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ORIGINAL RESEARCH REPORT

Chapter 6. Scaling Up Solutions to State, National and Global Levels

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Scaling-up solutions require learning and adapting lessons between locations and at different scales. To accomplish this, common metrics are vital to building a shared language. For California, this has meant careful financial, cradle-to-grave life-cycle assessment methods leading to carbon accounting in many avenues of government (via the Low Carbon Fuel Standard or the Cap and Trade program). These methods themselves interact, such as the use of carbon accounting for the resources needed to manage water and other key resources; the use of criteria air pollution monitoring to identify environmental injustices; and the use of carbon market revenues to address these inequalities, through investment in best available abatement technologies (BACT) and in job creation in disadvantaged communities anticipated in the emerging clean energy sector.

Creating interdisciplinary partnerships across the UC Campuses and the National Laboratories to innovate science and technology is critical to scalable carbon neutrality solutions. As an example, we can build coordinated research and development programs across UC and California, with strong partnerships with the Federal government to coordinate and "multiply" resources that accelerate development and deployment. These partnerships should be strongly goal-focused, i.e., they are created to solve specific, large problems, to enable quantitatively measurable outcomes within energy generation, efficiency and CO_2 abatement categories. Intersectoral partnerships should be fostered across campuses, laboratories, with state, federal and multi-lateral organizations funding to develop technologies and deploy solutions at scale. Integrated partnerships with industry are required to influence markets, deploy solutions, and create new industries and jobs.

Beyond California, we need to establish consortia with industry and foundations to deploy solutions at the regional, state, national, and international scale to create new industries, new jobs, and further UC and California's leadership position. Significant economic opportunities exist, such as promoting aggressive electric vehicle programs elsewhere in the world, where California-based companies could play a key role on many fronts, via electric vehicles themselves, but also through building-integrated smart meters, inverters, solar and other clean energy generation technologies. All work must include a focus on environmental justice both at home in California and through global partnerships.

Section 1: The Climate Challenge as Opportunity

The University of California and the State of California have for decades been engaged in a process of 'serial innovation' to meet an array of challenges, among them the need to invent and re-invent the energy system to meet changing supply, reliability, cost, and environmental objectives. Many of these ideas have both started as local pilots and scaled to the state, the 7th largest economy on the planet, and many of these innovations have, in turn, scaled to national implementation and to replication and adaptation internationally.

In November 2013, President Janet Napolitano announced the Carbon Neutrality Initiative, which

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commits UC to emitting net zero greenhouse gases from its buildings and vehicle fleet by 2025, something no other major university system has done [1]. The Carbon Neutrality Initiative is both part of a tradition of innovation on the UC campuses, and is a forum to innovate to support and test ideas needed for California to meet its own energy and climate challenges.

The California energy and climate policy landscape is headlined by AB32, the California Global Warming Solutions Act (2007) which calls for emissions to return to their 1990 level by 2020, and the 2006 Executive Order that calls for 80% reductions in emissions by 2050. The suite of innovations intended to meet these targets involves continued innovation sector by sector, as well as the implementation of a carbon cap and trade market (launched in 2014) that will gradually expand to link actions across sectors.

In September 2016 the California Legislature passed SB32 and the associated bill AB197, which extend the state's climate legislation to 2030, and requires 40% reduction in greenhouse gas emissions from the 1990 baseline levels. This legislation extends the states climate commitments as well as the carbon market. SB32 also directs the State Air Resources Board to achieve the state's more stringent greenhouse gas emission reductions in a manner that benefits the state's most disadvantaged communities and is transparent and accountable to the public and the Legislature. The State adopted SB 350 (2015) which codifies new targets for renewable energy and building efficiency for 2030, following Governor Jerry Brown's fourth inaugural address on January 5, 2015, in which he proposed a 50 percent target of California's electricity to come from renewable sources by 2030 (up from a 33 percent goal by 2020), a doubling the energy efficiency of existing buildings, and a reduction of motor vehicle dependency on oil and gas by up to 50 percent. These goals build on and knit together an expanding set of actions, including SB 375, the Sustainable Communities and Climate Protection Act of 2008, and the low-carbon fuel standard (LCFS), which sets life-cycle GHG emissions standards of 10 percent reduction per unit of energy for transportation by 2020 and was adopted into regulation by CARB in 2009.

The interplay of these regulations is based on the track-record that California has achieved in cost effectively meeting needed environmental standards while maintaining economic growth. In fact, since the passage of AB32, California's economic growth and environmental impact have trended strongly in opposite directions (**Figure 1**).

The interplay of existing and currently proposed legislation, behavioral incentives, and markets highlights the holistic nature of the climate, energy, and other resource management ideas implemented at the UC system and state levels. For example, the state has adopted ambitious light-duty vehicle GHG tailpipe standards, and a Zero Emission Vehicle mandate through 2025. These actions direct the

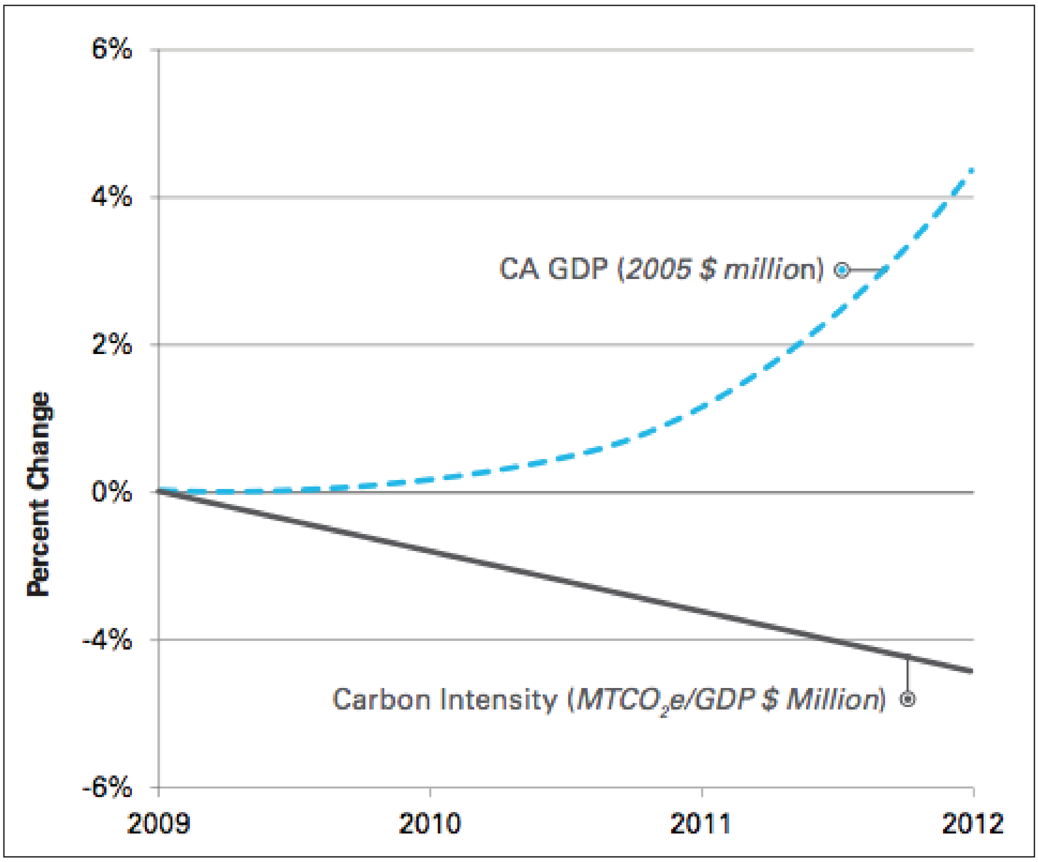


Figure 1: California's economy has grown significantly in the last five years, while the amount of carbon pollution per unit of economic output has declined. Source: Office of the Governor, Cal EPA, ARB (First Update to the Climate Change Scoping Plan, May 2014, Figure ES-1, page ES-3.

scale-up in adoption of both the decarbonization pathway needed for qualifying liquid fuels, and the crossover of clean electricity into the transportation sector (see, e.g. [2]).

In fact, this approach of developing coordinated targets such as the Million Solar Roofs and 1.5 Million Zero Emissions Vehicles targets (2025) mutually reinforce each other, and drive the sort of job creation that will make California more and more competitive globally as these standards diffuse around the world. The dramatic increase in manufacturing in California as evidenced by Tesla Motors and other EV startups, highlights the benefits that come from this systems-level approach to challenging targets for energy efficiency and clean energy commercial deployment opportunities. This policy provides a strong market-based avenue to advancing goals for integrating storage into the California (and regional) energy mix in a way that makes excellent use of commercial trends and opportunities. A key lesson is that with a network of innovative policies, California, and other like-minded states, regions, and the global community can leverage one innovation to scale up another.

Scaling solutions to meet the climate imperative

A number of assessments of the technical feasibility and economic impact of meeting both the AB32 and SB32 goals have been completed and are underway. In the energy system modeling work at UC Berkeley, UC Davis, and elsewhere, researchers found that a *diverse set of pathways are possible that all meet the 2020, 2030, 2040, and 2050 climate goals* [2, 3]. We use the SWITCH model (http://rael.berkeley.edu/project/SWITCH) to investigate decarbonization paths (**Figure 2**). For example, we find that the SunShot and Low-Cost Batteries scenario has the lowest costs of all scenarios investigated The combination of low-cost solar PV and low-cost battery technology, which have a synergetic relationship on a daily timescale, allows the design of a power system that meets aggressive carbon emission reduction targets while greatly containing the cost of decarbonization. Relative to the Reference scenario, costs in the SunShot and Low-Cost Batteries scenario are 25% lower in 2050 and also provide substantial savings in the near- and mid-term [5]. These prices range from $55 tC – $80tC in 2050. For comparison the price of carbon emissions in California in 2015 is $12/tC. Using either the current rate of inflation in the US of 1.4%/year (http://www.usinflationcalculator.com/inflation/current-inflation-rates/), or the current rate of electricity rate increase (2.8%/year) the business as usual price of power increases significantly in California over the coming decades. For comparison the US EPA uses a social cost of carbon (2015) of $33t/C (https://www.epa.gov/climatechange/evaluating-climate-policy-options-costs-and-benefits), which is also expected to rise steadily over the coming decades.

An important synergy between California's climate targets and economic growth is the ability of clean energy scenarios to create jobs and spur economic growth. In

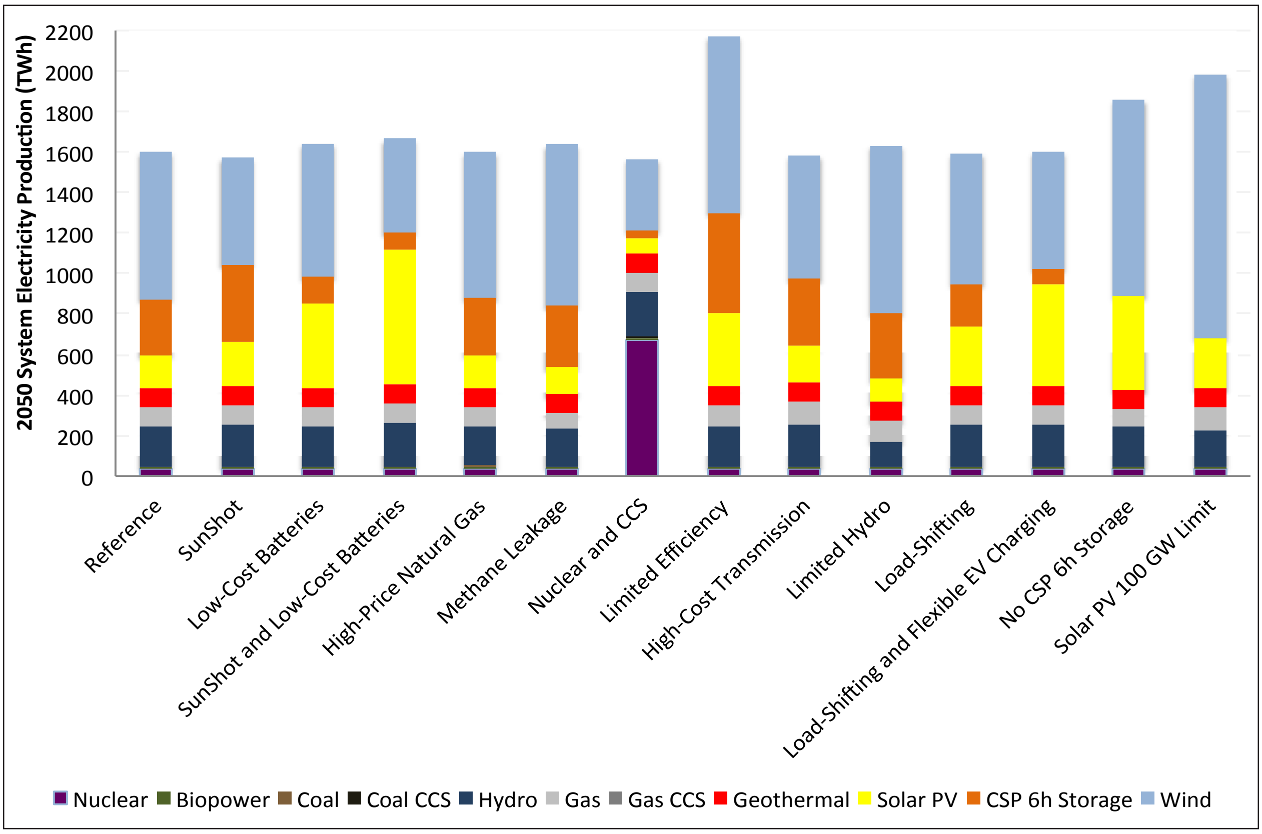


Figure 2: Example energy scenarios for California and Western North America that achieve 80% greenhouse gas emissions reductions in the electricity sector in 2050 generated with the SWITCH power system capacity expansion modeling tool [3, 4].

addition to meeting 2050 climate goals, a positive and synergistic finding is that coordination across the energy, transportation, building, agricultural, and other sectors is vital to achieve decarbonization goals in an economically efficient fashion. In fact the job creation in the form of direct employment but also, critically, in wealth creation through new innovative companies is a true, lasting, and global benefit of the process that AB32 started and SB32 would continue [6, 7].

Extension to include transportation

A number of energy sector models exist for California (for a side-by-side comparison, see [8]). Expanding the modeling framework to examine transportation options in detail has been conducted by a number of groups (see e.g., [5, 9, 10]). One such effort uses the CA-TIMES modeling framework developed at UC Davis. This tool has proven useful in assessing the suite of least-cost mitigation options that will be needed to meet California's long-term 80% greenhouse gas emission reduction goal. The model fills an important research gap in the literature by combining a detailed technology and cost database with an energy systems optimization tool.

A number of important mitigation strategies can be brought to bear to reduce energy sector emissions. Because of the inertia in energy system infrastructure and investments, however, rapid introduction and expansion of these technologies (e.g., low-carbon fuels and electricity conversion facilities; carbon capture and sequestration; advanced and highly-efficient end-use technologies, particularly in transport; and electrification of end-use appliances) needs to take place over the coming decade.

These results show that along with significant improvements in efficiency in each of the end-use sectors and travel demand reductions in the transportation sector, meeting the 80% reduction goal will likely require complete decarbonization of the electric sector. However, significant hurdles still remain for low-carbon electricity generation. For instance, the future development of renewable technologies and resources will need to address issues related to resource location, transmission and intermittency. Similar to the SWITCH model findings shown in **Figure 2** this effort find that while nuclear power and fossil and/or biomass CCS appear to be critical options for low-carbon baseload generation, CCS has several technical issues that still need to be worked out, not to mention that both nuclear and CCS possess real and perceived issues with respect to safety and risk [11].

The transportation sector emits close to half of California's GHG emissions at present and is the most costly and challenging sector to reduce emissions from. The study using CA-TMES finds that meeting California's 80% emission reduction goal can be achieved through a combination of mitigation strategies, including managing the growth in energy service demand, increasing investments in efficiency and low-carbon energy supply technologies, and promoting demand technologies that facilitate end-use device electrification and a decrease in the direct use of hydrocarbon fuels through efficiency improvement and fuel switching. Current strategies include the intelligent integration of the EVs with the grid to optimize the charging patterns as a tool for demand and supply response. In such deep emission reduction scenarios, the authors estimate that energy system costs (accounting for investments on the energy supply side and in transportation demand technologies, as well as fuel and O&M costs) could be around 8–17% higher than in a reference case. Average abatement costs could reach \$225/tCO2, but could be reduced significantly with a sustained focus on integrating abatement and mitigation policies. These estimates are very much dependent on a range of socio-political and technological uncertainties, for instance, the availability and cost of biomass, nuclear power, carbon capture and storage, and electric and hydrogen vehicles.

The climate dimensions of the water-energy nexus in California

In California water and electrical power are closely linked. Nearly 20 percent of the state's electricity is used to move, treat and heat water [12]: the best known examples of power for moving water being the State Water Project, Central Valley Project, and Colorado River Aqueduct [13]. Despite this interdependence, these resources are regulated by separate agencies and delivered by separate utilities. As a first step to enabling planning perspective, an integrated climate accounting metric, such as carbon emissions, is needed.

With California's current drought now in its fifth year and other parts of our nation plagued by water stress caused by population growth and competition over diminishing supplies, utilities and policymakers are recognizing the urgency of resource plans that manage water and electricity in an integrated manner. This is especially critical in light of the carbon footprint of many power generating sources, and the impact of climate change on water use.

California has taken a number of actions to reduce the amount of water used in power generation, and to decrease reliance on carbon-based energy sources – making it a recognized national leader. Power plant developers must consider dry cooling – using air, rather than water, to cool steam used in generators. The state also has a renewable portfolio standard to generate 33% of electricity through renewable energy sources by 2020, as well as a low-carbon fuel standard [14]. Moreover, between 1996 and 2004, 22 percent of all new electrical generating capacity in the state uses reclaimed wastewater, while over half of newly planned electric capacity is slated to use reclaimed water [15].

Integrated management requires concerted dialogue between the electricity and water sectors – and it needs to incorporate state and regional officials involved in regulating these industries, and with academics who study these issues and who try to apprehend, predict, and resolve barriers to collaboration.

On the supply side, it would be immensely valuable to create a program that is strongly focused on bringing down the energy consumption and thus the cost of desalinating water. This would be very similar to the

Department of Energy's "Sunshot Initiative" that is focused on bringing the cost of Solar Electricity down to Grid parity (~5c/kWh). This program that started in 2011, required an ~ 5X reduction in the installed cost of solar electricity. Indeed, a similar 5X reduction in the cost of desalinated water will dramatically change the supply-demand landscape for water.

Water and energy links are basic to civilization. Ancient Rome and China harnessed waterpower to saw wood, grind grain, and provide locomotion. Today, most forms of electricity production depend on reliable water supplies for cooling and direct power generation (e.g., hydro), or steam generation (fossil- and nuclear plants). Even the manufacture of solar panels can affect *water quality* if care is not taken in transforming metallurgical grade quartz into photovoltaic panels, for example [16].

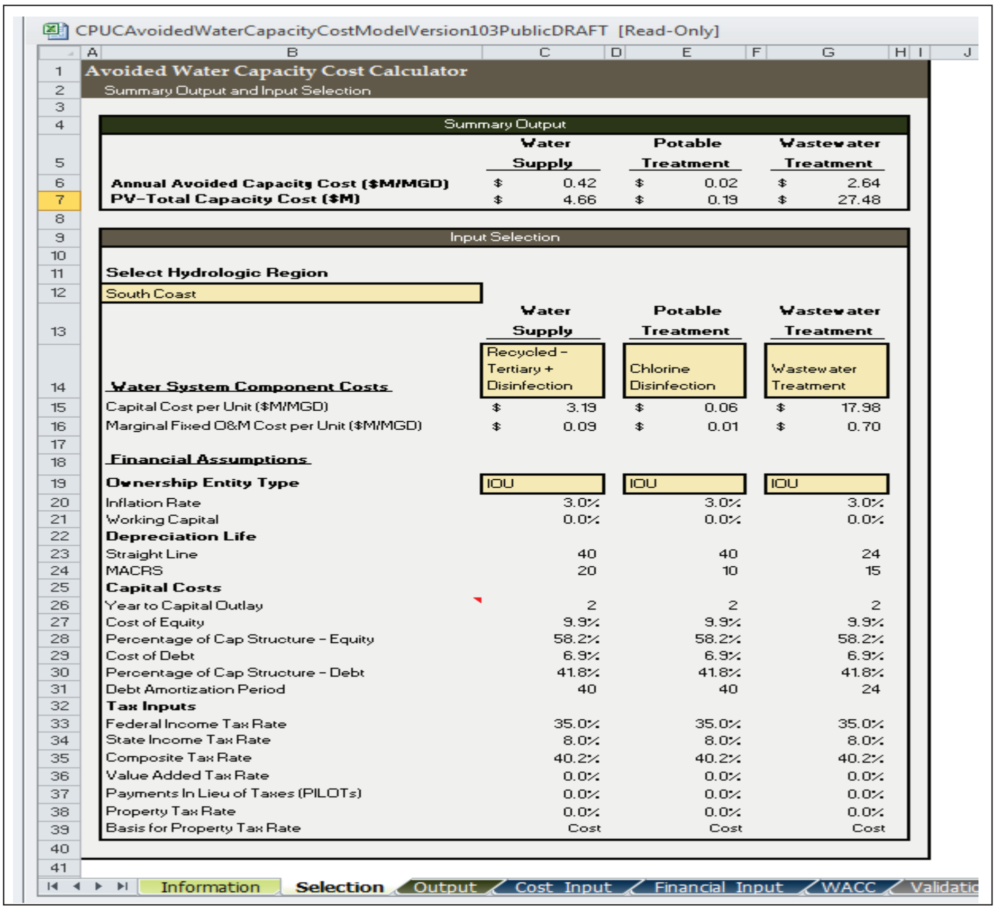
There is also the potential of better matching energy availability and water use through the so-called "duck curve" developed by the California Independent System Operator, which tracks electricity generation throughout a typical day. On most days, the curve produces a duck belly-shaped appearance by mid-afternoon – indicating the availability of surplus energy. By evening it evolves into an arch similar to a duck's neck as use exceeds supply. These abundant periods may afford an opportunity for water utilities to increase energy consumption without unduly taxing electricity supply. However, unlike the electricity sector, the water industry is wholly dependent on the availability of its sources and can't "generate" water on demand – nor compel customers to adjust needs accordingly.

Understanding supply and demand relationships are essential to improve efficiency, but energy and water can also be conserved through advanced automation and better forecasting. Foreknowledge of extreme weather events such as El Nino could help guide and inform siting and adaptation decisions for new power plants or water supply sources [14, 17].

Overcoming institutional barriers

Achieving integration requires interagency coordination and data sharing which, up to now, have rarely proven to be easy. There are opportunities for water and energy agencies to undertake conjoint water and energy planning, while incorporating agricultural needs, as one means of furthering water-energy resilience [18].

Adoption of combined water and energy efficiency programs face many hurdles, however. There are problems with inconsistent funding, insufficient staff support, and lack of guidance regarding how to fairly divide costs among partners. More reliable data on the energy intensity of water uses could help overcome such barriers. For example, the California Public Utility Commission is developing a "Water-Energy Cost Effectiveness Calculator," (shown in **Figure 3**). This tool allows comparison of energy demands imposed by different water uses, thereby permitting better forecasting, and – at household-scale – greater conservation.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Avoided Water Capacity Cost Calculator
Summary Output and Input Selection

Summary Output

	Water Supply	Potable Treatment	Wastewater Treatment
Annual Avoided Capacity Cost ($M/MGD)	$ 0.42	$ 0.02	$ 2.64
PV-Total Capacity Cost ($M)	$ 4.66	$ 0.19	$ 27.48

Input Selection

Select Hydrologic Region: South Coast

	Water Supply	Potable Treatment	Wastewater Treatment
Water System Component Costs	Recycled - Tertiary + Disinfection	Chlorine Disinfection	Wastewater Treatment
Capital Cost per Unit ($M/MGD)	$ 3.19	$ 0.06	$ 17.98
Marginal Fixed O&M Cost per Unit ($M/MGD)	$ 0.09	$ 0.01	$ 0.70
Financial Assumptions			
Ownership Entity Type	IOU	IOU	IOU
Inflation Rate	3.0%	3.0%	3.0%
Working Capital	0.0%	0.0%	0.0%
Depreciation Life			
Straight Line	40	40	24
MACRS	20	10	15
Capital Costs			
Year to Capital Outlay	2	2	2
Cost of Equity	9.9%	9.9%	9.9%
Percentage of Cap Structure - Equity	58.2%	58.2%	58.2%
Cost of Debt	6.9%	6.9%	6.9%
Percentage of Cap Structure - Debt	41.8%	41.8%	41.8%
Debt Amortization Period	40	40	24
Tax Inputs			
Federal Income Tax Rate	35.0%	35.0%	35.0%
State Income Tax Rate	8.0%	8.0%	8.0%
Composite Tax Rate	40.2%	40.2%	40.2%
Value Added Tax Rate	0.0%	0.0%	0.0%
Payments In Lieu of Taxes (PILOTs)	0.0%	0.0%	0.0%
Property Tax Rate	0.0%	0.0%	0.0%
Basis for Property Tax Rate	Cost	Cost	Cost

Information | Selection | Output | Cost Input | Financial Input | WACC | Validatio

Figure 3: Water-energy cost-effectiveness calculator.

Scaling up solutions at the Water-Energy Nexus

Innovations depicting the impacts of different energy and water uses must be more widely introduced as they become available: from precision water-energy reports on handheld devices useable in the home, to utility-level tools permitting better demand forecasting. While a number of water-management approaches, including wastewater reuse, desalination, and irrigation technologies have become much more energy efficient, greater R&D investment can yield even more improvements. Funding, as discussed momentarily, will be critical to this effort.

Four major additional steps have been recommended to increase the energy efficiency of water systems. First, the benefits of collaboration between water and energy organizations: utilities, agencies, and NGOs – need to be acknowledged, and cases where successful inter-institutional collaboration has occurred need to be widely disseminated. Once these benefits are recognized, logistical issues that hinder collaboration then need to be addressed. This can be done by dialogue with other regional stakeholders (i.e. agricultural water users) in decisions regarding the management of water and energy, and developing an information database to allow organizations to understand each other's terminology, organizational culture, and experiences.

Second, a central, federated database for water and energy utilities' operations that protects personal and proprietary information could assist in long-term planning. Available water and energy data is currently scattered in numerous data sets, often has limited accessibility to a wide-range of audiences, and is un-standardized in format. Water and energy utilities could collect relevant data for their respective operating regions, while regulatory agencies could provide data quality standards. Universities can help in developing standards and hosting federated data access points.

Third, conservation certification programs such as EPA's Energy Star, Water Sense, and the U.S Green Building Program's Leadership in Energy and Environmental Design (LEED) can play important roles in benchmarking and evaluating performance standards. While conservation certification programs exist for certain parts of the water and energy sectors, these certifications tend to only take into account the projected savings at the inception of a program, and rarely measure or verify actual savings after implementation. Moreover, they often do not take into account indirect water or energy savings due to a lack of knowledge about water/energy infrastructure couplings.

Finally, creative ways must be found to fund all innovations: cap and trade funds or surcharges on utility bills can help secure funding. Encouraging investment in efficiency programs requires agreement on how to assign benefits and costs to collaborators. Targeting areas offering the greatest savings is also important. And, demonstration projects that water and electrical utilities can work on together are needed. There are models of effective rebate programs to encourage water conservation and end-use efficiency – such as those for low-flow appliances, installation of more efficient landscape irrigation systems, and even installation and replacement of lawns with drought-tolerant landscaping. Many electric utilities have a good record of providing rebates for energy efficient appliances – analogues for water are available [19].

Developing solutions for scale: Integrated carbon and climate accounting

Education and community engagement in carbon, water, and other resource accounting, using both financial and carbon metrics are critical to build a transparent platform to compare the costs and benefits of meeting targets. In the Cool California Challenge, for example, municipalities (http://www.coolcalifornia.org/community-challenge/) and communities utilize the calculator tools we have found that residential cost savings, improved air quality are only two of the immediate benefits that can come from attention and management of your carbon footprint (**Figure 4**).

A lesson in visualizing and communicating climate impacts has been the use of life-cycle methods as the *climate lingua franca* in California agencies, such as in the evaluations use in the Low-Carbon Fuel Standard, which also serve as the compliance method, the first time life cycle analysis as been integrated and codified into a major regulatory program.

These tools have important application in the public dialog as well. One example has been the generation of own carbon footprints at the community and individual household level [20] *and the comparison to the average over a local area, in this case by zip-code* [21] is that this information empowers individuals to act. In fact the 'take action' pages on the Coolcaliforna.org website have been a huge source of excitement and conversation among users looking for means to reduce *both their carbon footprint and household expenditures* (**Figure 5**). The interactive maps this effort generated have been accessed up to 100,00 online views/day, widely inside and outside of California, and have facilitated conversations about the embedded carbon in the good, services, and food we consume. California must develop a plan to account for these embedded emissions in AB32.

Integrating behavior into sustainability studies

Sustainability implies responsible and proactive decision-making and innovation that minimizes negative impact and maintains balance between ecological resilience, economic prosperity, political justice and cultural vibrancy to ensure a desirable planet for all species now and in the future. An important step towards achieving sustainability is to encourage a wide uptake of more resource-efficient consumption patterns by the 'mainstream' sector of society. The question is how to influence people's behavior and lifestyles in pursuit of sustainable development. There is an emerging recognition of the importance of the role of information in helping individuals to change their behavior [22]. In a randomized controlled trial conducted in 118 UCLA family apartments, Asensio & Delmas, [23] compared the effectiveness of environmental and health information disclosures on residential energy consumption to more traditional cost based information strategies [23]. A range of findings described below, show that

Figure 4: Homepage of the cool California city challenge website.

environment and health-based information strategies can outperform monetary savings information to drive energy conservation in the home.

Health and Energy Generation

Public environmental and health damages from energy generation, which include premature mortality and morbidity (such as cancer, chronic bronchitis, asthma and other respiratory diseases), have not traditionally been the focus of energy conservation policies. Yet, decades of research on environment and health effects of air pollution have shown electricity generation to be one of the most important sources of pollution and with recognized impacts on global health such as childhood asthma and cancer.

However, the link between individual electricity use and the resulting impacts on human health (via energy-related

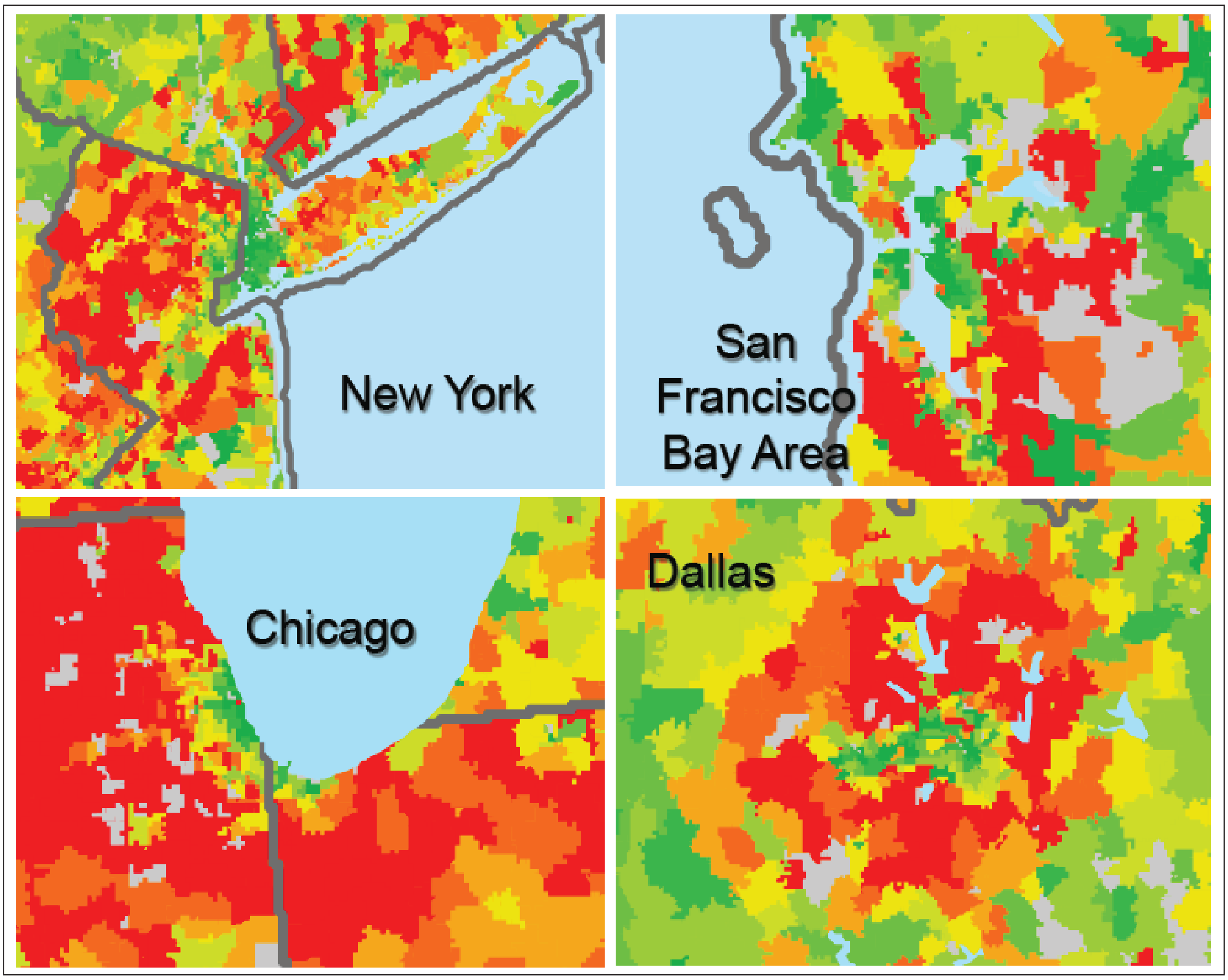

Figure 5: The carbon footprint of U. S. urban areas at the zip-code level in one California and three other U. S. cities [21]. The interactive calculator and map is available at: http://coolclimate.berkeley.edu.maps. These color-scaled plots reveal the 'carbon shadow' of suburban consumption around often quite low-carbon urban cores.

industrial emissions) remains elusive for most consumers. Household electricity use is typically 'invisible' meaning consumers have limited information about the external effects of their individual electricity consumption. This analysis can be taken further to investigate whether information about the environmental health effects of energy consumption could impact conservation behavior.

Research in psychology, economics, marketing, sociology, philosophy, and neuroscience, has shown that normative strategies can motivate human behavior in the interests of the long-term benefits of the social group rather than the short-term, self-interested behavior of one person. Learning that one's marginal consumption imposes social costs on others can lead to different *moral sensitivities* to external health damages.

The UCLA Experiment

To scale and test these findings a field experiment was conducted at University Village at UCLA, which is a large family housing community in Los Angeles with 1,103 units. On a per capita electricity basis, University Village residents are typical of California multi-family renter populations and are only slightly below the national average (due to the milder climate in the State of California). Our 118 participating households consist of single, married and domestically partnered graduate college students with and without children in the home.

With the use of an intelligent, wireless sensor network, it is possible to give consumers real-time access to detailed, appliance-level information about their home electricity consumption. To test these ideas at scale panel of 440,059 hourly kilowatt-hour (kWh) observations (or 3.43 million underlying appliance level kWh observations) for 118 residences over a time span of 8 months.

Asensio & Delmas provided treated households with high-resolution information about costs (weekly cost estimates as opposed to monthly billing) or environmental and health impacts (weekly emissions and listing of particular health consequences, e.g. childhood asthma and cancer). Informational messages were delivered via a specialized, consumer-friendly website with monitored page views and analytics; and weekly accessible e-mails by personal computer and portable electronic devices [24]. Information feedback was specific to each consumer. Environment and health-based information treatments, which communicate the environmental and public health externalities of electricity production –such as pounds of pollutants, childhood asthma and cancer— motivated 8% energy savings versus control. This strategy was particularly effective on families with children, who achieved up to 19% energy savings.

To give a practical sense for what these savings mean for a typical 2 bedroom family apartment, an 8% conservation effect would be equivalent to plugging out a laptop computer for an additional 87 hours per week, a flat screen TV for an additional 36 hours per week, or turning off one standard 60-watt light bulb for an additional 72 hours per week. Using published price elasticities for California, this conservation effect on the treated is equivalent to a long-run electricity price increase of 20.5% or a 60-day short-run price increase between 30 and 60%.

While one might expect some attenuation of these effects across larger study populations, we demonstrate the behavioral principle of using health damages and moralized consumer choice as a promising behavioral strategy for residential energy consumption. By contrast, participants who received messages informing them about monetary savings did not produce significant conservation by the end of the experimental period, net of all statistical controls. This result of conservation in one group, and no net conservation in another leads us to seek a deeper understanding of the underlying heterogeneity and individual behaviors driving household actions.

Policy Implications

Behavioral strategies in household electricity markets can be complements rather than substitutes for regulatory or price-based solutions. Energy conservation is desirable in the economy as an alternative to costly capital investments in new power generation, and can help delay managerial investment decisions for new generation capacity. While non-price behavioral strategies can be viable alternatives to new capital projects by promoting peak load shifting and conservation, they can also be implemented immediately, at scale and at relatively low cost. Behavioral strategies enabled through information technologies can be an effective component of sustainable development pathways and do not require long lead times typical of new capital investments in energy generation, distribution and storage.

Conclusion

Scaling-up solutions requires learning and adapting lessons between locations and often at very different scales. The pro-climate *and* pro-economic environment in California provides a critical nexus of factors that we find to be vital in sustaining both the rate of innovation and the necessary feedback between research and deployment. Those factors include: 1) an overall vision for sustainability into which individual innovations across all sectors fit; 2) a healthy funding environment in which a diverse suite of actors participate, drawn from academic, public and private sector research units, a vibrant and risk-tolerant private sector, and 3) an open and frank dialog about ideas that can be turned into practice, as well as when to move on to seek new solutions if elements of the path need to be altered along the way. This milieu of innovation and implementation may be called a 'robust' environment, where ideas can be thoughtfully developed and vetted, and – critically – where experimentation and even elements of failure are tolerated, examined, and used to move to new innovations.

The experience within and beyond the University of California systems makes clear that accomplishing such solutions requires two critical components. First, there is a need for accurate and comprehensive data on carbon emissions and related issues such as water and criteria pollutants. Carbon accounting is central to resource management. Without it everything from sending clear signals to industry, to ensuring environmental justice, to assessing the job creation and financial aspects of a climate plan cannot be honestly evaluated. Secondly, there is a need for expanded partnerships both within California and globally in order to facilitate the scaling of effective strategies. Building goal-focused partnerships across UC campuses (and beyond UC), national laboratories, foundations, and industry will multiple and accelerate the development and deployment of scaled solutions. Partnerships and deployed solutions at the regional, state, national, and international scale will create new industries, new jobs, and further UC and California's leadership position.

Additional Files

The additional files for this article can be found as follows:

- **Additional File 1: Appendix.** http://dx.doi.org/10.1525/collabra.65.s1

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Competing Interests

The authors have no competing interests to declare.

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