Optimizing the Use of Curtailed Power in the Electric Grid

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Introduction

Deep decarbonization of the energy system over the course of this century is a prerequisite to averting the worst consequences of climate change. Many decarbonization pathways have been proposed, most of which envision a substantial expansion in the deployment of variable and intermittent renewable energy sources, mainly solar and wind power [1-3]. What is new in more recent climate and energy models has been an increase in the likelihood that net negative emission technologies will be required to achieve the targets enshrined in international climate accords, whether the target is a 2°C or 1.5°C rise in average global temperatures [4].

To achieve this carbon removal, models employ a singular technology—bioenergy with carbon capture and sequestration (BECCS)—the scalability and environmental impacts of which remain uncertain [5,6]. On the other hand, solar and wind power have both proved scalable: over the past decade, decreasing costs and strong government incentives have propelled a more than fifty-fold increase in installed solar power capacity worldwide, from 9 gigawatts (GW) globally in 2007 to 500 GW in 2018 [7]. Installed wind power capacity has increased more than six-fold over the same period [8]. Concurrently, however, several major electricity markets have also seen an increase in both solar and wind power curtailment—the shutting down of electricity production from these generators because the system cannot integrate it. In the first four months of 2018, the California Independent System Operator (CAISO) was forced to curtail more than 210 Gigawatt hours of wind and solar power, and CAISO is expecting these levels of curtailment to increase as more renewables are installed in pursuit of the state's ambitious renewable energy goals [9]. This curtailment reduces generator availability and revenue; on the level of the system, it adversely impacts both power system reliability and generation expansion planning.

Here, we lay the groundwork for a new stream of research that investigates the extent to which the large-scale deployment of solar and wind power can encourage complementary carbon removal by other means. Specifically, we analyze how to transform curtailment risks into benefits by describing the extent to which curtailed electrons could power a suite of technologies that could amplify emissions reduction.

Data & Methods

Our model is empirically grounded in a four-year record of curtailment across the CAISO system and the locational marginal prices (LMPs) at each of the 2,202 aggregated pricing nodes within it. The relationship between these two parameters is shown in Figure 1.

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Using these data and cost and performance parameters for three technologies that could mitigate anthropogenic carbon emissions, we develop a large-scale technology portfolio optimization model that optimizes the location and scale of technology deployment required to exploit both curtailed generation and electric power from the grid when the price of electricity in CAISO is so intensely negative that it justifies the operation of these systems. The three technologies we investigate are direct air capture of carbon dioxide, power to gas technologies, and utility-scale deployment of energy storage in the form of Lithium-ion batteries.

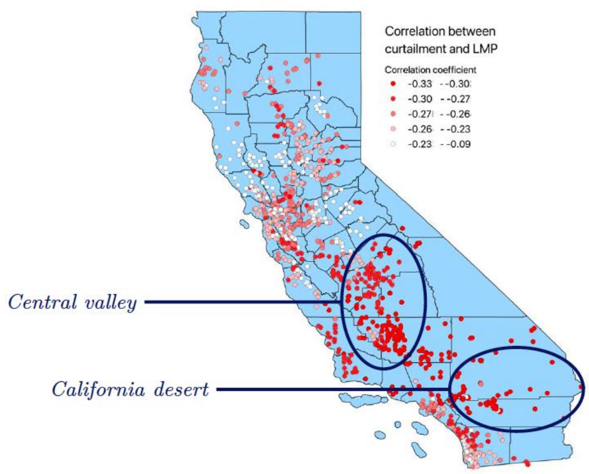

Figure 1: Pearson correlation between curtailed electric power and locational marginal prices (LMPs) across the CAISO system. Pockets of negative correlation exist in locations with high renewable generation and in urban areas, where local transmission constraints exist.

The large volume of empirical data necessitates decomposition of the optimization problem. We employ Bender's decomposition to solve the technology portfolio optimization.

Results

Our results suggest that carbon dioxide removal occurs through two methods. The vast majority is supported by curtailed energy, and this curtailment is done mostly through direct air capture technologies, which operate at lower cost than their alternatives, at least according to the fairly optimistic cost assumptions made by their developers [10]. Together, direct air capture technologies are responsible for the removal of more than 6.2 million tons of carbon dioxide over the course of the four years under investigation.

A small amount of CO_2 removal is supported in areas with characteristically negative locational marginal prices (LMPs). Ten percent of the CAISO system has LMPs negative enough to support carbon removal technologies, though these would operate intermittently and at high marginal cost. In total, these two methods could remove approximately 6.4 million tons of carbon dioxide over four years, which is equivalent to removing approximately 1.3 million cars from the road for a year. Figure 2 shows a summary of these results, identifying the location and type of technologies deployed across the CAISO system.

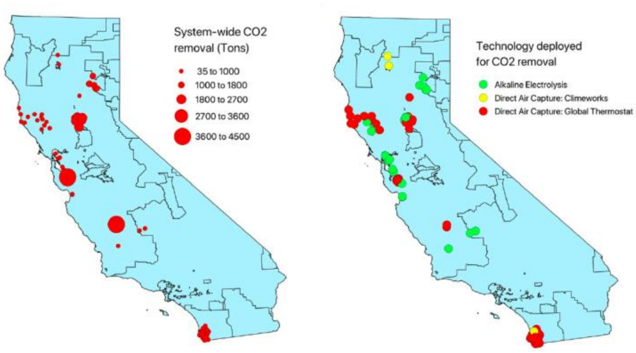

Figure 2: Assessments of the system-wide carbon dioxide removal potential across the CAISO system (left), and the type of technologies that are preferentially deployed throughout the state (right). Direct air capture technologies are preferred because they operate at lower costs, albeit according to the fairly optimistic cost assumptions made by their developers.

Conclusions

This research presents a novel method of amplifying the emissions reduction that could be achieved through deep penetration of renewable energy sources, while at the same time alleviating the problems inherent in their variability and intermittency. We employ a technology portfolio optimization model and Bender's decomposition to assess the extent to which curtailed and negatively priced electricity—a consequence of the deployment of variable and intermittent renewable energy sources—can be used to power a suite of technologies that reduce carbon dioxide emissions, either directly or by substituting the source of these emissions for products with lower carbon intensity.

Our work is intended to enable both energy system modelers and policy makers to begin considering the upside of curtailment, which is rightly deemed to be a major challenge to the power system. Moreover, we show how a range of emergent climate change mitigation strategies can produce fairly substantial benefits. If climate change mitigation becomes a bottom-up endeavor, as appears likely, these new strategies could work alongside traditional policy instruments as we seek to deeply decarbonize the global energy system.

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Attendee Comments

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"It is good to have an opportunity to hear international perspectives. There is not as much happening in climate policy in the US so sometimes you need to look abroad to learn what is working else ware."