

## The energy and emissions footprint of water supply for Southern California

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## Environmental Research Letters



## LETTER

## The energy and emissions footprint of water supply for Southern California

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27 October 2015A J Fang<sup>1</sup>, Joshua P Newell<sup>2</sup> and Joshua J Cousins<sup>2</sup><sup>1</sup> Humphrey School of Public Affairs, University of Minnesota, 301 19th Ave S., Minneapolis, MN 55455, USA<sup>2</sup> School of Natural Resources and Environment, University of Michigan, 440 Church Street, Ann Arbor, MI 48109, USAE-mail: [jpnewell@umich.edu](mailto:jpnewell@umich.edu)**Keywords:** water supply, carbon footprint, California, drought, water–energy nexus, life cycle assessment, energy

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**Abstract**

Due to climate change and ongoing drought, California and much of the American West face critical water supply challenges. California's water supply infrastructure sprawls for thousands of miles, from the Colorado River to the Sacramento Delta. Bringing water to growing urban centers in Southern California is especially energy intensive, pushing local utilities to balance water security with factors such as the cost and carbon footprint of the various supply sources. To enhance water security, cities are expanding efforts to increase local water supply. But do these local sources have a smaller carbon footprint than imported sources? To answer this question and others related to the urban water–energy nexus, this study uses spatially explicit life cycle assessment to estimate the energy and emissions intensity of water supply for two utilities in Southern California: Los Angeles Department of Water and Power, which serves Los Angeles, and the Inland Empire Utility Agency, which serves the San Bernardino region. This study differs from previous research in two significant ways: (1) emissions factors are based not on regional averages but on the specific electric utility and generation sources supplying energy throughout transport, treatment, and distribution phases of the water supply chain; (2) upstream (non-combustion) emissions associated with the energy sources are included. This approach reveals that in case of water supply to Los Angeles, local recycled water has a higher carbon footprint than water imported from the Colorado River. In addition, by excluding upstream emissions, the carbon footprint of water supply is potentially underestimated by up to 30%. These results have wide-ranging implications for how carbon footprints are traditionally calculated at local and regional levels. Reducing the emissions intensity of local water supply hinges on transitioning the energy used to treat and distribute water away from fossil fuel, sources such as coal.

**1. Introduction**

California's history is permeated with concerns and conflicts over water supply and water quality. Climate change and ongoing drought have only exacerbated threats to securing future supply, both for the state's vital agriculture sector as well as its growing urban centers. California's water supply infrastructure sprawls for thousands of miles across the American West, with sources ranging from the Colorado River to the Sacramento Delta (Cousins and Newell 2015). Bringing this water to its users is highly energy intensive, with roughly 8% of the state's electricity consumption devoted to the sourcing, conveyance,

and treatment of water (Klein *et al* 2005, CPUC 2010). California's Renewable Portfolio Standard (RPS) and Cap-and-Trade program are also influencing the way electricity is produced in the state by requiring reductions in greenhouse gas (GHG) emissions. Faced with the dual pressure to reduce GHG emissions while maintaining a reliable supply, water utilities across California are measuring the carbon footprint of water or the so-called water–energy nexus (LADWP 2010).

Water supplied to Southern California is of particular interest to water agencies. It is roughly 50 times more energy intensive than water supplied to Northern California (Klein *et al* 2005) and maintaining diverse and reliable water supply sources in a



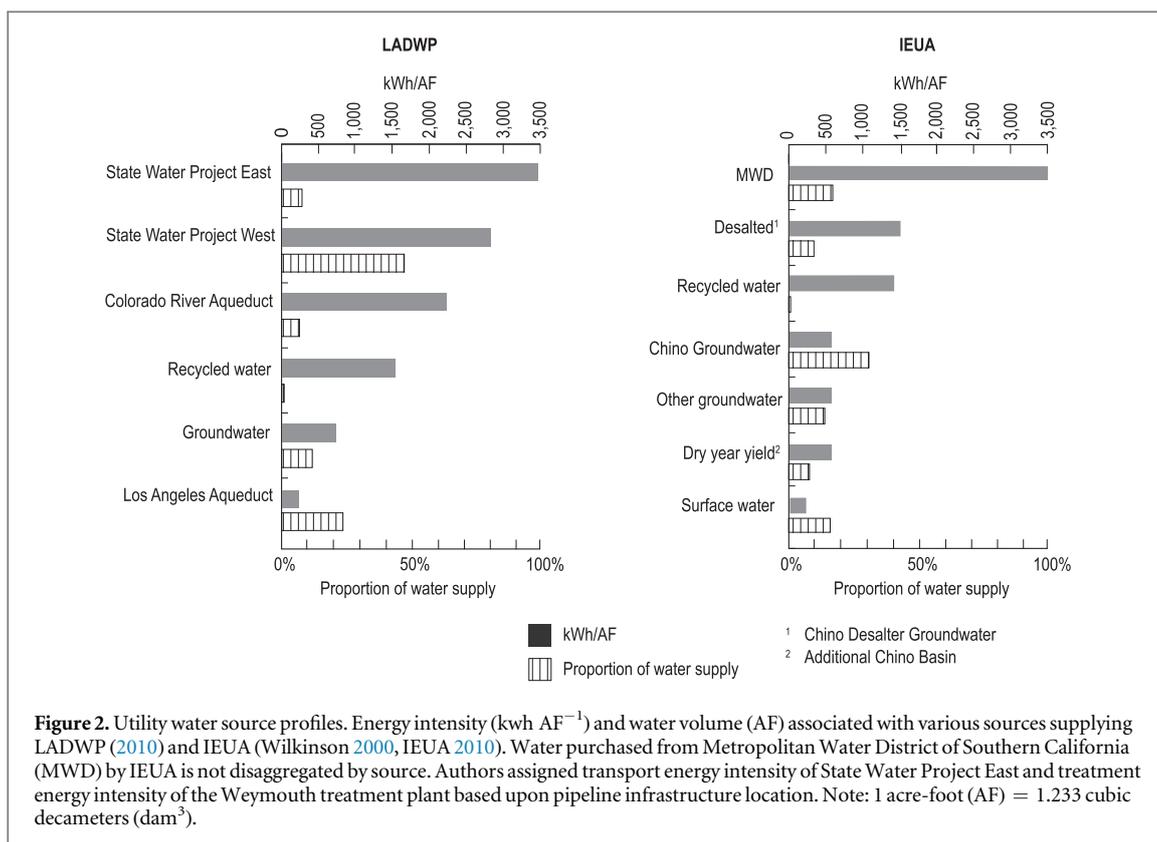
continual challenge. Throughout Southern California, cities are focusing on expanding local water supply sources (e.g. recycled water, groundwater recharge, desalination, stormwater capture). But the energy and emissions intensity of increasing these local supply sources remain uncertain. How, for example, does the carbon footprint of local sources compare to imported ones?

The objective of this study, therefore, is to quantify and compare the energy and emissions footprint of water supply sources for Southern California. Specifically, we focus on two urban utilities: (1) The Los Angeles Department of Water and Power (LADWP), which supplies four million residents in the City of Los Angeles; and (2) The Inland Empire Utilities Agency (IEUA), which serves approximately 850 000 residents in southwest San Bernardino County.

LADWP relies heavily on imported water provided by the Metropolitan Water District (MWD), which administers supplies from the State Water Project (SWP) and the Colorado River Aqueduct (CRA) (figure 1). LADWP's 'local' supply sources include the Los Angeles Aqueduct (LAA), groundwater, and recycled water. IEUA also imports water from MWD but

relies more heavily on local sources, namely recycled water, surface water, desalted groundwater, and untreated groundwater (figure 1). In addition, the energy grid mix of these utilities is significantly different. LADWP, for example, relies much more heavily on coal than does IEUA. It is for this reason that groundwater and recycled water have similar energy intensities between the two utilities, but IEUA has a lower emissions intensity. This is a result of IEUA self-generating more electricity and procuring more energy from a utility, Southern California Edison (SCE), with a cleaner generation portfolio than LADWP.

The traditional approach to quantifying the energy and emissions footprint of products and processes uses life cycle assessment (LCA), environmental input–output analysis, or some combination of the two (Lifset and Graedel 2002). LCA approaches typically use life cycle inventories based on activity data and emissions factors that utilize global, regional, or national averages. This practice tends to render LCAs aspatial as areal differentiation is minimized for the purposes of expedience and simplicity (Curran 2006, Newell and Vos 2011, Cousins and Newell 2015).



Typically, studies of California water utilities utilize eGRID—an Environmental Protection Agency database that provides generalized emissions factors for electric power plants generating in the United States. These factors are calculated by averaging energy and emissions profiles of plants across the CAMX sub-region, which encompasses California, and parts of Nevada, Arizona, and Mexico. eGRID emissions factors were used, for example, in studies the LADWP and IEUA conducted (or commissioned) of the energy and emissions footprints for portions of their water distribution systems (IEUA 2009, LADWP 2010).

Previous studies (Filion et al 2004, Stokes and Horvath 2011, Sanders and Webber 2012, Mo et al 2014) have relied on such regionalized average (e.g. eGRID) emission factors to calculate carbon footprints of water supplies in the US. While the argument for using these regional emission factors is that water utilities in California increasingly rely on localized water supply sources and are self-generating more electricity; making site-specific emission factors more consequential. Additionally, given the interconnectedness of water supplies and hydroelectric power generation in California, it is important to capture the nuance of this relationship in terms of who supplies power to this massive infrastructure system. As utilities transition towards localized sources of water, they will need to understand both where their emissions and electrons are coming from.

In addition to omitting this important spatial variation in terms of energy grid mix, the eGRID approach (hereafter ‘statewide average approach’) often only includes combustion emissions occurring at the power plant, excluding upstream emissions associated with the production of energy, such as coal, hydropower, solar, and wind. As a consequence many renewable resources become ‘carbon neutral’ and the carbon footprint of other sources is reduced. For example, water supply infrastructures, such as the LAA, that are gravity fed and use hydropower are considered carbon neutral. But upstream emissions can be significant for infrastructure sectors, such as transportation (Chester and Horvath 2009).

To capture both local variation and upstream emissions, we developed a spatially explicit approach that combines LCA with a Geographic Information System (GIS) to quantify the respective carbon footprints of the two utilities: LADWP and IEUA. We then compared our approach with the traditional statewide average (e.g. eGRID) approach. The results reveal that downscaling to the utility-scale to develop spatially explicit emissions factors can lower the emissions intensity by 20% or increase it as much as 40% depending on the water source. Again depending on the water source, including upstream emissions can increase the carbon intensity by up to 30%. This has important policy implications in terms of developing strategies for reducing carbon intensity based upon the differences in the utilities’ energy procurement practices and for fostering low carbon transitions. As

**Table 1.** Electricity and water source for water treatment plants. Distribution of water sources to treatment plants is based upon analysis of piping infrastructure locations and plant capacities (LADWP 2010). Electricity supplier for each plant is based upon its geographic location.

Water treatment plant	Electricity supplier	Water sources					
		CRA	LAA	SWP (East)	SWP (West)	Greywater	Groundwater
<b>LADWP</b>							
Robert A. Skinner	SCE	45%		55%			
Joseph Jensen	LADWP				100%		
F.E. Weymouth	SCE	45%		55%			
Robert B. Diemer	SCE	45%		55%			
Henry J. Mills	CoR			100%			
LAAFP <sup>a</sup>	LADWP		95%			5%	
Recycled water <sup>b</sup>	LADWP					100%	
<b>IEUA</b>							
RP-1	SCE					100%	
CCWRF	SCE					100%	
RP-4	SCE					100%	
RP-5	SCE					100%	
Chino desalter	SCE						100%

Note: IEUA only treats recycled and desalted water. Groundwater, surface water, and MWD water are either untreated or treated prior to delivery to IEUA.

<sup>a</sup> Los Angeles Aqueduct Filtration Plant (LAAFP).

<sup>b</sup> Water reclaimed after delivery, use, and waste treatment.

utilities increase their reliance on localized water sources, a spatially explicit approach provides improved measures to manage the carbon intensity of water supply by capturing the differences.

## 2. Methods

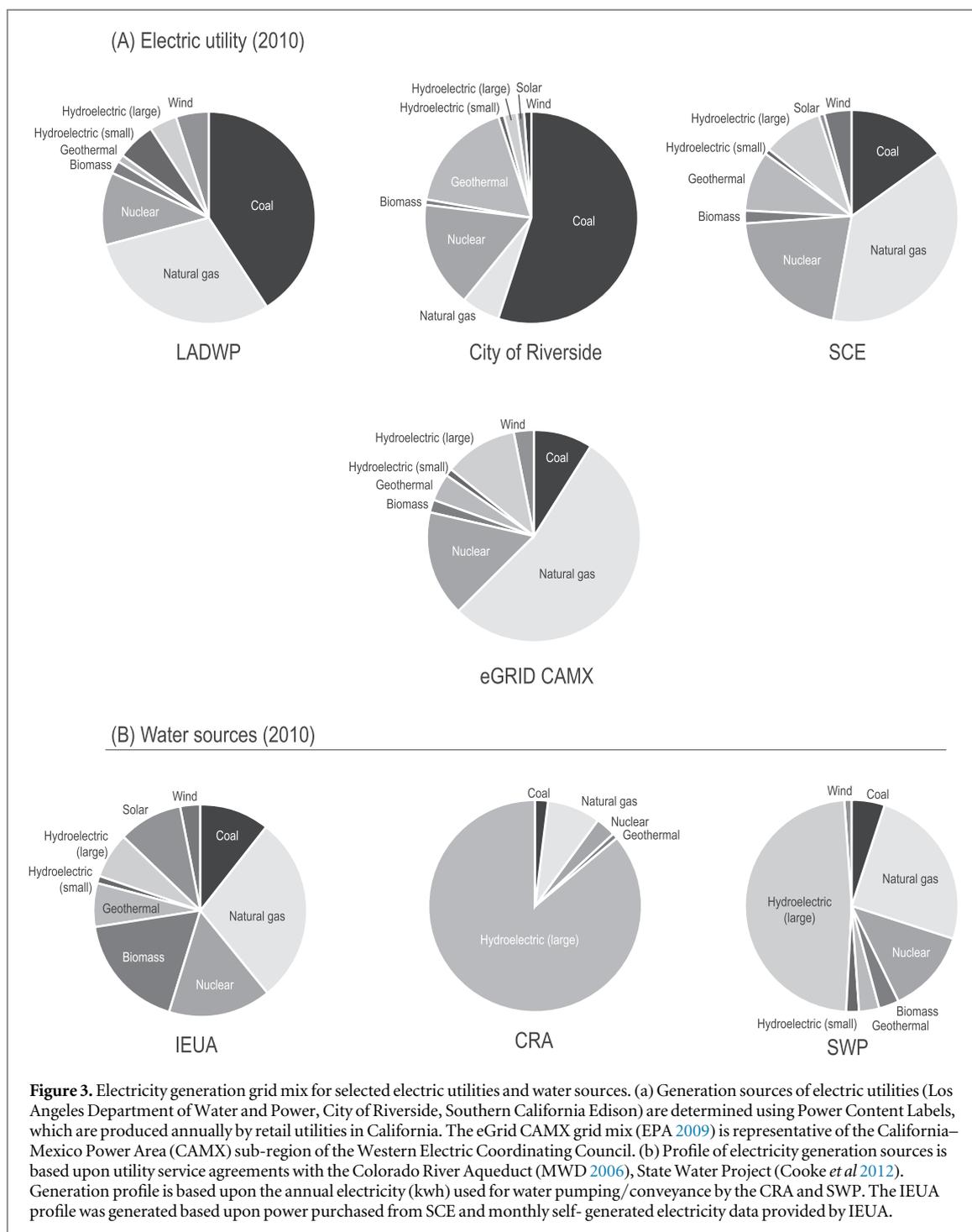
This study uses a spatially explicit LCA approach to measure the energy and emissions intensity of the water supply infrastructure for two Southern California utilities (LADWP and IEUA). This approach enables one to assess the importance of localized, regionally-specific emissions factors when quantifying the carbon footprinting of utilities and associated grid mixes. The system boundary of the study is limited to the delivery phases of the water–energy nexus most likely to show geographic variation: sourcing and conveying, treatment, and distribution to consumers (figure 1). This builds on work by Wilkinson (2000, 2007) who found that differences across water sources stem primarily from the varying pumping, treatment, and distribution processes required. Additionally, the energy and emissions related to the construction and maintenance of water infrastructure are generally overshadowed by the operation of the infrastructure (Stokes and Horvath 2006, 2009). The use and disposal phases, in-home energy usage for heating and cooling water were excluded. Due to data constraints, temporal variation was also excluded. Ideally, time-of-day could be used to determine electricity generation sources using location marginal pricing (Rogers *et al* 2013). Instead, the average annual

consumption and generation was used to calculate emissions. This approach, utilized by Weber *et al* (2010), both eliminates seasonal variation and isolates the geographic distinctions between water and electricity sources.

One acre-foot (AF) of water represents the functional unit and the emissions burden was measured in grams of CO<sub>2</sub>e generated per acre foot (gCO<sub>2</sub>e/AF). The activity data, such as the volume of water by source (AF), energy intensity (KWh AF<sup>-1</sup>), utility grid mix, water pumping, recycling, and treatment plant efficiency came primarily from the utilities' Urban Water Management Plans (IEUA 2009, LADWP 2010). Determining emissions factors for both the utility emissions and the upstream emissions of the energy sources consisted of three primary steps:

### 2.1. Assign specific utility for pumping and transport, treatment, and distribution phases

In GIS, we mapped the water supply infrastructure of LADWP and IEUA. Data that were not publicly available were obtained through correspondence with LADWP, MWD, and IEUA. Agency publications (MWD 2009, CDWR 2011) provided pumping plant locations that were geocoded by cross-referencing the estimated X, Y coordinates in Google Maps. Each of these plants was then assigned to a geographically-defined Electricity Utility Service Area (EUSA) as specified in the California Energy Almanac (CEC 2015). Groundwater and recycled water sources remain within the LADWP service area and were designated emissions burdens accordingly. IEUA and



LADWP provided data to match the utilities with the proper treatment plants (table 1). We assume potable water, after leaving the treatment plant, is distributed uniformly throughout the city, regardless of the source, requiring consistent energy inputs for all water sources of  $196 \text{ kWh AF}^{-1}$  ( $159 \text{ kWh dam}^{-3}$ ) from LADWP and  $220 \text{ kWh AF}^{-1}$  ( $178 \text{ kWh dam}^{-3}$ ) from IEUA.

## 2.2. Determine grid mix for each utility and emissions factors for energy sources

State-mandated power content labels provided the grid mix for each utility and their corresponding

emissions factors (figure 3). The direct and ‘upstream’ emissions associated with the various energy sources were calculated by averaging the results of studies obtained through a review of the literature (EPA 2009, Blanco *et al* 2012). To select these studies, three criteria were used: (1) must be geographically appropriate to the California region; (2) must consist of cradle-to-grave analysis covering emissions associated with construction, on-site assembly, production, transport, waste and disposal; and (3) must reflect similar output capacities and facility life expectancies to those facilities currently supplying or projected to supply the utilities with power.

**Table 2.** Upstream emissions of electricity generation sources. Estimated eGRID emissions are based upon a weighted average by net generation (MWh) of the plants located in the CAMX subregion. Upstream emissions ranges are based upon a literature review (Blanco *et al* 2012); the mean is used to calculate the difference between upstream and eGRID reported emissions factors. All values are in units of gCO<sub>2</sub>e/kWh.

Source	eGRID CAMX	Upstream emissions range	Upstream emissions average	Net difference
Coal	897	960–1050	1005	108
Natural gas	392	469–518	490	98
Biomass	76	15–52	31	-45
Geothermal	36	15	15	-21
Nuclear	0	15–52	20	20
Hydroelectric (small)	0	11	11	11
Hydroelectric (large)	0	128–380	240	240
Wind	0	2–29	14	14
Solar	0	21–71	50	50

Including upstream emissions is in contrast to eGRID, which only includes combustion emissions (i.e. those occurring at the plant). Emissions factors for eGRID (CAMX) were calculated as the weighted average of the power plants in the database based on annual electric output (MWh). Including upstream emissions results in higher emissions footprints for the energy sources, with the exception of biomass and geothermal, which are likely skewed due to a low number of generators reported for the CAMX region. For renewable sources, the effect is more nuanced because eGRID assumes these sources have zero emissions (no emissions from combustion). The primary difference is the additional +240 gCO<sub>2</sub>e/kWh attributed to large hydropower generation sources (table 2).

A Monte Carlo Simulation measured the sensitivity of the carbon footprint of each water source to the range of upstream emissions factors shown in table 2. Assuming a normal distribution over the range of values for each generation source (e.g. coal, natural gas, solar, wind, hydro), 1000 random trials were run to determine the minimum and maximum range of the carbon footprints. All local sources of water vary between  $\pm 1\%$ , while SWP varies between  $\pm 5\%$ . CRA varies the most at  $\pm 10\%$ . The larger variation in SWP and CRA water is due to a greater reliance on hydropower, which has the largest range of estimated emissions. Overall, the sensitivity analysis reveals that although there is uncertainty in the upstream emissions factors of each power plant, the carbon footprint of the water sources will not be significantly affected. Thus, the increase in emissions for each water source in figure 6 cannot be explained solely by the uncertainty in the upstream electricity emissions factors (table 2) and using an average, rather than plant-specific emissions factor will not disproportionately skew the results.

### 2.3. Calculate the energy and emissions footprint for the three life-cycle phases

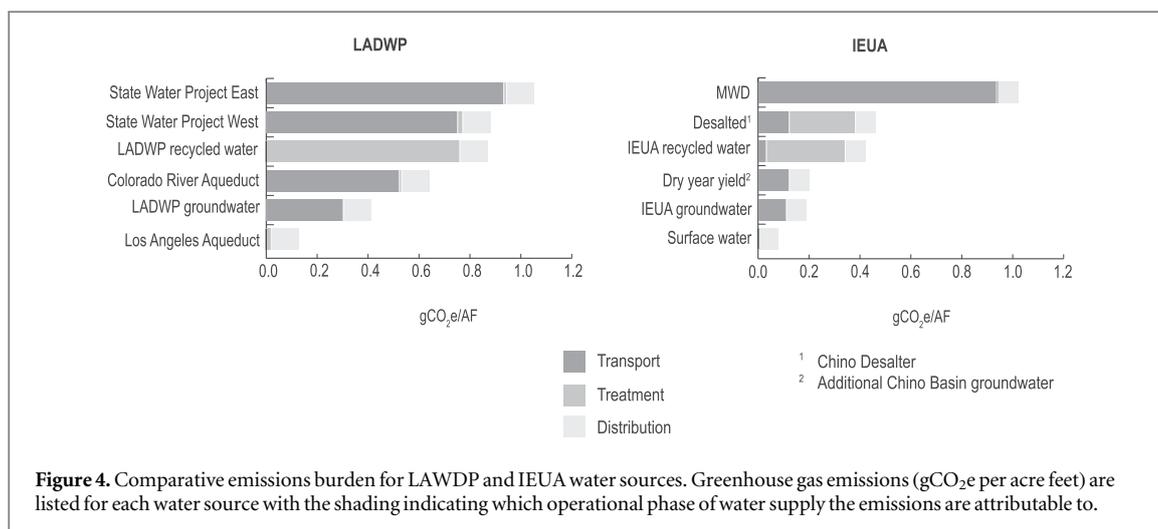
The activity data and the emissions factors were multiplied for all three phases. Emissions profiles for each pumping and treatment plant were generated

based upon the distribution of net electricity consumption that could be attributed to each EUSA. In addition to adjusting the emissions factors of the electricity, also adjusted was the distribution of electricity generation sources attributed to water conveyance. This change directly altered SWP and CRA emissions; previously the eGrid CAMX emissions factor had been used to approximate their emissions intensity. Power generation associated with the CRA and SWP conveyance systems required a calculation of self-generated electricity. Long-term power agreements with Pacific Gas & Electric (PG&E) and SCE support the electricity demanded by the pumping plants. This allows the operators of the SWP and CRA to sell their hydropower during peak demand times and buy electricity from the grid at cheaper off-peak rates.

In figure 3(b), the portfolio of electricity generation sources is aggregated for the CRA and SWP. The use of hydropower in the conveyance systems for pumping water was added to purchased electricity from the EUSA in order to determine an overall emissions factor for each conveyance system. For example, the SWP generates approximately 38% (2189 GWh yr<sup>-1</sup>) of its electricity from large hydropower projects (Cooke *et al* 2012), while CRA receives approximately 80% (1517 GWh yr<sup>-1</sup>) from dams along the Colorado River (MWD 2006). Using annual average electricity purchase data for each pumping plant (Cooke *et al* 2012), we estimated the electricity purchased by the SWP from PG&E (3183 GWh yr<sup>-1</sup>) and SCE (349 GWh yr<sup>-1</sup>). Based upon the proportion of self-generated and purchased electricity by the SWP, a weighted average of electricity generation sources (figure 3(b)) is calculated using 2010 Power Content Labels of SCE (SCE 2010) and PG&E (PG&E 2010).

## 3. Results

The conveyance of water constitutes the largest component of LADWP's and IEUA's water supply



carbon footprint, followed by treatment and distribution (figure 4). The result is due to their reliance on imported water from the MWD, which is pumped over great distances to Southern California. For supplies typically transported over short distances, such as recycled water and desalted groundwater, the treatment phase comprises the largest portion of the footprint. In order to ensure sufficient quality for non-potable use, recycled water treatment for the two utilities includes, aeration, microfiltration, and disinfection.

For LADWP, the most energy and emissions intensive water comes from the SWP (West and East Branch), followed by local recycled water (figure 4). This is an interesting finding as SWP-West and recycled water have carbon footprints of 0.88 gCO<sub>2</sub>e/AF (0.71 gCO<sub>2</sub>e/dam<sup>3</sup>) and 0.87 gCO<sub>2</sub>e/AF (0.71 gCO<sub>2</sub>e/dam<sup>3</sup>) respectively, countering the assumption that local sources necessarily have a lower carbon footprint. LADWP's emissions intensity for both recycled water and groundwater is approximately twice that of IEUA's, due to the latter's greater use of electricity from hydropower, solar and biomass sources (figure 2). The third most emissions intensive source for LADWP is water from the CRA. Although more energy intensive than recycled water, the CRA mainly uses electricity generated from hydropower, which reduces its emissions footprint. The least intensive water source, both in terms of energy and emissions, is water from the LAA, which is gravity fed and therefore requires no net energy to transport the water.

For IEUA, water from the SWP and the CRA is the most energy and emissions intensive (figure 2). In contrast to LADWP, local sources have a smaller footprint because of the cleaner grid mix. However, in the case of IEUA the desalted water has a higher footprint than recycled water (figure 4). This is because the treatment phase is highly energy intensive due to the reverse osmosis and ion exchange used to remove nitrates and total dissolved solids. Surface water requires a

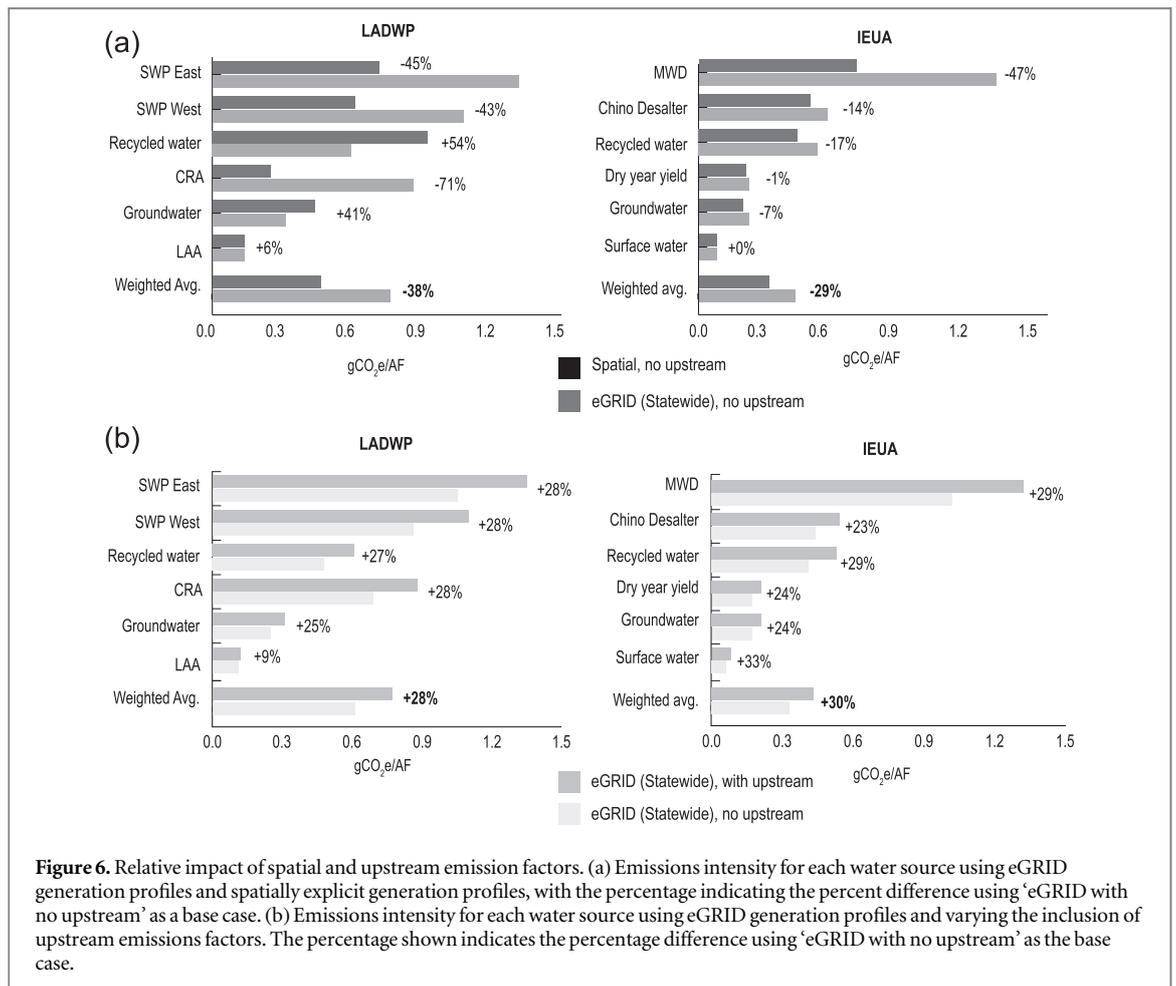
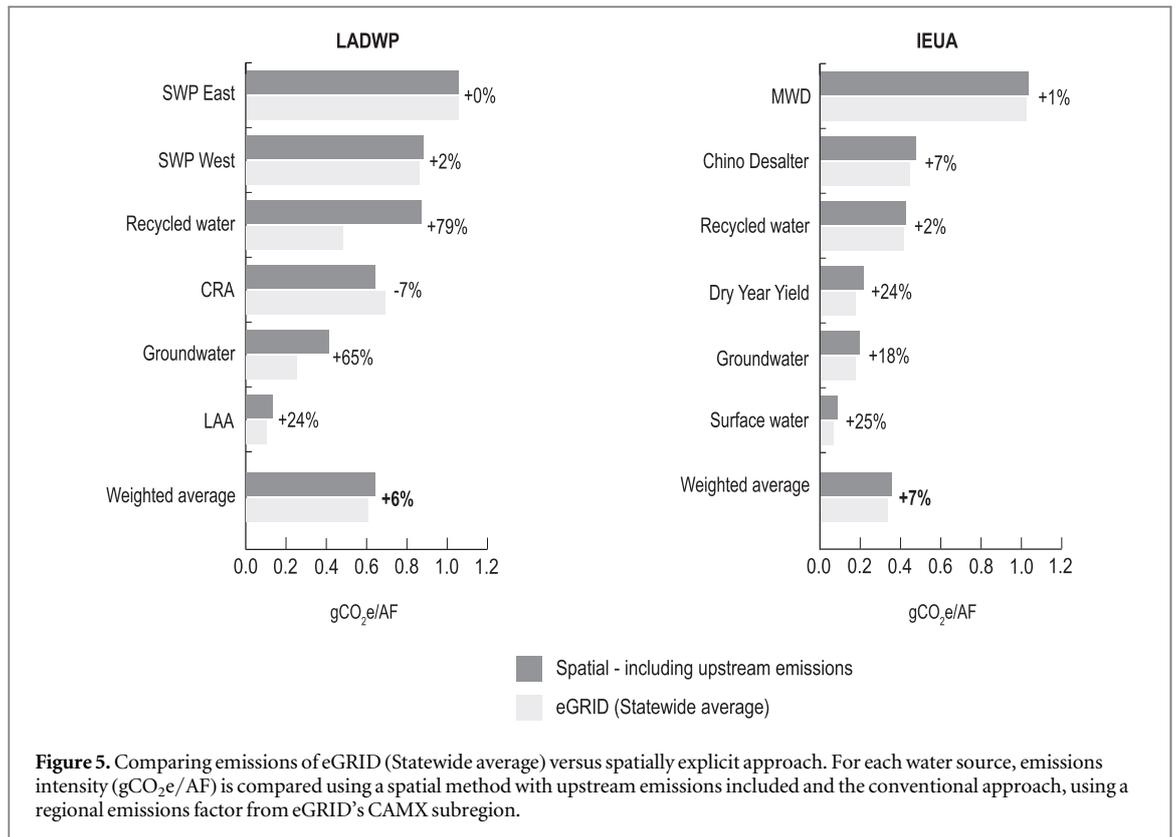
relatively small amount of energy for transport and treatment, with emissions largely in the distribution phase.

### 3.1. Spatial-upstream versus statewide average (e.g eGRID) approach

The fact that the carbon footprint of LADWP's local recycled water is higher than that sourced from the Colorado River was made evident by the spatial-upstream approach used in this study. With respect to broadly comparing the spatial-upstream approach with the statewide average approach, the former resulted in higher emissions profiles for the water supplies of the two utilities (figure 5). Specifically, the spatial-upstream approach resulted in an increase in the weighted average of the emissions intensity (gCO<sub>2</sub>e/AF) for both LADWP (+6%) and IEUA (+7%). Increases in emissions vary by water source. Emissions intensity for the CRA actually decreased by 7%. Differences in grid mixes can further be seen in the distinctions between IEUA's and LADWP's groundwater and recycled water emission footprints, because embodied energy for the water sources is similar. However, IEUA's groundwater and recycled water increased by 18% and 2% respectively, while LADWP's increased by 65% and 79%.

The overall higher carbon footprints of both utilities are primarily due to the inclusion of upstream emissions. Figure 6 illustrates the impact of upstream emissions. For example, including upstream emissions in the statewide approach resulted in a 28% and 30% weighted average increase for LADWP and IEUA respectively. Sources dominated by transport (MWD, SWP, CRA) have greater absolute differences on a gCO<sub>2</sub>e/AF basis. The MWD carbon intensity increases by 29% and the SWP East and SWP West increase by 28%, but the smallest increase is the LAA at 9%.

In terms of comparing the spatially explicit approach with the statewide approach without including upstream emissions, for both utilities the overall



emissions footprint is significantly lower (figure 6). LADWP's average emissions intensity decreases by 38% due to its heavy reliance on the SWP and CRA, where over 50% of its water supply is sourced. Emissions intensity of the SWP water falls by 40% and the CRA emissions falls by 70% as the eGRID CAMX emissions profile effectively underrepresents the proportion of electricity generated by hydropower used to transport the water. However, this is not the case for local sources of water (LAA, groundwater, recycled water) which shows increases in emissions intensity due to reliance on LADWP's relatively dirty electricity generation mix. This has important implications as the City of Los Angeles looks to expand efforts to generate more supply through recycled water, stormwater capture, and groundwater replenishment. All IEUA sources of water show a decrease in emissions intensity using a spatialized emissions factor, resulting in a 29% decrease in the weighted average (figure 6).

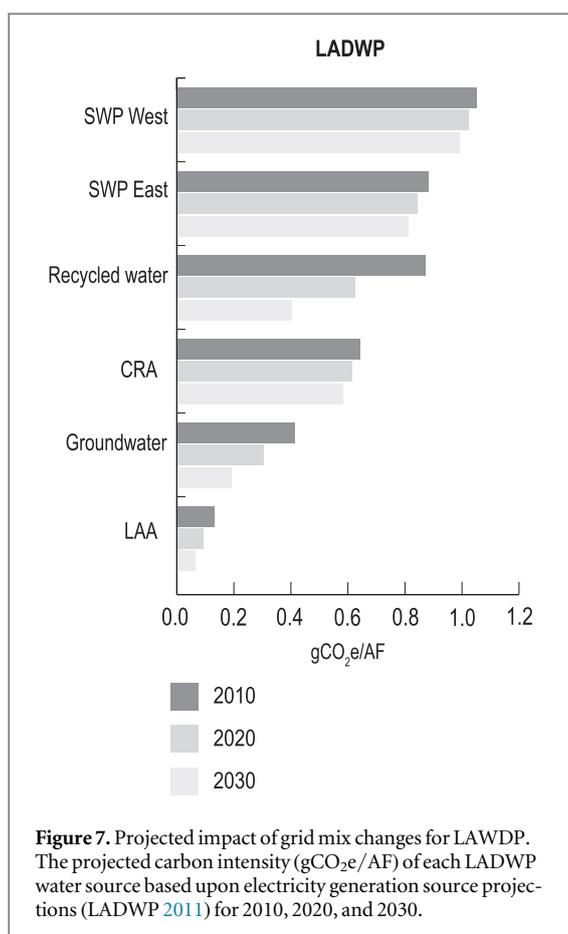
#### 4. Discussion

In addition to providing a detailed account of the energy and emissions footprint of two major water utilities in Southern California, this study exposes two important considerations when making such estimates. First, using spatially explicit emissions factors rather than regionalized averages provides a more accurate accounting of emissions intensity associated with sourcing, conveying, and treating water. As such the results call into question the validity of relying on eGRID emissions factors (e.g. regionalized averages) to estimate the carbon footprint of localized water supply, which has been the predominant approach (Filion *et al* 2004, Stokes and Horvath 2011, Sanders and Webber 2012, Mo *et al* 2014) to calculating carbon footprints of water supplies in the US. For relatively independent grids, where little electricity trading occurs; this approach is valid (Weber *et al* 2010). But using a regional emissions factor omits important variations in state and site-specific electricity generation, as Marriott and Matthews (2005) and Colett *et al* (2015) have shown. For water supplies in the Western United States, if the energy or carbon intensity is concentrated in the treatment stage, typical of localized water sources, then a spatially explicit emissions factor is especially important.

Second, the results demonstrate the importance of including upstream emissions for the various electricity generation sources. This study has revealed that the carbon footprint of water supply increases by 20%–30% (figure 6) depending on the portfolio of electricity it relies on. This has important implications not only for local entities like water utilities, but also for the calculation of GHG emissions at the state, regional, and federal levels.

Uncertainty in future supply, coupled with environmental mitigation in the Sacramento-San Joaquin Delta, Owens Valley, and Mono Lake basin, is driving the development of new sources to maintain a reliable water supply. To meet demand and account for shortfalls caused by drought and climate change, strategies in Southern California are increasingly focused on expanding local supply options such as large-scale desalination, recycled water, stormwater and groundwater projects (Hughes *et al* 2013). As our study has demonstrated however, for Los Angeles in particular, these local supply sources (e.g. recycled water) can have a higher carbon footprint than imported sources, such as water from CRA and especially the LAA, which is gravity fed. As a consequence, this may compound the water–energy nexus and produce an ironic situation where those sources advocated to mitigate the effects of climate change may actually exacerbate them (Cousins and Newell 2015).

The environmental sustainability of local water supply (in terms of carbon footprint), therefore, hinges on the electricity grid mix used to treat and distribute water. To gain a sense of just how influential the local grid mix is consider the example of LADWP and its proposed transition away from coal and towards a cleaner grid mix. Using LADWP's forecasted generation sources for 2020 and 2030 (LADWP 2011) and Integrated Resource Plans from relevant utilities, we calculated future GHG emissions to understand how LADWP's energy transition impacts the carbon footprint of its water supply system (figure 7). In this scenario, LADWP decreases its coal generation from 40% in 2010 to 28% in 2020 and to 0% in 2030. Meanwhile, the percentage of renewable generation increases from 18% (2010) to 40% (2030) and the percentage of natural gas increases from 30% (2010) to 50% (2030). Under this scenario, the reduction in carbon intensity of local water sources (LAA, groundwater, recycled) is especially pronounced (54%). Imported water, by comparison, is reduced just by 6%, 8%, and 10% for the SWP East, SWP West, and CRA, respectively. LADWP could follow IEUA, which was able to mitigate the emissions associated with recycled water and groundwater by self-generating more of the electricity needed to power its local water treatment plants. Of course, in addition to the grid mix, the energy intensity of the technology has to be considered as well. This is especially the case with desalination, which is highly energy intensive and even with a relatively clean energy grid, would have a considerable carbon footprint. Other considerations also include the extent to which efficiency improvements throughout the various phases of water pumping and transport, treatment, and distribution may yield greater overall emissions reductions as result of economies of scale.



## 5. Conclusion

Faced with unprecedented drought and climate change vulnerabilities, water utilities across California and the American Southwest are focused on increasing local sources of water supply. But as this study has shown local sources can have a higher carbon footprint than imported sources, at least with respect to the transport, distribution and treatment phases. The energy grid mix of the electricity that is used in these three phases is crucial with respect to assessing the carbon footprint of local versus imported water supply. This was made apparent by the spatially explicit approach utilized to determine the energy and emissions intensity of water supply for two utilities supplying Southern California: LADWP and IEUA. Comparing these two utilities revealed that the relatively dirty grid mix that LADWP relies on leads to much higher carbon footprints for local water sources than for IEUA. As utilities in California work to meet new state mandated emissions standards the spatially explicit measurement of emissions provides a more robust method than conventional eGRID emissions factors which do not sufficiently take into account geographic variability.

This study also clarified how upstream emissions for all types of energy sources is significant and needs to be considered as entities from local to federal scales

estimate the GHGs associated with their resource consumption. In the case of the two utilities we studied, the carbon footprint was 20%–30% higher when upstream emissions were included, in addition to combustion emissions.

Moving forward, utilities such as LADWP have an opportunity to greatly influence the emissions of their local sources of water supply. This was clearly illustrated in the case of LADWP's transitioning away from coal-based electricity towards more renewable sources. But this sustainability transition can only be captured using the spatially explicit/upstream modeling approach that we have introduced in this paper. This approach has implications not only for water and electric utilities but also for local entities of all kinds as they consider how best to transition to a lower carbon future.

Finally, it would be useful to extend this analysis to consider how green water (i.e. utilized precipitation and/or soil moisture) and greywater (i.e. wastewater previously used by residential/commercial end users) resources could be further utilized to help meet water demand. This study considered all water supplied to be blue (i.e. potable water), while acknowledging that recycled water is currently not utilized for direct potable water reuse. These types of water will become increasingly important for places that are seeking to diversify water sources in order to enhance resilience, such as California and the American West.

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## References

- Blanco H, Newell J P, Stott L and Alberti M 2012 *Water Supply Scarcity in Southern California: Assessing Water District Level Strategies* (Los Angeles, CA: Center for Sustainable Cities, Price School of Public Policy, University of Southern California)
- CDWR 2011 *California State Water Project at a Glance* (Sacramento, CA: California Department of Water Resources) (<http://water.ca.gov/recreation/brochures/swp.cfm>)
- CEC 2015 *California Electric Utility Service Areas Map* (Sacramento, CA: California Energy Commission) ([http://energy.ca.gov/maps/serviceareas/Electric\\_Utility\\_Service\\_Areas.html](http://energy.ca.gov/maps/serviceareas/Electric_Utility_Service_Areas.html))
- Chester M V and Horvath A 2009 Environmental assessment of passenger transportation should include infrastructure and supply chains *Environ. Res. Lett.* **4** 024008
- Colett J S, Kelly J C and Keoleian G A 2015 Using nested average electricity allocation protocols to characterize electrical grids in life cycle assessment: a case study of US primary aluminum production *J. Ind. Ecol.* at press (doi:10.1111/jiec.12268)
- Cooke R, Jercich S, Trombly C and Villalobos P 2012 *Management of the California State Water Project—Bulletin 132–12*

- pp 185–99 ([www.water.ca.gov/swpao/docs/bulletins/bulletin132/Bulletin132-12.pdf](http://www.water.ca.gov/swpao/docs/bulletins/bulletin132/Bulletin132-12.pdf))
- Cousins J J and Newell J P 2015 A political–industrial ecology of water supply infrastructure for Los Angeles *Geoforum* **58** 38–50
- CPUC 2010 *Embedded Energy in Water Studies, Study 1: Statewide and Regional Water–Energy Relationship* GEI Consultants and Navigant Consulting for the California Public Utilities Commission (31 August 2010)—appendix N
- Curran M A 2006 Report on activity of task force 1 in the life cycle inventory programme: data registry—global life cycle inventory data resources *Int. J. Life Cycle Assess.* **11** 284–9
- EPA 2009 *Clean Energy—eGRID* (Washington DC: US Environmental Protection Agency) (<http://epa.gov/cleanenergy/energy-resources/egrid/index.html>)
- Filion Y R, MacLean H L and Karney B W 2004 Life-cycle energy analysis of a water distribution system *J. Infrastruct. Syst.* **10** 120–30
- Hughes S, Pincetl S and Boone C 2013 Triple exposure: regulatory, climatic, and political drivers of water management changes in the city of Los Angeles *Cities* **32** 51–9
- IEUA 2009 *Annual Water Use Report for IEUA Service Area* (Chino Hills, CA: Inland Empire Utilities Agency) ([http://ieua.org/wp-content/uploads/2014/11/fy09\\_10\\_annualwaterusereport.pdf](http://ieua.org/wp-content/uploads/2014/11/fy09_10_annualwaterusereport.pdf))
- IEUA 2010 *Urban Water Management Plan* (Chino Hills, CA: Inland Empire Utilities Agency) (<http://ieua.org/urban-water-management-plan-2010-june-01-2011/>)
- Klein G, Krebs M, Hall V, O'Brien T and Blevins B B 2005 *California's Water—Energy Relationship* (<http://energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF>)
- LADWP 2010 *Urban Water Management Plan* (Los Angeles: Los Angeles Department of Water and Power) ([http://water.ca.gov/urbanwatermanagement/2010uwmps/Los%20Angeles%20Department%20of%20Water%20and%20Power/LADWP%20UWMP\\_2010\\_LowRes.pdf](http://water.ca.gov/urbanwatermanagement/2010uwmps/Los%20Angeles%20Department%20of%20Water%20and%20Power/LADWP%20UWMP_2010_LowRes.pdf))
- Lifset R and Graedel T E 2002 Industrial ecology: goals and definitions *A Handbook of Industrial Ecology* ed R U Ayres and L W Ayres (Northampton, MA: Edward Elgar) pp 3–15
- Marriott J and Matthews H S 2005 Environmental effects of interstate power trading on electricity consumption mixes *Environ. Sci. Technol.* **39** 8584–90
- Mo W, Wang R and Zimmerman J B 2014 Energy–water nexus analysis of enhanced water supply scenarios: a regional comparison of Tampa bay, Florida, and San Diego, California *Environ. Sci. Technol.* **48** 5883–91
- MWD 2006 *Power Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Operations—2006 Revised* (Los Angeles, CA: Metropolitan Water District of Southern California) (<http://ww2.wapa.gov/sites/western/es/irp/Documents/MetWaterDistIRP.pdf>)
- MWD 2009 *Energy Management and Reliability Study* (Los Angeles, CA: Metropolitan Water District of Southern California) (<http://collab.waterf.org/Workshops/FLwater/WaterEnergy%20Issues%20Library/MWD%20Energy%20Mgmt%20and%20Reliability%20Study.pdf>)
- Newell J P and Vos R O 2011 'Papering' over space and place: product carbon footprint modeling in the global paper industry *Ann. Assoc. Am. Geogr.* **101** 730–41
- LADWP 2011 *Power Integrated Resources Plan* (Los Angeles, CA: Los Angeles Department of Water and Power) ([http://swrcb.ca.gov/water\\_issues/programs/ocean/cwa316/docs/energy\\_comp/irp\\_2012\\_1.pdf](http://swrcb.ca.gov/water_issues/programs/ocean/cwa316/docs/energy_comp/irp_2012_1.pdf))
- PG&E 2010 Power Content Label ([http://energy.ca.gov/sb1305/labels/2010\\_labels/PGE\\_PCL.pdf](http://energy.ca.gov/sb1305/labels/2010_labels/PGE_PCL.pdf))
- Rogers M M, Wang Y, Wang C, McElmurry S P and Miller C J 2013 Evaluation of a rapid LMP-based approach for calculating marginal unit emissions *Appl. Energy* **111** 812–20
- Sanders K T and Webber M E 2012 Evaluating the energy consumed for water use in the United States *Environ. Res. Lett.* **7** 034034
- SCE 2010 Power Content Label ([https://sce.com/wps/wcm/connect/861a514f-a20b-4548-9526-66ce424b3baa/2010\\_SCE\\_PowerContentLabel.pdf?MOD=AJPERES](https://sce.com/wps/wcm/connect/861a514f-a20b-4548-9526-66ce424b3baa/2010_SCE_PowerContentLabel.pdf?MOD=AJPERES))
- Stokes J and Horvath A 2006 Life cycle energy assessment of alternative water supply systems *Int. J. Life Cycle Assess.* **11** 335–43
- Stokes J R and Horvath A 2009 Energy and air emission effects of water supply *Environ. Sci. Technol.* **43** 2680–7
- Stokes J and Horvath A 2011 Life-cycle assessment of urban water provision: tool and case study in California *J. Infrastruct. Syst.* **17** 15–24
- Weber C L, Jaramillo P, Marriott J and Samaras C 2010 Life cycle assessment and grid electricity: what do we know and what can we know? *Environ. Sci. Technol.* **44** 1895–901
- Wilkinson R 2000 *Methodology for Analysis of the Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits through Integrated Water–Energy Efficiency Measures* California Institute for Energy Efficiency
- Wilkinson R 2007 *Analysis of the Energy Intensity of Water Supplies for West Basin Municipal Water District* (Carson, CA: West Basin Municipal Water District) (<http://westbasin.org/files/general-pdfs/Energy-UCSB-energy-study.pdf>)