Assessing the Impacts of Water Constraints on the U.S. Power Sector

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Received September 01, 2017; Accepted February 14, 2018

Abstract: The dependence of the U.S. power sector on water makes electricity generation exposed to hydrologic constraints in some regions. The U.S. power sector is in a state of transition, driven by technological innovations, energy markets, and regulations, and changes in the future electricity generation mix will have important implications for water use. Most models for long-term electricity sector projections do not have sufficient regional detail for analyzing water-related impacts and important decisions on electricity and water usage. In this paper we analyzed how water consumption and usage constraints affect the U.S. electricity generation sector. In addition, we investigated whether current CO_2 emissions mitigation policies such as the Regional Greenhouse Gas Initiative (RGGI) and greenhouse gas emissions (GHG) cap-and-trade program in California would improve or magnify electric sector water reliance. Finally, we analyzed what generation technologies will likely be deployed under different constraint assumptions.

Keywords: MARKAL multi-regional model; CO2 emissions reduction policies; power generation technologies; CCS; R&D

This study uses power plant-specific fuel consumption, generation, and water use data to assess changes in the water withdrawn and consumption by thermoelectric power plants across nine census regions. Last decade the average water withdrawn per unit of electrical output decreased over this time, while changes in water consumption rates stayed relatively flat. Changes in water usage are unevenly distributed, as some water-scarce regions experienced increases in cooling water usage for thermal power plants, while others experienced significant water reductions and environmental benefits, especially where coal-fired generation was retired or retrofitted. The results from this study underscore the importance of

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DOI: 10.7569/JSEE.2018.629503

evaluating long-term water withdrawals and consumption at the regional levels under different scenarios projections, as the water availabilities are varied.

The approach, which makes use of the MARKet ALlocation (MARKAL) energy system model, allows policy instruments to be examined quantitatively in a dynamic energy system context. The study is focused on the interaction between climate policies and water usage, and will help guide policy making by identifying areas, and the extent to which, climate policy can reinforce energy security objectives. The study discusses multiple scenarios, considering the synergistic effects of energy development objectives, diversification in water consumption and withdrawals and environmental regulations in the U.S. at the regional level.

Methods

We adopt an integrated energy systems modeling platform MARKAL that was used to analyze energy, economic, and environmental issues at the global, national, and municipal level over a timeframe of up to several decades. MARKAL is a set of software tools that may be used to quantify the impacts of policy options on technology development and deployment, and resource depletion. MARKAL is a bottom-up, dynamic, linear programming optimization model to find the cost-optimal decarbonization pathway within the context of the entire energy system. MARKAL represents energy imports and exports, domestic production of fuels, fuel processing, infrastructures, secondary energy carriers, end-use technologies and energy service demands of the entire economy.

MARKAL does not contain an in-built database, so the user is obliged to enter input parameters. In this study, the publicly available EPAUS9r2016 database had been adopted and modified. The EPAUS9r2016 database divides the U.S. into nine regions based on the U.S. Census Divisions. Each region is modeled as an independent energy system with different regional costs, resource availability, existing capacity, and end-use demands. Regions are connected through a trade network that allows transmission of electricity and transport of fuels. Electricity transmission is constrained to reflect existing regional connections between North American Electric Reliability Corporation (NERC) regions as closely as possible.

We have examined the techno-economic impacts of the RGGI and GHG cap-and-trade program in California on carbon emissions reductions, electricity generation mix and water consumption and withdrawal through analyzing various assumptions using the following scenarios (see Table 1):

Results

Results are presented in scenario format at the national and regional levels. The modeling scenarios results are compared to each other and a base case scenario. The reduced diversity in electricity input fuels is an important challenge in some scenarios. The significance of electricity generation sector water demand depends

DOI: 10.7569/JSEE.2018.629503

Table 1 Scenario definitions.

Scenarios	Descriptions
BASE9R	Base case scenario calibrated at EIA AEO 2017 reference scenario
BASEREG	BASE9R with the RGGI and GHG cap-and-trade program in California
BASE9RW	BASE9R with water constraints
BASREGW	BASE9R with the RGGI and GHG cap-and-trade program in California with water constraints

to some extent on local conditions or on how much water is locally available and what water alternative uses would be. The greatest growth in water consumption in electricity generation sector in the scenarios without water constraints is expected in West South Central, South Atlantic and Pacific regions or in the regions that are already experiencing intense competition over water. By 2050, in the scenarios without CO_2 constraints, water withdrawal drops in New England, East North Central, South Atlantic and Mountain regions in response to decreased electricity generation and replacement of once-through cooling systems by recirculating systems.

Conclusions

Strategies for achieving either water reductions or CO_2 emissions reductions in the power generation sector have been explored independently in the literature but the interplay of these constraints have been examined to a lesser extent. Previous studies have focused on various aspects of the water and energy link, including aggregate views across energy sectors and impacts of regional variation in water shortages on electricity generation. The future water demand in the electricity generation sector will be affected by the increase of electricity demand and by the power generation mix at the technologies' levels. The electricity demand and generation mix projections vary, and are highly uncertain and depend on many factors, including market and economic conditions, energy policies, resource availability, technologies' deployment and environmental regulations. In comparison with previous work on this topic, our study summarizes interactions in multiple energy scenarios not previously explored in the context of the U.S. electric sector regional water usage.

Coal plant retirement along the associated cooling systems plays a major role in water withdrawal reductions in the scenarios with CO_2 constraints. Replacement of old facilities also increases generating efficiency and consequently decreases withdrawal. The significance of electricity generation sector water demand depends to some extent on local conditions or on how much water is locally available and

DOI: 10.7569/JSEE.2018.629503

what water alternative uses would be. The greatest growth in water consumption in electricity generation sector in the scenarios without water constraints is expected in the West South Central, South Atlantic and Pacific regions or in the regions that are already experiencing intense competition over water. Natural gas combined cycled units are replaced by natural gas simple cycle units in the scenarios with water constraints due to lower water usage.

While California is adopting an aggressive climate change mitigation policy, to meet the state's aggressive targets in 2050 will require widespread adoption of CCUS technologies. However, water is involved in most steps of the CCUS process and current capture technologies require additional water supplies at the site, either as a direct result of the capture process or indirectly by making the electricity needed to power the capture facility. Including water constraints into the model with aggressive climate change mitigation policy in California results in model instabilities.

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