Countdown to Shutdown

California's Clean Energy Future after Diablo Canyon Closes

Technical Appendix

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Modeling

The Union of Concerned Scientists (UCS) used two analytical tools in this analysis. The primary tool was the RESOLVE model, an electrical grid capacity expansion model used to determine the least-cost mix of new grid resources required to meet reliability, renewable energy, and emissions reduction requirements. In addition, we used the Clean System Power Calculator to estimate criteria air pollution emissions.

RESOLVE MODEL

In this analysis, UCS used the March 2020 version of the RESOLVE model, the same model and version used by the California Public Utilities Commission in the Integrated Resource Planning proceeding (CPUC 2020c). To solve the optimization problems generated by the RESOLVE model, we used the CPLEX Optimizer (version 12.9.0.0).

In general, UCS used the exact same inputs and assumptions used in the RESOLVE modeling that informed the California Public Utilities Commission's March 2020 decision selecting resource portfolios for the 2019-2020 cycle of the Integrated Resource Planning proceeding (CPUC 2020a). However, to conduct this analysis, UCS made the following updates to the RESOLVE model configurations:

- For every scenario in this analysis, UCS included every year in the 2020s in the RESOLVE optimization. That is, the UCS modeling included the years from 2020 through 2030 and 2045, whereas the California Public Utilities Commission's RESOLVE modeling included only the years 2020 through 2024, 2026, 2030, and 2045. We made this update in order to calculate cumulative global warming emissions over the next decade more accurately.
- For every scenario in this analysis in which Diablo Canyon did not shut down by 2025, each unit of the Diablo Canyon nuclear power plant was modeled as remaining online for an additional 20 years and ultimately shut down in 2044-2045. As a result, every scenario in this analysis had an identical amount of nuclear generating capacity in 2045.
- For one scenario, UCS created a custom emissions trajectory to estimate the resources that would be required to replace Diablo Canyon without increasing global warming emissions in the 46 million metric ton (MMT) pathway. For further details, see the explanation in the "Scenarios" section below.

UCS's RESOLVE model file, including all the inputs and results, is available upon request. Please contact Mark Specht at mspecht@ucsusa.org to obtain a copy.

CLEAN SYSTEM POWER CALCULATOR

UCS also used the Clean System Power calculator, another tool used by the California Public Utilities Commission, to estimate criteria air pollution emissions (CPUC 2020b). Because there are two different calculators available, one for the 46 MMT pathway and one for the 38 MMT pathway, we used the 46 MMT calculator for the 46 MMT scenarios and the 38 MMT calculator for the 38 MMT scenarios. We did not estimate criteria air pollution emissions for the 30 MMT pathway because no calculator was available.

Using the RESOLVE model outputs as inputs to the calculators, we estimated criteria air pollution emissions in each scenario. These calculations should be treated as estimates because the Clean System Power calculators were not designed for this specific application. When California load-serving entities develop their individual integrated resource plans, they use the calculators to determine the amounts of criteria air pollutant emissions for which their portfolios are responsible. Thus, this tool was designed to attribute emissions to the portfolios of individual load-serving entities *given a specific overall resource portfolio* (i.e., the 46 MMT and the 38 MMT overall resource portfolios specified in the California Public Utilities Commission's 2019-2020 reference system plan) (CPUC 2020a). In contrast, this analysis used the calculators to estimate the criteria air pollutant emissions from a *different* set of overall resource portfolios, and because the calculators were calibrated using slightly different portfolios, these results should be considered estimates only.

For more information on these calculations, see the "Analysis Using Clean System Power Calculator" section below.

Scenarios

UCS used the RESOLVE model to examine seven distinct scenarios in this analysis (Table A-1).

Table A-1. Summary of RESOLVE Modeling Scenarios

Scenario Number	2030 Global Warming Emissions Target	Diablo Canyon 20-year Extension	Custom Emissions Trajectory
1	46 MMT	No	No
2	46 MMT	Yes	No
3	38 MMT	No	No
4	38 MMT	Yes	No
5	30 MMT	No	No
6	30 MMT	Yes	No
7	43 MMT	No	Yes

UCS ran seven modeling scenarios using three different 2030 global warming emissions targets, two different assumptions about Diablo Canyon's retirement date, and one custom emissions trajectory.

Note: Scenarios shaded gray are those in which Diablo Canyon remains online for an additional 20 years.

UCS examined three different emissions pathways: statewide electricity sector emissions reductions to 46 MMT, 38 MMT, and 30 MMT by 2030. For each emissions pathway, UCS examined one scenario with Diablo Canyon remaining online until 2045 and another scenario with Diablo Canyon shutting down by 2025, for a total of six scenarios.

CUSTOM EMISSIONS TRAJECTORY

The seventh scenario used a custom emissions trajectory (Table A-2). UCS used this scenario for two purposes in this analysis.

First, UCS used this scenario to estimate the additional resources required to achieve the same level of cumulative global warming emissions by 2030 as the level achieved in Scenario 2 in Table A-1. Then, UCS compared the resource build-out in Scenario 7 to the resource build-out in Scenario 1 to calculate the resources required to close the 15.5 MMT gap in cumulative global warming emissions in the 46 MMT pathway (see the main text of "Countdown to Shutdown: California's Clean Energy Future after Diablo Canyon Closes" for additional information on the emissions gap).

Second, UCS used this scenario to estimate the overall level of Diablo Canyon replacement resources in 2030 in the 46 MMT pathway by comparing the resource build-out in Scenario 7 to the resource build-out in Scenario 2. In order to pinpoint the resources required to replace Diablo Canyon in the 46 MMT pathway, the 2030 resource build-outs in Scenarios 2 and 7 must result in the same level of global warming emissions in 2030. However, Scenario 2 achieves 43 MMT by 2030 because the combination of the 60 percent Renewable Portfolio Standard plus Diablo Canyon remaining online reduces emissions below the 46 MMT target. Therefore, we needed to use a custom emissions trajectory in Scenario 7 that produces the same level of 2030 emissions (i.e., 43 MMT by 2030) to pinpoint the resources that replace Diablo Canyon.

The custom emissions trajectory was designed in the following way:

- **2030 emissions:** Since Scenario 2 reduces 2030 global warming emissions below 46 MMT, the custom emissions trajectory was designed to reach the same 2030 emissions level achieved in Scenario 2: 43 MMT by 2030.
- **Cumulative emissions:** The custom emissions trajectory was also designed to produce the same level of cumulative global warming emissions by 2030 as the cumulative emissions in Scenario 2.
- **Process:** The custom emissions trajectory was developed using a guess-and-check process, adjusting annual emissions constraints until the cumulative emissions result in Scenario 7 was within 1 MMT of the cumulative emissions in Scenario 2. Ideally, instead of using these annual emissions constraints, Scenario 7 would have been developed using a cumulative emissions constraint (from 2020 through 2030), which would have more accurately determined the lowest-cost resource build-out to achieve a certain level of cumulative emissions. However, modifying the RESOLVE model to include a cumulative emissions constraint was outside the scope of this analysis.

Table A-2. Global Warming Emissions Targets in Custom Emissions Trajectory

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Target (MMT)	43.1	40.1	37.7	36.0	38.1	40.0	39.4	38.8	38.2	37.5	34.8

UCS used these annual global warming emissions targets in Scenario 7 to estimate the resources required to replace Diablo Canyon without increasing global warming emissions.

Note: These values are the emissions targets for the California Independent System Operator territory only, which encompasses approximately 81 percent of California's electricity sector.

Analysis Using Clean System Power Calculator

This analysis used both the 46 MMT and the 38 MMT version of the Clean System Power Calculator to estimate criteria air pollution emissions, specifically focusing on emissions of nitrogen oxides (NOx). For each scenario, we entered RESOLVE model outputs into the calculator; however, the calculator only outputs values for 2020, 2022, 2026, and 2030. To fill these gaps and calculate annual emissions values, we used linear interpolation between the four output values. However, because there is no significant change in the portfolio of grid resources between 2022 and 2023, we assumed that 2023 emissions remain the same as 2022 emissions. Finally, after estimating annual emissions for the scenario with Diablo Canyon retirement and the scenario with Diablo Canyon online, we calculated the difference in annual emissions and summed those values to calculate the total cumulative emissions difference (Table A-3 and Table A-4).

Table A-3. 46 MMT Clean System Power Calculator Outputs and Cumulative Emissions Calculation

	Scenario 1: Diablo Canyon Retirement (Tons of NOx)	Scenario 2: Diablo Canyon Online (Tons of NOx)	Difference (Tons of NOx)	Notes
2020	8,504	8,617	-113	Calculator output
2021	8,188	8,295	-107	Linear interpolation
2022	7,872	7,972	-101	Calculator output
2023	7,872	7,972	-101	Same as 2022
2024	8,130	8,093	37	Linear interpolation
2025	8,388	8,213	175	Linear interpolation
2026	8,647	8,334	313	Calculator output
2027	8,545	8,178	366	Linear interpolation
2028	8,442	8,023	419	Linear interpolation
2029	8,340	7,868	472	Linear interpolation
2030	8,238	7,713	525	Calculator output
Total Cumulative Emissions Difference:			1,887	

UCS used the 46 MMT Clean System Power calculator to estimate the cumulative difference in NOx emissions between the scenario with Diablo Canyon retirement (Scenario 1) and the scenario with Diablo Canyon remaining online (Scenario 2).

Note: Annual emissions values shaded gray are outputs from the calculator. All other values (except for 2023 values) were derived with linear interpolation between output values.

Table A-4. 38 MMT Clean System Power Calculator Outputs and Cumulative Emissions Calculation

	Scenario 3: Diablo Canyon Retirement (Tons of NOx)	Scenario 4: Diablo Canyon Online (Tons of NOx)	Difference (Tons of NOx)	Notes
2020	8,513	8,556	-43	Calculator output
2021	8,154	8,211	-57	Linear interpolation
2022	7,795	7,865	-70	Calculator output
2023	7,795	7,865	-70	Same as 2022
2024	8,015	7,970	45	Linear interpolation
2025	8,235	8,075	160	Linear interpolation
2026	8,455	8,180	275	Calculator output
2027	8,244	8,009	235	Linear interpolation
2028	8,033	7,838	195	Linear interpolation
2029	7,822	7,668	154	Linear interpolation
2030	7,611	7,497	114	Calculator output
Total Cumulative Emissions Difference:			938	

UCS used the 38 MMT Clean System Power calculator to estimate the cumulative difference in NOx emissions between the scenario with Diablo Canyon retirement (Scenario 3) and the scenario with Diablo Canyon remaining online (Scenario 4).

Note: Annual emissions values shaded gray are outputs from the calculator. All other values (except for 2023 values) were derived with linear interpolation between output values.

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