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Assessing carbon pollution standards: Electric power generation pathways and their water impacts

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ABSTRACT

This study evaluates transition pathways in electricity generation and their future water impacts. Scenarios that do or do not comply with the carbon pollution standards – based on the U.S. New Source Performance Standards and Clean Power Plan – are evaluated. Using the Electric Reliability Council of Texas region as an illustration, the scenarios with carbon regulations are shown to have lower CO_2 emissions and water use from the power sector than the continuation of the status quo with more electricity generation from coal than natural gas. The benefits are due to increases in electricity generation from renewable sources and natural gas combined cycle (NGCC) plants plus retirements of existing coal-fired plants, which depend on natural gas and CO_2 allowance prices. When CO_2 is captured and sold for enhanced oil recovery with a price higher than \$15 per short ton, water consumption is elevated because of more electricity generation from existing NGCC plants retrofitted with carbon capture and storage (CCS) technology. A stringent constraint on water withdrawals decreases electricity generation from existing power plants with once-through cooling, but increases overall water consumption because of an elevated share of plants with wet recirculating cooling systems in the fleet.

1. Introduction

To reduce greenhouse gas emissions for climate change mitigation, it is necessary to transition over time to a low-carbon electricity generation future. This may pose complex water supply challenges, as thermoelectric power plants are highly dependent on water, mainly for cooling purposes. Increasing droughts in some regions, such as in Texas in 2011 and California until mid-2016 (USDM, 2017), have exacerbated the water crisis. In 2010, the electric power industry made about 45% of total water withdrawals in the United States (Maupin et al., 2014). Without sufficient water supply, thermal generators will have to be shut down or curtail their operations (McCall et al., 2016). Thus, water should be an essential component of planning low-carbon electric power generation, especially in countries, states or regions with limited water resources (Zhai and Rubin, 2010).

Low-carbon energy options include fossil fuels with carbon capture and storage (CCS), renewables (wind and solar), and nuclear energy. Research has been conducted to explore the water impacts of low-carbon electric power generation at the plant, regional, and national levels. A shift to low-carbon electricity generation will either increase or decrease water use, depending on the choice of electricity generation systems and cooling technologies (Macknick et al., 2012a). Adding an amine-based CCS system for 90% CO_2 capture at a pulverized coal power plant using wet cooling towers nearly doubles water consumption (Zhai et al., 2011).

Macknick et al. (2012b) found that by 2030, the retirement of once-through cooling facilities will decrease national water withdrawals by 27–70% compared with 2010, whereas high penetration

Abbreviations: CC, Combined cycle; CCS, Carbon capture and storage; CCUS, Carbon capture, utilization, and storage; CEPCI, Chemical Engineering Plant Cost Index; CPP, Clean Power Plan; CPS, Carbon Pollution Standards; CPS + R, Carbon Pollution Standards with CCS retrofit; CPS + RW, Carbon Pollution Standards with CCS retrofit and water withdrawal constraint; CT, Combustion turbine; EFOR, Effective forced outage rate; EGU, Electric generating unit; EIA, Energy Information Administration; ELCC, Effective load carrying capacity; EOR, Enhanced oil recovery; EPA, Environmental Protection Agency; ERCOT, Electric Reliability Council of Texas; GJ/h, Gigajoules per hour; GW, Gigawatts; IECM, Integrated Environmental Control Model; IGCC, Integrated gasification combined cycle; IPM, Integrated Planning Model; kW, Kilowatts; kWh, Kilowatt hours; LCOE, Levelized cost of electricity; MW, Megawatts; MSCF, 1000 standard cubic feet; MWh, Megawatt hours; MWh-g, Megawatt hours-gross (all power output); MWh-net, Megawatt hours-net (less parasitic losses); NETL, National Energy Technology Laboratory; NREL, National Renewable Energy Laboratory; NG, Natural gas; NGCC, Natural gas combined cycle; NSPS, New Source Performance Standard; OG steam, Oil and gas steam; O&M, Operations & management; PC, Pulverized coal; PV, Photovoltaic; SCPC, Supercritical pulverized coal-fired; ST, Steam turbine; TSD, Technical support document; USDM, United States Drought Monitor; USGS, United States Geological Survey; WACC, Weighted average cost of capital

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of coal-fired plants with CCS and nuclear plants will increase them by about 22% by 2050 compared with the 2010 level. In contrast, Tidwell et al. (2013) found that national water withdrawals may increase by roughly 1% or decrease by up to 60% relative to 2009 levels, while the change in national water consumption will range from −28% to + 21%, depending on the implementation of CCS retrofit and a CO_2 emission price. However, Webster et al. (2013) found that a deep reduction requirement for CO_2 emissions will increase regional water withdrawals for electricity generation in the Electric Reliability Council of Texas (ERCOT) region because of additional water withdrawals for nuclear generation. Also, simultaneous constraints in both CO_2 emissions and water withdrawals will result in a different grid mix with a higher fleet cost of electricity generation, compared to a single constraint on CO_2 emissions (Macknick et al., 2015; Chen et al., 2013; Qin et al., 2015).

Carbon pollution regulations will aid in limiting CO_2 emissions and facilitating the transition to low-carbon electricity generation. In 2015, the U.S. Environmental Protection Agency (EPA) established the New Source Performance Standards (NSPS) for limiting CO_2 emissions from new fossil fuel-fired electric generating units (EGUs) (U.S. EPA, 2015a). Under Section 111(d) of the Clean Air Act, the U.S. EPA also issued the Clean Power Plan (CPP). It was intended to establish standards of performance for CO_2 emissions from existing EGUs, to cut sector CO_2 emissions by 32% by 2030 from their 2005 levels (U.S. EPA, 2015b). CO_2 emission reductions can be achieved by three suggested building blocks: (1) improving the heat rate of existing coal-fired power plants; (2) increasing generation from existing natural gas plants; and (3) increasing generation from new renewable energy sources (EPA, 2015b). Although retrofitting the entire existing fleet of power plants with CCS technology is not practical, it may be feasible for some coal-fired EGUs (Zhai et al., 2015; Talati et al., 2016). Although the Trump Administration indicated in 2017 its intention to renege on the CPP, it currently remains in force. States have the authority to manage their electric power grids. So, it is important to examine the consequences of possible planning pathways. The current analysis therefore remains instructive even if superseded by later changes in policy.

Planning low-carbon electricity generation pathways in a cost-effective, carbon regulation-compliant, and sustainable manner is important for the electric power sector. The goal of this study is to examine the possible transition pathways for power capacity expansion, while targeting compliance with regulations on the low-carbon pathways or the non-compliant pathways. Each pathway represents a scenario describing a possible expansion of the power system in the future. The business-as-usual (BAU) scenario is the pathway that continues without trying to implement the carbon pollution regulations in a meaningful way. The low-carbon scenarios are those that can comply with carbon pollution regulations by retrofitting CCS to existing coal-fired and NGCC plants or increasing generation from natural gas and renewables or low-carbon technologies.

The overarching research question is: How does each of the pathways affect water use for electricity generation? We further ask: What are the water impacts of complying with the carbon regulations? If retrofitting CCS to existing plants is considered, how will it affect electricity generation and water use? Additionally, how will water availability affect electricity generation under the carbon constraint and the choice of low-carbon and cooling technologies? To address these questions, this study comparatively examines the technological mix and water use of alternative pathways toward an energy future with or without carbon regulations.

In Texas, the electric power sector accounted for 36% of total state-level water withdrawal in 2005 (Kenny et al., 2009). This state experienced severe droughts in the past years (USDM, 2017), which has increasingly limited the availability of water resources for the electric power and other sectors. ERCOT in Texas manages a power grid for 90% of the state's total electricity supply (ERCOT, 2015a, 2016).[1] Hence, is the region chosen for this case study-based scenario analysis.

2. Carbon regulations on existing and new power plants

The NSPS limits CO_2 emissions to 1400 lb CO_2/MWh-g for new coal-fired EGUs and 1000 lb CO_2/MWh-g for new natural gas-fired EGUs or 1030 lb CO_2/MWh-g for base load natural gas-fired EGUs (U.S. EPA, 2015b). To meet the emission limit, new supercritical pulverized coal-fired (SCPC) power plants have to reduce emissions by about 20% by requiring CCS for partial CO_2 capture (Ou et al., 2016). However, there is no need for CO_2 emission reductions at new NGCC power plants.

The CPP aimed to establish national emission performance standards for existing fossil fuel-fired EGUs. The rules present state-specific rate-based goals and equivalent mass-based goals, reflecting their power generation mix in 2012. States are flexible to choose the emission compliance plan and mitigation measures, so this study focuses on mass-based compliance as it relatively easily controls overall emissions. For such a plan, each state must implement a cap for the allowable CO_2 emission level that is distributed across the existing affected EGUs. The affected sources include coal, steam from oil and gas, and natural gas (combined cycle) that were in operation or commenced construction as of January 8, 2014. They had to meet two criteria: serve a generator capable of selling greater than 25 MW to a utility power distribution system; and have a base load rating of greater than 260 GJ per hour (U.S. EPA, 2015b). In the mass-based plan without a CO_2 emissions cap for new sources, the state should address the potential generation leakage to new fossil fuel-fired sources.

To mitigate the risk of leakage, the U.S. EPA proposed set-aside allowances, such as the Clean Energy Incentive Program (CEIP) for rewarding early emission reduction projects (U.S. EPA, 2016), as well as output-based set-asides to incentivize existing NGCCs to increase their utilization (U.S. EPA, 2015c), and renewable set-asides to mitigate the leakage of CO_2 emissions to new NGCCs (U.S. EPA, 2015d). Assuming a national average allowance price of $13 per short ton, the EPA estimated that 5% of the total allowance represents a reasonable renewable set-aside level to mitigate the impacts of the transition (U.S. EPA, 2015d).

This study also considers renewable set-asides and output-based set-asides. With their implementation, the total allowance for the existing EGUs is the mass-based target minus the set-asides. Under the CPP, the total allowance was to be assigned proportionately to each unit's share of state-level historical generation (U.S. EPA, 2015c). The EPA also proposed an allowance trading program between the affected existing EGUs and renewable units within a state or with other states (U.S. EPA, 2015e). But, a recent study (Van Atten, 2016) showed that the EPA's proposed approach for allocating allowances in a program for existing plants may have a minor impact on emissions leakage to new fossil-fired power plants outside the program. So, we use the mass-based approach which limits such new-source emissions.

The EPA also estimated new source emissions based on meeting electricity demand in 2030 (U.S. EPA, 2015f). The incremental generation needed was calculated using the projected load growth from 2012 minus the estimated generation from facilities under construction and generation growth in the affected EGUs and incremental renewable energy. Using the NSPS emission rate for NGCCs (1030 lbs/MWh), the incremental generation needed to satisfy new electricity demand was converted to new source emissions. ERCOT's mass-based emission target is 157 million (M) short tons. This is calculated by summing the allocated CO_2 allowances of ERCOT's existing EGUs proposed by the EPA (U.S. EPA, 2015c) plus the estimated set-aside allowances. Detailed

[1] Other electricity in Texas is from Western Elec. Coordinating Council, Southwest Power Pool, and Southeastern Elec. Reliability Council (Public Utility Commission of Texas, 2013). These are excluded: the ERCOT grid is managed separately.