Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California

Executive Summary

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Introduction

The California 2030 Low Carbon Grid Study (LCGS) analyzes the grid impacts of a variety of scenarios that achieve 50% carbon emission reductions from California's electric power sector. Impacts are characterized based on several key operational and economic metrics, including production costs, emissions, curtailment, and impacts on the operation of gas generation and imports. We used the PLEXOS model to simulate the unit commitment and dispatch of the generating fleet in the western United States for 23 different scenarios, which included a variety of assumptions regarding the generator portfolios, energy efficiency, storage, and grid flexibility. A focus of the study is the impacts of electric system flexibility measures on key operational and economic metrics. The LCGS study comprises three reports: 1) this NREL report on the operational impacts of a low-carbon grid, 2) a report by JBS Energy on the capital costs of the scenarios (Marcus 2015), and 3) a report by GE Energy on the dynamic grid issues caused by high renewable penetrations (Miller 2015). A Steering Committee helped guide the study and a Technical Review Committee helped review the study; members of these committees are acknowledged in the report.

Portfolios and Major Assumptions

The portfolios (Figure ES-1) for this study are:

- **Baseline**: Assumes prior renewable portfolio standard (RPS) legislation (33% by 2020) and energy efficiency projected by the California Energy Commission (CEC) (this scenario has 36% renewable penetration[1] and 340 TWh annual load).
- **Target**: Achieves LCGS goal of 50% carbon reduction by 2030 using a higher level of energy efficiency and a diverse mix of renewable resources (56% renewable penetration[1] and 320 TWh annual load). This Target portfolio includes 2.2 GW additional storage.
- **High Solar**: Assumes the same quantity of renewables, storage, and load as Target but with a less diverse mix of resources: more photovoltaics (PV) and less wind, concentrating solar power (CSP), biomass, and geothermal (56% renewable penetration[1] and 320 TWh annual load).

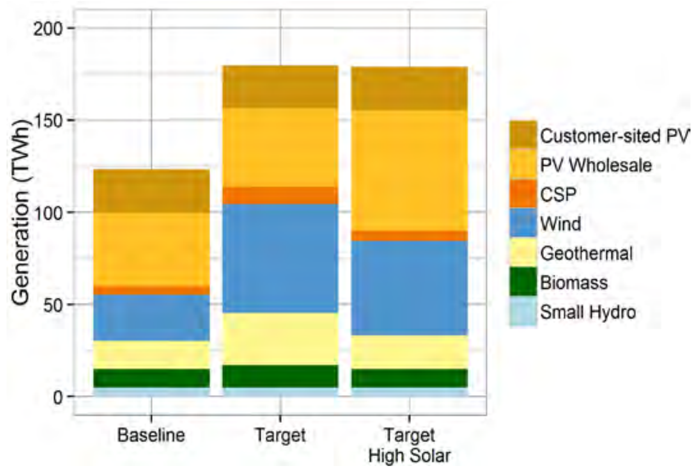

Figure ES-1. Renewable generation in LCGS portfolios

All portfolios include 23 TWh of rooftop or customer-sited PV penetration (7% of annual load).

In order to understand how changes in operational practices could impact the flexibility of the system, we created the two grid flexibility frameworks listed in Table ES-1. These assumptions (and others) were tested in various combinations with the portfolios.

[1] Renewable percentages include rooftop PV and are a fraction of total California load plus transmission losses, which differs from current RPS calculations.

Table ES-1. Conventional vs Enhanced Flexibility Assumptions

Conventional Flexibility	Enhanced Flexibility
70% of out-of-state (CA-entitled[2]) renewable, nuclear, and hydro generation must be imported	Only physical limitations on imports and exports
25% of generation in California balancing authorities must come from local fossil-fueled and hydro sources	No minimum local generation requirements
1.5 GW battery storage to meet CA Public Utility Commission requirement in addition to existing storage	In addition to the existing storage and 1.5 GW mandated battery storage, 1 GW new pumped hydro, and 1.2 GW new out-of-state compressed-air energy storage that are only added in the Target and High Solar portfolios, as noted above.
Limits on ability of hydro and pumped storage for providing ancillary services[3]	Less strict limits on hydro and pumped storage for providing ancillary services

By not enforcing the conventional flexibility constraints, the enhanced flexibility scenarios increase California's ability to export California-entitled energy, shut down gas generation to make room for renewables and use storage to reduce curtailment and peak-load energy needs. The conventional flexibility assumptions are not intended to be an exact replica of today's operating conditions (see Table ES-3 for differences), and the modeling assumptions are not policy recommendations but proxy representations of potential operating conditions based on recent proposals and policies.

Key Findings

- California can achieve a 50% reduction in CO_2 levels by 2030 in the electric sector under a wide variety of scenarios and assumptions (Figure ES-2). Conventional grid flexibility assumptions and the less diverse portfolio (High Solar) led to 14% more carbon emissions than the more diverse Target portfolio with enhanced flexibility. The Baseline portfolio shows significant reductions in carbon compared to today due to more PV generation (under the 33% RPS) and the retirement of California-entitled coal generation outside California. The only scenario that did not achieve a 50% reduction had conventional grid flexibility and dry hydro assumptions.

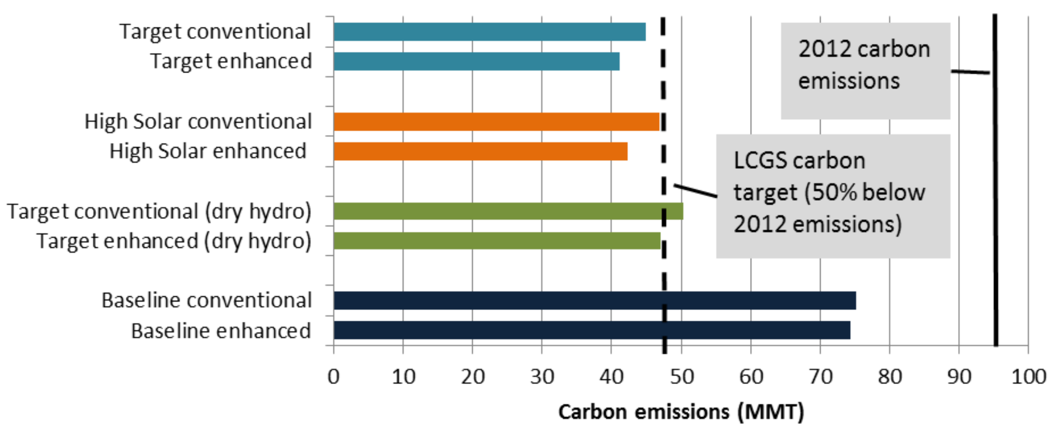

Figure ES-2. Carbon emissions (MMT) in eight selected LCGS scenarios

[2] CA-entitled refers to generation that is owned by or contracted to California utilities but located out of state.
[3] Ancillary service limitations were tuned so that ancillary service provisions were similar to 2013 in CAISO.

- The energy efficiency and renewable energy additions reduce production costs by $4.85 billion in the model with enhanced flexibility (see Table ES-2). The conventional grid flexibility assumptions increase production costs by $65 million in the Baseline and $550 million in the Target scenario. The model shows the cost reduction of enhanced flexibility is much higher in scenarios with high penetration of renewables.

Table ES-2. Reduction in Production Cost Compared to Baseline Enhanced

Portfolio	Conventional flexibility	Enhanced flexibility
Baseline	-$65m	0
Target	$4,300m	$4,850m

- For comparison, a companion report by JBS Energy (Marcus 2015) found that the annualized capital costs of the incremental renewable generation, transmission, and storage capacity between the Target and Baseline portfolios was $5.1 billion, or about $230 million more than the production cost reduction from the Target portfolio. This cost difference represents 0.6% of the annual revenue requirement for California utilities. Depending on technology costs, economic conditions, natural gas, and carbon prices, the overall (capital and production costs) cost impact of the Target scenario with enhanced flexibility (compared to the Baseline scenario) ranges from -3% to 6% of the annual revenue requirement for California utilities.

- Curtailment of renewable generation is much lower in the enhanced flexibility cases (<1%) than the conventional flexibility cases (up to 10%); see Figure ES-3. The level of grid flexibility can be as significant as the portfolio in driving curtailment: the Baseline conventional scenario has higher curtailment (0.6%) than the Target enhanced (0.2%). The modeling indicated that the combination of the import rule and local generation rule drives curtailment in the conventional grid flexibility assumptions although each of these assumptions alone has only modest impact on the results. In the scenarios with conventional flexibility, diversity of renewable resources led to lower costs and emissions.

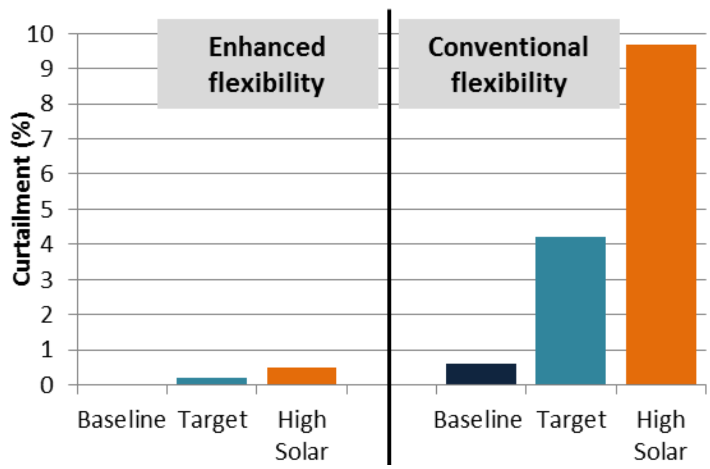

Figure ES-3. Curtailment in six selected LCGS scenarios

- The enhanced operational flexibility options tend to increase cycling at California gas generators; storage and demand response can help reduce emissions and curtailment while reducing cycling.

- Imports from fossil-fuel generation are reduced from today's levels in the Baseline scenario due to out-of-state coal retirements and in-state PV generation. Imports from out-of-state renewable generation in the Target scenarios replace imports from fossil fuel generation in the Baseline scenario.

- Achieving high levels of renewable penetration in the rest of the western United States does not change the key conclusions on curtailment, emissions, and production costs in California based on the optimal west-wide dispatch modeled. Achieving enhanced levels of flexibility may be more difficult if neighboring states will not purchase California-entitled generation even when that is the lowest-cost option.
- Flexibility comes from a wide variety of sources. During the steepest hourly ramp of the year in the Target enhanced flexibility scenario, the primary resources ramping to meet the 11 GW hourly ramp include physical imports (4.5 GW ramp), storage (3.2 GW), the gas fleet (3.2 GW), and demand response (0.2 GW). Other high-ramp hours have different combinations of those resources contributing to serve the ramp, often including hydro generation.
- GE Energy examined the dynamic grid issues associated with the LCGS scenarios. Miller (2015) found that California should be able to procure enough frequency response from renewable generation, demand-side participation, and energy storage to meet obligations without curtailing additional renewable generation. Transient stability could present risks in the LCGS scenarios, although mitigation options (e.g., synchronous condensers, transmission) do exist today. More detailed modeling of low-carbon scenarios will be needed to fully assess these risks.

Comparison with Today's Grid and Sensitivities Analyzed

Some key differences exist between today's grid and the assumptions used in the conventional flexibility grid framework. These differences are shown in Table ES-3 (more detail in report):

Table ES-3. Key Differences Between Today and Conventional Flexibility Assumptions for LCGS

Difference	Impact
Model assumes optimal west-wide dispatch subject to constraints and hurdle rates	In reality, bilateral contracts and other market inefficiencies can lead to out-of-market dispatch and possibly more significant integration impacts of renewables.
Diablo Canyon nuclear generating station is assumed to retire	Diablo Canyon is a zero-carbon resource that would make hitting a carbon target easier, but could increase integration challenges.
3 million electric vehicles adding 13 TWh of load	Half of the vehicles are assumed to be optimally charged, creating the potential for up to 3,000 MW of load during times of curtailment.
Non-renewable generation fleet changes include coal retirements outside California	Coal retirements and gas-fleet changes are taken from Western Electricity Coordinating Council and CA Independent System Operator projections. Combined heat and power facilities are assumed to have some operational flexibility, per CA Public Utilities Commission policy.
Transmission is added in the Target portfolio to bring renewable resources to load	This includes a north-south line from Idaho to southern Nevada that helps relieve north-south congestion and improves ability to use resource diversity throughout the west. Scenarios produce larger intertie flow changes than seen historically in some cases.
Rooftop PV generates 24 TWh in all scenarios (7%–8% of total annual generation)	The Baseline and Target portfolios both include 24 TWh of rooftop PV generation, which reduces emissions compared to today in both portfolios.

Model scenarios in this study examined various types of flexibility differences, including:

- Resource investments: Diverse (Target) compared to high solar (High Solar) portfolios with and without additional storage
- Operational or institutional changes: Physical import requirements, local generation requirements, ancillary service provision limitations on hydro resources, and real-time flexibility in import schedules (e.g., due to an efficient energy imbalance market)
- Demand-side flexibility: Higher levels of demand response (optimal or utility-influenced charging of half of electric vehicles is included in all scenarios)

In addition to scenarios with various combinations of these assumptions (including the conventional and enhanced flexibility scenarios), we also modeled scenarios with higher west-wide renewable penetrations, lower gas prices, higher CO_2 prices, and different hydro resource levels.

Conclusion

The modeling results indicate that achieving a low-carbon grid (with emissions 50% below 2012 levels) is possible by 2030 with relatively limited curtailment (less than 1%) if institutional frameworks are flexible. Less flexible institutional frameworks and a less diverse generation portfolio could lead to higher curtailment (up to 10%), operational costs (up to $800 million higher), and carbon emissions (up to 14% higher).

Future work should examine issues related to bilateral contracts and other sources of market friction and what can be done to limit any impact that these institutional barriers could present to a low-carbon grid. Also, further work is needed to understand stability impacts of a low-carbon grid and ways to cost-effectively mitigate these potential issues.

List of Associated Publications

Grid modeling: Brinkman, G., J. Jorgenson, J. Caldwell, A. Ehlen. *Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California*. National Renewable Energy Laboratory. 2015.

Capital cost analysis: Marcus, B. *Low Carbon Grid Study: Comparison of 2030 Fixed Cost of Renewables and Efficiency, Integration with Production Cost Savings*, JBS Energy, 2015.

Dynamic reliability analysis: Miller, N. *Low Carbon Grid Study: Discussion of Dynamic Performance limitations in WECC*, GE Energy Consulting, 2015.

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