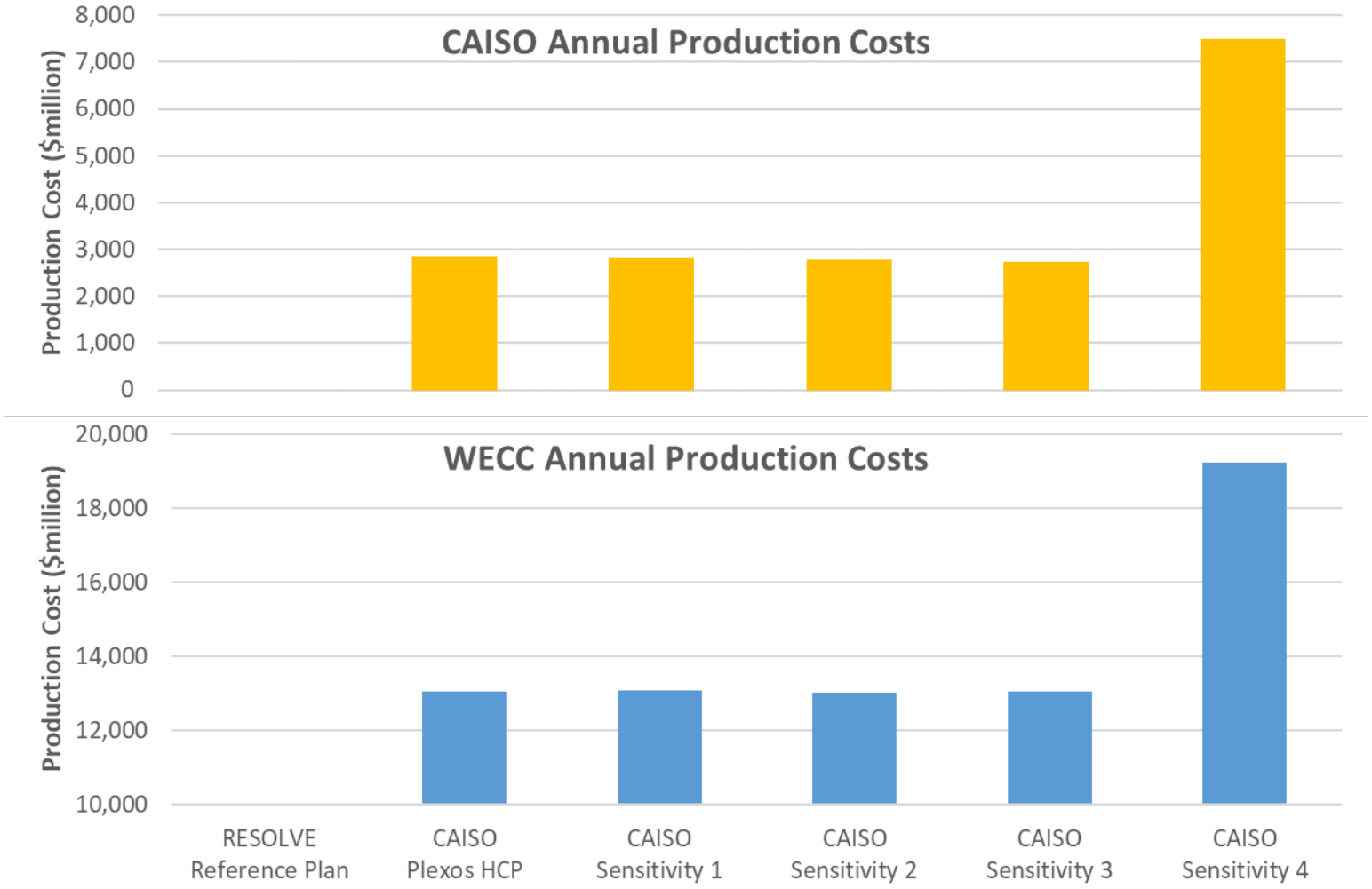
CAISO cases rely more on import and less on in-CAISO gas generation than the RESOLVE case.



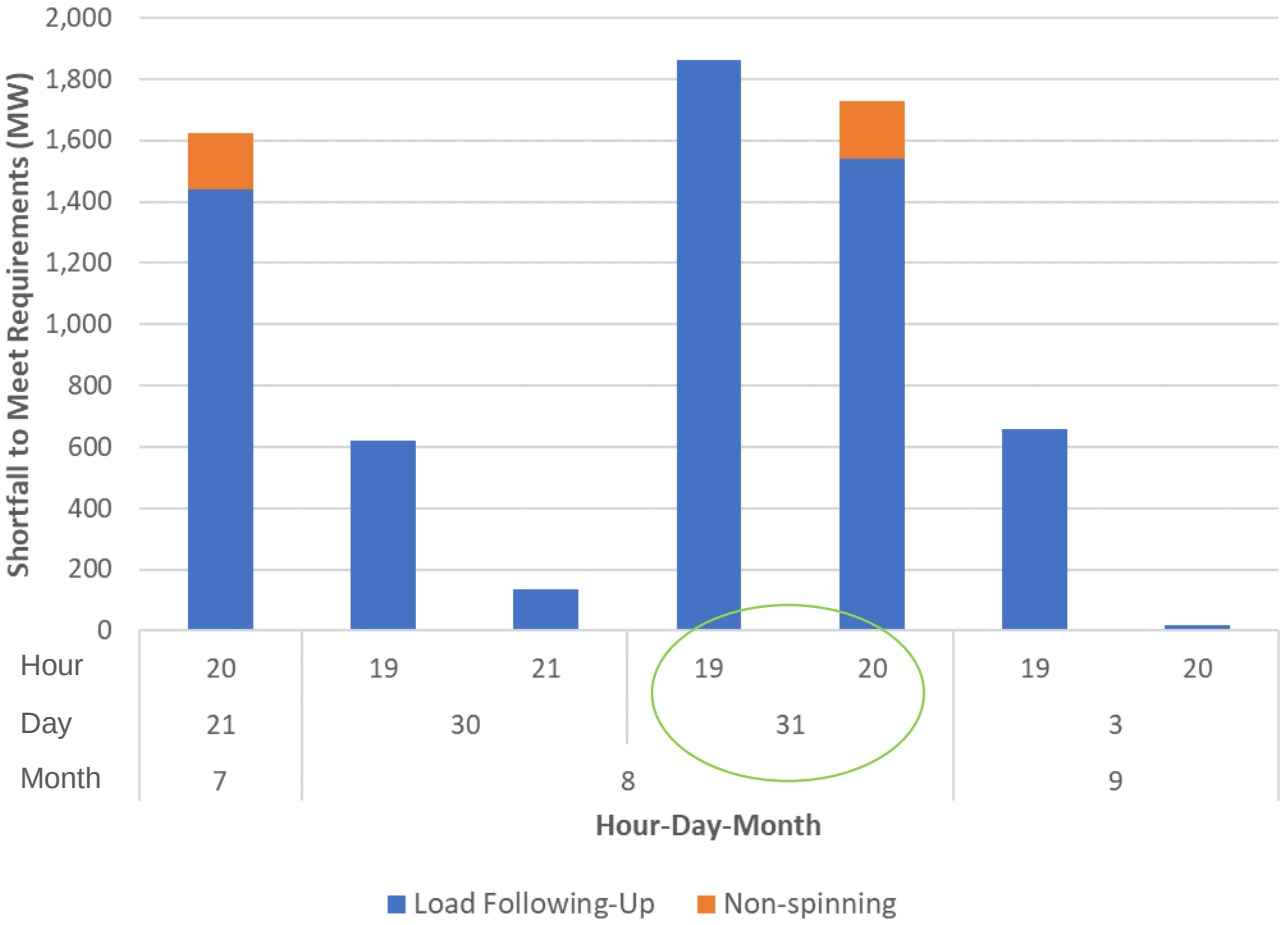
Imports and exports are affected by modelling assumptions.



High CO2 price causes significant increase in production costs.



CAISO supply becomes insufficient in the HCP case.



Capacity Changes (MW)	
Battery	**-949**
1-hour	-1,927
4-hour	978
BTM PV	**0**
Renewable	**714**
Biomass	163
Geothermal	-1,197
Small Hydro	0
Solar	891
Wind	856
Thermal	**-3,227**
CCGT	-1,078
CHP	-1,854
GT	-295

CAISO hourly load and generation balance of the HCP case on August 31, 2030

Hour	Load (MW)	Generation (MW)											Net Import (MW)	Reserve Shortfall	
		Total Generation	BTMPV	CCGT	CHP	DR	GT	Hydro	Pumped Storage	Renewable	ST	Storage		Load Following-Up	NonSpin Reserve
1	32,447	22,227	0	6,683	616	0	335	6,894	84	5,252	0	2,363	10,221	0	0
2	30,705	20,510	0	6,096	590	0	335	6,894	0	5,231	0	1,363	10,195	0	0
3	29,396	19,055	0	6,027	590	0	335	6,894	0	5,205	0	4	10,341	0	0
4	28,802	19,006	0	6,055	573	0	335	6,894	0	5,149	0	0	9,796	0	0
5	28,843	18,830	0	6,125	573	0	335	6,894	0	4,903	0	0	10,013	0	0
6	28,891	19,283	71	6,197	580	0	332	6,894	0	4,483	0	726	9,608	0	0
7	31,436	26,035	2,822	5,370	543	0	252	6,161	0	10,886	0	0	5,402	0	0
8	32,316	28,820	6,722	5,471	516	0	252	1,041	0	14,819	0	0	3,496	0	0
9	37,093	35,585	10,446	5,471	523	0	252	2,039	0	16,853	0	0	1,508	0	0
10	41,783	40,473	13,504	5,507	516	0	252	2,125	0	18,571	0	0	1,310	0	0
11	43,973	42,656	15,255	5,585	516	0	252	1,245	0	19,804	0	0	1,317	0	0
12	46,472	45,079	15,763	5,720	523	0	252	2,834	0	19,987	0	0	1,393	0	0
13	48,735	47,412	15,953	6,014	523	0	252	4,037	0	20,632	0	0	1,323	0	0
14	48,994	47,732	14,578	6,310	533	0	252	5,587	0	20,472	0	0	1,262	0	0
15	49,024	47,812	12,815	6,881	554	0	252	6,891	0	20,419	0	0	1,212	0	0
16	48,525	45,948	9,867	9,187	628	0	332	6,889	199	18,846	0	0	2,577	0	0
17	47,619	42,847	6,400	10,878	719	0	1,312	6,889	813	15,835	0	0	4,772	0	0
18	45,953	39,100	2,524	12,667	1,078	0	3,456	6,890	1,831	10,644	10	0	6,853	0	0
19	44,635	35,729	65	13,493	1,078	1,168	3,811	6,890	1,831	5,523	10	1,858	8,907	1,862	0
20	45,811	36,167	0	13,609	1,078	1,168	3,866	6,890	1,831	5,504	10	2,210	9,644	1,538	189
21	43,689	33,348	0	13,393	1,071	0	3,772	6,890	1,831	5,827	10	554	10,341	0	0
22	40,204	30,019	0	12,537	747	0	2,189	6,890	1,831	5,821	4	0	10,185	0	0
23	36,718	27,724	0	11,198	734	0	1,949	6,891	1,340	5,609	4	0	8,995	0	0
24	33,472	24,919	0	10,034	695	0	1,061	6,891	581	5,657	0	0	8,552	0	0

- Renewable and BTM PV generation drops quickly in early evening
- Net import in hour 19 and 20 is below the CAISO net import limit
- Supply is insufficient to meet load-following up and non-spinning reserve requirements in hour 19 and 20

Breakdown of renewable generation on August 31, 2030 (MW)

Hour	Biogas	Biomass	Geothermal	Small Hydro	Solar PV	Solar Thermal	Wind	Total
1	187	690	1,329	227	0	0	2,819	5,252
2	187	690	1,329	222	0	0	2,803	5,231
3	187	690	1,329	198	0	0	2,801	5,205
4	187	690	1,329	200	0	0	2,743	5,149
5	187	690	1,329	219	0	0	2,478	4,903
6	187	690	1,329	253	99	22	1,902	4,483
7	187	690	1,329	282	6,800	279	1,319	10,886
8	187	690	1,329	359	11,091	628	534	14,819
9	187	690	1,329	384	13,029	1,022	212	16,853
10	187	690	1,329	401	14,504	1,319	141	18,571
11	187	690	1,329	415	15,511	1,498	173	19,804
12	187	690	1,329	399	15,465	1,633	284	19,987
13	187	690	1,329	431	15,704	1,586	704	20,632
14	187	690	1,329	441	15,179	1,393	1,252	20,472
15	187	690	1,329	444	15,010	1,230	1,529	20,419
16	187	690	1,329	454	13,274	943	1,967	18,846
17	187	690	1,329	440	10,613	566	2,009	15,835
18	187	690	1,329	453	5,976	164	1,844	10,644
19	187	690	1,329	456	4	0	2,857	5,523
20	187	690	1,329	457	0	0	2,841	5,504
21	187	690	1,329	443	0	0	3,177	5,827
22	187	690	1,329	388	0	0	3,227	5,821
23	187	690	1,329	312	0	0	3,091	5,609
24	187	690	1,329	211	0	0	3,239	5,657

Load forecast and modifiers during peak net load hours on August 31, 2030

CAISO Load Forecast and Load Modifiers (MW)

Hour	Load Forecast	AAEE	Pump Load	EV	TOU	Load with Modifiers
16	51,565	4,596	1,158	681	-282	48,525
17	50,532	4,532	1,160	759	-299	47,619
18	48,486	4,194	1,159	795	-292	45,953
19	46,750	3,892	1,274	794	-292	44,635
20	45,791	3,714	1,394	2,630	-289	45,811
21	42,970	3,468	1,424	2,636	127	43,689

- August 31, 2030 is a Saturday. Compared to weekdays of the same week
  - AAEE is about 2,000 MW lower
  - Pump load is about doubled
  - EV charging load is higher
  - TOU is in the same range

Generation capacity usage during peak net load hours on August 31, 2030

Generation and Import (MW)

Hour	BTMPV	CCGT	CHP	DR	GT	Hydro	Pumped Storage	Renewable	ST	Storage	Net Import
16	9,867	9,187	628	0	332	6,889	199	18,846	0	0	2,577
17	6,400	10,878	719	0	1,312	6,889	813	15,835	0	0	4,772
18	2,524	12,667	1,078	0	3,456	6,890	1,831	10,644	10	0	6,853
19	65	13,493	1,078	1,168	3,811	6,890	1,831	5,523	10	1,858	8,907
20	0	13,609	1,078	1,168	3,866	6,890	1,831	5,504	10	2,210	9,644
21	0	13,393	1,071	0	3,772	6,890	1,831	5,827	10	554	10,341

Provision of Upward Load-following and Reserves (MW)

16	0	3,063	0	0	1,462	0	300	0	0	1,642	0
17	0	1,459	0	0	1,882	0	900	0	0	2,481	0
18	0	1,358	0	0	3,058	0	0	0	0	2,481	0
19	0	533	0	0	2,667	0	0	0	0	623	0
20	0	416	0	0	2,624	0	0	0	0	272	0
21	0	633	0	0	2,718	0	0	0	0	1,927	0

Outages (MW)

16	0	28	0	0	301	0	374	0	0	0	0
17	0	616	0	0	298	0	0	0	0	0	0
18	0	616	0	0	298	0	0	0	0	0	0
19	0	616	0	0	333	0	0	0	0	0	0
20	0	616	0	0	321	0	0	0	0	0	0
21	0	616	0	0	321	0	0	0	0	0	0

Total Usage (MW)

16	9,867	12,278	628	0	2,095	6,889	873	18,846	0	1,642	2,577
17	6,400	12,954	719	0	3,492	6,889	1,713	15,835	0	2,482	4,772
18	2,524	14,642	1,078	0	6,812	6,890	1,831	10,644	10	2,482	6,853
19	65	14,642	1,078	1,168	6,812	6,890	1,831	5,523	10	2,482	8,907
20	0	14,642	1,078	1,168	6,812	6,890	1,831	5,504	10	2,482	9,644
21	0	14,642	1,071	0	6,812	6,890	1,831	5,827	10	2,482	10,341

Total Available Capacity (MW)

16	9,867	14,642	1,078	1,168	6,813	6,889	1,831	18,846	10	2,482	10,341
17	6,400	14,642	1,078	1,168	6,813	6,889	1,831	15,835	10	2,482	10,341
18	2,524	14,642	1,078	1,168	6,813	6,890	1,831	10,644	10	2,482	10,341
19	65	14,642	1,078	1,168	6,813	6,890	1,831	5,523	10	2,482	10,341
20	0	14,642	1,078	1,168	6,813	6,890	1,831	5,504	10	2,482	10,341
21	0	14,642	1,078	1,144	6,813	6,890	1,831	5,827	10	2,482	10,341

Notes

- Some demand response programs are not available on weekend
- BTM PV and renewable generation drops quickly starting hour 16, solar has almost no contribution from hour 19 on
- Storage provides a large portion of upward load-following and reserves because the energy requirements for storage to provide such services have not been enforced
- 4.2% CCGT and 4.9% GT forced outages
- At hour 19 and 20 all available generation capacity is fully utilized, but import is below the maximum import limit

Findings from CAISO's deterministic production cost simulations

- CAISO supply is insufficient in the HCP case
  - Capacity shortfalls in meeting load-following up and non-spinning reserve requirements are found in 7 peak net load hours
  - It is mostly due to retirement of thermal resource and loss of effective capacity of battery and geothermal
  - Import up to the 10,341 maximum limit is not always available. During the hours with capacity shortfall, import is below the limit. That is consistent with the trend observed in the CAISO market operation today.

Findings from CAISO's deterministic production cost simulations (cont.)

- CAISO HCP case achieves lower RPS target than RESOLVE for RSP because
  - Plexos and RESOLVE serve different purposes and have different optimization methodologies and objectives
  - In Plexos model more renewable energy is curtailed than in RESOLVE model
  - HCP portfolio has less renewable energy than RSP portfolio

Findings from CAISO's deterministic production cost simulations (cont.)

- CAISO HCP case does not achieve the 34 MMT CO2 emission target set by RESOLVE for RSP because of
  - More stringent operational constraints in Plexos model
  - Lower renewable generation in HCP
  - Differences in other modeling assumptions between RESOLVE and CAISO Plexos models

Findings from CAISO's deterministic production cost simulations (cont.)

- CAISO net export limit has significant impact on achieving RPS target. This assumption needs to be assessed carefully.
- Lower Northwest import CO2 intensity results in much lower total emissions, though still higher than 34 MMT. The -2.8 MMT after-the-fact offset is a mismatch of the impact of the lower CO2 intensity.
- The case of $217.58/MTon CO2 emission price also does not achieve the 34 MMT emission target

Stochastic Modeling

The stochastic model is developed based on the HCP deterministic model.

- The purpose of CAISO stochastic modeling is to identify the likelihood and magnitude of capacity shortages in HCP after the 40-year thermal retirement rule is applied
- The stochastic model has a CAISO-focused scope, including PG&E_BAY, PG&E_VALLEY, SCE, SDG&E zones, and an outside zone
- Inside the CAISO footprint, the stochastic model has the same inputs as in the deterministic model, except the stochastic variables

The outside zone represents the regions outside CAISO.

- The outside zone holds
  - Out-of-state RPS resources
  - Non-RPS dedicated import resources (Hoover, Palo Verde, etc.)
  - A “market station” representing other outside resources and load for economic import and export
- The same net import and export limits between CAISO and the outside zone, as in the deterministic model, are enforced

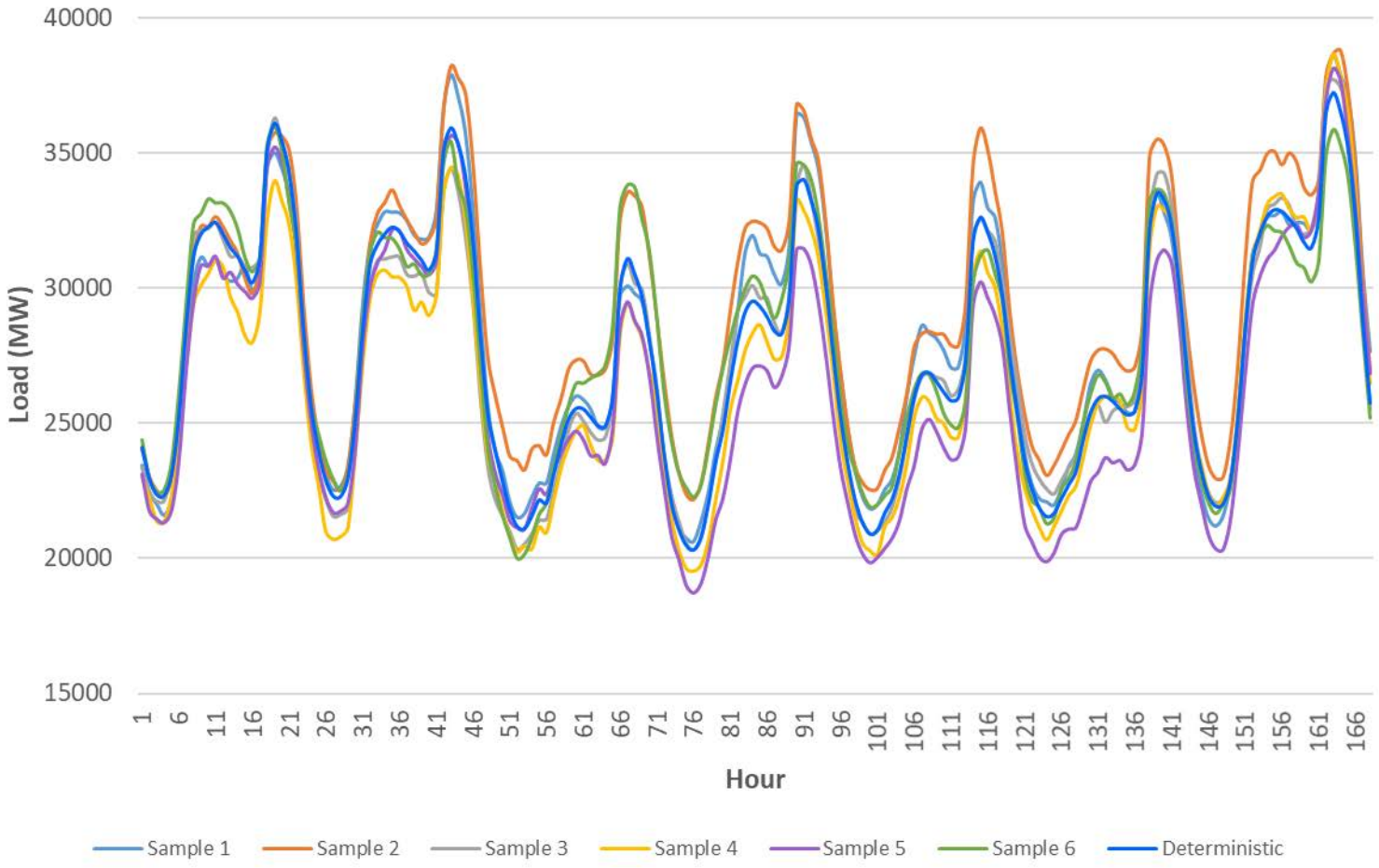
Stochastic variables in the model

- The model has four stochastic variables
  - Forced outage, load, solar and wind generation
- Forced outages are generated randomly and independently for each generation resource in each iteration
- Load, solar and wind stochastic samples of 500 iterations are generated
  - Randomly with built-in cross-correlations among them
  - Chronologically by hour for the whole year of each iteration

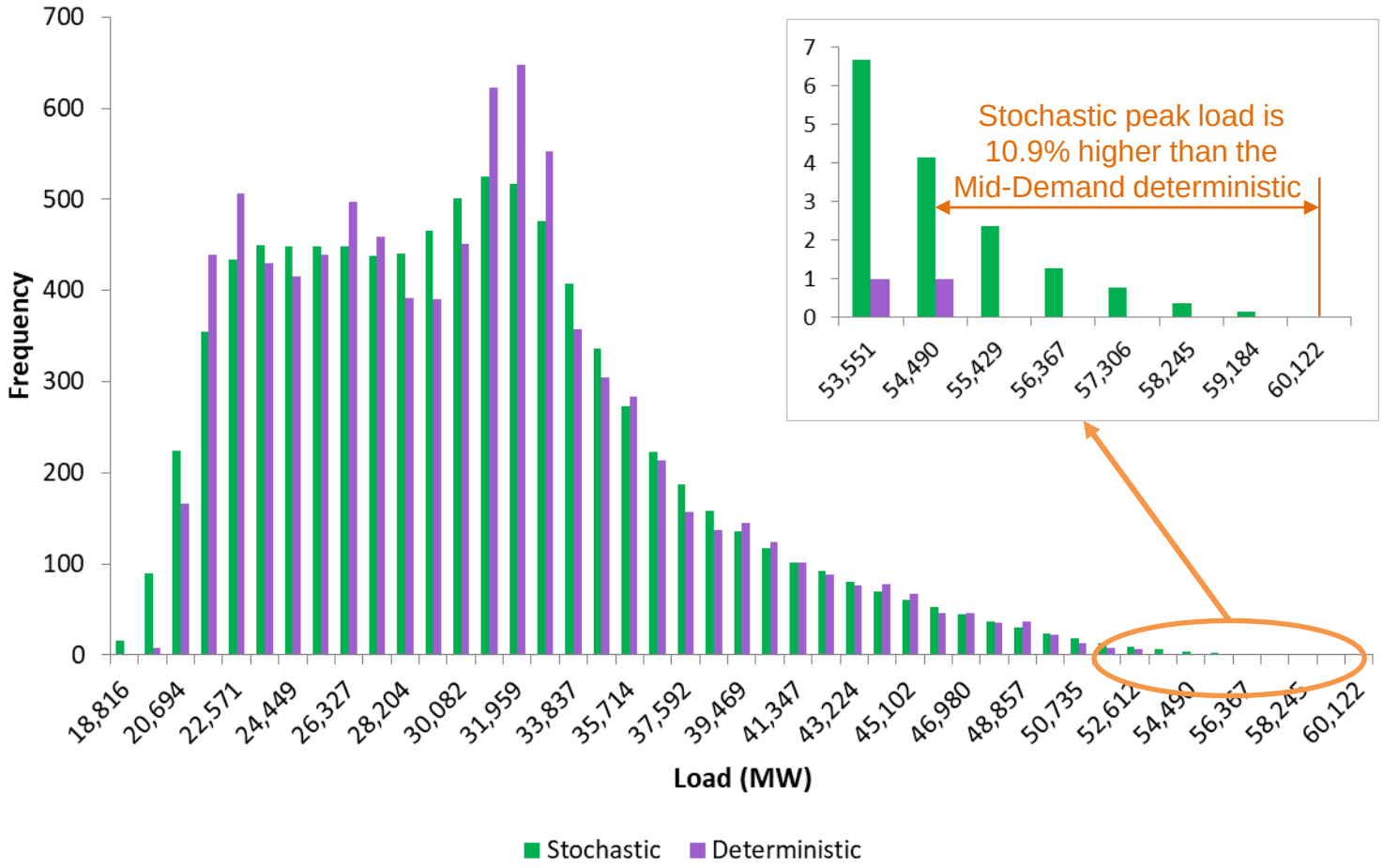
Reliability metrics for stochastic simulations

- Use the same metrics as defined in the IRP ALJ production cost modeling ruling
  - A lose of load (LOL) event: a day with insufficient capacity to meet the sum of load and requirements for regulation, frequency response, and spinning reserve for at least one hour
  - Loss of load expectation (LOLE) criterion: the average of LOL events of all iterations of full-year simulations should be no higher than 0.1 (day/year)
  - For 500 iterations (500 years), up to 50 LOL events are allowed to meet the LOLE criterion

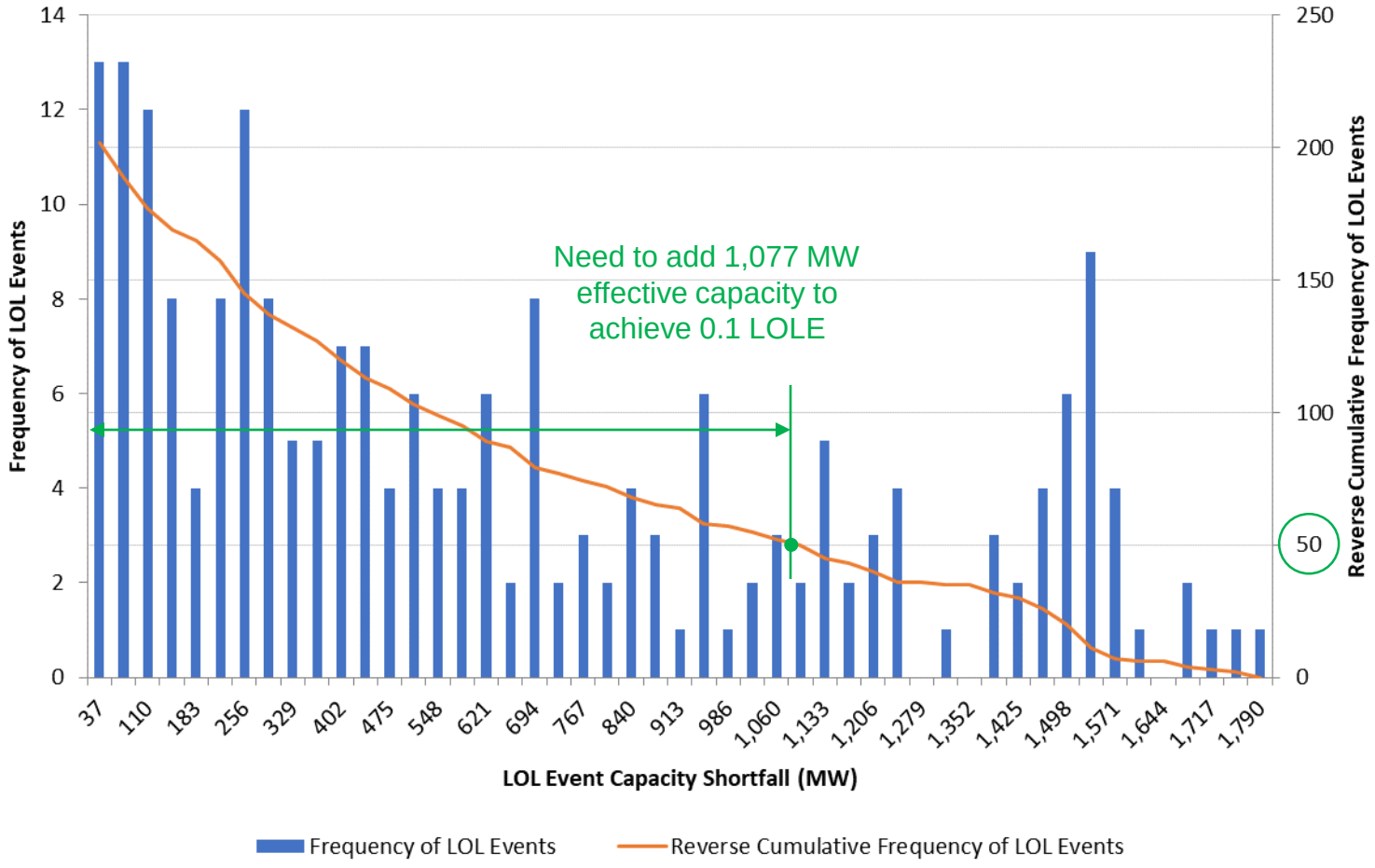
Hourly load of one week: load of the deterministic model vs. 6 stochastic samples



Histogram of 2030 hourly load: deterministic vs. 500-iteration stochastic values



Stochastic simulation results: histogram of loss of load events in 500 iterations



CAISO supply insufficiency is confirmed through stochastic simulations.

- Stochastic simulations confirmed the capacity insufficiency found in the deterministic simulation
- To meet the 0.1 LOLE criterion, it needs to
  - reinstall 1,077 MW* of the 3,227 MW thermal resources retired by the 40-year rule, i.e., allow retirement of only 2,150 MW; or
  - add new resources with equivalent capability to serve load and reserves during critical periods.

* It will need about 4.5% more capacity to count for forced outages.

Thank you!