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Transitioning to zero freshwater withdrawal in the U.S. for thermoelectric generation

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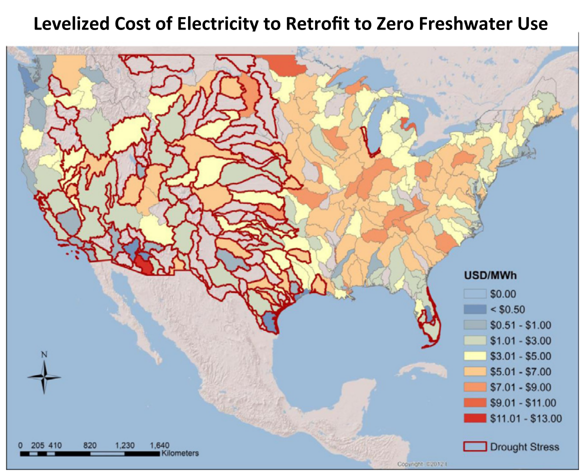
HIGHLIGHTS

- Scoping level cost analysis to retrofit thermoelectric generation to achieve zero freshwater use.
- Least cost alternative is determined for 1178 freshwater using power plants in the U.S.
- Projected increase in levelized cost of electricity has a median value of $3.53/MW h.
- Retrofits would alleviate system vulnerabilities and save 3.2 Mm^3/d of water in stressed basins.
- Impact on wastewater and brackish water supply is minimal as are parasitic energy requirements.

GRAPHICAL ABSTRACT



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ABSTRACT

Drought poses important risks to thermoelectric power production in the United States because of the significant water use in this sector. Here a scoping level analysis is performed to identify the technical tradeoffs and initial cost estimates for retrofitting existing thermoelectric generation to achieve zero freshwater withdrawal and thus reduce drought related vulnerabilities. Specifically, conversion of existing plants to dry cooling or a wet cooling system utilizing non-potable water is considered. The least cost alternative is determined for each of the 1178 freshwater using power plants in the United States. The projected increase in levelized cost of electricity ranges roughly from $0.20 to $20/MW h with a median value of $3.53/MW h. With a wholesale price of electricity running about $35/MW h, many retrofits could be accomplished at levels that would add less than 10% to current power plant generation expenses. Such retrofits would alleviate power plant vulnerabilities to thermal discharge limits in times of drought (particularly in the East) and would save 3.2 Mm^3/d of freshwater consumption in watersheds with limited water availability (principally in the West). The estimated impact of retrofits on wastewater

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and brackish water supply is minimal requiring only a fraction of the available resource. Total parasitic energy requirements to achieve zero freshwater withdrawal are estimated at 140 million MW h or roughly 4.5% of the total production from the retrofitted plants.

1. Introduction

In 2005 thermoelectric power generation was the largest user of freshwater in the United States, withdrawing over 530 million cubic meters per day (Mm^3/d) [1]. The high dependence on freshwater puts power production at risk in times of drought or heat waves as evidenced by past climate impacts on power production [2–5]. Vulnerabilities arise both from reduced water availability as well as thermal intake/discharge limits (i.e., intake water is too hot to efficiently operate the power plant or the power plant discharge poses a threat to the environment due to its elevated temperature). Drought is likely to intensify in many areas of the United States [6–8], given projected effects of climate change combined with growing demands on freshwater supplies by the energy sector [9] and other sectors (e.g., agriculture, industry, public) [10].

There are a variety of ways to reduce the dependency of the electricity sector on freshwater. Others have assessed the water and financial impacts of fuel switching from coal to natural gas technologies [11], shifting to higher renewable energy scenarios [12,13], or retrofitting existing once-through cooled facilities to recirculating cooling systems [14]. One additional way of reducing the electricity sector's vulnerability to drought would be to lessen the dependence of thermoelectric generation on freshwater. This could be achieved by retrofitting current power plants to use non-potable water (e.g., brackish groundwater or municipal wastewater) or converting to a dry cooling system [15]. Such measures would help to avoid competition over limited freshwater supplies and reduce effluent discharge to aquatic systems (e.g., streams, rivers, and reservoirs). However, such efforts would not necessarily alleviate all water vulnerability concerns for the power sector as the availability of municipal wastewater and brackish groundwater resources are subject to competition among different sectors.

Several research efforts have focused on the current and possible future application of municipal wastewater in thermoelectric cooling [16–20]. One assessment of wastewater effluent as a cooling water supply for existing coal-fired power plants determined that 81% of existing plants' demand could be met with wastewater within a 10 mile radius of the power plant and 97% could be met by wastewater sources within a 25 mile radius [18]. Li et al. [20] briefly assessed the technical challenges and regulations associated with using wastewater in energy production. In addition, ALLConsulting developed the Alternative Water Source Information System (http://www.all-llc.com/projects/coal_water_alternatives/page.php?13) which identifies alternative water sources within a 15 mile radius of coal-fired power plants and displays the results in Google Earth.

The intent of this effort is to provide a "coarse," scoping level analysis of the feasibility, technical tradeoffs and initial cost estimates for retrofitting existing thermal generation to achieve zero freshwater withdrawal. The analysis also explores how such adaptive measures impact water resources; particularly in relation to the potential for reducing the vulnerability to drought. Assumptions on anticipated water and temperature constraints and unit level operational water requirements draw upon existing references. These data are used to determine the least cost alternative for existing power plant retrofits of either dry cooling or a wet cooling system that utilizes municipal wastewater or brackish groundwater. Where needed, conversion from open-loop to recirculating cooling is also considered. This analysis does not consider the cost tradeoffs of retrofitting a facility compared with the plant and societal-level costs associated with power plant shut downs and curtailments, nor does it evaluate the physical and legal feasibility of retrofits at individual power plants; these remain areas of future research.

2. Methods

To assess the potential of retrofitting power plants in the United States to achieve zero freshwater use, the following steps were taken:

- The existing fleet of 1178 freshwater using power plants was characterized, including their water use requirements and cooling system technology.
- Available non-potable water sources were identified based on type, size, availability, and location.
- Cost models were developed for retrofitting a particular power plant from once-through cooling to recirculating cooling and dry cooling, as well as for converting a recirculating cooling system to use brackish groundwater or municipal wastewater instead of freshwater.
- Drought vulnerable regions were identified based on a metric constructed from the ratio of consumptive water use to gauged streamflow.

This data was then incorporated into a custom algorithm that identified the least cost alternative among the three cooling technologies for each of the 1178 power plants based on nearby non-potable water resource availability and the cost of the cooling retrofit. The three technologies include: dry cooling, recirculating cooling using brackish water, and recirculating cooling using municipal wastewater. The results for each individual power plant were then aggregated at the 6-digit Hydrologic Unit Code (HUC) [21] watershed level (total of 377 watersheds) to determine the cost and potential to retrofit the fleet across the United States with particular focus on drought vulnerable regions. Plant level results are aggregated by 6-digit HUC to provide a convenient basis for evaluating water resource implications of retrofitting the thermoelectric power plant fleet, and to avoid singling out potentially sensitive results for individual power plants.

2.1. Resource evaluation

2.1.1. Power plant characteristics

The impacts of alternative cooling systems on water usage and system efficiency were projected for each freshwater-using power plant in the U.S. For the purposes of this analysis, power plants recorded in the Energy Information Agency [EIA] forms 860 [22] and 923 [23] were distinguished according to fuel type (coal, nuclear, oil, natural gas, biopower/biogas, concentrating solar power, and geothermal), prime mover technology (steam plant and combined cycle), and cooling system type (once-through, recirculating, and pond which is treated the same as once-through). This plant classification scheme, which is driven by the availability of data, lacks some of the resolution available in the EIA databases. For example, subcritical and supercritical coal steam