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Identifying future electricity–water tradeoffs in the United States

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ABSTRACT

Researchers for the electricity industry, national laboratories, and state and federal agencies have begun to argue that the country could face water shortages resulting from the addition of thermoelectric power plants, but have not attempted to depict more precisely *where* or how *severe* those shortages will be. Using county-level data on rates of population growth collected from the US Census Bureau, utility estimates of future planned capacity additions in the contiguous United States reported to the US Energy Information Administration, and scientific estimates of anticipated water shortages provided from the US Geologic Survey and National Oceanic and Atmospheric Administration, this paper highlights the most likely locations of severe shortages in 22 counties brought about by thermoelectric capacity additions. Within these areas are some 20 major metropolitan regions where millions of people live. After exploring the electricity–water nexus and explaining the study's methodology, the article then focuses on four of these metropolitan areas – Houston, Texas; Atlanta, Georgia; Las Vegas, Nevada; New York, New York – to deepen an understanding of the water and electricity challenges they may soon be facing. It concludes by identifying an assortment of technologies and policies that could respond to these electricity–water tradeoffs.

1. Introduction

Current rates of population growth, expected thermoelectric capacity additions by electric utilities, and an increasing prevalence of droughts could induce possible water shortages in some areas of the United States. These shortages could be brought about or exacerbated by increased rates of water consumption and withdraws from new thermoelectric power plants in some regions along with forced power plant shutdowns due to lack of water in others.

The US Census Bureau (2004) projects that the national population will balloon from 282 million people in 2000 to 364 million by 2030 and 420 million by 2050. The US Department of Energy (DOE) estimates that total electricity consumption will grow at an annual rate or 1.3% per year, or from 3821 billion kilowatt-hour (kWh) in 2006 to 5149 billion kWh by 2030 (DOE, 2008, p. 6). If the projection is accurate it means that nationwide electricity demand will actually *double* before 2050. The US Department of Interior (2005, p. 1) calculates that due to an increasing frequency and duration of droughts throughout the country, demands for water in many basins will exceed available supply even in normal years, especially for those living on the West Coast (water shortages nationwide can also result from low water quality due to toxic contamination, lack of availability due to saltwater intrusion of aquifers, and low quality and lack of availability due to malfunctioning water pumping, purification, and treatment systems).

However, many electric utilities have virtually ignored water concerns and continue to propose new, water-intensive nuclear and fossil fueled plants as the best way to produce electricity (Southern Alliance for Clean Energy, 2007), and water use and consumption have not been significant factors in decisions related to the permitting and siting of power plants (Clean Air Task Force, 2003). Those within the electricity industry often downplay the importance of water management techniques for minimizing thermoelectric water consumption, and those in water management rarely promote electricity conservation as a water resource tool.

Federal and state agencies seem equally fragmented. Rather than pursue a synergistic approach to water and energy problems, the National Research Council (NRC) warned that government organizations lack any sort of coordinated or effective approach to them (Committee on Assessment of Water Resources Research, 2004). The NRC cautioned that water management does not fall logically or easily within the purview of a single federal agency, and that destructive interagency competition is more common than helpful collaboration. The US Geological Survey (Anderson and Woolsey, 2005), National Energy Technology Laboratory (2006), National Renewable Energy Laboratory (2006), Sandia

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National Laboratory (2007), and Electric Power Research Institute (2002), as well as various academic and professional researchers (King and Webber, 2008; Roy et al., 2005; Inhaber, 2004; Gleick, 2003), have each warned that power plant additions could complicate water management efforts.

Yet these reports and insights, while useful, do little to inform electricity and water planners about more precisely *where* and how *severe* such shortages will be. In this study, we attempt to depict the communities that will the hardest hit by the confluence of population growth, thermoelectric capacity additions, and drought. Our intention is to highlight the most likely locations of severe shortages are in 22 counties. Within these counties are some 20 major metropolitan areas where millions of people live. Emphasizing the electricity–water nexus and identifying future electricity and water challenges is important because water shortages caused by electricity demand will most likely increase water and electricity prices, necessitate more energy-intensive water pumping and treatment, induce subsidence, and deteriorate water quality (Rosegrant et al., 2002).

The approach taken in this study is to first explore the electricity water nexus before explaining how trends in population growth, demand for electricity, and drought influence water supplies, and will create pressing challenges for 22 metropolitan areas. The paper then focuses on four of these specific areas – Houston, Texas; Atlanta, Georgia; Las Vegas, Nevada; New York, New York – to deepen an understanding of how the dynamics, magnitude, and consequences of water scarcity will differ greatly between them. It concludes by emphasizing the available technological and policy tools that can reduce the water needs of the electricity industry.

2. The electricity–water nexus

Thermoelectric power plants – power stations that combust coal, oil, natural gas, biomass, and waste to produce electricity, or fission atoms in a nuclear reactor – use water by "consuming" and "withdrawing" it. These plants "withdraw" water from rivers, lakes, and streams to cool equipment before returning it to its source, and they "consume" water (often through evaporative loss) that does not return to the local water table. For this study, the term use is therefore meant to encompass both water withdraws and consumption together unless otherwise specified. Nationally, nuclear plants use the most water at about 43 gal of water for every kilowatt-hour generated. Coal and waste-incineration plants use about 36 gal of water for every kWh generated. Natural gas plants use about 14 gal of water for every kWh generated (Sovacool, 2009; Sovacool and Sovacool, 2009). The industry average is 25 gal of water for every kWh generated, or 0.5 gallons consumed and 24.5 withdrawn per kWh (National Energy Technology Laboratory, 2006). (see Fig. 1)

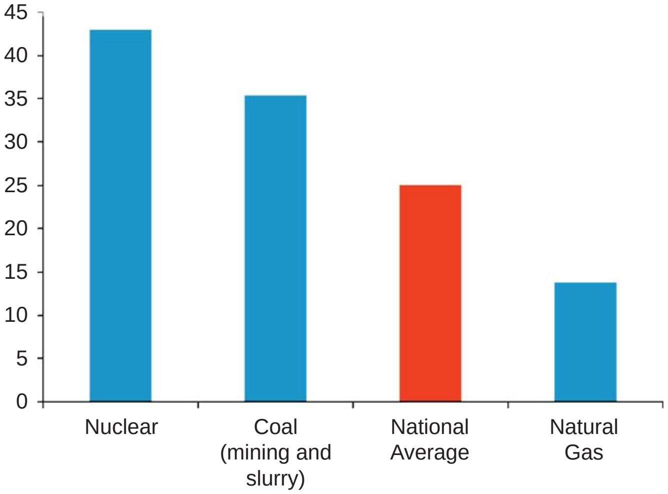

Fig. 1. Total water use for thermoelectric generators (gallons/kWh).

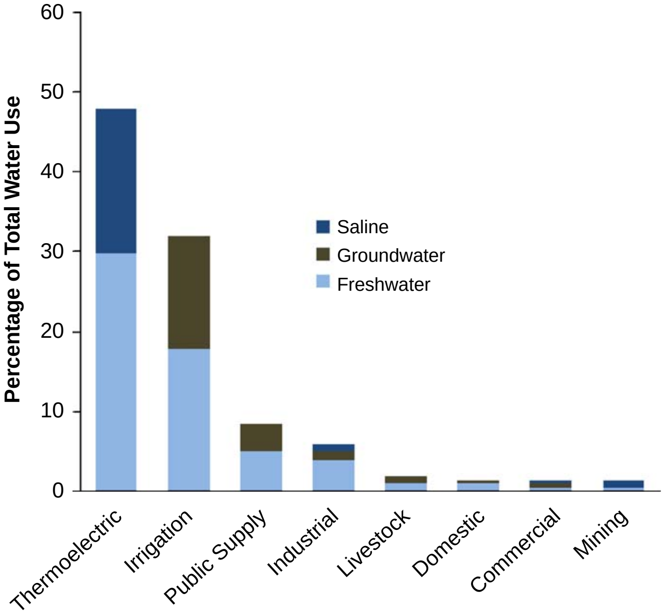

Fig. 2. US water use (consumption and withdrawals), 2000.

The numbers quickly aggregate into astronomical amounts of water. Relying on industry averages to assess likely water use, coal-fired power stations generated 1957 billion kWh in 2006, meaning that they used almost 58 trillion gallons of water. Nuclear facilities generated 787 billion kWh and used about 34 trillion gallons. Natural gas plants produced an additional 877 billion kWh and consequently used slightly more than 12 trillion gallons (US EIA, 2007). Utilizing the most recent data available from the US Geologic Survey (2004), thermoelectric power plants used more than 190,000 million of gallons of water per day, or 47% of the country's total. This means that on average thermoelectric power plants use more water than the entire country's agricultural and horticultural industry, which cover the nation's irrigation, frost protection, field preparation, cropping, self-supplied landscaping, and maintenance of golf courses, parks, nurseries, cemeteries, and landscaping needs (See Fig. 2). To put these differing numbers in perspective, researchers from the National Energy Technology Laboratory projected that Americans use about three times as much water turning on their lights and running appliances than for taking showers and watering lawns (Hoffmann et al., 2005).

To their credit, utilities and system operators have dramatically improved the water-efficiency of the electricity industry so that consumption is falling in per-capita terms, but it is still rising in absolute terms. Largely through the installation of more efficient cooling systems and water conservation efforts, the industry has reduced the water withdrawals needed per unit of power generated by a factor of three. In 1950, for example, about 63 gal of water were withdrawn to produce every kWh of electricity, while today that number is 25 gal per kWh. All the while, the industry has increased output of electric power by a factor of fifteen (Freedman and Wolfe, 2007; Sovacool and Sovacool, 2009).

Contrary to these improvements in efficiency, water use for electric power plants in absolute terms increased five-fold from

14.6 trillion gallons in 1950 to 71 trillion gallons in 2000, and has since risen to about 90 trillion gallons in 2007 (Sovacool and Sovacool, 2009). While efficiency of water use at power plants improved significantly during this period, increased demand for electricity has placed a growing burden on water supplies. Already, today, 23,000 gal of water are needed to produce the electricity an average American home consumes in one month (Hoffmann et al., 2005). Newer technologies, while they withdraw less water, actually consume more. Advanced power plant systems that rely on re-circulating, closed-loop cooling technology convert more water to steam that is vented to the atmosphere. Closed-loop systems also rely on greater amounts of water for cleaning and therefore return less water to the original source. Thus, while modern power plants with closed-loop systems using cooling towers may reduce water withdrawals by up to 90%, they can contribute even more to the nation's water scarcity by consuming up to 10% more (NREL, 2006). Consequently, by the year 2030, the electricity industry could withdraw approximately 108 trillion gallons of water per year for electric production—a 66% increase from 2000 (Freedman and Wolfe, 2007).

3. Methodology for identifying electricity–water tradeoffs

Such a large increase in water use for the thermoelectric power sector could have serious consequences for water-scarce locations of the country. In times of water scarcity, existing plants have to either shutdown due to lack of water, or continue to operate and risk exacerbating water shortages. In essence, three interactive trends will increase the risk of severe water shortages for the electricity industry by 2025: population growth, thermoelectric power plant additions, and more frequent droughts in the summer.

3.1. Population growth

Perhaps the most fundamental factor behind both increased electricity and water consumption is population growth (Roy et al., 2005). There are more people being born every year; those born now live longer; and many of them are moving to places of the country where water is scarce, bringing with them increased electricity and water needs. The country's population is expected to double by the end of this century, and a demographic shift is occurring in the American population as millions of people migrate west, the same part of the country where water resources have been the most stressed.

The population in Nevada, for instance, grew 66% from 1990 to 2000; Arizona's grew 40%; Colorado's grew 31%; Utah's grew 30%; Idaho's grew about 29% (Anderson and Woolsey, 2005). California, New Mexico, Arizona, and Nevada are expected to see their population increase more than 50% between now and 2025 (US GAO, 2003). California's population currently grows at a rate of about 7,00,000 per year and is expected to surpass 50 million by 2020 (Atwater, 2004). The population estimates for each of these states may be low, moreover, because they do not account for unexpected increases in legal immigration or growth associated with illegal immigration.

Even if the projections about population growth are accurate, these regions are also the driest in terms of annual precipitation. The High Plains aquifer underlying some of the midwestern and western states holds less than half the water held prior to the commencement of ground-water pumping (Anderson and Woolsey, 2005). The impact of this population growth and shift has been record-setting levels of water use and consumption. Historically low water levels were set back-to-back in 2003 and 2004 for the Rio Grande, Colorado, and Missouri Rivers.

3.2. Thermoelectric capacity additions

Coupled with rapid population growth in western and urban areas comes significant capacity additions for electric utilities. According to the North American Electric Reliability Corporation, utilities will add 2,50,000 MW of electric capacity from 2000 to 2014 (NERC, 2005) (see Fig. 3). The National Energy Technology Laboratory conducted an analysis to estimate the amount of freshwater needed to meet projected increases in thermoelectric generating capacity. Under a high consumption case, by 2025 they noted that the thermoelectric sector could see a 165% increase over 1995 levels (Lavelle, 2007; McNemar, 2007). As a result, 30,529 MW of anticipated capacity additions, including

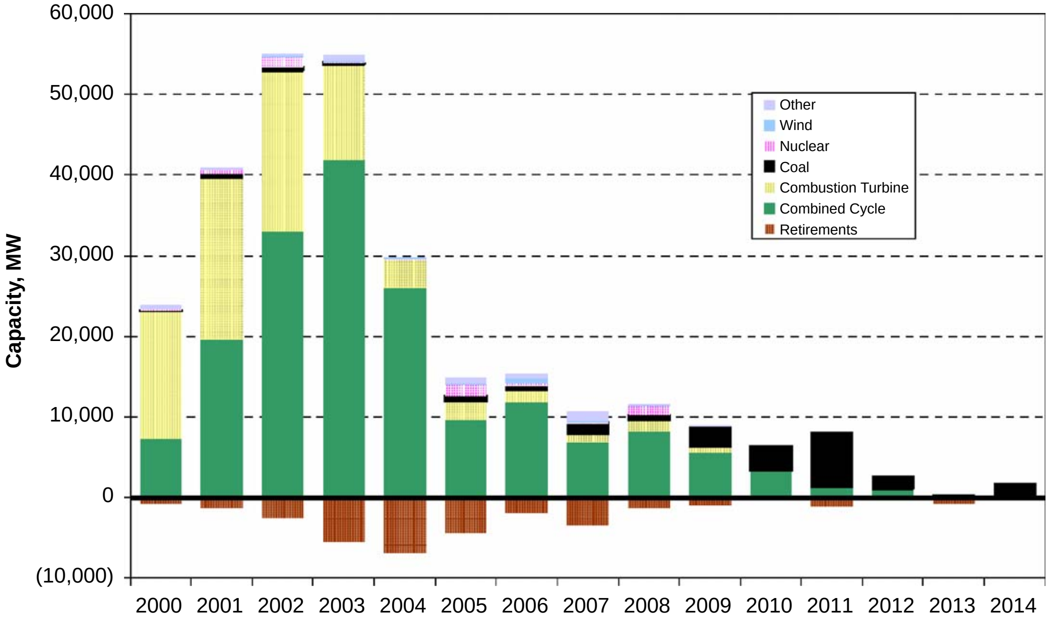

Fig. 3. US power plant capacity additions by type, 2000–2014.

large pulverized coal, hydroelectric, nuclear, and natural gas plants, could be denied construction and operating permits for water limitations.

3.3. Increasing summer water deficits

Drought and flood are a normal, recurring part of the North American hydrologic cycle. Even though meteorological droughts, identified by a lack of measured precipitation, are difficult to predict and can last months to decades, every part of the country has experienced severe or extreme drought conditions at least once since 1896—with about *half* of the country suffering drought conditions 10–15% of the time (USGS, 2004). The nation's capacity for storing surface-water is becoming more limited and groundwater is being depleted faster than it can be replenished. At the same time, growing population and pressure to keep water in streams for fisheries places new demands on the existing freshwater supply. Even under normal conditions, water managers in 36 states anticipate shortages in localities, regions, or statewide in the next 10 years (US GAO, 2003). Similarly, geologists predict that almost one-fourth of the country will risk severe droughts by 2040 (Smith et al., 2002).

3.4. Mapping electricity water tradeoffs

Given the intensity the electricity industry's current water needs, if the industry expanded as planned and predicted, it could face dire shortages of water by 2025. We base this claim on three separate trends:

- Rates of population growth in the contiguous United States from 1995 to 2025 per square mile (using data from the US Census Bureau);
- Utility estimates of future planned capacity additions in the contiguous United States from 2000 to 2025 (using data reported to the US Energy Information Administration);
- Scientific estimates of the anticipated "summer water deficit," or the difference between water supply and demand during July, August, and September, in inches of water for the contiguous United States in 2025 (using data from the US Geologic Survey and National Oceanic and Atmospheric Administration, also compiled by Roy et al., 2003)

We analyzed these three trends at the county level (rather than state or regional scale), and we also forecasted the percent increase in power plant construction from 2000 to 2025 for all counties within a census division that had any form of power generation. Counties that had no generation at present were not allocated any new generation, and all new generation was assumed to be thermoelectric and to rely on a mix of once-through and closed-loop cooling systems so that 25 gal were used for every kWh of electricity generated (24.5 gal withdrawn and 0.5 consumed). New thermoelectric power plants were presumed to be state-of-the-art and operate 24 h a day, 365 days per year, at a 90% capacity factor within the country. The water for these power plants was also assumed to have been "used" within the county.

Our methodology does have a number of shortcomings that deserve mentioning. The presumption that the electricity for a given county comes from within that county and stays there ignores the possibility of electricity imports and exports between counties. The study also presumed that once water was consumed by the cooling cycles of thermoelectric power plants, it left the local water table entirely, and it did not make distinctions between water losses due to once-through cooling and those due to evaporative cooling. In actuality small amounts of the water "consumed" by these cooling cycles may return to other parts of the county through precipitation. Our high capacity factor of 90% may be optimistic in that both very old and very new thermoelectric power plants often have lower capacity factors. Older plants tend to require more maintenance and have more frequent unplanned outages, whereas operators sometimes lack experience with very new plants and need to go through a learning curve before efficiency improves. The industry average of 25 gal of water used per kWh could change dramatically if more nuclear power plants come online (meaning it will increase), if natural gas plants and wind farms continue to displace coal facilities (meaning it will decrease), or if new cooling cycles that use less water are commercialized and widely diffused (meaning it will decrease). For example, if all existing thermoelectric power plants were converted to run on evaporative and dry cooling, they would use about one-fifth the water that they do today. Lastly, relying on self-reported data from electric utilities about the power plants they intended to build from 2000 to 2025 may not reflect changes in utility planning, plant cancellations, and retrofits and plant upgrades that have since occurred or will occur.

Fully acknowledging these drawbacks, our analysis showed two surprising results. First, *every* state in the country is home to at least one county that will face rapid population growth, large additions in thermoelectric power plant capacity, or expected shortages of water in the summer (See Figs. 4–6). Second, while thousands of counties were at risk of either rapid population growth, significant increases in thermoelectric capacity, or the increased likelihood of summer water deficits, and hundreds were at risk from two out of the three, 22 counties were most at risk from all three at once. In these 22 areas, water development needed to satisfy increased population growth could tradeoff severely with the water needed for new power plants. These areas will have a combined population growth of at least 500 people per square mile, electricity demand for at least 2700 MW of thermoelectric capacity, and a summer water deficit of at least 1.5 in. by 2025 (see Fig. 7 and Table 1).

4. The consequences of water scarcity

A look at just four of these areas – Houston, Atlanta, Las Vegas, and New York – reveals the complex differences in the scope and nature of these water–electricity challenges.

4.1. Houston, Texas

The Houston, Texas metropolitan area reports plans to construct 26,989 MW of thermoelectric capacity between 2000 and 2025 when all of its surrounding counties are included in projections, power plants that would consume an additional 106 billion gallons of water per year and withdraw 5.21 trillion gallons from local water sources (presuming they operated continually at a 90% capacity factor, consumed 0.5 gal per kWh and withdrew 24.5 gal per kWh per the industry average, and had to generate their power within the metropolitan area).

If electric utilities build the thermoelectric capacity planned for by 2025, those new power plants would need about 14.6 billion gallons of water per day, potentially conflicting with the city's drinking water needs. The Natural Resources Defense Council has noted that Houston used to depend primarily on groundwater to provide 80% of its drinking water supply, but rapid depletion has lowered that amount to only 67% today, forcing the city to take more water from the Trinity, San Leon, and San Jacinto Rivers (along with the reservoirs they support) (Natural Resources

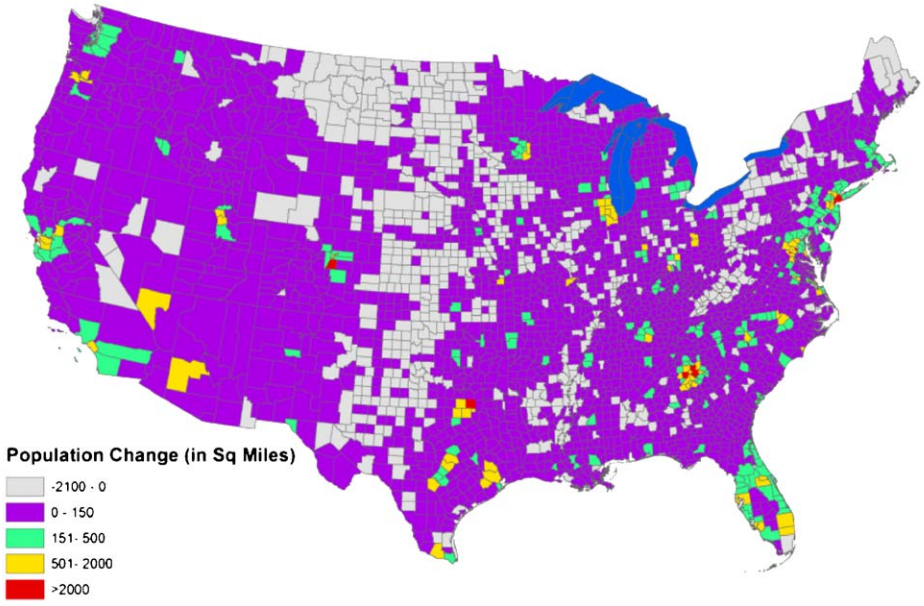

Fig. 4. National population growth 1995 to 2025 (by county, per square mile).

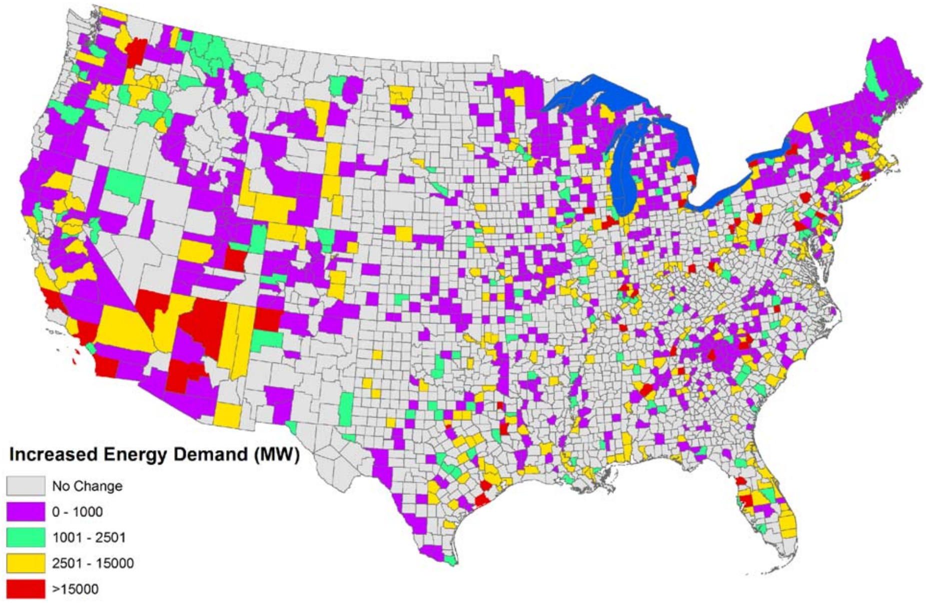

Fig. 5. Construction of new thermoelectric power plants 2000 to 2025 (by county, in MW).

Defense Council, 2003). These rivers, however, are precisely the ones where new power plants will likely be built, and where existing power plants, such as the 2211 MW P.H. Robinson coal facility and the 1498 MW Cedar Bayou natural gas facility, already draw their water from. With Houston water planners predicting rising demands for drinking water, there may not be enough water for both power plants and Houston residents.

Surface water upstream from Houston is also needed to irrigate agriculture. During the last serious water shortage caused by a prolonged drought in 1996, the agricultural sector was the first to suffer as water was diverted to supply power plants and drinking water systems. In June 1996, for instance, lack of water induced agricultural losses for cotton, wheat, feed grains, cattle, and corn at a cost of $2.4 billion for Texas, with an additional $4.1 billion in losses for agriculture-related industries such as harvesting, trucking, and food processing. Reduced irrigation also contributed a drop in vegetable production, with concomitant losses in jobs and income and drastic increases in the price of foodstuffs (Wilhite, 2006).

4.2. *Atlanta, Georgia*

Georgia Power and Southern Company have reported to the EIA that they intend to build at least 3480 MW of new capacity between 2000 and 2025, power plants that would consume 13.7 billion gallons of water per year and withdraw an additional 672.2 billion gallons of water. Fed by the waters of the Chattahoochee and Chestatee rivers, Lake Sidney Lanier, a federally managed reservoir, provides most of Atlanta's drinking water. While Lake Lanier has the potential to hold almost 1.1 million acre feet of water, however, four years of a recent drought have taken their toll and the reservoir was at a historic 18 feet below its average level in late 2007. The drought was so serious that US Army Corps

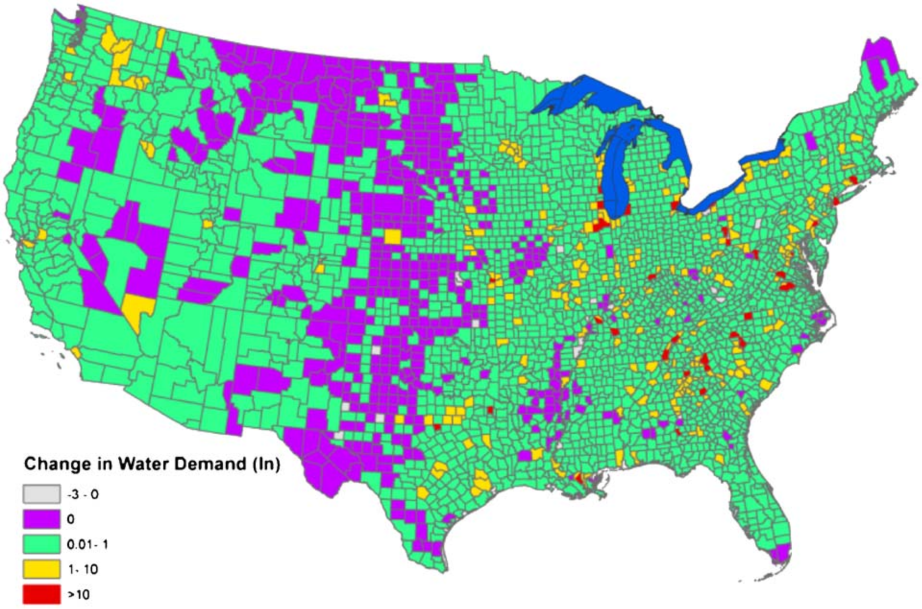

Fig. 6. National summer water deficit in 2025 (by county, in inches).

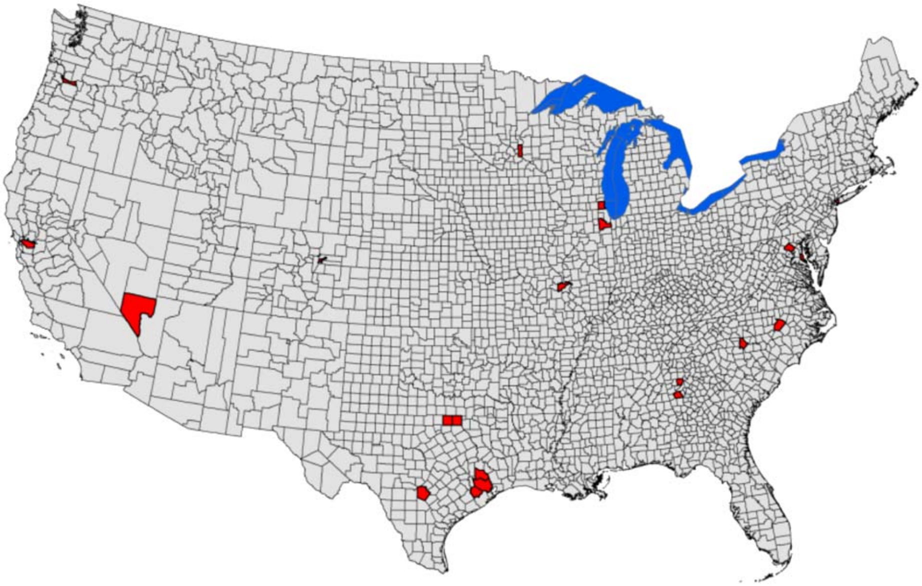

Fig. 7. Metropolitan areas in the United States most at risk to water shortages due to electricity generation (in 2025).

of Engineers is rewrote control manuals for vessel navigation on low river levels, and the federal government had to intervene in water discussions between Georgia, Tennessee, Alabama, and Florida.

Thermoelectric plants use slightly more than half of all surface water within Georgia, and those that consume and withdraw water in the northern part of the state reduce flows to Lake Lanier (Southern Alliance for Clean Energy, 2007). The most immediate consequence of increased thermoelectric water consumption in Atlanta could therefore be eventual tradeoffs with other major industrial and commercial water users in the region. These include Georgia-Pacific Corporation (one of the world's largest manufacturers of tissue, packaging, paper, pulp and building products), Mohawk Industries (the world's largest producer of flooring and carpets), and the city's water utility, as well as the Coca-Cola Corporation, Pepsi Cola Corporation, Lockheed Martin Corporation, and Edwards Baking Corporation. Together, these industries and corporations report billions of dollars of gross sales every year.

If Atlanta runs drastically short of water, a state-wide crisis could ensue as inter-basin water transfers across the 17-county metropolitan area increase, especially from the Coosa River Basin (Johnson et al., 2007). Greater water consumption for new power plants near Atlanta could contribute to the deterioration of ground water quality throughout Georgia, especially since aquifers in the middle of the state are already heavily tapped. A 2005 assessment of ground water conditions found that at least 16 groundwater sources were below the 25th percentile water level for the period on record (Leeth, 2005). State policymakers seem to recognize this, and a fierce legal battle has erupted. Georgia is fighting to hold back more water along its river basins and reservoirs, but Florida and Alabama have argued that Georgia

Table 1
Metropolitan Areas in the United States Most at Risk to Water Shortages due to Electricity Generation by 2025.

Rank	County	State	Total electricity in 2025 (in MW)	Pop growth 1995 to 2025 (per sq mile)	Summer water deficit in 2025 (in.)	Metropolitan area
1	Mecklenburg	NC	17,950	1528	28.7	Charlotte, NC
2	Lake	IL	12,987	1064	18.1	Chicago, IL
3	Will	IL	27,399	806	16.7	Chicago, IL
4	Queens	NY	11,613	8056	12.7	New York, NY
5	Cobb	GA	3480	2049	9.3	Atlanta, GA
6	Dallas	TX	6170	1437	6.6	Dallas, TX
7	Coweta	GA	6180	510	5.6	Atlanta, GA
8	Denver	CO	4503	1925	5.0	Denver, CO
9	Montgomery	MD	3776	757	4.4	Washington, DC and Baltimore, MD
10	St. Charles	MO	3350	533	4.3	St. Louis, MO
11	Washington	MN	3203	632	4.2	St. Paul, MN
12	Bexar	TX	9222	555	3.0	San Antonio, TX
13	Calvert	MD	12,938	533	2.9	Washington, DC and Baltimore, MD
14	Harris	TX	4462	1179	2.4	Houston, TX
15	Tarrant	TX	2704	1170	2.3	Dallas, TX
16	Multnomah	OR	5402	548	2.2	Portland, OR
17	Contra Costa	CA	4759	678	2.0	San Francisco, CA
18	Fort Bend	TX	19,656	851	1.9	Houston, TX
19	Wake	NC	5967	1266	1.7	Raleigh, NC
20	Suffolk	MA	5062	1184	1.7	Boston, MA
21	Clark	NV	20,148	642	1.5	Las Vegas, NV
22	Montgomery	TX	2871	647	1.5	Houston, TX

has mismanaged water resources and that extra Georgian withdrawals would dry up river flows that support out of state power plants, farms, fisheries, and industrial users along the river (Evans, 2008). Alabama, for example, says that restrictions on water use in Georgia would impede electricity production at their Farley Nuclear Plant, also on the Chathoochee River, threatening power outages among 8,00,000 residents in three states. Tri-state water negotiations have so far only precipitated in eight active lawsuits, and Georgia's state assembly passed a resolution calling on the governor to set up a commission looking into having the border redrawn through the middle of Chattanooga, Tennessee. Resolutions were later introduced in both the state House and Senate to annex part of Tennessee to increase Georgia's access to water (Sovacool, 2009).

4.3. Las Vegas, Nevada

Nevada Power Company and Sierra Pacific Power Company intend to add 20,148 MW of thermoelectric capacity between 2000 and 2025, power plants that would consume 78.8 billion gallons of water per year and withdraw an additional 3.86 trillion gallons of water. State demographers expect the addition of another 1.6 million residents, or an increase in population of more than 80%, to the Las Vegas area from 2008 to 2026 (Illis, 2007). Water is so important for the region that state Representative Jon Porter calls it "liquid gold" (Young, 2003, p. 2). Because of its arid climate, more than 90% of the water for Las Vegas comes from Lake Mead on the Colorado River. Lake Mead, one of the largest reservoirs in the world, was created by the Hoover Dam's blockage of the Colorado River (which receives most of its water from melting snowpack). It holds roughly the same amount of water flowing through that very river over a two-year period. During the past decade a shortage of precipitation has induced a widespread drought and a serious decline in water levels. The National Aeronautics and Space Administration (NASA, 2004) and the US Drought Monitor placed the Lake Mead region in "extreme hydrological drought," only one category above the worst in their drought intensity scale. Researchers from the Federal Bureau of Land Reclamation estimate that the Lake Mead water system is losing 326 billion gallons of water per year (Madrigal, 2008). This water loss is so significant that it can easily be seen from satellite images from space.

An increase in the water needs for Nevada Power's generation portfolio could directly deplete more water from Lake Mead, which supplies cooling water for a majority of the power plants operating in the region. The Nevada Department of Conservation and Natural Resources and the Nevada Division of Environmental Protection report that the thermoelectric capacity additions sought by Sierra Pacific and Nevada Power Company could need an additional 1.38 trillion gallons of water per year coming from Lake Mead by 2010 (Saunders, 2005).

If Lake Mead continues to be depleted, the result could be an agricultural crisis. Lake Mead, in addition to providing drinking water to the Las Vegas Valley Water District and cooling water for power plants, affects the availability of water for downstream withdrawals from the Colorado River. These downstream withdrawals directly irrigate about a million acres of farmland in southern California's Imperial Valley, and another half million acres in northern Mexico as part of an international water treaty. In addition, the water in Lake Mead powers the Hoover dam whose electricity feeds into 5,00,000 homes and pumps water over the Sierra Nevada Mountains to irrigate southern California (Allen and Simmon, 2003). If water continues to be depleted from Lake Mead faster than it can be replenished, agricultural collapse could strike the entire region and possibly spread to Mexico.

4.4. New York, New York

New York systems operators and utilities have reported they plan to add 11,613 MW of capacity near New York City between 2000 and 2025, power plants that would consume 45.4 billion gallons of water per year and withdraw and additional 2.22 trillion gallons. Interestingly, in New York City there is no direct tradeoff between drinking water and the water needed to cool conventional electricity generators. According to the New York Department of Environmental Protection, the City's water comes from 19 reservoirs, three controlled lakes, and about 300 miles of aqueducts spanning the Catskill Mountains to Westchester

County. This latter system comprises the Croton, Catskill, and Delaware Watershed systems and a groundwater supply consisting of the Jamaica Wells in Queens.

However, due to constraints on transmission and distribution, the New York Independent Systems Operator (2008) has warned that the city will need to generate most of its future power within its limits (NYISO recommended that local generators supply 80% of electricity load). Because of these limitations, most power serving New York City comes from a collection of fossil and nuclear plants nearby along the Hudson River. Seven facilities constituting 6691 MW of capacity – Bethlehem Energy Center (previously the Albany Steam Station), Danskammer Generating Station, Roseton Power Plant, Indian Point Energy Center, Lovett Power Plant, Bowline Power Plant, and the IRT Power Plant on 59th Street – use 6.1 billion gallons of water directly from the Hudson for coolant every day (Levinton and Waldman, 2006). If planners add another 11,613 MW to the Hudson, total water use would grow by at least 12.2 billion gallons of water per day.

New power plants would consequently have a devastating impact on local fisheries and ecosystems through the discharge of heated effluent, entrainment, and impingement (Sovacool, 2009). A collection of extensive fishery surveys along the Hudson River determined that thermoelectric power plants were devastating freshwater fisheries in the early 1970s (Levinton and Waldman, 2006). The federal and state government passed extensive regulations to limit the damage, but utility restructuring this past decade has renewed concern that electric utilities, more focused on competition and profits, will be less focused on environmental compliance. Additional thermoelectric power additions along the Hudson could increase mortality of striped bass, bay anchovy, and Atlantic tomcod (Levinton and Waldman, 2006). Another study from researchers within New York warned that the withdrawal of cooling water for new thermoelectric plants would have "profound impacts on aquatic environments" along the Hudson River including reductions of phytoplankton, zooplankton, fish, and shellfish and stresses to overall communities and ecosystems (Kass et al., 2007).

5. Implications for policy

Electric utility planners, water managers, and state and federal policymakers can do much to respond to the water-related challenges facing the electricity industry. While a variety of new different technologies and policies can be promoted, five may hold the most promise: (1) continuing to improve the thermoelectric cooling cycles of conventional power plants and other associated technologies; (2) placing a moratorium on the construction of power plants with once-through cooling cycles; (3) changing provisions of the National Environmental Policy Act related to power plant permitting; (4) aggressively promoting demand-side management and energy efficiency; (5) quickly deploying solar panels and wind turbines to displace new thermoelectric power plants.

5.1. Improve thermoelectric cooling cycles

The US Department of Energy, through different programs at the National Energy Technology Laboratory (NETL) and Sandia National Laboratory, has started researching how to make conventional power plants more water-efficient, and a number of emerging technologies can greatly reduce water use. Researchers working in conjunction with NETL, for example, have investigated treating and reusing "impaired," "nonpotable," "produced," "brackish," "reclaimed," or "gray" water to cool power plants. The most common applications include using secondary-treated municipal waste water, passively treated coal mine drainage, and ash pond effluent (Sovacool, 2009). Fifty-seven power plants, mostly in the arid western part of the United States, already rely on cooling cycles that utilize reclaimed water, and abundant sources of reclaimed water are available in Alaska, California, Kansas, Louisiana, Oklahoma, Texas, and Wyoming (accounting for 90.1% of produced water) (Sovacool, 2009; Zammit and DiFilippo, 2005).

Another option being researched is enabling power plants to produce some of their own water, either through capturing water vapor from flu gas or using the thermal discharges from power plants to desalinate water. Water is naturally present in all deposits of coal, constituting as much as 60% of its weight. The coal combustion process thus releases water vapor which can be recovered from flu gas using liquid desiccant-based absorption systems or modified electrostatic precipitators (Sovacool, 2009). Engineers at NETL expect that such capture technologies could reduce 5% of evaporative water loss at power plants (Feeley and Pletcher, 2006). Diffusion driven desalination, a process that uses the excess waste heat from power plants to produce distilled water, can also minimize the water needs of power plants situated in coastal areas (Klausner and Mei, 2005). Still other options include advanced water storage systems and infrastructure enhancements such as long distance power transmission that could reduce the water needs of the industry.

Thermoelectric power plants, simply put, do not always need to consume and withdraw water as they do today. Opportunities exist to notably improve the efficiency of thermoelectric cooling cycles and other associated technologies. While many of the technologies discussed here are yet commercially available, tripling the funding for the research programs at Sandia and NETL could lead to the technological breakthroughs that greatly reduce water use at future power plants.

5.2. Ban once-through cooling cycles for new power plants

One bold and perhaps controversial option would be for public utility commissioners, state regulators, and/or federal policymakers to ban once-through cooling cycles at all new power plants being constructed. Perhaps the most relevant actors that could implement such a ban are those at the Federal Energy Regulatory Commission or the Environmental Protection Agency. Once-through cooling cycles, because they use the most water compared to all other cooling cycles, possess two intrinsic water-related risks: they are unable to withdrawal water needed for normal operation in times of scarcity, and can cause and worsen existing water shortages when their fuel cycles consume water (Sovacool, 2009). A moratorium on the use of these cooling cycles at new thermoelectric power plants would therefore directly help preserve water resources. A moratorium may become more palatable when implemented in conjunction with the other measures discussed in this section.

5.3. Change National Environmental Policy Act (NEPA) permitting guidelines

President Richard Nixon signed the National Environmental Policy Act into law on January 1, 1970, establishing the President's Council on Environmental Quality and setting up procedural requirements for the preparation and monitoring of environmental impact statements. Parts of the Act, as amended, set strict guidelines relating to the permitting, siting, and relicensing of thermoelectric power plants. While intended to create a relatively transparent decision-making process by giving states and local governments a voice in federal decisions, the process has faced criticism for becoming more inefficient and ineffective over time. In some recent cases of power plant permitting in the northeast and the pacific northwest, public comments have been either discouraged or limited, exemptions created, or guidelines relaxed. The NEPA process could be strengthened, not weakened, to ensure that power plant permitting decisions relating to water use are open to the public and more comprehensive (Buccino, 2005). Many of the earliest debates over water use were instigated by the preparation and defense of environmental impact statements, and an improvement of the permitting process would help serve as a crucial check on the approval of excessively water-wasteful power plants.

5.4. Implement demand-side management and energy efficiency

In concert with researching new cooling cycles, banning inefficient ones, and altering the permitting process, energy efficiency and demand-side management programs can cost-effectively displace the need to build many conventional power plants. While their numbers can be contested, one study estimated in 1999 that if American businesses implemented minor mechanical alterations to their industrial processes they could cut their electricity consumption in half – with net savings of $110 billion a year (Lovins et al., 1999). The nonpartisan National Commission on Energy Policy calculated in 2003 that electricity consumption in the United States could be 40% higher than cost-minimizing levels (Cavanagh, 2003). Economists at the American Council for an Energy-Efficient Economy concluded in 2005 that the US could cost-effectively reduce energy use 25% or more during the next 15 years in ways that increased overall productivity (Nadel et al., 2005). Another 2007 study projected that a national DSM program aimed at reducing peak demand by just 5% would yield $3 billion in net generation, transmission, and distribution savings per year and displace some 625 infrequently used peaking plants and associated delivery infrastructure (Faruqui et al., 2007). Clearly, an immense amount of energy efficiency potential exists and some of it can be used to displace the need to build scores of new thermoelectric power plants.

5.5. Deploy wind farms and solar panels

Finally, electric utilities can draw on two types of electricity generators that require almost no water at all: solar panels and wind farms. Solar PV systems use about 0.03 gal of water per kWh and wind turbines 0.001 gal of water per kWh. Solar thus uses 145 times less water per unit of output and wind about 180 times less water than conventional coal and nuclear power plants (see Fig. 8).

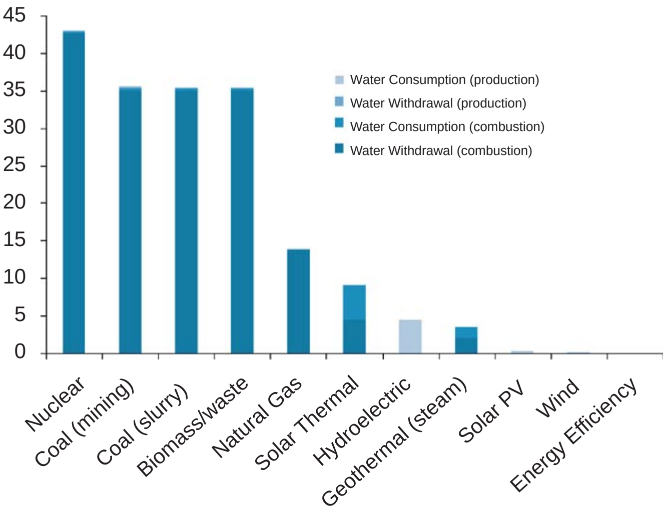

Fig. 8. Total water use for conventional and renewable electricity generators (gallons/kWh).

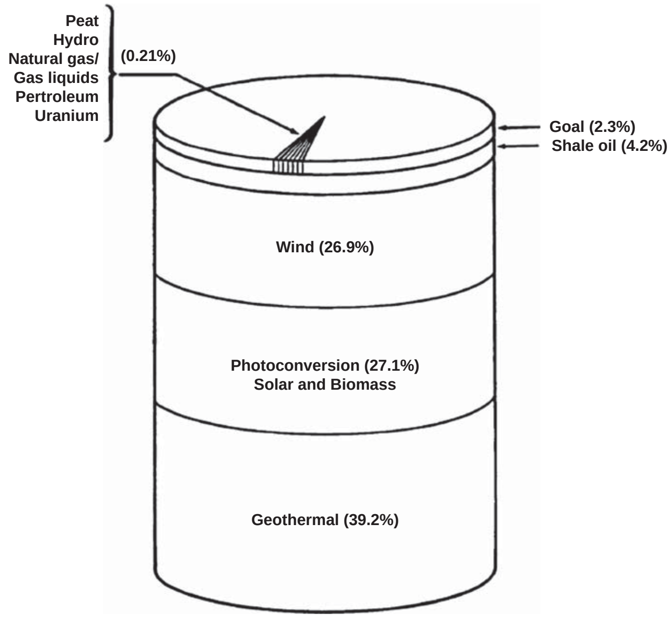

Fig. 9. Domestic US energy resources and reserves.

Fortuitously, the United States has an enormous cache of these renewable energy resources. While a bit dated, a comprehensive study undertaken by the US Department of Energy (1989) calculated that more than fifty percent of all domestically available energy resources were in the form of just wind and solar (see Fig. 9). The amount of wind and solar resources found within the country, in other words, amounted to a resource base the equivalent of more than 300,000 billion barrels of oil, or over 20,000 times the annual rate of national energy consumption at that time. Perhaps the only other terrestrial source of so much energy would be fast breeder nuclear reactors or nuclear fusion, both technologies that are still at least twenty to thirty years away and would likely require large amounts of water. While the DOE's estimate is more than 20 years old, it is referenced here because it was reviewed and validated by researchers at USGS, ORNL, Pacific Northwest National Laboratory, Sandia National Laboratory, NREL, the Colorado School of Mines, and Pennsylvania State University. Using a compilation of published, nonpartisan, and peer-reviewed estimates (and excluding estimates from manufacturers and trade associations), the United States currently has about 2,998,000 MW of technical wind and solar PV potential (Sovacool, 2008, p. 95). That is, wind and solar PV power plants alone have the capability to provide almost three times the total amount of installed electricity capacity operating in 2008, and so far the country has harnessed less than one percent of this possible generation.

6. Conclusions

Business as usual within the American electric utility system could induce direct tradeoffs between the water needed to cool new power plants and the water needed for drinking, irrigation, fisheries, and agriculture. Twenty-two regions of the country will be most at risk if current trends continue, yet the scope and nature of the challenges facing each of these areas are distinct. For

Houston, new power plants would likely continue to use water from the Trinity, San Leon, and San Jacinto rivers and reservoirs, depleting the water available for drinking and possibly interfering with the water needed for irrigation and agriculture. In Atlanta, new thermoelectric power plants would deplete the water recharging Lake Lanier in Georgia, reducing available supply for commercial and industrial users in the region and complicating water management downstream in Alabama and Florida. To supply Las Vegas, new thermoelectric power plants would have to take water from Lake Mead, exacerbating an already existing drought and reducing the water needed to irrigate Southwestern California and Mexico. In New York, new thermoelectric power plants would risk impinging and entraining millions of fish, with deleterious impacts on local fisheries and riparian ecosystems.

History suggests that power plants will continue to improve their water efficiency. The analysis here presumes that electric utilities will be using today's technology in 2025, withdrawing 24.5 gal of water for every kWh and consuming another 0.5 gal per kWh, while instead those power plants are likely to get better over time. The dilemma is that the amount of total electricity they will have to generate in 2025 will also be much greater. Moreover, the risks could even be understated here since the study looked only at water use at the point of the power plant, and not spread across the various fuel cycles connected to power plants such as coal and uranium mines, natural gas and oil wells, refineries and processing stations, pipelines and barges, cooling ponds and storage facilities, all which also rely on noteworthy amounts of water.

The impending water associated challenges with thermoelectric power plants serve an important reminder that climate change is not the only serious environmental issue facing the electricity industry or the energy sector. To be sure, the two are connected – especially as climate change alters precipitation patterns and influences the frequency and severity of floods and drought – but the water–electricity challenge is serious in its own right, and deserving of swift and decisive policy intervention. This intervention should include ramping up R&D projects on advanced thermoelectric cooling cycles, banning the construction of new water-intensive power plants, altering power plant permitting procedures, promoting energy efficiency and demand-side management, and relying more on wind and solar power plants to produce electricity.

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