An Analysis of Solar Curtailment in California's Energy Market

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ABSTRACT

California leads the United States in transitioning to renewable energy with ambitious targets that have underscored the state's commitment to clean power. The rapid integration of renewable energy sources into the power grid introduces challenges in balancing energy supply with fluctuating demand. Curtailment, or the intentional reduction of renewable energy output, emerges as a critical tool for maintaining grid stability. However, it also signifies potential economic losses and inefficiencies in energy utilization. With substantial investments in infrastructure including energy storage solutions and transmission lines, California's approach to managing the surplus energy represents a critical area of study. This research analyzes the impact of curtailment on California's energy production and grid reliability by leveraging statistical analysis and machine learning to enhance the efficiency and sustainability of renewable integration.

INTRODUCTION

As the United States' frontrunner in transitioning to clean energy, California has set ambitious targets for transitioning to renewable energy (Golden et al., 2015).

Since 2016, California has more than doubled its Solar Generation, with plans to double again by 2030. The crux of managing the energy transition more effectively lies in addressing factors affecting solar curtailment.

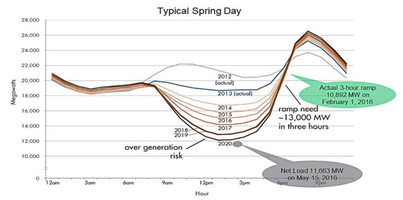


Figure 1.
"Duck Curve" Showing Mismatch Between Supply and Demand

If solar and wind are providing more energy than the grid needs, it is **curtailed, or intentionally reduced to match demand.** As renewables have increased in California, so has curtailment.

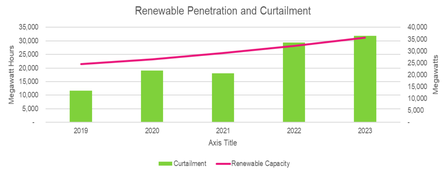


Figure 2.
Renewables and Curtailment

This study explores two relationships: 1) the relationship between production and curtailment of renewable energy (Owolabi et al., 2023; Maniatis et al. 2022; 2) the connection between curtailment and possible mitigation strategies, focusing on battery storage and development of transmission lines.

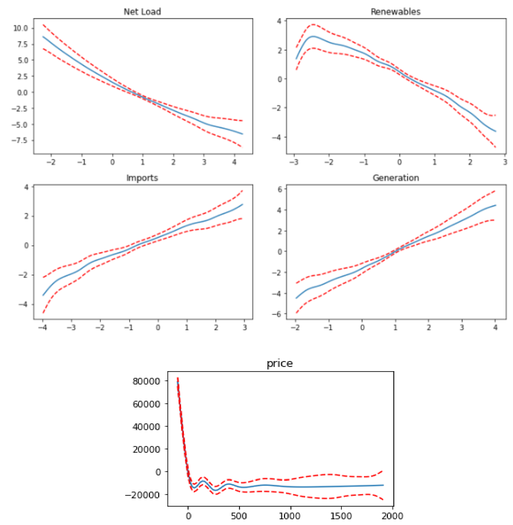
METHODOLOGY

- The methodology employs a multifaceted approach to assess the dynamics of renewable energy prices, production, transmission, storage, and curtailment, and storage within California.
- Data spanning from 2019-2023, when the transition to clean energy has been accelerated, was compiled from the California Independent System Operator (CAISO).
- After cleaning the data and exploring the potential relationships between variables through exploratory data analysis, an analysis was conducted on hourly data.
- Following the data preparation and feature engineering phases, three different models were created considering the linear and non-linear relationships between the variables: Linear Regression, Support Vector Machine (SVM) Regression, and Generalized Additive Model (GAM).
- As the relationships between the variables were mostly non-linear, GAM turned out to be the most successful model and was able to explain 25% of the variance in the data (López et al., 2023).
- GAM can be represented as the following:

$$y=\beta 0+f1(price)+f2(\text{demand})+f3(\text{transmission})+f4(\text{renewables})+f5(\text{import})+f6(\text{generation})+\varepsilon$$

FINDINGS

- Solar curtailment has approximately doubled from 2019 (3.7%) to 2023 (7.3%).
- Peaks occur in March, April, and May, and noon hours between 11 AM and 3 PM.
- Curtailment increases as the demand for energy decreases during the day.
- As the demand for energy increases, curtailment decreases.
- Curtailment increases with the rise in energy imports and total energy production, as prices decline.
- No significant relationship was found between transmission capacity and curtailment.
- Although storage capacity has dramatically increased since 2019, it is not sufficient to reduce the increase in curtailment.
- The rise in electric vehicles and their charging during daytime hours have the potential to reduce curtailment (Dumlao et al., 2022).



CONCLUSIONS & RECOMMENDATIONS

This study shows the effect that distinct factors have had on curtailment in CAISO. As the energy transition progresses, these affects will be compounded unless measures are taken to mitigate curtailment.

To be able to propose that storage and transmission capacity can be cost-effective solutions, geographic analysis with finer granularities should be done.

Although the scope of this study is limited by the data from CAISO; future research could expand on the interplay between renewable integration, curtailment practices, and emerging storage technologies.

ACKNOWLEDGEMENTS

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