SEI STOCKHOLM ENVIRONMENT INSTITUTE

POLICY BRIEF

Integrated water-energy-emissions analysis: Applying LEAP and WEAP together in California

Key Findings

- **Climate, water and energy are intricately linked, so choices in any one sector can often reverberate across the others. To achieve the best possible outcomes, policy-makers need to understand cross-sector interactions and tradeoffs – the so-called 'nexus'. This requires new tools for integrated analysis.**
- **Seeking to meet this need, SEI has built a link between its water and energy decision support systems, which are already used in policy-making and planning around the world: the Water Evaluation and Planning (WEAP) system, and the Long-range Energy Alternatives Planning (LEAP) system. The integrated tools allow users to model evolving conditions in both water and energy systems and examine cross-sectoral impacts of different policy choices.**
- **The value of such integrated analyses is demonstrated here by a case study of the implications of meeting roughly 5% of Southern California's current urban water demand with desalinated seawater through 2049. By linking a WEAP model of the U.S. Southwest with a LEAP model of California, the study was able to quantify the impact on water imports, electricity demand from the water sector, and greenhouse-gas emissions.**
- **The WEAP model shows that in normal water years, desalination could reduce the need for water imports by about 300 million cubic meters per year. However, integration of climate projections shows significant variations between dry and wet years, and LEAP shows desalination increases the water sector's electricity use by about 3 terawatt-hours per year, and emissions, by 1.4 million tonnes of CO_2e per year, by 2049.**

The water-energy nexus

Water, energy and climate are intricately linked. Energy is needed to pump, treat and transport water and sewage. Water is needed in many aspects of energy generation: from mining and processing of fuels (and growing biofuels crops), to hydropower production, to power-plant cooling. Climate, meanwhile, affects both water supply and demand, especially for agricultural irrigation but also for power-plant cooling. And it influences energy demand: when it's cold, more energy is needed for heating; when it's very hot, there is more demand for air conditioning. If it's also dry, more energy may be needed to pump water, and in some areas, for desalination. Finally, most forms of energy production – especially those involving fossil fuels – generate greenhouse gas (GHG) emissions, so both the energy sector and the water sector, through its energy use, have an impact on climate change.

The complexity of these linkages means that choices about water resources, energy and climate change can all affect one another, sometimes considerably. Real-life examples abound, especially in places with limited and shrinking water resources: The rise in biofuels production – a widely embraced climate change mitigation strategy – has increased demand for irrigation water, sometimes at the expense of food crops and urban and environmental uses. Hydraulic fracturing ('fracking') for natural-gas and oil extraction also requires copious water supplies, and has led energy companies to buy water from farmers during the 2012 U.S. droughts. In China, India and other countries, meanwhile, agricultural irrigation systems are major energy users and, by extension, GHG emitters. And from Florida to California to the Middle East, energy-intensive desalination is gaining appeal as a way to meet water demand. Careful consideration of cross-sectoral impacts will be essential to ensuring that policies in all three realms are viable and do not have unwanted consequences.

The technical challenge

While policy-makers and planners increasingly recognize the need for integrated water-energy-climate analyses, until now, they have lacked the necessary tools. Using separate water and energy planning systems, they can typically explore only one-way linkages (e.g. energy-intensity of water, or water-intensity of power production).

California – Antelope Valley & Resevoir ©Flickr/Ben+Sam

The project described in this policy brief, supported by the U.S. National Oceanic and Atmospheric Administration (NOAA), addresses this challenge by linking two modeling and planning software systems developed by SEI – one for water and one for energy and mitigation – so they can be used together for integrated decision-making.

- The Water Evaluation And Planning (WEAP) system is used in 170 countries around the world for integrated water resources management and planning at a range of spatial and temporal scales. WEAP models both water demand – and its main drivers – and water supply, simulating real-world policies, priorities and preferences.

- The Long-range Energy Alternatives Planning (LEAP) system, used in more than 190 countries, is a powerful, versatile software system for integrated energy and GHG mitigation planning. It is widely used for energy assessments and Low Emission Development Strategies (LEDs), and has been used for dozens of National Communications on Climate Change to the United Nations.

Individually, both LEAP and WEAP already address some aspects of water and energy planning, respectively. Through this project, they have been closely integrated so they can exchange key model parameters and results and, together, represent evolving conditions in both water and energy systems.[1]

This policy brief describes the first application of these newly integrated tools: an evaluation of key water-energy tradeoffs arising in California, a state with a long history of energy conservation and environmental stewardship.

California context: Water for energy

California's Global Warming Solutions Act (AB32), passed in 2006, commits the state to reducing GHG emissions to 1990 levels (427 million tonnes of CO_2e) by 2020. Electricity generation currently accounts for about 24% of total emissions – 13% from in-state production and 11% from electricity imports. Emissions reduction in the energy sector will be driven largely by California's aggressive Renewables Portfolio Standard (RPS), which mandates that by 2020, 33% of electricity must come from eligible renewables including biomass, geothermal, solar, wind and small-scale hydropower. In 2011, official figures show, 14.5% of the state's power mix came from those sources, and another 13.4% from large-scale hydropower.

California – Water treatment plant ©Flickr/Aquafornia – Chris Austin

Driven to a great extent by the RPS, California's energy sector has been investing aggressively in renewables. The California Public Utilities Commission's list of RPS projects in the pipeline shows they would generate a minimum of 30 terawatt-hours (TWh) per year – still less than half the ultimate 75 TWh goal. Yet the water implications of the RPS have not been fully examined; a recent SEI analysis found that if California meets its RPS targets, water consumption for power generation would increase by 219 million cubic meters compared with 2010 levels.[2] The analysis also showed, however, that different technology choices (primarily for thermal power plant cooling systems, but also more use of solar photovoltaic and less water-demanding solar thermal) could result in a much-smaller consumption increase.

California context: Energy for water

The water sector accounts for 19% of California's electricity consumption, including energy for pumping, transporting and treating water, and energy-intensive residential, commercial and agricultural water end-uses. The State Water Project (SWP), which carries water from water-rich Northern California to the water-scarce south, is the state's single largest power consumer, using 3% of total electricity. Each year, the SWP alone pumps roughly 4 billion m^3 of water, to supply more than 20 million people and more than 3,500 km^2 of irrigated farmland. It includes 9,600 km of aqueduct, 30 dams, and 29 pumping and generating plants. Another major aqueduct, meanwhile, brings water from the Colorado River basin to users in California.

Climate change is expected to increase the water sector's energy needs. 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. This means more groundwater has to be pumped. The southern part of the state, meanwhile, already faces high water stress, which climate change threatens to worsen. Water supply for Southern California from the SWP and other imports is variable from year to year, driven by climate variability. During dry years, water shortages are common.

As a result, several Southern California utilities are investigating new seawater desalination plants to reduce dependence on imported freshwater. The San Diego County Water Authority, for example, is working with a desalination plant developer and also planning its own facility. The Long Beach Water Department, the Los Angeles Department of Water & Power, and the U.S. Bureau of Reclamation, meanwhile, have built a roughly 1,100 m^3-per-day prototype seawater desalination facility, the largest research and development facility of its kind in the United States.

One of the first applications of the integrated WEAP-LEAP systems is an analysis of the potential impact of desalination on California's water and energy systems and GHG emissions.

1 For a more detailed description of the WEAP-LEAP linkage, see the SEI factsheet *Integrating the WEAP and LEAP systems to support planning and analysis at the water-energy nexus,* available at www.sei-international.org.

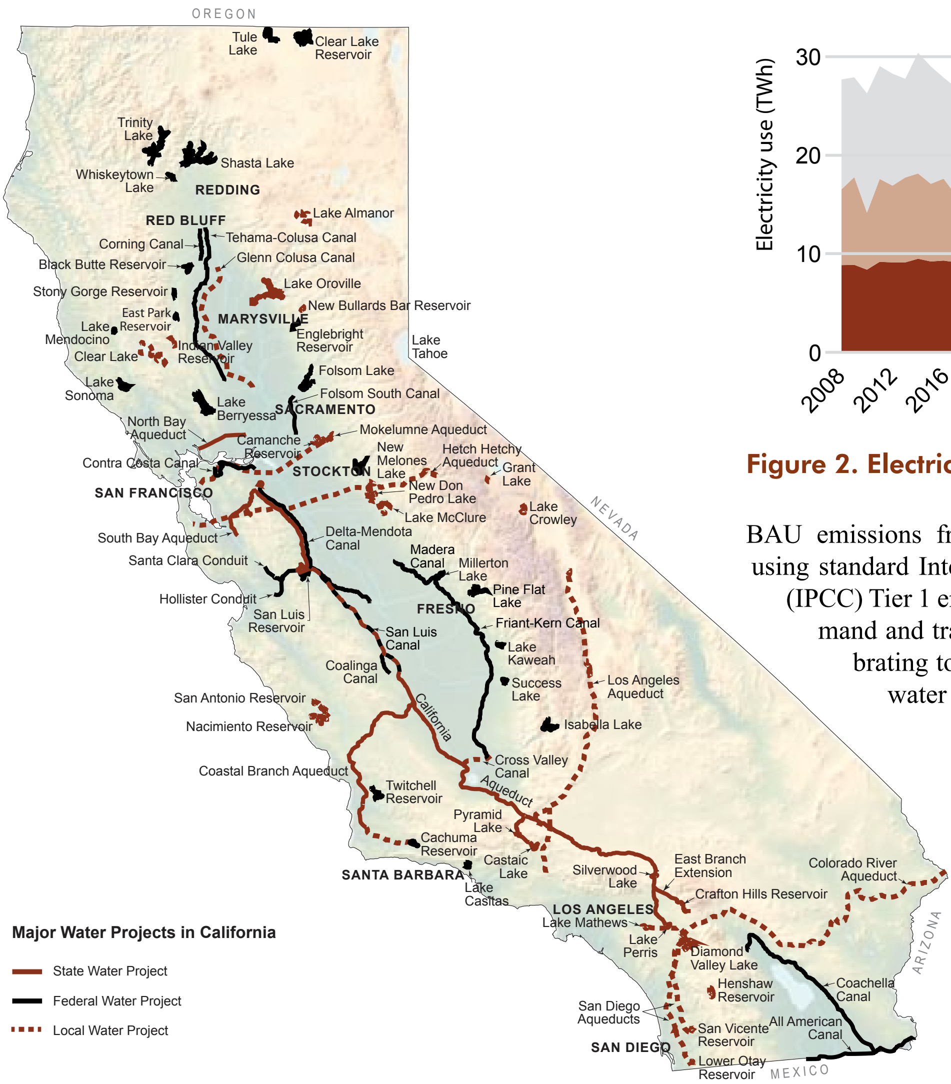
2 See Fencl et al. (2012), *Water for Electricity: Resource Scarcity, Climate Change and Business in a Finite World*, available at www.sei-international.org.

Modeling desalination in Southern California

We built two scenarios for this analysis: Business As Usual (BAU) and a Southern California desalination scenario (DESAL). Both simulate to 2049, climate-driven hydrology and water systems operations, climate-sensitive electricity and water demand by sector, and electricity generation and emissions by primary fuel.

BAU electricity demand is simulated by sector, with residential, commercial, and water-sector electricity both spatially disaggregated and explicitly climate-sensitive. In particular, water-sector electricity demand is dependent on climate-driven hydrology and water table depths, which influence groundwater pumping. As municipal and agricultural water demand grows over time, so does water-sector electricity demand for pumping and treatment.

BAU electricity generation to meet electricity demand is assumed to be dispatched in the same proportion as the current mix in California. We realize compliance with the RPS could change the fuel mix considerably, and are building it into the model, but in our first runs, to demonstrate the WEAP-LEAP linkage, we have not yet included the RPS. Hydropower generation in particular is climate-sensitive, and its availability each month is simulated in WEAP and linked to LEAP. While cooling-water availability can also affect the power generation mix, we have not modeled it here, because California's power plants mostly use seawater for cooling.



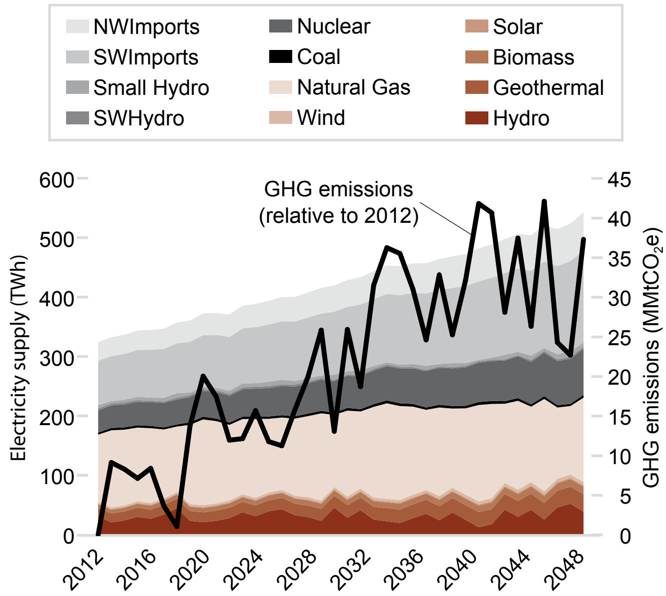


Figure 1. California electricity supply and related GHG emissions in BAU Scenario.

Note that in this initial version of the model, the BAU Scenario assumes the primary fuel mix holds steady from 2010 to 2049, except for varying hydropower generation. A later version will incorporate the impact of California's RPS, which should reduce GHG emissions.

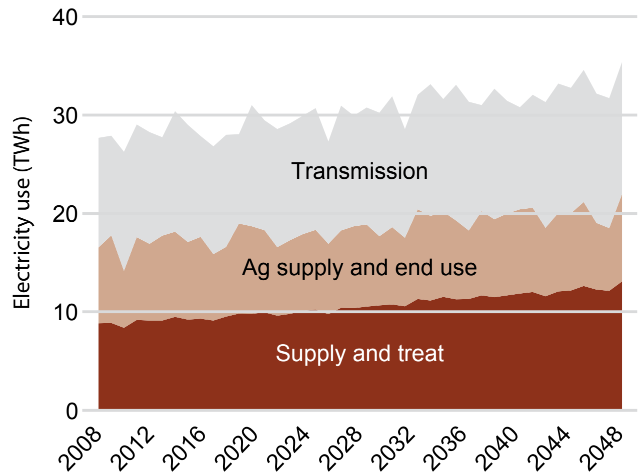


Figure 2. Electricity use by the water sector

BAU emissions from electricity generation are calculated using standard Intergovernmental Panel on Climate Change (IPCC) Tier 1 emission factors. BAU hydrology, water demand and transfers are simulated in WEAP, after calibrating to historical hydrology, reservoir levels and water transfers.

Figure 1 shows statewide electricity generation and corresponding emissions for the BAU Scenario. Electricity demand rises to over 500 TWh from the current 300 TWh, and emissions rise by close to 40 million tonnes of CO_2e. Water-sector electricity use (not including residential and commercial water-related end use) rises from current estimates of about 29 TWh to 36 TWh by 2049 (Figure 2).

Policy insights and recommendations

- Until now, a lack of suitable modeling tools has hindered efforts to explore the water-energy nexus. But there is a clear need for such analyses, especially in the context of climate change, population growth and water scarcity. Integrated water-energy-climate modeling with WEAP and LEAP allows a more sophisticated view of evolving conditions, linkages and tradeoffs than any single model can provide. This means more realistic and complete projections to guide policy-makers in the face of climate change, population growth, water scarcity, and other uncertainties.
- Modeling software such as WEAP and LEAP are only tools. Successful analysis requires input from experts in all the relevant sectors, to ensure that the models reflect real-world conditions and plausible trends, and that the right 'moving parts' and linkages are identified. Close consultation between modelers and policy-makers can also help maximize the usefulness and policy-relevance of the resulting models.
- Integrated water-energy-climate modeling can highlight tradeoffs and potential problems, but it cannot resolve them. Take the desalination analysis: it shows how much water imports can be reduced, how much electricity will be used, and the potential impact on carbon emissions. What it doesn't show is whether desalination is a good idea for Southern California. It is up to policy-makers and stakeholders to weigh the pros and cons, see how they might minimize negative outcomes, and then decide. The value of the integrated model is that it can help them understand the many implications of their choices.

DESAL scenario

The DESAL scenario assumes that up to 340 million m³ of Southern California's water –roughly 5% of current urban demand – could be supplied by new seawater desalination plants. Figure 3 shows the resulting reduction in water transfers from Northern California and the Colorado River basin: about 300 million m³ less than under BAU in most years up to 2030. After 2030, model results show substantial annual variation due to the combination of growing demand and the variability of climate-linked local supplies. As a result, despite desalination, the region has to go back to importing large volumes of water.

Figure 3 also shows the implications of large-scale desalination for electricity use in the water sector and for GHG emissions. By 2049, water sector electricity consumption goes up by almost 3 TWh above BAU. Correspondingly, emissions also increase. Figure 3 shows a gradual rise in emissions, reaching 1.4 million tonnes of CO_2e above BAU by 2049. Though the difference is only about 0.3% of California's target emissions level for 2020, it does provide an incentive for planners to explore low-carbon technologies, such as solar-powered desalination, if they wish to avoid increasing emissions. Such an approach would be consistent with the RPS mandate, which applies to all utilities in California.

It should be noted that energy use and GHG emissions are not the only potential issues with desalination. Critics in California have also raised concerns about the impact on marine ecology, the cost, and other factors. Because our focus is on demonstrating the value of integrated water-energy modeling to address 'nexus' questions, here we have only examined the tradeoff between reducing dependence on water imports and increasing electricity use and GHG emissions.

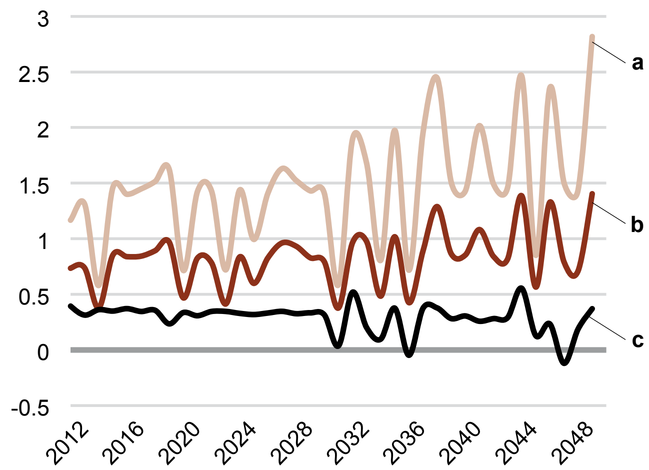


Figure 3. Changes in DESAL Scenario compared with BAU.

From top to bottom:

a. Increase in water-sector electricity use (TWh)
b. Increase in water-sector GHG emissions (million tonnes CO_2e)
c. Reduction in water imports (billion m³)

This policy brief is based on an ongoing analysis by Vishal K. Mehta, of SEI's U.S. Center, and David Yates, an SEI associate and a scientist at the National Center for Atmospheric Research, in Boulder, Colo. Funding for this project has come from the U.S. National Oceanic and Atmospheric Administration (NOAA) Sectoral Applications Research Program, and in an earlier stage, from the California Energy Commission. Any opinions expressed here are the sole responsibility of the authors and have not been reviewed by the project funders.

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2012

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