BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

Order Instituting Rulemaking to Integrate and Refine Procurement Policies and Consider Long-Term Procurement Plans	Rulemaking 13-12-010 Filed December 19, 2013

CALIFORNIA INDEPENDENT SYSTEM OPERATOR CORPORATION
DETERMINISTIC STUDIES

Pursuant to the March 25, 2015 Administrative Law Judge's Ruling, the California Independent System Operator Corporation (CAISO) submits its deterministic studies of the existing Trajectory and 40% Renewable Portfolio Standards scenarios with no renewable curtailment. Data underlying the CAISO's no renewable curtailment studies can be found on the CAISO's secured ftp site. Interested parties can contact the undersigned to request access to this data.

Respectfully submitted,
By: *<u>/s/ Jordan Pinjuv</u>*

Roger E. Collanton
General Counsel
Anthony Ivancovich
Deputy General Counsel
Anna McKenna
Assistant General Counsel
Jordan Pinjuv
Counsel
California Independent System Operator Corporation
250 Outcropping Way
Folsom, CA 95630
Tel: (916) 608-7146
Fax: (916) 608-7222
jpinjuv@caiso.com

Attorneys for the California Independent System Operator Corporation

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Report of the No Renewable Curtailment Sensitivity Cases Studies

1. Executive Summary

The California Independent System Operator (CAISO) studied two sensitivities based on the Trajectory and the 40% renewable portfolio standard (RPS) in 2024 scenarios to evaluate the CAISO systems' capability to mitigate over-generation assuming that renewable generation is non-curtailable. The studies found that there are significant upward and downward reserve shortfalls along with unsolved over-generation (sometimes referred to as dump energy[1]) in the spring months in the no curtailment Trajectory scenario and for all months except August for the no curtailment 40% RPS in 2024 scenario. The no curtailment cases do not represent a way to reliably operate the system. As a result, the CAISO continues to recommend that the Commission explore options to mitigate over-generation to ensure reliable operation of the system.

2. Introduction

The CAISO studied four Commission-identified scenarios in its long-term procurement plan (LTPP) testimony filed on August 13, 2014. These scenarios were the Trajectory, High load, Expanded Preferred Resources, and 40% RPS in 2024 scenarios.[2] In the CAISO's deterministic studies conducted on these four scenarios, renewable generation was curtailed at a price of -$300/MWh in order to balance generation and load. Based on this curtailment price point, the original deterministic studies indicated significant levels of renewable curtailment.[3]

Based on the results of the deterministic studies, the CAISO believed it was necessary to conduct additional studies to provide a bookend analysis of system reliability without assuming an unlimited ability to curtail renewables. The CAISO has conducted two additional sensitivity studies based on the Trajectory and 40% RPS in 20124 scenarios. In these sensitivities, the CAISO did not allow curtailment of renewable resources to mitigate reliability issues.

3. Assumptions

The CAISO's additional no curtailment sensitivities studies for the Trajectory and the 40% RPS in 2024 used primarily the same assumptions as those used in the CAISO's 2014 LTPP deterministic studies. In particular, the CAISO used the same model for the Trajectory and 40% RPS in 2024 scenarios based on the Assigned Commissioner's Ruling on Assumptions & Scenarios issued on February 27, 2014. In the 2014 LTPP deterministic studies, the CAISO treated combined heat and power (CHP), run-of-river hydro, and the Diablo Canyon nuclear plant as must-run resources. The CAISO modeled generation from these resources as non-curtailable. In the no curtailment sensitivities, these resources remain must-run and non-curtailable, even when there is unsolved over-generation.

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[1] Dump energy represents excess energy that cannot be consumed. It is a modeling mechanism to come up with a simulation solution to quantify the amount of energy that cannot be balanced by demand. For te purpose of this report, the CAISO uses the term "unsolved energy" synonymously with "dump energy."

[2] Assigned Commissioner Ruling, issued February 27, 2014.

[3] See the Phase 1.A. Direct Testimony of Dr. Shucheng Liu at http://www.caiso.com/Documents/Aug13_2014_InitialTestimony_ShuchengLiu_Phase1A_LTPP_R13-12-010.pdf.

The only significant difference between the CAISO's 2014 LTPP deterministic study and the sensitivities presented in this proceeding is the treatment of renewable resources. In the 2014 LTPP deterministic studies, the CAISO assumed a -$300/MWh curtailment price for renewable generation. In the present sensitivities, the CAISO treated renewable generation as non-curtailable resources.[4]

In the no curtailment sensitivities, the model optimization may try to mitigate or reduce over-generation by sacrificing reserves by, for example, not meeting the ancillary services and load following requirements. Actions will be taken automatically in the simulation in the following order, depending on the magnitude of over-generation:

- Reducing net import to a minimum of zero;
- Charging storage resources;[5]
- Backing down online dispatchable resources to their minimum capacity, which may cause downward load following and regulation shortfalls;[6]
- Shutting down online dispatchable resources, which may cause upward load following and ancillary services shortfalls;[7]
- Relaxing the 25% regional generation requirements when there would otherwise be unsolved over-generation; and
- Dumping energy when there is no other resource to back down.[8]

Based on the assumptions, shortfalls in both upward and downward reserves and load following were observed in hours with significant over-generation. When there is unsolved over-generation, the 25% regional generation requirements are not enforced because the model prioritize resolving over-generation over the need to maintain minimum regional generation.

4. Simulation Results

Assuming no renewable curtailment affects the hours with over-generation, but not the system peak net load hours. Therefore the upward capacity shortfalls at the system peak hours should not change from the original Trajectory and 40% RPS in 2024 scenarios.[9] However, as discussed above, the

[4] Generally renewable power purchase contracts allow certain amount of renewable generation to be curtailed based on economic means or based on emergency system conditions. The non-curtailable renewable is a bookend sensitivity.

[5] Storage resources have round-trip efficiencies between 70 and 85%. The cycle of charging and discharging will consume about 15–30% of energy. It is an economic way to dump (dispose) energy when the over-generation duration is longer than the storage charging duration. That is why in multiple continuous hours of over-generation the storage resources with short charging duration (for example 2 hours) may show the cycles of generating and discharging.

[6] Under such circumstances some generation resources outside the CAISO may still provide some reserves and load following to the CAISO. The generation of these resources does not add to the CAISO over-generation situation.

[7] See footnote 6.

[8] Dump energy is a modeling method. It does not represent a feasible way to dispose energy. In actual operation load and generation there is no way to dump energy. Dump energy is actually unsolved over-generation.

[9] Note that the 2,242 MW maximum capacity shortfall in the August 3, 2014 testimony was from the result of the Need Run. The capacity shortfalls presented in this report were from the Production Cost Run. They are slightly different.

limit on curtailment of renewable resources increases the number of hours and volume of upward reserve shortfalls in the sensitivities based on significant over-generation. This occurs because the shutdown of flexible generation leads to insufficient online flexible resources to provide necessary upward reserves.

The following situations lead to flexibility shortfalls.

- The over-generation during midday caused by lack of flexibility in the online base-load generation resources; and
- Insufficient online resources to meet the evening peak net load in ramping up from the midday low net load on the non-system peak load days.

The flexibility shortfalls are different from one sensitivity to another, depending on the volume of over-generation.

Short of assuming no renewable curtailment, there are multiple ways to resolve the significant over-generation issues that are expected at 40% renewable levels after all assumed dispatchable resources have been shut down. One is to curtail a portion of renewable generation according to terms specified in the power purchase contracts. Another option is to increase export by enhancing regional coordination. The options can be further explored based on the sensitivities presented in this report.

Monthly and annual results

Table 1 compares the monthly results of upward and downward reserve shortfalls and unsolved over-generation of the Trajectory scenario presented in the CAISO's 2014 LTPP testimony and the non-curtailable renewable Trajectory sensitivity.

Table 1. Reserve Shortfalls and Unsolved Over-Generation (Dump Energy) in the Trajectory Scenario (with and without Renewable Curtailment)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Trajectory Scenario - with Curtailable Renewable													
Total Upward Reserve Shortfall (GWh)							2.3						2.3
Max Upward Reserve Shortfall (MW)							1,065						1,065
Number of Hours of Upward Reserve Shortfall							4						4
Total Downward Reserve Shortfall (GWh)													0
Max Downward Reserve Shortfall (MW)													0
Number of Hours of Downward Reserve Shortfall													0
Total Renewable Curtailment (GWh)		0.5	48.3	76.7	21.7	6.2							153
Max Renewable Curtailment (MW)		243	5,927	5,410	2,984	2,025							5,927
Number of Hours of Curtailment		2	26	47	16	5							96
Sensitivity Case with Non-Curtailable Renewable Generation													
Total Upward Reserve Shortfall (GWh)			8.9	5.1	3.7	0.7	2.3						20.8
Max Upward Reserve Shortfall (MW)			1,608	887	1,167	356	1,065						1,608
Number of Hours of Upward Reserve Shortfall			14	14	7	3	3						41
Total Downward Reserve Shortfall (GWh)			0.8	0.7	0.0	0.9							2.4
Max Downward Reserve Shortfall (MW)			578	290		453							578
Number of Hours of Downward Reserve Shortfall			2	5		3							10
Total Dump Energy (GWh)			22.2	20.1	3.1	0.0							45
Max Dump Energy (MW)			4,133	3,986	991	0							4,133
Number of Hours of Dump Energy			9	14	5	1							29

As shown in Table 1, the upward reserve shortfall on the peak load hours in July did not change significantly from the original scenario to no curtailment sensitivity. The over-generation observed in the original scenario resulted in upward and downward reserve shortfalls and unsolved over-generation in

the no curtailment sensitivity. Eliminating the 153 GWh total renewable curtailment caused 68.2 GWh upward and downward reserve shortfalls and unsolved over-generation.[10] The maximum single hour of unsolved over-generation, or dump energy, is 4,133 MW, less than the 5,927 MW maximum renewable curtailment. In the no curtailment sensitivity additional reserves were provided by out-of-CAISO resources.[11] The small amount of renewable curtailment in February in the original scenario did not cause any reserve shortfall in the no-curtailment sensitivity. The model mitigated this potential over-generation by redispatching generation resources more expensive than $300/MWh, including startup and variable operation costs (renewable curtailment price was -$300/MWh).

Table 2 shows the monthly upward and downward reserve shortfalls and unsolved over-generation in the 40% RPS in 2024 scenario and the associated no curtailment renewable sensitivity.

Table 2. Reserve Shortfalls and Unsolved Over-Generation (Dump Energy) in the 40% RPS in 2024 Scenario (with and without curtailment)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual
40% RPS Scenario - with Curtailable Renewable													
Total Upward Reserve Shortfall (GWh)							5.9						5.9
Max Upward Reserve Shortfall (MW)							2,068						2,068
Number of Hours of Upward Reserve Shortfall							6						6
Total Downward Reserve Shortfall (GWh)													0
Max Downward Reserve Shortfall (MW)													0
Number of Hours of Downward Reserve Shortfall													0
Total Renewable Curtailment (GWh)	14.6	58.6	582.7	1,013.5	593.9	290.8	46.6	1.5	70.2	87.7	47.7	16.9	2,825
Max Renewable Curtailment (MW)	3,384	7,484	12,927	13,402	10,035	9,363	5,006	557	4,770	5,849	2,805	2,862	13,402
Number of Hours of Curtailment	15	29	141	202	165	114	20	5	36	33	42	20	822
Sensitivity Case with Non-Curtailable Renewable Generation													
Total Upward Reserve Shortfall (GWh)	0.8	9.0	83.5	149.3	88.6	69.3	21.7		21.7	31.3	5.8	2.7	484
Max Upward Reserve Shortfall (MW)	531	1,540	2,301	2,588	2,497	2,046	2,069		1,589	2,493	1,410	706	2,588
Number of Hours of Upward Reserve Shortfall	3	18	119	187	116	78	23		25	34	10	6	619
Total Downward Reserve Shortfall (GWh)	0.4	4.2	19.0	26.7	11.7	36.0	5.8		22.6	14.1	9.4	1.8	152
Max Downward Reserve Shortfall (MW)	249	977	1,776	1,281	1,201	1,347	745		1,599	1,062	1,117	670	1,776
Number of Hours of Downward Reserve Shortfall	3	18	126	192	122	93	23		35	36	24	5	677
Total Dump Energy (GWh)	1.4	22.7	335.3	572.1	265.4	103.9	14.5		13.4	29.8	1.6	2.4	1,363
Max Dump Energy (MW)	778	5,966	11,845	11,807	8,842	7,834	3,321		3,212	3,643	943	1,242	11,845
Number of Hours of Dump Energy	2	10	87	155	93	43	11		11	18	2	3	435

The total unsolved over-generation in the no curtailment sensitivity is 1,363 GWh, which is lower than the 2,825 GWh of total renewable curtailment in the original 40% RPS in 2024 scenario. The 11,845 MW maximum single hour unsolved over-generation in the sensitivity case is also less than the 13,402 MW maximum curtailment in the original scenario. This occurs because making renewable generation non-curtailable forces re-dispatch of generation resources that are more expensive (including startup and variable operation costs) than curtailing renewable generation at the -$300/MWh price. In the original 40% RPS in 2024 scenario, the system did not try everything possible, regardless of cost, to mitigate over-generation before curtailing renewable generation. In the CAISO's 2014 deterministic studies, curtailment renewable generation was modeled as an economic decision, not strictly a reliability decision. However, the economic decision to curtail renewable generation, even at the extreme price of -$300/MWh, represents a loss of resources that could have otherwise reduced CO2 emissions and helped the state meet its RPS goals. In addition, the levels of renewable curtailment

[10] 20.8 GWh in total upward reserve shortfall + 2.4 GWh in total downward reserve shortfall + 45 GWh in dump energy.

[11] See footnote 6.

observed in the 2014 deterministic studies indicates a serious reliability issue because the CAISO will not be able to operate the system reliably by curtailing up to 13,402 MW of renewable generation.[12]

Upward and downward reserve shortfalls and unsolved over-generation occur in eleven months of the year, with significant unsolved over-generation observed in March, April, and May. As with the Trajectory scenario, the small amount of renewable curtailment in August in the 40% RPS in 2024 scenario 40% RPS in 2024 scenario was resolved in no curtailment sensitivity. August is the only month the 40% scenario that did not show reserve shortfalls or unsolved over-generation. The re-dispatch of more expensive resources eliminated the need for curtailment.

To eliminate over-generation, there are other options than the assumptions of the three sensitivity cases. One option is to curtail renewable generation. In the no curtailment sensitivity case of the 40% RPS in 2024 scenario, the total downward reserve shortfall (including unsolved over-generation) is 1,514 GWh (152+1,363). To eliminate over-generation in this sensitivity, more than 1,514 GWh renewable generation would have to be curtailed.[13] In the 40% RPS in 2024 scenario the CAISO total renewable generation is 84,023 GWh.[14] The 1,514 GWh needed to be curtailed is about 1.8% of the CAISO total renewable generation. The maximum hourly curtailment is more than 11,845 MW.

Hourly results of March 24, 2024

March 24, 2024 is one of the days with the highest levels of over-generation. In Tables 3 and 4 below, the CAISO presents a detailed overview of the hourly upward and downward reserve shortfalls and unsolved over-generation in the Trajectory and 40% RPS in 2024 scenarios and their no curtailment sensitivities.

Table 3. Trajectory Scenario Reserve Shortfalls and Unsolved Over-Generation (Dump Energy) on March 24, 2024

Hour	8	9	10	11	12	13	14	15	16	17
Original Trajectory Scenario - with Curtailable Renewable										
Load Following-Up (MW)										
Spinning (MW)										
Total Upward										
Renewable Curtailment (MW)		392	3,437	5,927	4,579	4,718	4,224	3,620	724	
Load Following-Down (MW)										
Total Downward (MW)		**392**	**3,437**	**5,927**	**4,579**	**4,718**	**4,224**	**3,620**	**724**	
Sensitivity Case with Non-Curtailable Renewable Generation										
Load Following-Up (MW)		805	635	211	284	238	264	965	1,396	
Spinning (MW)									205	
Total Upward		**805**	**635**	**211**	**284**	**238**	**264**	**965**	**1,601**	
Dump Energy (MW)			2,383	4,133	3,432	3,625	2,819	2,629		
Load Following-Down (MW)										
Total Downward (MW)			**2,383**	**4,133**	**3,432**	**3,625**	**2,819**	**2,629**		

[12] See the Phase 1.A. Direct Testimony of Dr. Karl Meeusen, p. 8. http://www.caiso.com/Documents/Aug13_2014_InitialTestimony_KarlMeeusen_Phase1A_LTPP_R13-12-010.pdf.

[13] The total renewable curtailment should be 1,514 GWh plus the minimum generation of all resources needed to be committed to provide load following-down and regulation-down reserves.

[14] See footnote 3.

As discussed above, both upward and downward reserve shortfalls (including unsolved over-generation) can occur in the same hour with significant over-generation. The CAISO observed this in both no curtailment sensitivities. For the hours with unsolved over-generation, the shortfalls in both the upward and downward direction result from the model shutting down all dispatchable resources in the CAISO, which are the main sources for reserves. However, there are also hours with dump energy, but no shortfalls in load regulation-down or load following-down because fully or partially charged battery storage provided the necessary downward regulation and load following (as well as upward reserves). Some resources outside of the CAISO were also providing reserves and load following during these times.

Table 4. 40% RPS Scenario Reserve Shortfalls and Unsolved Over-Generation (Dump Energy) on March 24, 2024

Hour	8	9	10	11	12	13	14	15	16	17
40% RPS Scenario - with Curtailable Renewable										
Load Following-Up (MW)										
Spinning (MW)										
Total Upward										
Renewable Curtailment (MW)	163	6,010	10,700	12,927	12,291	12,572	11,215	10,349	6,144	956
Load Following-Down (MW)										
Total Downward (MW)	**163**	**6,010**	**10,700**	**12,927**	**12,291**	**12,572**	**11,215**	**10,349**	**6,144**	**956**
Sensitivity Case with Non-Curtailable Renewable Generation										
Load Following-Up (MW)	1,023	1,514	971	18		307	363	1,387	1,828	1,671
Spinning (MW)										
Total Upward	**1,023**	**1,514**	**971**	**18**		**307**	**363**	**1,387**	**1,828**	**1,671**
Dump Energy (MW)		4,912	9,343	11,563	11,298	11,845	9,960	9,197	4,130	
Load Following-Down (MW)		209						250	829	347
Total Downward (MW)		**5,121**	**9,343**	**11,563**	**11,298**	**11,845**	**9,960**	**9,447**	**4,960**	**347**

For hours immediately before there was unsolved over-generation (for example, hour 8 of the no curtailment sensitivity for the 40% RPS in 2024 scenario), most of the CAISO dispatchable resources were shut down. The remaining online resources did not have sufficient headroom to provide upward reserves and load following (see discussion in next section of ramping resources). This is a flexibility shortfall.

In the hours immediately following hours with unsolved over-generation (for example, hour 17 of the sensitivity case of the 40% RPS in 2024 scenario), some fast-start resources were committed and ramping up to follow the upward net load. However, these resources were operating near maximum capacity and, as a result, there was not enough online headroom to provide all the upward reserves. This is also a flexibility shortfall because the fleet could not react quickly enough to the change of direction of net load from over-generation to evening peak. One hour later the fleet could be committed and dispatched to follow the load and provide upward reserves.

Ramping resources

Figure 1 and Figure 2 below show the resources online on March 24, 2024 in the 40% RPS in 2024 scenario and the associated no curtailment renewable sensitivity case. March 24, 2024 is the day with highest renewable generation curtailment. The Trajectory scenario and its associated no curtailment

sensitivity case have similar patterns, but smaller volumes of renewable curtailment and unsolved over-generation.

Figure 1. Ramping Processes of March 24, 2024 – 40% RPS Scenario

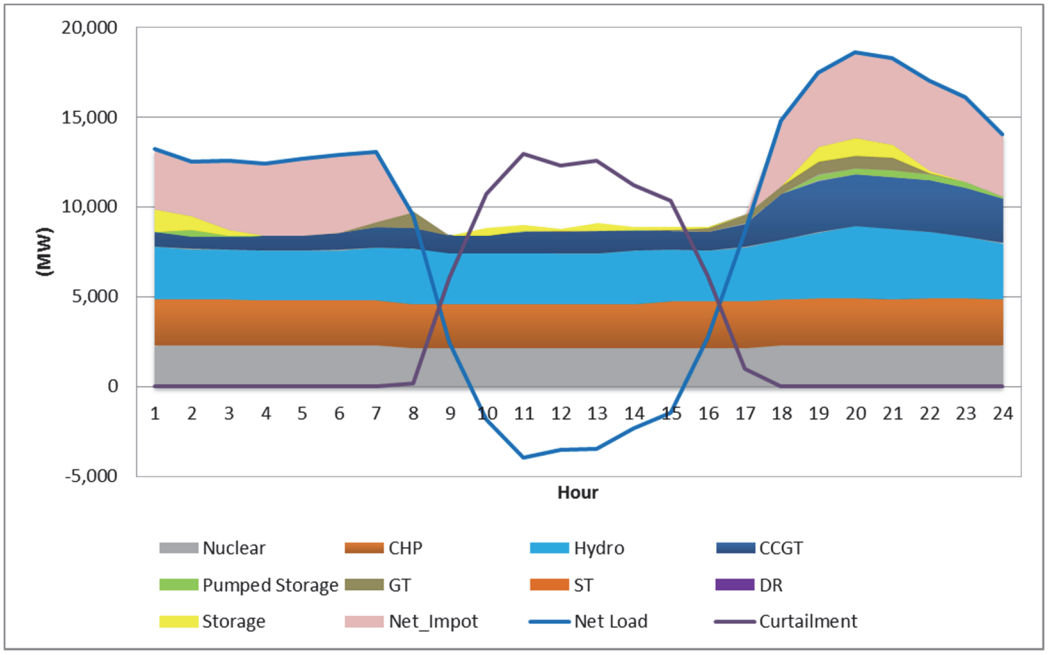


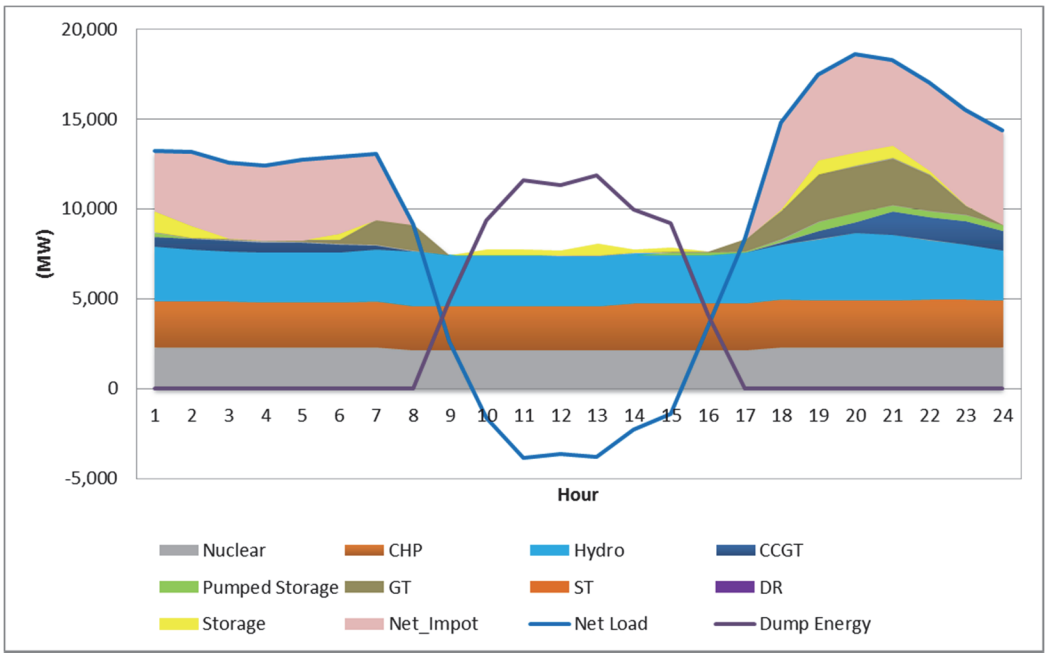
Figure 1 shows the generation and net load in the original 40% RPS in 2024 scenario on March 24, 2024.[15] During the hours with renewable generation curtailment there was generation from base load resources, including nuclear, combined heat and power (CHP), run-of-river hydro, and from combined cycle gas turbines (CCGT), gas turbines (GT), and storage. In the original 40% RPS in 2024 scenario, it is economic to curtail renewable generation in order to meet the reserve requirements. CCGT and GT were dispatched to provide upward and downward reserves. In addition to providing reserves, storage resources with short charging duration may show the cycles of generating and discharging in order to dispose of excess energy, as discussed in Footnote 5.

The evening upward ramping started at hour 18, ramping up from the total generation of hour 17. The ramping process lasted for only three hours. Net import contributed most during this ramping process, a 3,607 MW jump at hour 18.

GT was dispatched up at hour 8 to smooth the downward ramping. It was dispatched up again in the evening to help follow the upward net load.

[15] Net load equals total load minus renewable and DG PV generation. Net load could be negative if load is smaller than the sum of renewable and DG PV generation. Total load includes the energy consumed to pumped storages to pump water and by battery storage to charge the batteries. This energy consumption may vary from case to case. Therefore the total load in the original 40% RPS in 2024 scenario and in the three sensitivity cases may be different.

Figure 2. Ramping Processes of March 24, 2024 – 40% RPS Scenario No Curtailment Sensitivity



In the no curtailment sensitivity for the 40% RPS in 2024 scenario there was unsolved over-generation from hour 9 to hour 16. At hour 7 and 8, GT was committed and dispatched up to cover the reduction in net import and CCGT. The GT was then quickly ramped down at hour 9 to reduce over-generation. In the evening ramping up net import and GT contributed most to following the load, especially in the first three hours (hour 17-19). Net imports increase by 4,809 MW from hour 18 to 19. GT was dispatched from 30 MW at hour 16 to 2,658 MW by hour 19. Pumped storage and storage were ramped up at hour 19. The CCGT reached its maximum generation of the day at hour 21.

Note that the net load was at hour 11, but the upward ramping actually started at hour 17 because excess generation was dumped from lowest hour 11 to hour 16.[16]

CO2 emissions

Table 5 shows the CO2 emissions of the Trajectory and 40% RPS in 2024 scenarios and the associated no curtailment sensitivities.

[16] Net load is indicated as a negative number in Figure 1 where renewable generation and distributed generation exceed gross load.

Table 5. California and WECC CO2 Emission (million ton)

Scenario	Scope	Curtailable Renewable	Non-Curtailable Renewable
Trajectory	California	45.0	45.1
Trajectory	WECC	309.9	309.8
40% RPS in 2024	California	44.1	44.0
40% RPS in 2024	WECC	300.9	300.7

As shown in the table, the CO2 emissions did not change significantly between the original scenarios and the sensitivities.

To understand the changes in CO2 emissions, one must look at the role of CCGT and GT in the different sensitivities. In the original scenarios with curtailable renewable resources, CCGT and GT were dispatched to provide reserves and load following during hours with renewable curtailment. In the non-curtailable renewable sensitivity cases, the CCGT and GT were shut down to reduce unsolved over-generation. This resulted in a reduction in CO2 emission compared to the original scenarios. However, in the sensitivities GT was dispatched immediately before and after the hours with unsolved over-generation to help follow the net load. This role was performed primarily by CCGT in the original scenarios. The higher utilization of GT produced more CO2 emission in the sensitivity cases. For example, in the 40% RPS in 2024 scenario California CCGT had capacity factor of 38.2% and GT had 6.0%. In its associated no curtailment sensitivity case, the CCGT capacity factor dropped to 36.7% while GT capacity factor increased to 7.7%.

The total CO2 emissions are not significantly changed in the no curtailment scenarios, as shown in Table 5.

5. Conclusion

With no curtailment of renewable resources, the CAISO identified upward and downward reserve and load following shortfalls and unsolved over-generation in both the Trajectory and 40% RPS in 2024 scenarios. The unsolved over-generation is significant in the 40% RPS in 2024 scenario. Simply adding more flexible generation resources cannot solve the problem. The frequency and magnitude of the reserve shortfalls and unsolved over-generation reflect conditions that do not support reliable grid operations. As a result alternative options must be explored, including:

1) improving time of use rates to match with the pattern of over-generation;
2) targeting energy efficiency at hours without over-generation;
3) decarbonizing transportation fuels to create flexible load;
4) increasing demand response and storage;

5) allowing additional economic dispatch of renewables;

6) retrofitting of existing power plants to increase fleet flexibility; and

7) deepening regional collaboration through participating in the CAISO Energy Imbalance Market and increasing the CAISO operating footprint.

The CAISO appreciates the opportunity to provide this information. Additional data underlying the CAISO's no curtailment sensitivities can be found at the CAISO secured ftp site. Interested parties can request access to download the results.