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Assessing the impact of drought on the emissions- and water-intensity of California's transitioning power sector

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ABSTRACT

This study investigates how technological transitions across California's power sector have shifted its state-level carbon dioxide emissions and cooling water consumption intensities. Its ultimate goal is to evaluate how the state's climate mitigation and environmental policies have affected the power sector's vulnerability to extreme drought and how extreme drought has affected progress towards the state's climate mitigation priorities. The study analyzes the period spanning 2010–2016, which includes one of the state's most severe droughts on record. The results indicate that the growth of variable renewable energy generation has helped offset some of the negative consequences of drought, which include increased emissions and cooling water usage by natural gas generators during periods of low hydropower. However, the retirement of the San Onofre nuclear power plant has delayed the overall decarbonization of the state's power sector, and the closure of significant coastal power plant capacity could increase the freshwater consumption of the power sector if replacement capacity is not cooled with alternative cooling water sources or dry cooling systems. The noted tradeoffs between greenhouse gas mitigation priorities, freshwater dependency, and vulnerability to climatic events highlight the importance of holistic decision making as regional power grids transition to cleaner generation sources.

1. Introduction

California has been a leader in enacting policies to reduce the climate change and environmental consequences of power generation across the state. Recent regulations have been passed to reduce statewide greenhouse gases (California Legislative Information, 2006; California Legislative Information, 2017a; Office of Governor, 2015), increase the development of renewable energy (California Legislative Information, 2017b), decrease the impacts of power plant cooling systems on aquatic ecosystems (California State Water Resources Control Board, 2010), and promote demand-side interventions such as demand response and energy efficiency (California Legislative Information, 2006; California Public Utilities Commission and California Energy Commission, 2008; California Energy Commission, 2017a). Collectively, these policies have led to large technological transitions in electricity generation units across the state, away from large, inefficient thermal power generators, towards more efficient natural gas combined cycle and renewable generators (California Energy Commission, 2017d).

At the same time, unprecedented drought between 2012 and 2016 challenged the operation of some of California's electricity generation infrastructure, especially those generators with large freshwater dependencies, namely hydropower (Belmecheri et al., 2016; Gleick, 2017). Even in the period prior to the recent drought, an analysis assessing the lifecycle water use across California's energy system between 1990 and 2012 using an input-output method, concluded that California has higher water and CO_2 footprints when regional hydroelectricity capacity is reduced (Fulton and Cooley, 2015). More generally, drought events have been recognized in the literature for exacerbating the power grid's vulnerability to disruptions (Voisin, 2016; Kern and Characklis, 2017), increasing risks of insufficient generation (particularly during periods of peak summer demand) (Voisin, 2016; Kimmell et al., 2009), and increasing electricity-related carbon dioxide (CO_2) emissions (Hardin, 2017; Turner et al., 2017). These drought events have also been associated with increased electricity generation costs (Kern and Characklis, 2017; Gleick, 2016), as well as the social costs associated with power generation (Gleick, 2017; Eyer and Wichman, 2016).

Opportunities to support adaptation and resiliency strategies in the power sector to reduce these climate-induced vulnerabilities have also been addressed in literature (Miara et al., 2017; Pfenninger et al., 2014; Koch and Vögele, 2009), mostly for Western Interconnection and Texas

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(Harto et al., 2012; Bartos and Chester, 2015; Fowler and Shi, 2016). In a recent California-based study, Hardin et al. estimated that 22 million more metric tons of CO_2 were emitted from California's power sector during 2012–2014 drought compared to the period spanning 2009–2011, which is equivalent to a 33% increase in its annual CO_2 emissions compared to 2011 (Hardin, 2017). They conclude that increasing solar photovoltaic panels (PV) and wind renewables by 250% of their 2014 levels would be required to fully offset the drought-related increase in CO_2 emissions (Hardin, 2017) and suggest that having a comprehensive and integrated energy-water management plan could help minimize CO_2 emissions during drought events. Other studies have also highlighted the potential role of increasing renewable energy resources to mitigate these drought consequences (Christian-Smith et al., 2015; Brummitt et al., 2013; Scorah et al., 2012).

Creating holistic climate change mitigation and environmental policies that provide societal benefits, without increasing the power sector's vulnerability to future climatic conditions, requires the careful consideration of the interdependencies between energy, environment and climate. While the many publications have assessed the role of renewable integration on future power sector emissions (Greenblatt, 2013; Greenblatt, 2015; Barbose et al., 2015; Walmsley et al., 2015) and cooling water use (Meldrum et al., 2013; Fthenakis and Kim, 2010; Mouratiadou, 2017; Miglietta et al., 2018) trajectories, much less attention has been directed to assessing the tradeoffs in regards to CO_2 emissions and the water dependency of the power sector, particularly during periods of extreme drought. This paper assesses the time-varying changes in the water intensity and CO_2 emissions intensity of California's grid during the period of 2010 through 2016, which was a period that includes wet periods, extreme drought, as well as technological transitions in the electricity generation fleet. The major research question investigated is whether or not the expansion of water-lean renewable electricity sources over this time-period, namely wind and solar PV, markedly reduced California's vulnerability to drought-related increases in emissions and cooling-water usage due to diminished hydropower resources. First, a brief discussion of significant policies affecting the CO_2 emissions and cooling water usage intensities of California's power sector are discussed. Second, an analysis of how statewide cooling water requirements and CO_2 emissions changed during the period between 2010 and 2016, which includes the state's unprecedented drought, is presented. Finally, a discussion of how current policies have affected the environmental performance of the grid, and its resilience to disruptions due to drought, are discussed. The results are important for identifying policies that synergistically align mitigation (i.e. reducing greenhouse gas emissions) and adaptation (e.g. increasing the power sector's resilience to drought) priorities, and by contrast, those policies that potentially pose unintended consequences to either priority. California presents an important case study because of its aggressive mitigation and environmental policy goals, as well as its susceptibility to drought and water stress.

2. An overview of recent policy initiatives affecting the environmental impacts of California's electricity sector

California's recent changes in the power sector and the evolving fuel mix have been motivated by a number of policy-driven initiatives. As part of its climate change mitigation efforts, the state of California enacted legislation to reduce greenhouse gases to 40% and 80% below 1990 levels by 2030 and 2050, respectively (Office of Governor, 2015). The 2050 goal was established in 2005 via Executive Order S-03–05, while the 2030 goal was recently enacted through Executive Order B-30-15 (Office of Governor, 2015; Office of Governor), which was signed by Governor Brown in April 2015 to accelerate the state's greenhouse gas reductions and better prepare it for reaching its 2050 goal. Based on the California Air Resources Board (CARB) climate change scoping plan, the electricity sector, one of the biggest emitters of CO_2, must reduce its carbon footprint as much as 43–61% from its 1990 level by 2030 to facilitate economy-wide targets (California Air Resource Board, 2017b).

In order to align its climate goals with the electricity sector's planning and procurement activities, the state passed Senate Bill 350 (SB 350) in 2015 to strengthen support for its statewide Renewable Portfolio Standard (RPS) targets and energy efficiency programs, which effectively shift the trajectory of future of power generation technologies across the state (California Legislative Information, 2015). California's renewable RPS, a regulatory mandate to increase utility-scale production of electricity from eligible renewable sources as defined by the California Energy Commission (CEC), includes biomass, geothermal, solar, wind, and small hydroelectric (< 30 MW) facilities across all load serving entities (i.e. investor-owned utilities, publicly owned utilities, electric service providers, and community choice aggregators) (Green, et al., 2015). While California is on track to get 33% of its retail electricity from renewable resources by 2020 as mandated by Senate Bill X1–2 (passed in 2011) (California Legislative Information, 2011), SB 350 increases this share to 50% by 2030 (Green et al., 2015).

Complimentary to the state's RPS program, the California Solar Initiative (CSI) and Self-Generation Incentive Program (SGIP) has stimulated the development of demand-side distributed renewable generation (Blackney and Lee, 2016). These programs incentivize the customer to install distributed renewable energy generation technologies that directly serve their own load. Electricity generated from power systems installed under CSI and SGIP is generally not counted towards utilities' RPS obligation. These programs have successfully supported the growth of distributed solar PV generation from 1300 GWh in 2010–9000 GWh in 2016 (California Public Utilities Commission).

The California Global Warming Solutions Act (Assembly Bill 32 or AB-32) Cap-and-Trade program became effective in 2013 and was designed by CARB to provide a backstop for the growth of statewide greenhouse gas emissions. In 2017, California, Quebec and Ontario Canada signed an agreement to create a joint carbon market, which is currently the second-largest in the world (California Air Resource Board, 2017b). The Cap-and-Trade program provides monetary incentives for greenhouse gas emitters to reduce their emissions by creating a market for polluting entities to buy and sell pollution credits. Large polluters can buy pollution credits from lesser-polluting entities, and therefore, are incentivized to become cleaner over time so that they do not need to purchase credits. California has quarterly auctions for large power plants, factories, and fuel distributors with a rising annual price floor ($13.57 per metric ton by 2017) (California Air Resource Board, 2017a). Overall limits on emissions will be reduced over time to ensure that the AB-32 target is met, by establishing a statewide cap that controls the total amount of emissions released by all market participants, with the expectation that the cap will decline over time (California Air Resource Board, 2017a; California Air Resource Board, 2017b). The program is expected to facilitate a reduction of as much as 40–85 $MMTCO_2$ equivalent in CARB's scoping plan for 2030 emissions target (California Air Resource Board, 2017b). In 2017 it was extended until 2030, beyond its initial expiration of 2020 (AB 398) (California Legislative Information, 2017a). Most of the funds from the trades are allocated for green projects in the state.

In addition to its climate change mitigation policies, California is progressive in its environmental regulations, which also impact the power sector. In response to US Environmental Protection Agency's (EPA's) Clean Water Act section 316(b) regulations (EPA, 2002), a policy affecting once-through cooled power plants was approved by California's State Water Resources Control Board (SWRCB) and took effect on October 1, 2010 to protect ocean ecosystems by reducing mortality due to the entrainment and impingement of organisms on cooling water intake screens (California Energy Commission, 2018). This policy recognizes the closed-cycle evaporative cooling system as the best available technology, and therefore, creates a benchmark for compliance requiring a 93% minimum reduction from design uptake