SEI STOCKHOLM ENVIRONMENT INSTITUTE

POLICY BRIEF

Water in a Low-Carbon Economy: Resource Scarcity, Climate Change and Business in a Finite World

Key Findings

- **Low-carbon electricity technologies are critical components of efforts to reduce greenhouse gas emissions in the energy sector. However, some low-carbon technologies may use as much or more water than fossil-fueled generation, which could make them less viable in water-constrained settings.**
- **We developed a case study for water use for electricity generation in California, focusing on the water and emissions implications of the state's renewable energy portfolio standard (RPS). We found under business as usual (BAU), greenhouse gas emissions, water withdrawals and water consumption all increase. Under the RPS, which would boost the share of renewable electricity from 25 to 34 per cent by 2020, emissions and water withdrawals drop, but water consumption (the water that is not reused or returned to the source) increases.**
- **Adjustments to California's RPS could significantly reduce water demand. A scenario we called RPS+Technology, using more photovoltaics and less solar thermal power, and incrementally switching once-through to wet-recirculating and dry-cooling systems, reduced both water withdrawals and consumption. Some of the adjustments would reduce energy-efficiency, and thus increase emissions, but our scenario shows this could be offset by introducing carbon capture and sequestration (CCS) in a portion of natural-gas plants.**

A critical resource

The need to keep climate change within safe thresholds will require rapid emission reductions, and widespread deployment of low-carbon technologies to help achieve them. Yet many low-carbon energy sources require considerable amounts of water – and given competing demands, resource depletion and projected climate impacts, sufficient water may not be available to meet all needs.

This policy brief, based on research conducted as part of a partnership between the business leaders' initiative 3C (Combat Climate Change) and the Stockholm Environment Institute, examines the potential impact of low-carbon electricity generation technologies on water resources – and how these water inputs might shape renewable choices.

We begin by exploring the ways in which a changing climate and associated hydrologic changes may impact current electricity generation strategies; in particular, where future climate change may significantly decrease water availability. We then examine the water use implications of different electricity generation pathways, as well as potential ways to reduce the water use of future electricity generation technologies. Finally, we provide a case study of water and electricity generation considerations in California, a renewable-energy leader in the U.S.

California's Global Warming Solutions Act (AB32), passed in 2006, commits the state to cut greenhouse gas (GHG) emissions to 1990 levels by 2020 and by another 80 per cent by 2050. California has the nation's most aggressive renewable portfolio standard (RPS), mandating that 33 per cent of electricity deliveries come from renewables by 2020. The goal is of AB32 is to show that an economy can reduce emissions and strive for sustainability, while maintaining profitability.

Water and the low-carbon economy

Water is used in the production and processing of fuels, in electricity generation, as a coolant in power plants, in energy storage, and for other energy-related purposes. Yet predicting how the low-carbon economy will intersect with water resources is challenging, both because of inherent uncertainties in climate scenarios and water-supply projections, and because it is hard to estimate the future technical potential and adoption of key technologies.

This analysis focuses only on one aspect of the low-carbon economy: electricity generation. The links between climate, water and energy are much broader; the water management implications of biofuels production, for example, are a pressing concern. However, focusing on electricity provides a more manageable scope for our study, and better matches both the expertise of the authors and the profile of the 3C member companies.

Iceland – geothermal power plant ©Flickr/Scott Ableman

Electricity generation and water tradeoffs

Water is required in nearly all electricity production. Fossil-fuelled and nuclear power plants, which generate the majority of many countries' electricity, rely heavily on water for cooling. Hydropower depends on river flow and reservoir storage and contributes to substantial manipulation of hydrologic regimes, as well as to potential water losses through evaporation from reservoirs.

Water availability thus constrains the operation and siting of power plants, and any shortages will have implications for electricity production. Yet some of the same factors that restrict water supplies – competing demands due to economic and population growth, and expected thermal extremes due to climate change, will likely increase energy demand, and with it, demand for water for the energy sector.

Water requirements for power generation depend on several factors, including the generation technology, the type of cooling technology used in thermoelectric power generation, and electricity demand itself. In general, however, because of the substantial need for cooling, fossil-fuel electricity generation is typically more water-intensive than many alternatives – although some low-carbon technologies have similarly large water requirements.

It should be noted that climate-related water constraints are already affecting electricity generation in many places, sometimes forcing power plants to curtail output or shut down. Acute water-energy conflicts are already arising during droughts and summers, when electricity demand is high and water availability is low. For example, in 2006, a drought in Uganda reduced hydropower capacity by one-third, leading to electricity shortages. And in 2003, increased river water temperatures due to a heat wave led authorities in Germany and France to curtail nuclear power generation – 4,000MW in France alone. Climate change is expected to bring more droughts and extreme heat to many areas, exacerbating these types of problems.

Water use in conventional power generation

Water use in electricity production is measured in two ways: withdrawal and consumption. Water withdrawal involves removing water from a source and either returning it to the source, or making it available elsewhere. Consumed water is not returned to the source, typically due to evaporation.

Conventional coal, nuclear, natural gas and oil power plants account for 90 per cent of U.S. electricity generation and 81 per cent of global generation, according to the U.S. Energy Information Administration (USEIA). These thermoelectric power plants heavily rely on water for cooling purposes: in the U.S., they accounted for 41 per cent of freshwater withdrawals in 2005, the single biggest share. In addition, thermoelectric power plants require smaller amounts of water for resource extraction, fuel processing and post-combustion activities.

The three methods of cooling being used today are once-through, wet-recirculating and dry cooling. Once-through cooling systems take water from nearby sources, circulate it through the plant, and return almost all the freshwater, albeit at a warmer temperature, to its source, with maybe 1 per cent lost. In wet-recirculating cooling systems, less water is withdrawn from the source, but 70-90 per cent is lost through evaporation. Dry-cooling systems use air and can reduce water

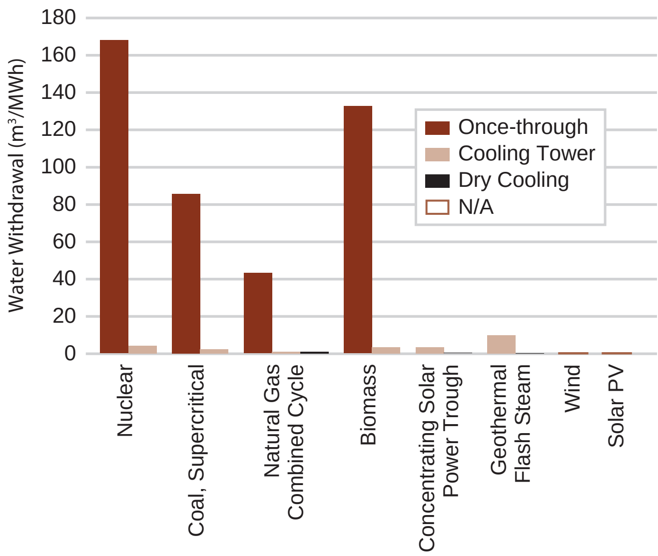

Figure 1. Water withdrawals by fuel and cooling technology

Source: Macknick, J., Newmark, R., Heath, G. and Hallett, K. (2011) *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies*. NREL/TP-6A20-50900. NREL, Golden, CO.

consumption by more than 90 per cent compared with wet-recirculating systems, but they are expensive and less efficient.

According to U.S. government estimates, most thermoelectric power plants currently use once-through (43 per cent) or wet-recirculating cooling (56 per cent); only1 per cent use dry-cooling. Unless companies install more dry-cooling systems or shift generation to non-thermal renewables, rising demand for electricity is likely to lead to an increase in overall water withdrawal and consumption by thermoelectric plants.

Water use in a low-carbon economy

As of 2009, low-carbon electricity generation technologies made up over 23 per cent of total installed capacity in the world in 2009, according to the USEIA, and this share is expected to grow as the global community responds to climate change. In 2007, European members of the Organisation for Economic Co-operation and Development (OECD) produced more than 20 per cent of their electricity from renewable resources, while in Central and Latin America, the share was nearly 70 per cent; both regions rely heavily on hydropower.

Low-carbon energy sources produce fewer GHG emissions than conventional fossil fuels, but that doesn't necessarily mean they have no environmental impacts. Solar thermal and geothermal technologies both require water for cooling, though far less than nuclear or fossil-fueled plants with once-through systems. Water requirements for biomass vary widely depending on feedstock, generation technology and cooling technology, but they can be on par with fossil-fuel technologies' water use. Figure 1 shows the cooling water requirements for various fossil-fuel and low-carbon energy technologies.

Case study: Water and electricity in California

California has a long history of supporting renewable energy through market-based incentives. In 2010, approximately 25 per cent of the generated electricity came from renewable resources such as wind, solar, geothermal, biomass and hydroelectric facilities. The state generates, on average, 70 per cent of its electricity, and imports the rest from the Pacific Northwest and the U.S. Southwest.

Much of California's surface water comes from winter precipitation and spring snowmelt in the state's mountain ranges. Over the last 30 years, the region has seen warmer winters, reduced snowpack, and changes in spring stream flow timing, all consistent with climate change projections. The southern part of the state, meanwhile, is already an area of high water stress, which climate change threatens to worsen.

California's water constraints have forced the state to confront the so-called water-energy nexus – both in terms of water use for energy, and in terms of the energy used to transport water across the state (the State Water Project, which provides water for more than 20 million people and more than 350,000 hectares of irrigated farmland, uses a net 2 million MWh per year, making it the single largest consumer of electricity in California). There is a growing body of research in this field, using scenario analysis to gauge water consumption with different fuel mixes and/or different water-efficient cooling technologies.

Our technical analysis focuses on cooling water needs for electricity generation, with special attention to the state's RPS program, a major driver for emissions reductions from the electricity sector. Our main objective is to investigate the projected emissions *and* water use impacts of the RPS. In addition, we investigate the potential impacts of modifying the RPS to favour technologies that reduce both emissions and water use; we call this scenario RPS+Technology. In our analysis, total electricity generation rises only modestly from 2010 to 2020, and is the same under business as usual (BAU) or the RPS scenarios. But in both RPS scenarios, the share of generation from renewables (e.g. solar, wind, hydropower, biomass, geothermal) rises from 25 per cent in 2010 to 34 per cent in 2020, with accompanying reductions in natural gas, coal and nuclear. Solar power increases dramatically, from less than 1 per cent to 8 per cent under the RPS scenario.

For the RPS+Technology scenario, we assume the same fuel mix as the RPS scenario, but switch technologies. We alter the RPS solar portfolio, dominated by solar thermal (70 per cent vs. 30 per cent photovoltaic), to a 50:50 mix by 2020, and change a portion of once-through systems to wet-recirculating, and a portion of biomass and natural gas wet-recirculating to dry-cooling. Because some of these changes affect plant efficiency, leading to slightly higher greenhouse gas emissions, we also add carbon capture and sequestration (CCS) technology to some recirculating natural gas plants (17 per cent of the state's natural gas generation capacity). Adding CCS modestly reduces the water savings, but also leads the RPS+Technology scenario to yield larger emission reductions than the standard RPS scenario.

Figures 2, 3 and 4 show our findings. Under BAU, emissions, water withdrawals and consumption all increase. Emissions rise by 13 million tonnes CO_2e (about 10 per cent) by 2020; water withdrawals and consumption rise by 1,423 and 97 million cubic metres (Mm^3), respectively (about 13 per cent). Under the RPS scenarios, both emissions and water withdrawals stay almost constant, emissions dropping by 1.9 million tonnes CO_2e and water withdrawals rising by 2.6 Mm^3. Changes in water withdrawals are driven by reduced deployment of natural gas

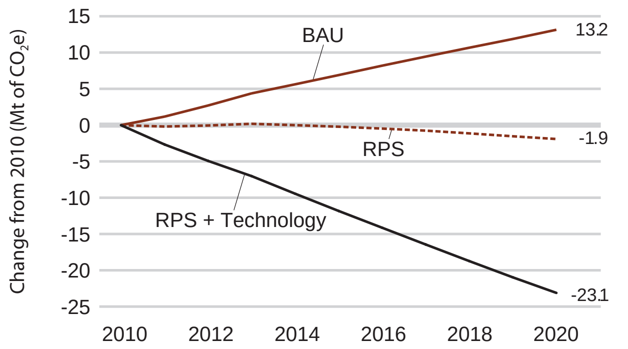

Figure 2. Projected emissions under the three scenarios.

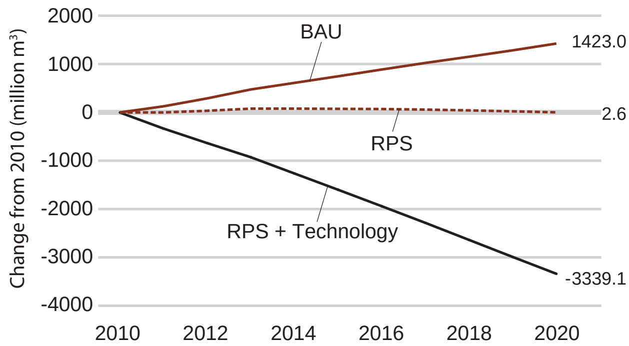

Figure 3. Projected water withdrawals under the three scenarios.

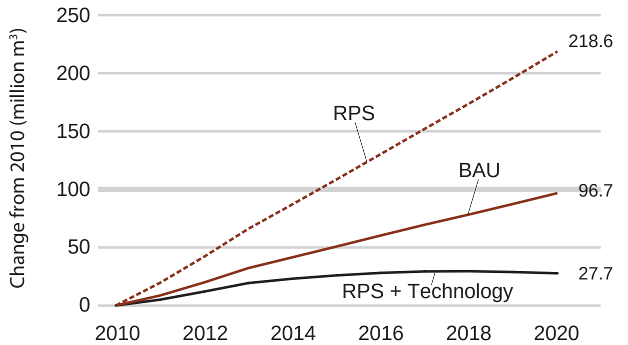

Figure 4. Projected water consumption under the three scenarios.

and nuclear power, but water consumption increases substantially, by 219 Mm^3, due to increases in geothermal and biomass, recirculating cooling systems, and the use of solar thermal.

Under RPS+Technology, water withdrawals drop by 3,339 Mm^3, while water consumption rises only modestly, by 28 Mm^3, driven by the intentional switch to recirculating and dry cooling systems, and a more balanced mix between solar PV and solar thermal. Thus, we find, only with strategic technology choices (the RPS+Technology scenario) can we secure co-benefits of reducing water withdrawals, significantly moderating increases in water consumption, and achieving deeper cuts in emissions.

This policy brief is based on an SEI report with the same title, by Victoria Clark, Amanda Fencl, Vishal Mehta and David Purkey, which is available on our website. This research has been carried out within the partnership programme between the Stockholm Environment Institute and the business leaders' initiative 3C (Combat Climate Change).

Policy options and considerations

- All energy planning – including efforts to boost renewable capacity, should carefully consider future water availability under multiple usage and climate scenarios, and any new generation capacity should be viable even in the lowest water availability scenarios.
- Given projected water shortages and competing demands in many places, energy planners may want to prioritise low- and no-water renewable energy technologies such as solar PV, wind, small hydro and binary-cycle geothermal. Thermoelectric renewables such as solar thermal and geothermal steam technologies are arguably at a higher risk than conventional thermoelectric power plants, as they must be sited near solar and geothermal resources, respectively, which are often in hot, arid areas.
- Choosing water-efficient cooling technologies can also significantly reduce water demand. However, efficiency may sometimes be compromised, especially in very hot areas. In these cases a hybrid cooling system that uses wet cooling for hot days in parallel with dry cooling may be most appropriate.
- There is significant potential to reduce demand for electricity – and thus for water for power plants – through efficiency improvements in electrical devices, electricity transmission and distribution systems, and power plant operations. All these options should be explored and pursued when feasible.
- Water recycling and reuse could decrease the need for water withdrawals. Several types of wastewater are being considered for power plant cooling: Treated municipal wastewater, also called grey water, is a huge unclaimed water resource, with 32 billion gallons treated daily in the U.S. Water discharged during oil and natural gas mining, wastewater from industrial processes, and agricultural runoff may also be options.
- Energy storage can help even out demand for power generation (smooth the load) and enable power plants to operate at maximum efficiency, making it critical to a low-carbon future. Technologies such as pumped hydro and compressed energy storage system (CAES) offer the largest and most economical grid-scale energy storage options. In terms of water use, these technologies can also give power plants more flexibility to reduce production during times of drought or high demand for other uses.

New Mexico – National Solar Thermal Test Facility at Sandia National Laboratories ©Flickr/NNSANews

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